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Културни центар "Бански двор" Бања Лука
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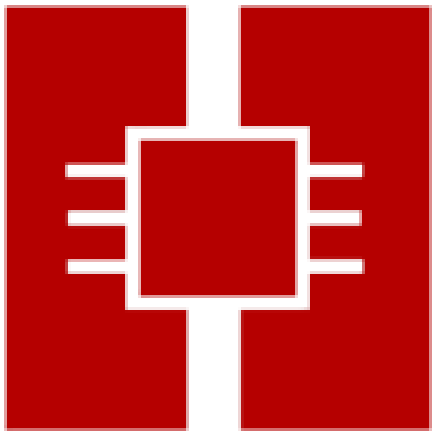

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ЗБОРНИК РАДОВА
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Издавач **Универзитет у Бањој Луци**
Publisher **Архитектонско-грађевинско-геодетски факултет**

University of Banja Luka
Faculty of Architecture, Civil Engineering and Geodesy

За издавача **др Бранкица Милојевић, ванр. професор**
On behalf of publisher Brankica Milojević, PhD, associate professor

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Бања Лука, 2018.
Banja Luka, 2018

ISSN 2566-4484

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САДРЖАЈ TABLE OF CONTENTS

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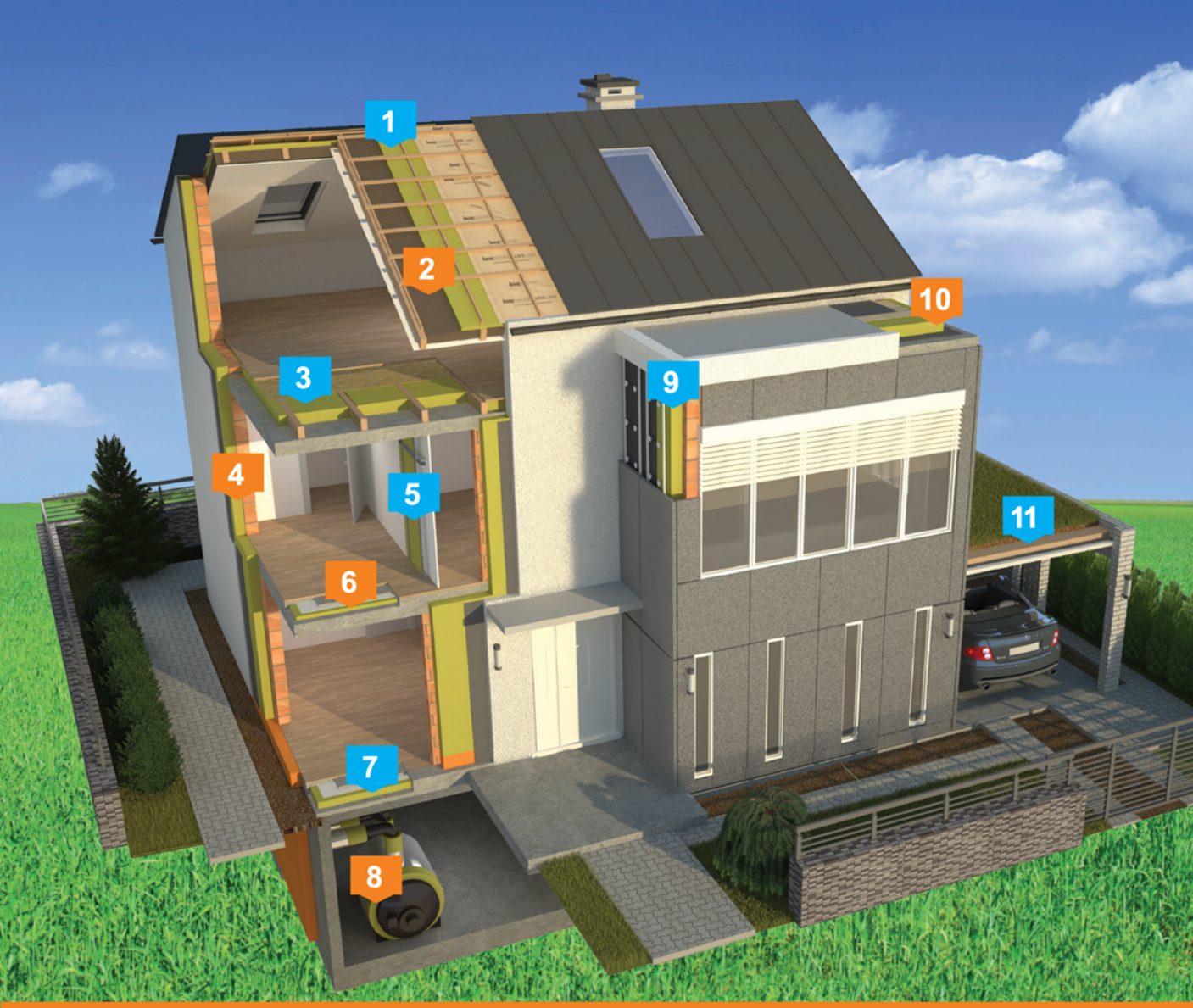

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doi 10.7251/STP1813030B ISSN 2566-4484

PRESSURE OPTIMISED VISCOELASTIC VIBRATION AND IMPACT INSULATION

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Abstract:

Within this contribution we present recently published findings [1] on the new way of utilizing polymeric materials for vibration damping. We present and demonstrate patented dissipative bulk and granular systems technology [2], based on which we have developed granular damping elements (GDE). The damping elements consist of granular viscoelastic material encapsulated and pressurized within a woven container made of basalt, carbon, and/or glass fibres. The hydrostatic pressure changes material properties and consequently the performance of the vibration isolation. Within this contribution, properties of three TPU materials in solid state are investigated, which after granulation are potential candidates for producing new GDE damping elements. We have demonstrated that for the case of TPU materials the stiffness and energy absorption capability of insulation may be increased between 10 to 100 times.

Keywords: vibration insulation, viscoelasticity, granular damping elements, pressure

VISKOELASTIČNE VIBRACIJE OPTIMIZOVANE PRITISKOM I IZOLACIJA OD UDARCA

Apstrakt:

U okviru ovog rada predstavljamo nedavno objavljena otkrića [1] o novom načinu korištenja polimernih materijala za prigušenje vibracije. Prikazujemo i demonstriramo patentovanu tehnologiju disipativnih i granularnih sistema [2] na osnovu kojih smo razvili granularne elemente za prigušivanje (GDE). Elementi za prigušivanje se sastoje od granularnog viskoelastičnog materijala koji je ugrađen pod pritiskom u kalup istkan od bazalta, ugljenika i/ili staklenih vlakana. Hidrostatički pritisak mijenja svojstva materijala, a samim tim i svojstva vibroizolacije. U okviru ovog istraživanja su ispitana svojstva tri tipa termoplastičnih (TPU) materijala u čvrstom stanju, koji su nakon granulacije potencijalni kandidati za proizvodnju novih granularnih elemenata za prigušivanje. Pokazali smo da se u slučaju termoplastičnih materijala krutost izolacije i njena sposobnost absorpcije energije može povećati između 10 i 100 puta.

Ključne riječi: vibroizolacija, viskoelastičnost, granularni elementi za prigušivanje, pritisak

1. INTRODUCTION

Controlling and damping of vibrations and noise is becoming increasingly important element of engineering. On one hand due to machine and element protection against wear and fatigue. On the other hand, to protect people for example from earthquakes. The role of vibrations control is to minimize the vibration transmission between source and receiver by appropriate selection of vibration isolation elements, where system parameters such as mass, stiffness and damping of material determine the effectiveness of vibration isolation [3]. Due to their good damping properties polymers are commonly used for isolation of vibration. Besides their good damping, low specific density and good design and production flexibility makes them appealing for the use in vibration damping engineering applications [4]. However, there is one major drawback - their low stiffness [5], especially when damping elements should carry large loads, such as in the case of earthquake damping elements. In addition, properties of polymeric materials are very different; polymers with high damping (energy absorption capability), typically elastomeric materials, have lower stiffness compared to polymers with lower damping, typically thermoplastic polymers [6], [7]. Due to their lower stiffness, polymers with higher damping usually cannot be used for vibration isolation. In addition, these materials exhibit maximal values of damping (energy absorption) at very high frequencies, often at frequencies far away from the working range of machines and devices. It becomes clear, that at present, we do not have a solution allowing us to utilize the full damping potential of (especially) elastomeric materials. To summarize, the ideal material for damping would combine sufficient stiffness with maximal damping values in the frequency range of excitation. We have solved the two challenges by using the patented Dissipative bulk and granular systems technology [2], which utilizes two scientific findings:

- We found that exposing polymeric materials to selected hydrostatic pressure [8], [9], causes a shift of mechanical properties to lower frequencies. Hence, by selecting a proper (elastomeric) material with high damping properties and exposing it to a properly selected hydrostatic pressure, we can match the frequency range where material exhibits its maximal dissipation properties with the excitation or resonance frequency range of a vibrating structure. Using this principle, materials energy dissipation properties can be enhanced for several orders of magnitude. Unfortunately, pressures required for adjusting the frequency range of damping properties may be quite high, i.e., from 50 - 100MPa, and even higher. Exposing bulk materials to such pressure levels in uniaxial compression will inevitably lead to appearance of cracks due to excessive accompanying shear stresses, and eventually to material failure.
- We have solved this problem with an inventive patented solution described below. We have realized that granular materials with a proper particles size-distribution may exhibit a flow-like behavior while maintaining all properties of a bulk material. To study the flowability of granular materials we have used the self-developed GFA apparatus (Granular Friction Analyzer) [10], which allows studying the ability of granular materials to flow in case when driving force is high (hydrostatic) pressure. Based on the studies of granular materials flowability we have concluded that polymeric granular materials with proper particles size-distribution may be used as a pressurizing media (similar as air in tires) to impose hydrostatic pressure on themselves (i.e., self-pressurization) and, as a result, change frequency dependence of their own damping properties. With a proper adjustment of the hydrostatic

pressure, we can also adjust the stiffness of the damping element (again, similar as with air in tiers). Since energy dissipation of a damping element is proportional to the volume of used granular materials, whereas the stiffness in addition depends on geometry of a damping element, the two parameters (damping and stiffness) may be adjusted independently.

Utilizing described approach Granular damping elements (GDE), were developed. GDE consists of a container, made of woven basalt, carbon and/or glass fibers, which is filled and pressurized with polymeric granular materials with multi-modal particles size-distribution (Fig. 1a). Due to the flow-like behavior of granulated polymers, the generated pressure within the container will be hydrostatic and will act on polymeric particles themselves, and consequently modify frequency dependence of their energy absorption properties. Hence, with a proper pressurization we may shift the material energy absorption maximum to any desired frequency (Fig. 1b).

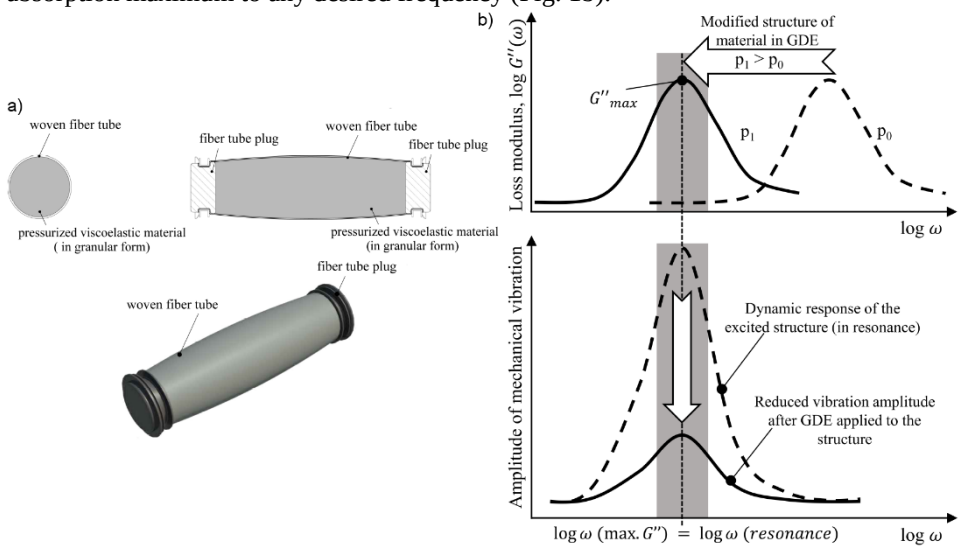

Figure 1. a) Granular damping elements (GDE) and b) working principle of GDE elements , addopted from [1].

More specifically, let us assume that a vibrating structure is equipped with a damping element made of a polymeric material of which its frequency dependent damping properties at environmental pressure p_0, expressed with the loss modulus G"(ω), are shown in Fig.1b as a dashed line in upper diagram. In the frequency range where the structure is in resonance, indicated as a shadowed area, the damping properties of this material are low. Consequently, the structure vibration amplitudes in the resonance frequency range will be large, as shown with a dashed line in Fig.1b - lower diagram. Now, if we take the very same material in a granular form with a proper particles-size distribution and self-pressurize it within a woven container, we obtain the new GDE damping element described in previous section. This is achieved by selecting a proper hydrostatic pressure p_1 within the container that shifts the loss modulus maximum to the resonance frequency range of the structure, as shown in upper diagram of Fig.1b with a solid line. As a result, the vibration amplitudes of the structure will substantially diminish, as shown as a solid line in lower diagram of Fig.1b.

In light of the presented GDE element the goal of this contribution is to analyze the effect of pressure on frequency-dependence of three polyether-based thermoplastic polyurethane (TPU) materials. The investigated materials are three BASF Elastollan TPU materials: (i) 1190A, (ii) 1175A, and (iii) 1195D. We investigated properties of TPU materials in solid state, which after granulation are potential candidates for producing the new generation GDE damping elements.

2. EXPERIMENTAL PROCEDURE

Due to space limitation the experimental methodology is briefly explained here and some details are given in continuation of this chapter, a detailed description on every step can be found in our published paper [1].

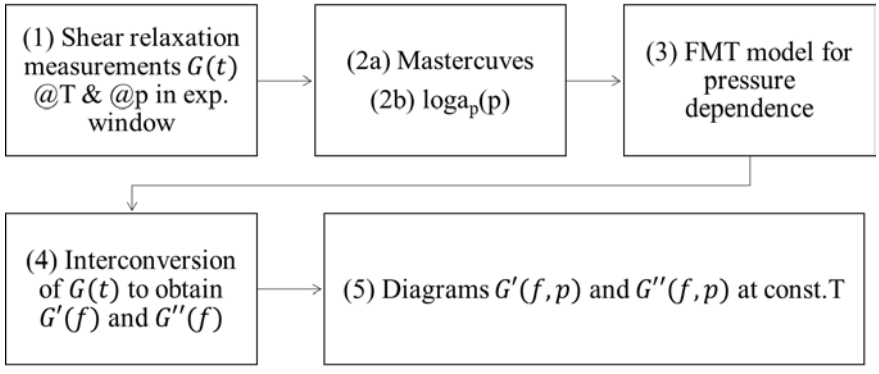

Figure 2. Shematical repersentation of experimental procedure.

As a first step (1) shear relaxation experiments were done at selected temperature and pressure range within a selected experimental window. Measured segments were assembled into mastercuves (step 2a) using time-temperature-pressure superposition. In this step we have also obtained pressure shift factor (step 2b). In the third step we have modeled the pressure behavior of tested material using the FMT model (step 3). In order to obtain the dynamic data, we have used interconversion procedure (step 4) and finally we have assembled dynamic data and pressure sensitivity of materials into 3D diagrams (5) for the analysis of GDE potential.

2.1. SAMPLE PREPARATION

We have investigated three polyether-based thermoplastic polyurethane (TPU) materials from the Elastollan® 11 series, i.e., (i) 1190A, (ii) 1175A, and (iii) 1195D, produced by BASF, that are already used in manufacturing of vibration insulation. Since Elastollan® is hygroscopic material, all materials were dried at 100°C for at least 3 hours in a commercial dryer (SP105-C, Kambič, Slovenia), to avoid bubbles formation during the extrusion process.

Due to measuring limitations of the CMS apparatus (described in next sub-chapter), we had to prepare samples with different diameters for measurements at different pressure-temperature boundary conditions. Samples were prepared with PolyLab HAAKE Rheomex PTW 16 extruder (Thermo Haake, Germany) equipped with two co-rotating 16mm screws. Thicker samples (ϕ=~6mm and ~11mm) were prepared by extrusion into glass tubes that were coated from the inside with a silicon rubber (Tesacoma, silicone

pastry board), to prevent the extruded melt from sticking to the glass. Coated glass tubes were pre-heated to 100°C before they were filled with materials, and then-after naturally cooled at room conditions. Thinner samples (ϕ=~2mm and ~4.5mm) were prepared by continuous extrusion into a water bath. The speed of a subsequent conveyor belt together with the screw speed enabled us to alter diameters of thin samples. After extrusion, the thin samples were let to free hang under their own weight for about 12 hours at room conditions, to make them straight. Next, materials were cut with a razor blade to the specified length and the cut surfaces were finished with a sand paper (using very fine P220 and super fine P1200 sand paper).

To remove residual stresses in samples resulting from extrusion, cutting, and gluing, all samples were annealed prior measurements. The starting point of this procedure was raising the temperature in the commercial dryer (SP105-C, Kambič SP105-C, Slovenia) from room conditions to 90°C. The temperature was held constant for three hours, followed by slow cooling. Cooling was done in two stages, 1st stage was done inside the oven to room conditions, around 20°C, and in the second stage samples were removed from the oven and placed inside insulation box (to assure required rate of cooling) that was placed inside a freezer. Using this procedure temperature of -20°C was achieved. During the cooling, the average cooling rate was ~0.15°C/min.

2.2. EXPERIMENTAL SETUP

All experiments were performed on unique apparatus, called CEM Measuring System, shortly CMS [8], [9]. CMS enables measurements of shear relaxation and bulk creep compliance properties of polymers in solid state. Measured specimens can be simultaneously subjected to pressures up to 500MPa, with a precision of ±0.1MPa, and to temperatures ranging from -40°C to +120°C, with a precision of ±0.01°C. The CMS apparatus is shown schematically in Fig.3. More details on the CMS apparatus may be found elsewhere [9].

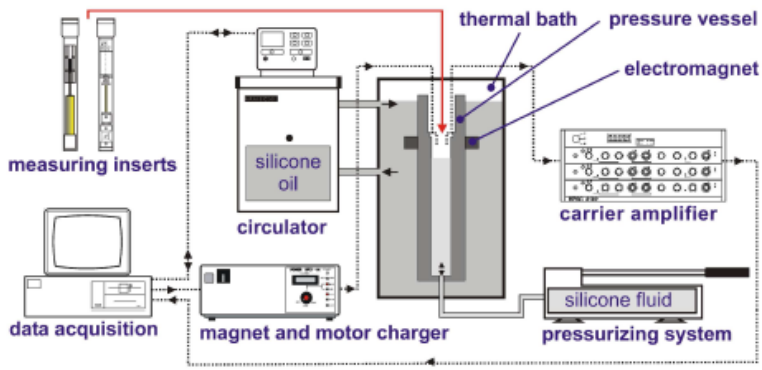

Figure 3. Schematic representation of CMS apparatus [9].

The pressure inside the pressure vessel is generated by the pressurizing system using silicone oil. The pressure vessel is contained within the thermal bath, where another silicone oil circulates from the circulator, used for precise temperature control.

The apparatus utilizes two separate measuring inserts, which can be inserted into the pressure vessel, the relaxometer and the dilatometer. Signals from the measuring inserts pass through the carrier amplifier prior to being collected in digital format by the data

acquisition system. The magnet and motor charger supplies current to the electromagnet, which activates the measurement. The same charger also supplies current to the electric motor of the relaxometer, which pre-loads the spring that then applies the desired torsional deformation (angular displacement), to the specimen.

2.3. MEAUSRING PROCEDURE

For obtaining the shear relaxation properties, experiments were performed at two different sets of boundary conditions. The 1st Set of experiments was performed at constant pressure p = 0.1MPa, and different constant temperatures between -20 and 60°C. The exact temperatures are provided within diagrams. The 2nd Set of experiments was performed at isothermal conditions, at constant temperature T = -20°C, and different constant pressures ranging between 0.1 and 300MPa. Fig.4. schematically shows boundary conditions of both sets of experiments, while the corresponding temperature and the pressure loading profiles for each of the three TPU's are presented in Fig.5.

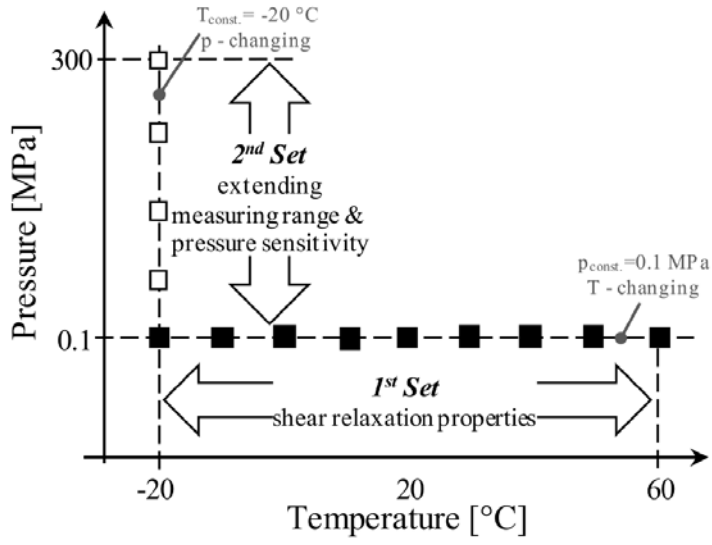

Figure 4. Boundary conditions for determining shear relaxation properties and pressure sensitivity of selected materials [1].

In all experiments, each loading step consists of 3 hours stabilization time and 1000s (~ 15min) measuring time. All experiments started at conditions where material is closer to glassy state, i.e., at lowest temperature for the 1st Set and at highest pressure for the 2nd Set of experiments. In all cases at least three repetitions of measurements were performed, where for each repetition different sample was used. After averaging segments measured at the same boundary conditions, we have applied the Closed Form Shifting algorithm to create the shear relaxation, G(t) mastercurves. The latter were then interconverted into the frequency domain, to obtain the storage G'(ω), and the loss G"(ω), moduli for the three examined materials.

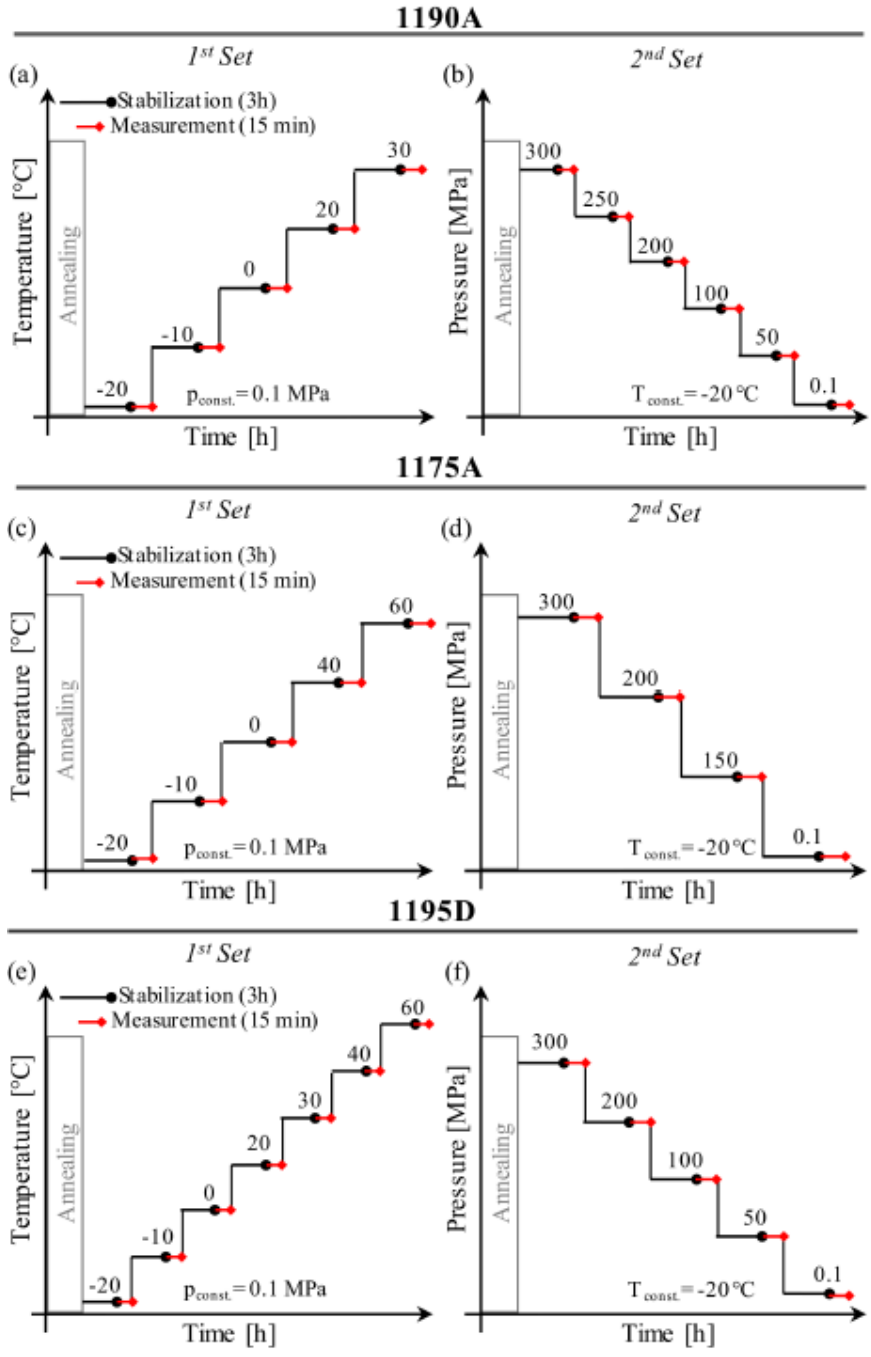

Figure 5. Temperature/pressure loading profiles for individual materials used in shear relaxation experiments [1].

3. RESULTS AND DISCUSSION

As we have mentioned, to model the effect of pressure, we have used the FMT model, proposed by Fillers, Moonan and Tschoegl [11], [12]. The FMT model can be viewed as an extension of the WLF equation to account for the effect of pressure in addition to that of temperature. The shift factor as function of temperature and pressure is given in the form:

$$\log a_{T,p} = -\frac{C_1^{00}\left[T - T_0 - \theta(p)\right]}{C_2^{00}(p) + T - T_0 - \theta(p)}, \tag{1}$$

where

$$\theta(p) = C_3^0(p)\ln\left(\frac{1 + C_4^0(p)}{1 + C_4^0(p_0)}\right) - C_5^0(p)\ln\left(\frac{1 + C_6^0(p)}{1 + C_6^0(p_0)}\right), \tag{2}$$

and C's follow as

$$C_1^{00} = B / 2.303 f_0, \tag{1}$$

$$C_2^{00} = f_0 / \alpha_f(p), \tag{2}$$

$$C_3^0(p) = 1 / k_e \alpha_f(p), \tag{3}$$

$$C_4^0 = k_e / K_e^*, \tag{4}$$

$$C_5^0(p) = 1 / k_\phi \alpha_f(p), \tag{5}$$

$$C_6^0 = k_\phi / K_\phi^*. \tag{6}$$

The 00 superscript indicates that the parameter is referred to the reference temperature T_0(first place) and to the reference pressure p_0 (second place). A single 0 superscript refers to the reference temperature only. The * superscript refers to zero (in practice, atmospheric) pressure, while subscripts e and f stand for “entire-” and “free-” volume, respectively. Eq.1 is the Fillers-Moonan-Tschoegl (FMT) equation. K_e^* and k_e and thus C_4^0, can be determined from separate volume-pressure measurements through a fit to the equation

$$\ln\frac{V}{V_0} = -\frac{1}{k_e}\ln\left[\frac{K_e^*(T) + k_e p}{K_e^*(T) + k_e p_0}\right], \tag{7}$$

by a non-linear least-squares procedure. In Eqs.1-9, α_f denotes expansivity (i.e., the isobaric cubic thermal expansion coefficient) of the fractional free volume, $f_0 = f(p_0)$ is the fractional free volume at reference pressure, $K_e^*(T) = K_e(T)|_{p=0}$ is the bulk modulus at atmospheric pressure, and k_e is a proportionality constant deemed independent of either pressure or temperature. FMT constants C_1 and C_2 were obtained through time-temperature-pressure superposition. Volumetric measurements were used to determine material parameters K_e^* and k_e (and thus C_4 using Eq.6) by fitting the Eq.9. For the calculation of the remaining constants C_3, C_5 and C_6, experimental shift factors obtained from measurements at constant temperature ($T = -20°C$) and varying pressures, were

fitted to Eq.1 using Levenberg-Marquardt algorithm (MATLAB R2015a). Table 1 shows FMT parameters for all three materials.

Table 1. FMT paramaters.

Mater.	C1	C2 [ºC]	$\alpha_f \times 10^{-4}$ [ºC-1]	Ke [MPa]	ke	Kϕ [MPa]	kϕ
1190A	31.24	202.43	1.26	2763	12.54	3092.74	12.59
1175A	11.46	52.35	1.87	2434	12.89	2494.02	13.97
1195D	24.92	105.19	1.98	2762	13.44	2877.39	15.21

Due to the space limitation, we do not show results on shear relaxation, G(t), mastercurves, which were interconverted into the frequency domain, to obtain the storage G'(ω), and the loss G"(ω), moduli for the three examined materials. Frequency domain material functions, the storage G'(ω), and the loss G"(ω), moduli, are shown in Fig.6, in double logarithmic and semi-logarithmic coordinate systems. Figs.6(a) and (c) show the storage modulus G'(ω), whereas Figs.6(b) and (d) the loss moduli G"(ω).

The storage modulus G'(ω), which defines the vibro-isolation stiffness, increases with excitation frequency for about 100 times for 1190A and 1195D, and for about 10 times for 1175A. However, as seen from the semi-logarithmic diagrams, within the frequency range indicated as shaded area that is of interest for engineering applications, their stiffness is quite low. In the case of 1175A we may see that it behaves elastically, i.e., its storage modulus is almost constant, up to 10^4Hz, whereas, within the same frequency range, the stiffness of other two materials exhibit quite strong frequency dependence. From double logarithmic diagram, we see that 1175A exhibits abrupt transition at 10^4Hz, while for the other two materials this transition is much more gradual.

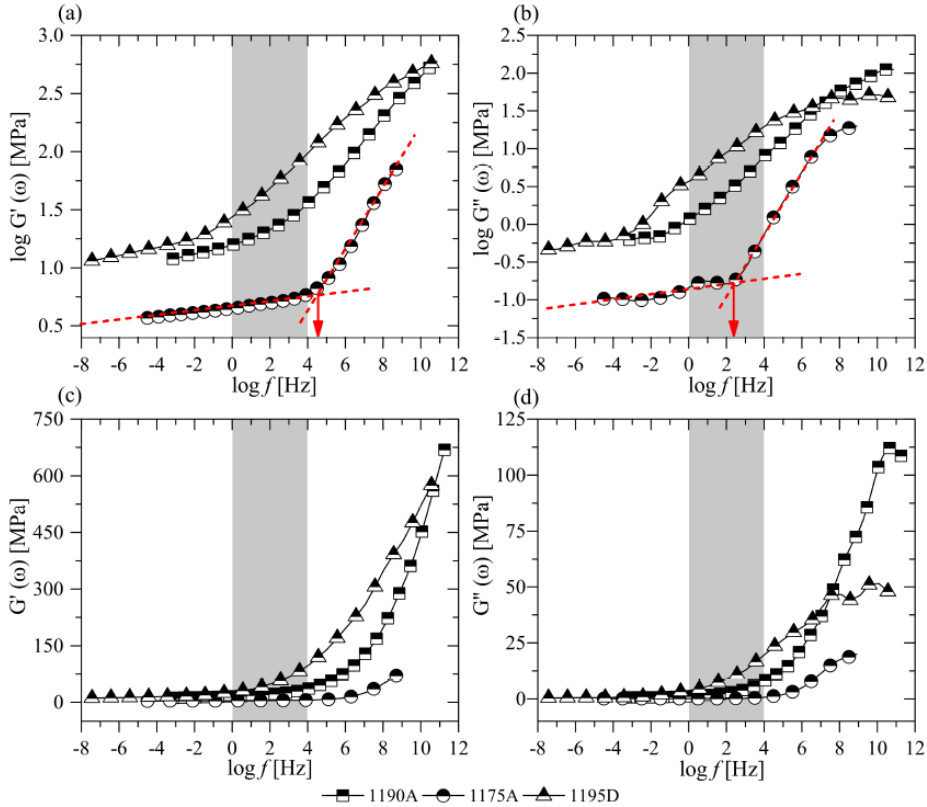

Figure 6. Shear storage modulus G'(ω) in (a) double logarithmic and (b) semi-logarithmic coordinate systems; and shear loss modulus G''(ω) in (c) double logarithmic and (d) semi-logarithmic coordinate systems. All figures are shown at Tref=20°C and pref=0.1MPa [1].

The loss modulus G''(ω), also increases with excitation frequency for all three materials, again for about 100 times for 1190A and 1195D, and for about 10 times for 1175A. Since the loss modulus G''(ω), defines the damping ability of a vibro-isolation, the higher values mean better damping. However, from the Figs.6(b) and (d) we may see that maximal measured values in all three cases are located at very high frequencies, between 108-1012Hz. In addition to this, it may also be seen that in the frequency range that is of interest in most engineering applications, shown as shaded area, values of loss modulus G''(ω), are relatively low, i.e., in the range between 0.1 to 25MPa, which is not bad in comparison to metals, however far away from real potentials of TPU materials.

Comparing the three TPUs shows that material 1175A has the lowest loss modulus G''(ω), through the whole frequency range. As in the case of storage modulus G'(ω), 1175A at about 103 Hz abruptly enters the transition state where its energy absorption properties are strongly excitation frequency dependent, before that its dissipation properties are more or less constant, see Fig.6(b). This transition is for 1190A and 1195D much more gradual.

3.1. ANALYSIS OF GDE POTENTIALS

Combining the information on dynamic viscoelastic material functions presented in Figs.6 with materials hydrostatic pressure sensitivity, we may construct 3D diagrams showing

interrelation between the storage, G'(ω), and the loss, G"(ω), moduli, excitation frequency, and hydrostatic pressure to which material is exposed. The results are shown in Fig.7 for the storage modulus G'(ω), and in Fig.8 for the loss modulus G"(ω).

The 3D diagrams provide a general inside how the two material functions depend on hydrostatic pressure and excitation frequency. The differences between the three materials are obvious, particularly when comparing their loss moduli.

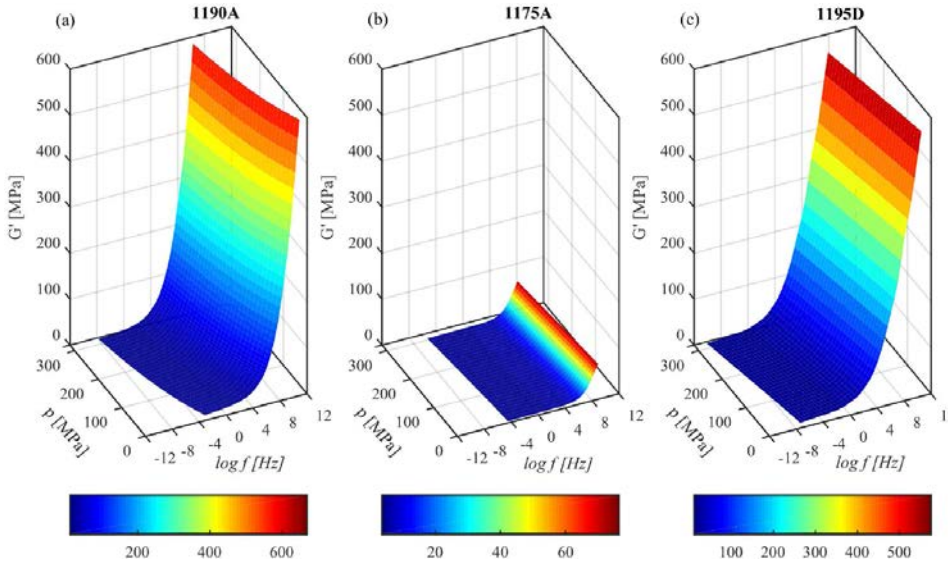

Figure 7. Frequency dependent shear storage modulus G'(ω) in dependence of hydrostatic pressure for (a) 1190A, (b) 1175A and (c) 1195D at Tref = 20°C.

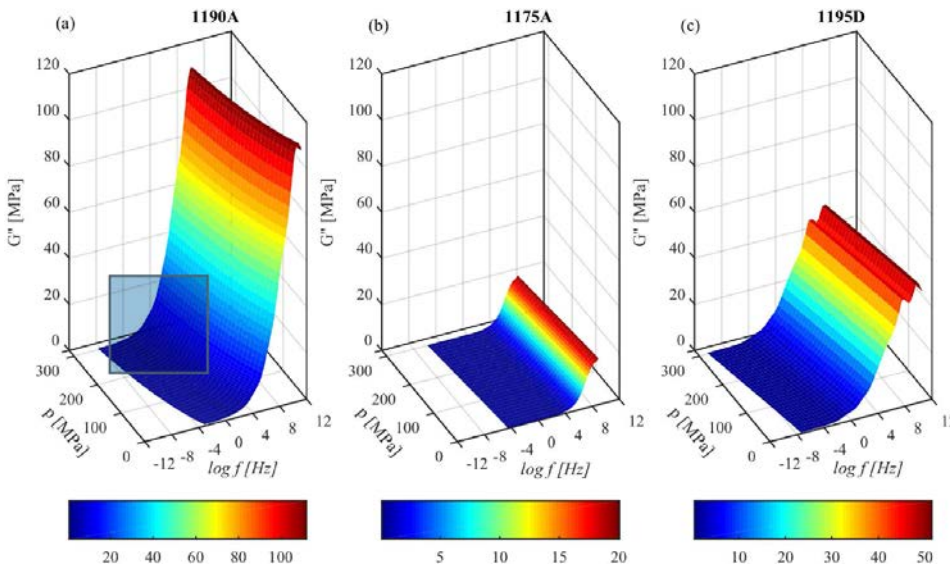

Figure 8. Frequency dependent shear loss modulus G"(ω) in dependence of hydrostatic pressure for (a) 1190A, (b) 1175A and (c) 1195D at Tref = 20°C.

Comparing the three diagrams in Figs. 7, we clearly see the huge difference between the three materials in the effect of pressure on improvement of isolation stiffness. Within the frequency range of interest TPU 1190A and TPU1195D are very sensitive, both, to pressure and to excitation frequency to which material (insulation) is exposed. In case of isolation energy absorption properties, displayed in Fig. 8, we again observe strong difference between the three materials, however, the effect of pressure is in this case even stronger and different than in the case of isolation stiffness.

High energy absorption and an increase of isolation stiffness caused by excitation frequency makes TPU 1190A a very attractive material for the new generation DGE damping elements. The two characteristics work hand-in-hand, high energy absorption diminishes vibrations per se, in addition an increase of isolation stiffness will move away mechanical system resonance frequency causing additional reduction of vibrations.

4. SUMMARY AND CONCLUSIONS

The paper presents analysis of pressure dependence of three Elastollan® materials, i.e., 1190A, 1175A, and 1195D in frequency domain, that are used in manufacturing of vibration insulation. The aim of the investigation was to analyze how much one can enhance performance of an insulation by using these materials in breakthrough Granular damping elements (GDE), that are based on the patented Dissipative bulk and granular systems technology. DGE insulation uses polymeric materials in granular form to enhance their dynamic properties by exposing them to hydrostatic pressure, which shifts material energy absorptions maximum towards lower frequencies, to match the excitation frequency of dynamic loading to which a mechanical system is exposed.

From the obtained results, one may draw the following conclusions:

- The three polyether-based thermoplastic polyurethane (TPU) materials from the Elastollan® 11 series, i.e., 1190A, 1175A, and 1195D, with similar chemical structure, exhibit significantly different frequency-dependent properties.
- All three materials are quite sensitive to pressure, and 1190A proofs to be the most sensitive of the three materials. At 300MPa, properties of 1190A are shifted along the logarithmic frequency scale for around 5.5 decades, for 1195D and 1175A this shift is only about 3.5, and 1.5 decades, respectively. These shifts may be achieved by exposing materials to selected hydrostatic pressure.
- The storage modulus $G'(\omega)$, which defines the vibro-isolation stiffness within the frequency range of interest, may be increased with pressure for about 100 times for 1190A and 1195D, and for about 10 times for 1175A.
- The loss modulus $G''(\omega)$, which defines the vibro-insulation energy absorption capability within the frequency range of interest, may be increased with pressure for again about 100 times for 1190A and 1195D, and for about 10 times for 1175A.

In conclusion, among the three measured materials it was shown that material 1190A seems to be the most promising for the use in Granular damping elements. Besides having the largest values of loss modulus $G''(\omega)$ it is also the most sensitive to pressure. Meaning, that even at relatively small applied hydrostatic pressures the increase of loss modulus $G''(\omega)$ is higher compared to the other two materials.

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Research paper
Doi 10.7251/STP1813043M ISSN 2566-4484

PHENOMENA OF INSTABILITY IN NON-CONSERVATIVE DYNAMICAL SYSTEMS

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Abstract:

If the loading is non-conservative, the loss of stability may not manifest itself as the system going into another equilibrium state, but as exhibiting oscillations of increasing amplitude. To take account of this possibility, we must consider the dynamic behavior of the system, because stability is essentially a dynamic concept. In the paper the author's theory, named the rheological-dynamical analogy (RDA), is used to examine the phenomena of instability in linear internally damped inelastic (LIDI) dynamical systems. Apart from quantitative research, qualitative research is presented to demonstrate the influence of inelasticity and internal friction on dynamic response.

Keywords: non-conservative loading; phenomena of instability; LIDI dynamical systems; RDA.

POJAVA NESTABILNOSTI U NEKONZERVATIVNIM DINAMIČKIM SISTEMIMA

Rezime:

Ako je opterećenje nekonzervativno, gubitak stabilnosti se možda ne manifestuje tako da sistem ide u drugo ravnotežno stanje, nego ispoljava oscilacije povećavajućih amplituda. Da bismo uzeli u obzir ovu mogućnost moramo razmatrati dinamičko ponašanje sistema, jer stabilnost je u suštini dinamički koncept. U ovom radu autorova teorija, pod nazivom reološko-dinamička analogija (RDA), se koristi za ispitivanje pojave nestabilnosti u linearnim interno prigušenim neelastičnim (LIPN) dinamičkim sistemima. Pored kvantitativnog istraživanja, kvalitativno istraživanje je predstavljeno da se pokaže uticaj neelastičnosti i unutrašnjeg trenja na dinamički odgovor.

Ključne reči: nekonzervativno opterećenje; pojava nestabilnosti; LIPN dinamički sistemi; RDA.

1. INTRODUCTION

The characterization of the internal friction and damping capacity of vibrating structures has traditionally been limited in structural dynamics because of the complexity of this problem both in terms of material and structure. The topic of damping has been a problem for quite a long time and it presents severe difficulty in view of physical damping mechanisms. Thus, reliable information on damping is as yet rather scanty [1]. All damping ultimately comes from frictional effects, which may however take place at different scales. But occasionally, the engineer uses damping devices designed to produce beneficial effects. Those devices can often be idealized as lumped objects, modeled as point forces or moments, and said to produce localized damping. One modeling complication is that friction may depend on fabrication or construction details that are not easy to predict; e.g., bolted versus welded connections. Damping models have been criticized by many investigators for various justified reasons and they cannot easily be used without a proper understanding of damping mechanisms [2]. The purpose of this paper is to investigate the stability or instability of LIDI systems due to the initial conditions in the material and various values of the modal damping ratio.

Damping analysis of LIDI systems includes two different classes, one involving the material damping, and the other damping the system under various conditions such as damage and sinusoidal loading. There have been detailed studies into the material damping [3], and also into energy dissipation mechanisms in structural elements [4, 5]. But here difficulty lies in representing these two mechanisms in different parts of the structure in a unified manner. In practice, engineering structures are usually complex, and their dynamic analysis is traditionally performed using the conventional finite element method (FEM). Finite element solutions in dynamics are obtained by employing two different methods [6, 7], the modal method and time marching schemes. In modal analysis, responses of individual modes are superimposed to determine the total response. Traditionally, energy dissipation in a structure is represented as an idealized viscous damping force (non-conservative force), i.e. a force directly proportional to the velocity of the corresponding dynamic system. In this case, the structure mass and stiffness matrices remain constant during the analysis and satisfy the well-known orthogonality conditions. If the damping matrix also satisfies the criterion of orthogonality, the equations of motion for a discretized multiple degree-of-freedom (MDOF) structure can be decoupled into *i* independent equations, one for each normal mode of the structure. Therefore, it is assumed that the modal damping matrix is diagonal, with the modal damping terms $2\xi_i\omega_i$. Ratio ξ_i is defined as the ratio of damping in mode *i* to the critical damping in mode *i*. Consequently, the modal analysis originally developed for undamped systems is used herein to analyze LIDI systems taking into account the viscoelastoplastic (VEP) modal damping ratios [2]. Note that this procedure directly delivers a diagonal modal damping matrix rather than the real damping matrix, which need not be explicitly constructed. To obtain the real damping matrix, mode orthogonality relations must be taken into account.

Nowadays, there is a growing interest in developing a theory which would enable the prediction of non-conservative forces using a unique mathematical formulation, which would include both the material and structural elements. This may be done using the RDA. The RDA inelastic theory has been developed to describe the dynamic response of structures using both the dynamic modulus and modal damping ratios [8, 9]. The dynamic modulus is obtained based on the concept of the complex modulus of VEP materials, whereas the modal damping ratios are obtained by observing critically damped dynamic

systems in the steady-state response. It has been proved that the dynamic modulus is equal to the tangent modulus at selected moments in time in some plastic materials [10]. Also, internal damping is a significant factor, considered as a damage variable in low-cycle fatigue. The investigation in the paper [2] shows that internal damping that is unevenly distributed over the elements of a structure causes deterioration of the material named the fatigue damage. The eigenvalues of a structure must first be solved for a dynamic system relieved of external masses, which is required to critically damp it. This is necessary in order to calculate the modal damping ratios for systems composed of consistent or lumped external masses. A system composed of external masses has its own eigenvalues. Also, the RDA is an analytical method whereby resonant frequencies may simply be calculated using the zero modal damping ratios.

The aim of this paper is to demonstrate the validity and applicability of the RDA theory to the problem of the loss of stability of LIDI dynamical systems as non-conservative mechanical systems.

2. VIBRATION AND INELASTIC INSTABILITY

2.1. STEADY-STATE RESPONSE AND THE DAMPING RATIO

The purpose of developing a mathematical model for the rheological behaviour of solids is to permit realistic results to be obtained from mathematical analyses of complicated structures under various conditions, such as sinusoidal, random, and transient loading. Here we consider a damaged long symmetrical rod (e.g., with a square or circular cross-section A_0) of length l_0 and mass density ρ. Let us assume that the load variation is sinusoidal, where Q_A is the amplitude and ω_Q is the frequency. Consider the single degree-of-freedom (SDOF) system of rod shown in Fig. 1.

The continuous model of a rod has only its own mass (m), and it may be modeled as a simple critically damped SDOF system shown in Fig. 1a) using the RDA. Consider the following sinusoidal law of stress,

$$\sigma = \sigma_0 + \sigma_A \sin\left(\omega_\sigma t\right) \tag{1}$$

with σ_0 being a constant and σ_A a variable component of the cycle. $\omega_\sigma = \omega_Q$ is the stress frequency.

The starting point of RDA analysis is the governing differential equation [11],

$$\begin{aligned} \ddot{\varepsilon} m + \dot{\varepsilon} c + \varepsilon k = \sigma_A \left(\frac{k}{E_H} + \frac{E_K + H'}{\gamma} - \omega_\sigma^2 \frac{m}{E_H} \right) \sin\left(\omega_\sigma t\right) + \\ + \sigma_A \left(\frac{c}{E_H} + \frac{\lambda_K + \lambda_N}{\gamma} \right) \omega_\sigma \cos\left(\omega_\sigma t\right) + \sigma_0 \left(\frac{k}{E_H} + \frac{E_K + H'}{\gamma} \right) - \sigma_Y \frac{E_K}{\gamma} \end{aligned} \tag{2}$$

where E_H is the elastic modulus, σ_Y the uniaxial yield stress, and $Y = \sigma_Y + H' \varepsilon_{vp}\left(t\right)$ the VEP yield condition. The four properties at fixed step times are the extensional viscoelastic viscosity λ_K, the extensional viscoplastic viscosity λ_N, the viscoelastic modulus E_K, and the viscoplastic modulus H'.

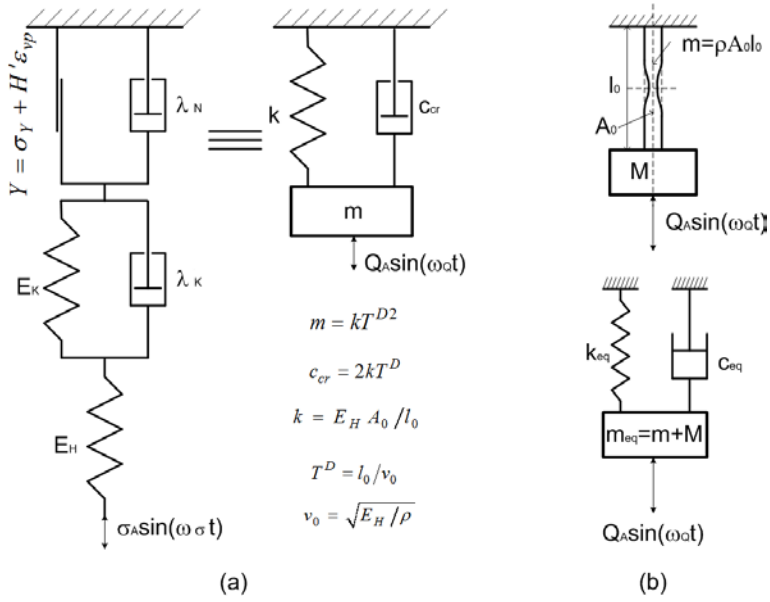

Figure 1. Models of rods: (a) a distributed critically damped RDA model; (b) an SDOF system

The particular solution (steady-state response) of the second-order governing equation in the case of critical damping ($E_K/\lambda_K = H'/\lambda_N$, $\lambda_K = E_K T_K$, $\lambda_N = H'T^*$, $T_K = T^* = T^D$) can be written as [12],

$$\varepsilon_p(t) = \frac{\sigma_A}{E_H}\sqrt{\frac{(1+\varphi)^2+\delta^2}{1+\delta^2}}\sin\left(\omega_\sigma t - \arctan\frac{\delta\varphi}{1+\delta^2+\varphi}\right) \tag{3}$$

where φ is the creep coefficient, $\delta = \omega_Q / \omega = T^D \omega_Q$ the relative frequency, and T^D the delay time.

First, we define a conservative mechanical system as one whose generalized forces are completely derivable from the potential energy function $Q_\alpha = -\partial V / \partial q^\alpha$ (principle of virtual work). Further, for non-conservative systems, non-conservative forces must be added. A discrete linear SDOF system is characterized by one resonant frequency, and it may comprise a single element of mass and one or more elements of stiffness, or a single element of stiffness and one or more elements of mass. Consequently, we can form a non-conservative SDOF system, as shown in Fig. 1b), which consists of its own mass and an attached external mass *M*, with the following equation of motion,

$$m_{eq}\ddot{u} + c_{eq}\dot{u} + k_{eq}u = Q_A \sin(\omega_Q t), \tag{4}$$

where

$$m_{eq} = m + M = m(1+\eta),\ c_{eq} = \xi c_{cr} = 2\xi\sqrt{k_{eq}m_{eq}},\ k_{eq} = E_R A_0 / l_0. \tag{5}$$

m_{eq} is the equivalent mass, where $\eta = M/m$ is the mass ratio, whereas the equivalent damping is denoted by c_{eq}, with ξ as the damping ratio. k_{eq} is the equivalent axial stiffness, through which the internal damping is included taking into account the dynamic modulus [10],

$$E_R = E_H \frac{1+\delta^2+\varphi}{(1+\varphi)^2+\delta^2}, \qquad \underset{\lim \delta \to 0}{E_R} = E_H \frac{1}{1+\varphi} \tag{6}$$

The natural ω^* and relative δ^* frequencies, respectively, are as follows,

$$\omega^* = \sqrt{\frac{k_{eq}}{m_{eq}}} = \omega \frac{1}{\sqrt{(1+\varphi)(1+\eta)}}, \tag{7}$$

$$\delta^* = \frac{\omega_Q}{\omega^*} = \frac{\omega_Q}{\omega}\sqrt{(1+\varphi)(1+\eta)} = \delta\sqrt{(1+\varphi)(1+\eta)}. \tag{8}$$

The well-know particular solution (steady-state response) is given by

$$u_p(t) = A\sin\left(\omega_Q t - \arctan\left(\frac{2\xi\delta^*}{1-\delta^{*2}}\right)\right). \tag{9}$$

Dynamic measurements supply information not only on the dynamic modulus E_R, but also on the phase or loss angle α. The loss angle is a measure of the amount of energy dissipated in the material during one cycle. The variation of the loss angle with frequency δ is shown in Fig. 2.

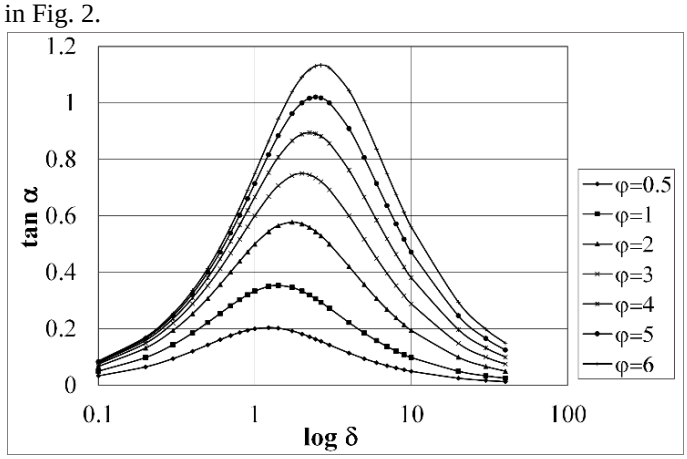

Figure 2. Variation of the loss angle with relative frequency δ

According to the principle of analogy [8], the phase angle at a point of a continuum must be described by both the critically damped RDA model and the corresponding SDOF system in the steady-state response. As a result, we can form an equality in order to obtain the VEP damping ratio based on the phase angle.

$$\frac{\delta\varphi}{1+\delta^2+\varphi}=\frac{2\xi\delta^*}{1-\delta^{*2}}\Rightarrow\xi=\frac{\delta\varphi\left(1-\delta^{*2}\right)}{2\delta^*\left(1+\delta^2+\varphi\right)}. \tag{10}$$

Fig. 3 (left) presents the modal damping ratio as a function of relative frequency δ for the creep coefficient $\varphi=2$ and three mass ratios η. The dependence of ξ on δ^* shows that ξ has negative values for $\delta^*\rangle 1$. As shown in Fig. 3 (right), the smaller the mass ratio, the greater the modal damping ratio. Similarly, the greater frequency δ^*, the smaller the modal damping ratio.

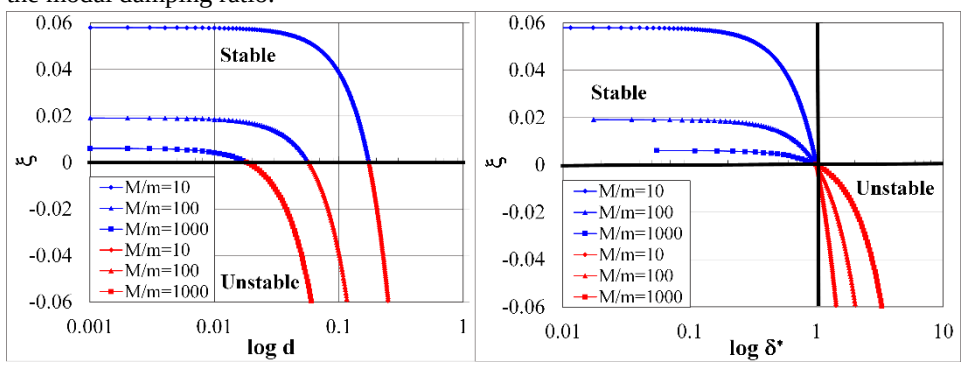

Figure 3. Variation of the VEP damping ratio with frequencies δ (left) and δ (right)*

2.2. COMPLEMENTARY SOLUTIONS

The usual form of the complementary solution is

$$u_h(t)=C_1e^{r_1t}+C_2e^{r_2t}, \tag{11}$$

where C_1 and C_2 are arbitrary constants determined by the initial conditions imposed on the system, and r_1 and r_2 are the roots of the auxiliary equation $m_{eq}\ddot{u}+c_{eq}\dot{u}+k_{eq}u=0$, $\omega^*=\sqrt{k_{eq}/m_{eq}}$ and $\xi=c_{eq}/2m_{eq}\omega^*$. Consequently,

$$r_1=\omega^*\left(-\xi+\sqrt{\xi^2-1}\right),\quad r_2=\omega^*\left(-\xi-\sqrt{\xi^2-1}\right). \tag{12}$$

These values of r may be real and distinct, real and equal, or complex conjugates, depending on the magnitudes of ξ.

2.2.1. Non-oscillatory stable motion, $\xi>1$

If ξ is greater than unity, the values of *r* are real and negative. Therefore, no oscillatory motion is possible according to the complementary solution of the equation of motion, regardless of the initial conditions u^0 and $\dot{u}^0$ imposed on the system. This is a case of overdamping of the system, where

$$u_h(t)=e^{-\xi\omega^*t}\left[u^0\cosh\hat{\omega}t+\frac{1}{\hat{\omega}}\left(\dot{u}^0+u^0\xi\omega^*\right)\sinh\hat{\omega}t\right], \tag{13}$$

and

$$\hat{\omega} = \omega^* \sqrt{\xi^2 - 1} \,. \tag{14}$$

2.2.2. Non-oscillatory critically damped stable motion, $\xi = 1$

If ξ is equal to unity, the values of *r* are equal to $-\omega^*$. Again, the motion is not oscillatory, and its amplitude will eventually diminish to zero. Here, the system is critically damped, where

$$u_h(t) = \left[u^0 + \left(\dot{u}^0 + \omega^* u^0 \right) t \right] e^{-\omega^* t} \,. \tag{15}$$

2.2.3. Stable motion oscillates about the equilibrium configuration and decays toward it, $1 > \xi > 0$

If ξ is less than unity, the values of *r* are complex conjugates. They are then

$$r_1 = \omega^* \left(-\xi + i\sqrt{1-\xi^2} \right), \quad r_1 = \omega^* \left(-\xi - i\sqrt{1-\xi^2} \right). \tag{16}$$

The complementary solution takes the following form,

$$u_h(t) = Be^{-\xi\omega^* t} \cos\left(\omega^d t - \arctan\left(\frac{\dot{u}^0 + u^0 \xi \omega^*}{u^0 \omega^d} \right) \right). \tag{17}$$

where

$$B = \sqrt{\left(u^0\right)^2 + \left(\frac{\dot{u}^0 + u^0 \xi \omega^*}{\omega^d} \right)^2} \,, \tag{18}$$

and

$$\omega^d = \omega^* \sqrt{1-\xi^2} \,. \tag{19}$$

This is a harmonic motion of the damped natural frequency ω^d, the amplitude $Be^{-\xi\omega^* t}$ of which decreases exponentially with time.

2.2.4. Harmonic oscillatory undamped stable motion, $\xi = 0$

The equation of motion of a dynamical system that is relieved of external masses ($\eta \to 0$) and made from an idealized purely elastic material ($\varphi \to 0$) becomes $m\ddot{u} + ku = 0$. Two initial conditions must appear in the general solution,

$$u_h(t) = u^0 \cos \omega t + \frac{\dot{u}^0}{\omega} \sin \omega t \,. \tag{20}$$

Physically, this equation represents an undamped free vibration. The angular natural frequency is

$$\omega = \sqrt{k/m} \,. \tag{21}$$

2.2.5. Unstable motion oscillates about and grows toward another equilibrium configuration, $-1 < \xi < 0$

If ξ is between -1 and 0, the complementary solution is given by

$$u_h(t) = e^{-\xi\omega^* t}\left(u^0 \cos\omega^d t + \frac{1}{\omega^d}\left(\dot{u}^0 + u^0\xi\omega^*\right)\sin\omega^d t\right). \tag{22}$$

This is a harmonic unstable motion, which oscillates about and grows toward another equilibrium configuration.

2.2.6. Unbounded non-oscillatory unstable motion, $\xi < -1$

If ξ is less than -1, the complementary solution is in terms of hyperbolic functions,

$$u_h(t) = e^{-\xi\omega^* t}\left[u^0 \cosh\hat{\omega}t + \frac{1}{\hat{\omega}}\left(\dot{u}^0 + u^0\xi\omega^*\right)\sinh\hat{\omega}t\right]. \tag{23}$$

This is non-oscillatory motion, and it is unstable and unbounded.

2.3. DYNAMIC CRITERIA FOR THE STABILITY AND INSTABILITY OF MOTION BY DAMPING RATIO

For the analysis of the stability of a mechanical system, the method of small vibrations is commonly used. The method entails the derivation of equations of motion for small displacements from the equilibrium state. Small displacements make it possible to take into account only those terms which are homogeneous and linear in the displacements or their derivatives. The homogeneous and linear equations derived in this manner have solutions whose dependence on time is characterized by their common factor e^{pt}.

The Liapunov definition of stability can thus be informally written as follows: *The equilibrium state under consideration is stable if and only if, for all solutions of this form, the real part of p is non-positive. Otherwise, it is unstable.*

All real dynamical systems in physics and engineering are characterized by stable steady state vibration, which involves the dissipation of some energy as heat, even if negative damping occurs, because of the member $(2\xi\delta)^2$ in the steady-state solution of vibration. In case of the negative damping ratio, the amplitude of complementary vibration, which is multiplied with member e^{pt}, will not subside due to this member. A mechanical system with a positive damping ratio can be called a dynamically stable system, whereas one with a negative ratio can be called dynamically unstable. Consequently, the dynamic stability and instability of mechanical LIDI systems can be defined using the damping ratio, Table 1.

Table 1. Dynamic criteria for the stability and instability of motion according to the daming ratio.

$\xi > 1$	Non-oscillatory stable motion
$\xi = 1$	Non-oscillatory critically damped stable motion
$1 > \xi > 0$	Stable motion oscillates about the equilibrium configuration and decays toward it
$\xi = 0$	Harmonic oscillatory undamped stable motion
$-1 < \xi < 0$	Unstable motion oscillates about and grows toward another equilibrium configuration
$\xi < -1$	Unbounded non-oscillatory unstable motion

Fig. 4 shows various types of motion as determined by the damping ratio.

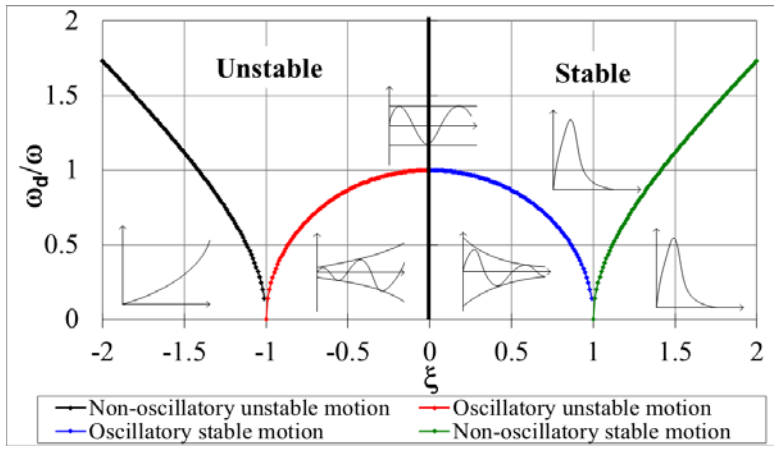

Figure 4. Various types of motion determined according to the damping ratio

3. RHEOLOGICAL-DYNAMICAL ASPECTS OF DAMAGE

Once the VEP damping ratio is determined, it can be formulated as a function of the greatest value of the loss angle,

$$\xi = \max \tan\alpha \frac{1-\delta^{*2}}{\sqrt{1+\eta}\left(1+\delta^2+\varphi\right)}. \tag{24}$$

Let us now consider the quasi-static loading ($\omega_Q \to 0$) of an LIDI system that is relieved of external masses ($\eta \to 0$),

$$\xi = \max \tan\alpha \frac{1}{1+\varphi}. \tag{25}$$

In this case the damping ratio depends of the creep coefficient only. As the creep coefficient φ is always higher than zero in accordance with the second law of thermodynamics, the damping ratio has a positive value. Therefore, a dynamical system is stable if quasi-static loading is applied.

The RDA approach used to consider both the initial (undamaged) and damaged state of the cylindrical rod for the analysis of the influence of Poisson's ratio on the creep coefficient has already been described in [12]. Fig. 5 presents a relation whose results are in excellent agreement with the experimentally obtained values.

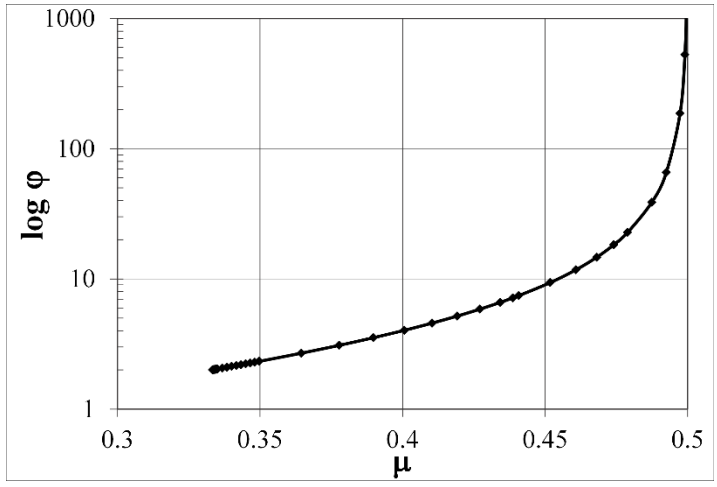

Figure 5. Variation of the creep coefficient with Poisson's ratio

Using the RDA inelastic theory, based on Bernoulli's energy theorem and assuming that $\varepsilon_E = \sigma_E/E_H = 0.001$, the creep coefficient is expressed by the formula

$$\varphi(\mu) = \left[\left(\frac{1}{1-0.001\mu}\right)^4 - 1\right]\frac{1}{2\cdot 0.001} \Bigg/ \left\{1 - \left[\left(\frac{1}{1-0.001\mu}\right)^4 - 1\right]\frac{1}{2\cdot 0.001}\right\}. \quad (26)$$

Eq. (26) can be simplified by neglecting the products of second-order exponents,

$$\left[\left(\frac{1}{1-0.001\mu}\right)^4 - 1\right]\frac{1}{2\cdot 0.001} = \frac{2\mu}{1-0.004\mu} \approx 2\mu\,. \quad (27)$$

Hence, the mathematical expression for obtaining the value of the creep coefficient from Poisson's ratio is

$$\varphi = \frac{2\mu}{1-2\mu}\,. \quad (28)$$

Poisson's ratio as defined in an idealized purely elastic material is an elastic constant. However, such a material is hypothetical because it does not exist in the strict sense of the word. In any mechanical deformation the deformation energy is not only stored elastically, but part of it is invariably dissipated by viscous forces, in accordance with the second law of thermodynamics. This dissipation is responsible for the time dependence of the mechanical properties of any real material. Consequently, the VEP Poisson ratio in the time domain chosen can be defined as suggested in [13],

$$\mu(t) = \mu_e - (\mu_e - \mu_g)e^{-\frac{t}{T^D}}, \quad (29)$$

where $\mu_e = 0.5$ and $\mu_g = 0.333$ are the equilibrium and instantaneous Poisson ratios, respectively.

Experiments with ductile mild steel show that the measured value of Poisson's ratio corresponds to the instantaneous value of 0.333. An axial fatigue experiment was performed on an isolated reinforced steel rod, l_0=50 cm, Φ=1.9 cm [12]. T^D = 0.0000967s

is the delay time for the steel rod (prototype). It has been proved that the limit of elasticity of ductile mild steel is in good accordance with the slenderness ratio of $l_0/i = 105.26$, where $i = \sqrt{I/A_0} = \Phi/4 = 0.475cm$. The critical stress at the limit of elasticity of the two-hinged rod is defined by Euler's formula $\sigma_E = \pi^2 E_H \big/ (l_0/i)^2 = 187MPa$, where E_H = 210000 MPa. Fig. 6 presents Poisson's ratio as a function of time for the steel rod (prototype).

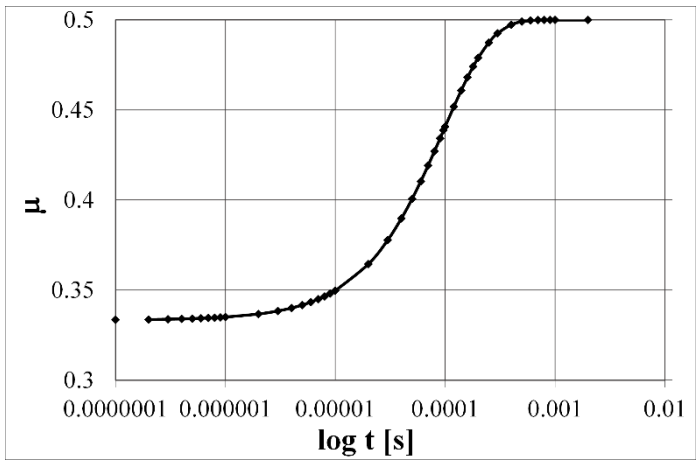

Figure 6. Poisson's ratio versus time for the steel rod (prototype)

At the limit of elasticity, the following equality has already been derived in [11],

$$\frac{\pi^2}{(l_0/i)^2} = \frac{\gamma\varphi}{(l_0/i)\left(i^3/I\right)}. \tag{30}$$

This is the intersection of Euler's and RDA buckling curves, which is important for determining the creep coefficient. Hence,

$$\varphi = \pi^2 \left(i^3/I\right) \frac{1}{\gamma(l_0/i)} = \pi^2 \cdot 0.1675315 \frac{1}{7.86 \cdot 10^{-3} \cdot 105.26} = 2.$$

The following symbols are used in the above expression, $i^3/I = 1/(\Phi \cdot \pi) = 0.1675315$ and γ, which is the specific gravity of steel. The value of the creep coefficient corresponds exactly to the value that can be obtained from Eq. (28) using $\mu_g = 0.333$,

$$\varphi_g = \frac{2\mu_g}{1 - 2\mu_g} = 2.$$

Knowing the value of $\mu(t)$, we can calculate the change in the volume of the rod under tension or compression. The relative change in the volume resulting from uniaxial extension is as follows [13],

$$\frac{\Delta V(t)}{V_0} = (1-2\mu)\varepsilon - \mu(2-\mu)\varepsilon^2 + \mu\varepsilon^3 . \tag{31}$$

In the above equation the viscoelastic (VE) strain in the case of critical damping is given as follows [11],

$$\varepsilon = \frac{\sigma_E}{E_H}\left[1+\varphi\left(1-e^{-\frac{t}{T^D}}\right)\right]. \tag{32}$$

Thus, $\Delta V(t)=0$ yields the traditional incompressibility relation for Poisson's ratio, $\mu_e = 0.5$, only if all higher strain terms are neglected. However, since for the majority of materials $\mu \langle 0.5$, tension is accompanied by an increase in the volume, and compression by a decrease in the volume. The change in the volume of the steel rod (prototype) with Poisson's ratio is shown in Fig. 7, where

$$\gamma(t) = 1 + \frac{\Delta V(t)}{V_0}. \tag{33}$$

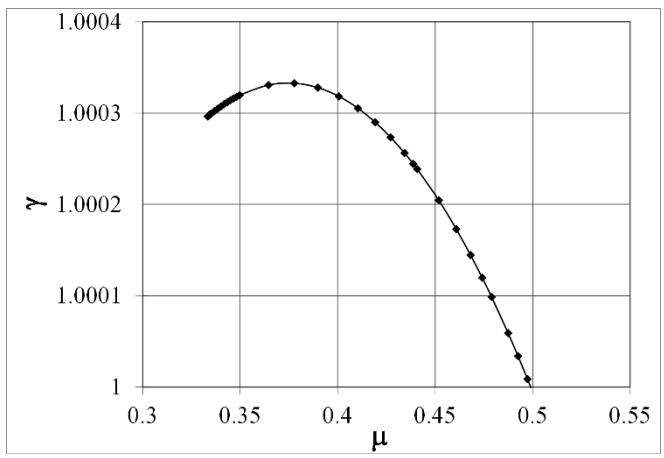

Figure 7. Relative change of volume versus Poisson's ratio for the steel rod (prototype)

Fig. 8 presents the variation of the greatest value of the loss angle with Poisson's ratio according to the expression

$$\max \tan\alpha = \mu\sqrt{\frac{1}{1-2\mu}} . \tag{34}$$

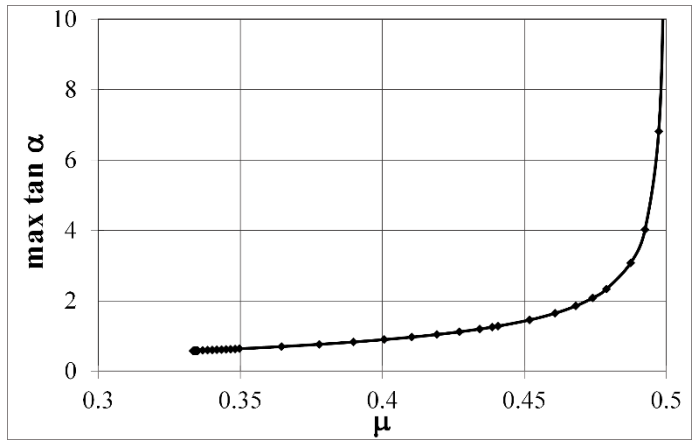

Figure 8. Greatest value of the loss angle versus Poisson's ratio

The relationship of the damping ratio versus Poisson's ratio is given by

$$\xi = \mu\sqrt{1-2\mu}\ . \tag{35}$$

The variation of the VEP damping ratio with Poisson's ratio is shown in Fig. 9.

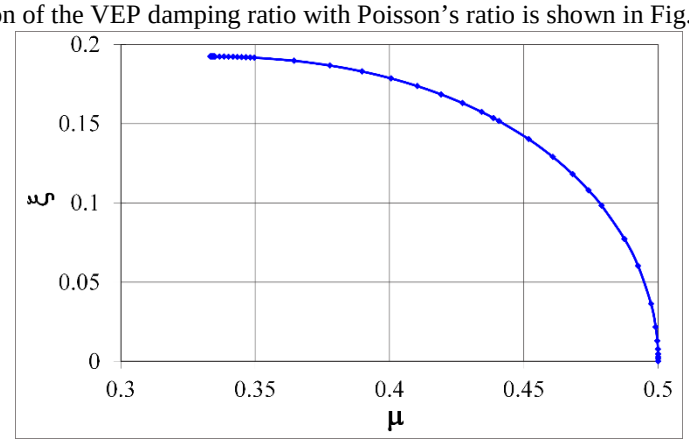

Figure 9. Damping ratio versus Poisson's ratio

The above analysis shows that any real material at the limit of elasticity is a VE material whose $\varphi \neq 0$ and which must thus be treated as damaged. Since the development of micro cracks induces a reduction in the stiffness of the material, the damage state can also be characterized by a variation in the elastic modulus [14]. If we suppose that the variation from an undamaged to a damaged state is equal to the dynamic modulus E_R, the damage variable can be defined as follows [15],

$$D = \frac{(1+\varphi)\varphi}{(1+\varphi)^2 + \delta^2}, \quad \underset{lim\delta\to 0}{D} = \frac{\varphi}{1+\varphi}. \tag{36}$$

Hence, the damage is described by a scalar variable D, which ranges between 0.666 and 1 in the case of the steel rod (prototype), Fig. 10.

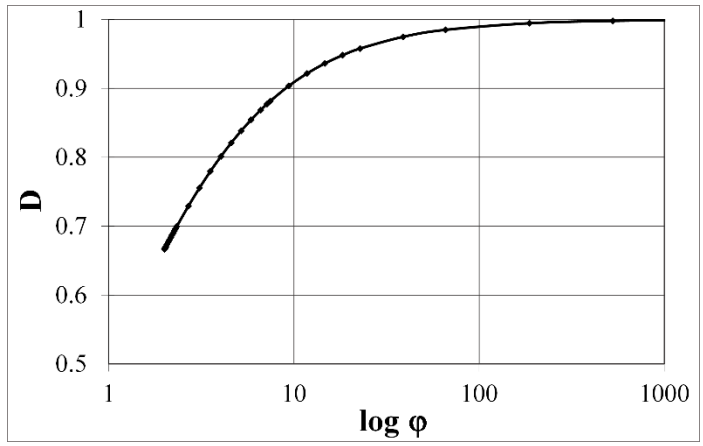

Figure 10. Damage variable versus the creep coefficient

Finally, Fig. 11 presents the variation of the VEP damping ratio with the damage variable according to the expression

$$\xi = \frac{D}{2}\sqrt{1-D}\,. \tag{37}$$

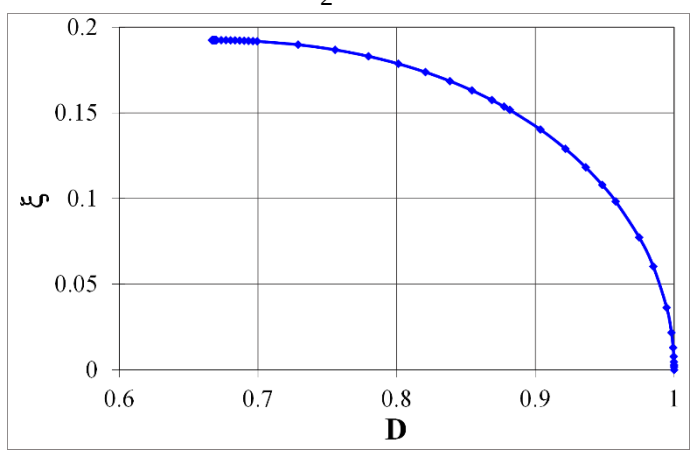

Figure 11. Damping ratio versus the damage variable

It is clearly seen from the above expressions that the values of the VE Poisson ratio play an important role in dictating the response in a given medium. Poisson's ratio is an elastic constant defined as the ratio of the lateral contraction to the elongation in the infinitesimal uniaxial extension of a homogeneous isotropic body. In a VEP material Poisson's ratio is a function of time [13]. The damping ratio decreases with time in a stable LIDI system if quasi-static loading is applied. Energy is usually dissipated as heat due to viscous forces. Therefore, the motion oscillates about the equilibrium configuration and decays toward it, whereas the total energy in the system decreases with time. Also, the RDA improves the prediction of instantaneous values of mechanical parameters at the limit of elasticity,

which are defined by Poisson's ratio only, i.e. $\mu_g = 0.333$, $\varphi = 2$, $\xi = 0.19245$, $D = 0.666$ and $E_R = E_H/3$.

4. PHENOMENA OF INELASTIC INSTABILITY BASED ON THE FREQUENCY OF EXCITATION

Resonance occurs when the damping ratio is zero, i.e. $\delta^* = \omega_Q / \omega^* = 1$, and it can be expressed as follows,

$$\omega_Q = \omega^* = \omega \frac{1}{\sqrt{1+\varphi}}. \tag{38}$$

When this happens, the amplitude of vibration increases without bound. In this case, motions are neutrally stable and present a transition between stable and unstable motions.

Fig. 12 presents the VEP damping ratio as a function of relative frequency, according to the expression

$$\xi = \frac{\varphi}{\sqrt{1+\varphi}}\left(1-\delta^{*2}\right) \Big/ 2\left(1+\frac{\delta^{*2}}{1+\varphi}+\varphi\right). \tag{39}$$

Three Poisson's ratios are used in this analysis. The dependence of ξ on δ^* shows that the VEP damping ratio has negative values for $\delta^* \rangle 1$. It means that the corresponding motion is unstable (marked with red).

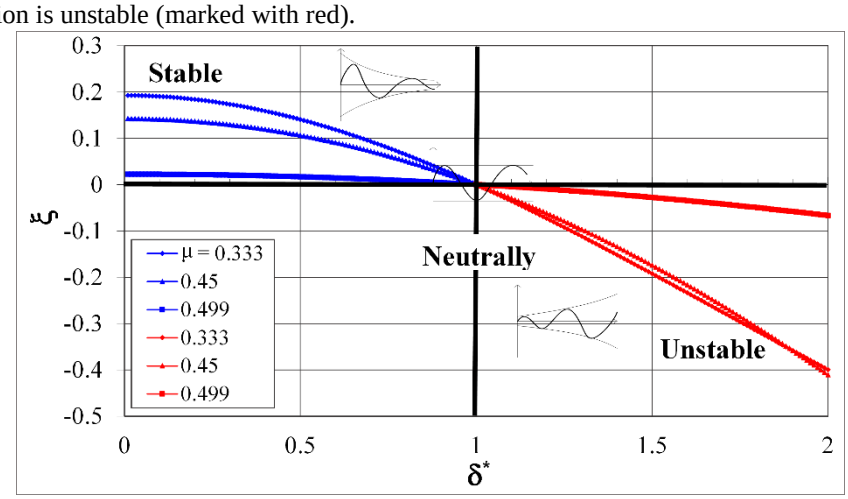

Figure 12. Damping ratio versus frequency δ^*: stable motion (blue) and unstable motion (red)

For the unstable LIDI system, energy must have been kept and added to the system because of the continuous increase in the amplitude of vibration. In this case, work is performed on a linear system by a viscous force due to the frequency of excitation, which must be higher than the resonant frequency. Therefore, the VEP damping ratio for the

unstable system must be negative. Unstable motion oscillates about the equilibrium configuration and grows toward another configuration.

Fig. 13 left shows the VEP damping ratio as a function of Poisson's ratio using three relative frequencies. Two motions are described with two lines, stable motion ($\delta^* = 0$, marked with blue), and unstable motion ($\delta^* = 2$, marked with red). The neutrally stable or resonant motion ($\delta^* = 1$) is marked with black. The highest value of the damping ratio ($\xi = 0.19245$) corresponds to the instantaneous Poisson ratio ($\mu_g = 0.333$) in stable motion. Fig. 13 right presents the VEP damping ratio as a function of the creep coefficient. The highest value of the damping ratio corresponds to the instantaneous creep coefficient ($\varphi = 2$).

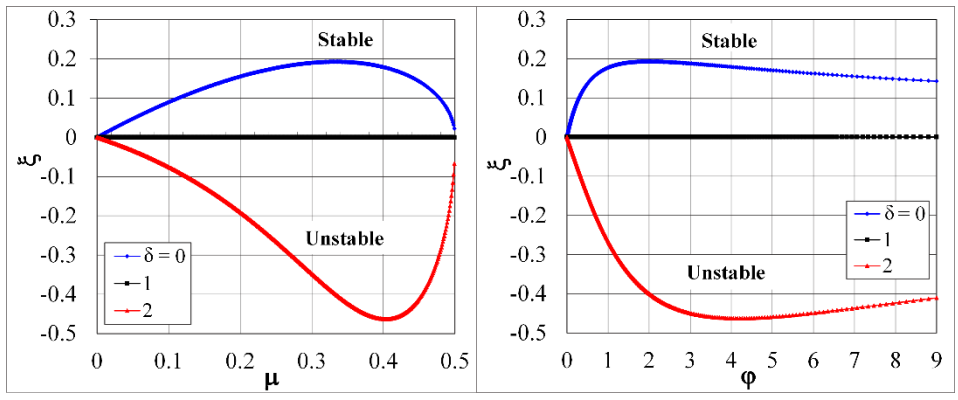

Figure 13. Damping ratio versus Poisson's ratio (left) and damping ratio versus the creep coefficient (right): stable motion (blue), unstable motion (red), and neutrally stable motion (black)

Consequently, the dynamic stability and instability of an LIDI mechanical system can be defined according to the value of the frequency of excitation, Table 2.

Table 2. Dynamic criteria for the stability and instability of motion based on the frequency of excitation.

$\omega_Q \langle \omega^*$	$\delta^* \langle 1$	$\xi \rangle 0$	Stable motion oscillates about the equilibrium configuration and decays toward it.
$\omega_Q = \omega^*$	$\delta^* = 1$	$\xi = 0$	Neutrally stable or resonant motion.
$\omega_Q \rangle \omega^*$	$\delta^* \rangle 1$	$-1 \langle \xi \langle 0$	Unstable motion oscillates about and grows toward another equilibrium configuration.
$\omega_Q \rangle \omega^*$	$\delta^* \rangle 1$	$\xi \langle -1$	Unbounded non-oscillatory unstable motion.

It should be noted that in the case of quasi-static loading, i.e. when the frequency of excitation is zero, the VEP damping ratio always has a positive value, and the LIDI system is stable. However, increasing the frequency of excitation even insignificantly may make the system unstable if damage growth is nonetheless sufficient, or if external mass is

added. Otherwise, in the case of dynamic loading and initial conditions in the material, when there is no growth of damage and no external mass is added, the main cause of instability is a rise of the frequency of excitation.

5. CONCLUSIONS

This paper presents the use of the RDA for a systematic study of the vibration and stability of LIDI dynamical systems. The current literature appears to ignore the true nature of damping mechanisms. Summarized below are the paper conclusions, with recommendations for work in areas which have so far been neglected. The following points are emphasized:

- In any mechanical deformation the deformation energy is not only stored elastically, but part of it is invariably dissipated by viscous forces, in accordance with the second law of thermodynamics. This dissipation is responsible for the time dependence of the mechanical properties of any real material.
- In VEP materials Poisson's ratio is a function of time that depends on the time regime chosen to elicit it. The function that has been suggested in [13] is used in this paper for the analysis of the steel rod (prototype). It is proved that the RDA improves the prediction of instantaneous values of mechanical parameters at the limit of elasticity.
- The RDA approach has already been used for the analysis of the influence of Poisson's ratio on the creep coefficient [12]. Hence, if the creep coefficient is to be used in conjunction with Poisson's ratio, it must be determined using Eq. (28).
- Because of the analogy, a critically damped RDA model has the same phase angle as the equivalent SDOF system in the steady-state response [8]. Therefore, if the VEP damping ratio is to be used in conjunction with the creep coefficient, it must be determined using Eq. (10).
- The dynamic stability or instability of an LIDI system can be defined as follows:

  $\xi \rangle 0$; Stable motion oscillates about the equilibrium configuration and decays toward it.

  $\xi = 0$; Neutrally stable or resonant motion.

  $-1 \langle \xi \langle 0$; Unstable motion oscillates about and grows toward another equilibrium configuration.

  $\xi \langle -1$; Unbounded non-oscillatory unstable motion
- The RDA is very efficient when applied to inelastic MDOF systems, because it reduces a material non-linear problem to a linear dynamic problem, which allows the use of modal analysis. On the other hand, the classical solutions are not in accordance with the actual damping mechanisms of LIDI systems. Note that this procedure assumes a constant damping factor typically lower than 10%.
- In the case of quasi-static loading, i.e. when the frequency of excitation is zero, the VEP damping ratio is always positive and the LIDI system stable.
- In the case of dynamic loading and initial conditions in the material, the main cause of instability is a rise of the frequency of excitation. However, for frequencies that are smaller than the smallest resonant frequency of the LIDI system, the motions of all DOF will be stable.

Acknowledgements
The work presented in this paper is a part of the investigation conducted within the research projects ON 174027 "Computational Mechanics in Structural Engineering" and TR 36017 "Utilization of by-products and recycled waste materials in concrete composites for sustainable construction development in Serbia: investigation and environmental assessment of possible applications", supported by the Ministry of Science and Technology of the Republic of Serbia. This support is gratefully acknowledged.

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03| Оригинални научни рад
Research paper
doi 10.7251/STP1813061Z ISSN 2566-4484

STUDY ON SEISMIC REINFORCEMENT MEASURES AND SCHEMES OF IRREGULAR FRAME STRUCTURES

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Abstract:

The SAP2000 finite element analysis software was applied to model the original frame and carry out the elasto-plastic time-history analysis method, with an existing irregular plane framework in Tianjin as the object of the study. Buckling-Restrained Brace (BRB) damping and anti-torsional reinforcement scheme was proposed based on the analysis results and the characteristics of the project. The results indicate that compared with the original frame, the period ratio of BRB frame was reduced by 26%; torsional displacement ratio was decreased by 15%; decreasing of inter-story displacement angle could reach 31%, and the maximum displacement angle of the top layer can be controlled within the scope of the code. BRB not only increases the anti-lateral stiffness of the structure, but also improves the seismic performance of the structure, which is an effective approach to control torsional effect of irregular structures.

Keywords: irregular plane, time-history analysis, BRB, seismic reinforcement

ISTRAŽIVANJE O SEIZMIČKIM MJERAMA I ŠEMAMA ARMIRANJA NEREGULARNIH OKVIRNIH KONSTRUKCIJA

Apstrakt:

Predmet istraživanja je postojeći neregularni ravanski okvir u Tjencinu. Modeliranje originalnog okvira i analiza elasto-plastičnog ponašanja u vremena izvršeni su programom na bazi konačnih elemenata SAP2000. Na osnovu rezultata analize i karakteristika konstrukcije predložena je šema prigušenja pomoću okvira sa dijagonalnim podupiračima otpornim na izvijanje (BRB – Buckling-Restrained Braces) i armiranja za torziju. Rezultati pokazuju da je, u poređenju sa originalnim okvirom, odnos perioda okvira sa dijagonalnim podupiračima (BRB frame) smanjen za 26%; odnos torzionog izvijanja je smanjen za 15%; smanjenje međuspratnog ugla torzije bi mogao dosegnuti 31%, a maksimalni ugao torzije posljednjeg sloja se može kontrolisati u okviru koda. Dijagonalni podupirači (BRB) ne samo da povećavaju bočnu krutost konstrukcije, već i poboljšavaju seizmička svojstva, što predstavlja efikasan pristup kontroli uticaja torzije na nepravilne konstrukcije.

Ključne riječi: nepravilna ravan, analiza u vremenu, , seizmičko armiranjeKljučne riječi: nepravilna ravan, analiza u vremenu, BRB, seizmičko armiranje

1. INTRODUCTION

Due to mis-alignment of rigidity center and center of mass, irregular plane structures[1] would generate obvious shear-torsion coupling effect encountering horizontal earthquake, making even worse earthquake damage of buildings, as well as structural damage even collapse. Therefore, the key to enhance seismic performance of torsional irregular structures is how to strengthen torsional stiffness of structures in aseismic design. In addition, braces were generally added in frame structures to dissipate earthquake energy in the case of improving fortification intensity, however, traditional brace-frame structures are easy to buckle when compressed under severe earthquake, thus the energy-dissipating capacity of which could not be fully exerted. Compared with brace-frame structures, Buckling Restrained Brace[2-3] (referred to as "BRB") could effectively solve the problem of misalignment of stiffness center and center of mass in irregular structures' floors, and also has good ductility, as well as stable and plump hysteretic feature, so as to ensure safety and normal usage of structures under severe earthquake. Studies of Prof. Guo Yanlin, Liu Jianbin from Tsinghua University[2], Prof. Zhou Yun from Guangzhou University[3], Dr. Jia Mingming from Harbin Institute of Technology[4] also indicated that BRB could greatly consume earthquake energy, and reduce displacement of the structure during earthquake.

Original earthquake fortification intensity in Tianjin was 7 degrees (0.15g), which was adjusted to 8 degrees in 2016 (0.2g)[5]. Thus, it's necessary to review seismic performance of certain specific existing buildings.SAP2000 finite element analysis software was used to model an existing irregular building located in Tianjin, and carried out elasto-plastic time-history analysis, BRB seismic reinforcement scheme was proposed,seismic performance of structures were compared and analyzed before and after reinforcement.

2. ANALYSIS OF PROJECT CASE

2.1. PROJECT PROFILE

The building is located in Tianjin, which is a ten-storied frame structure, and mainly used for offices, stores and hotel. Story height of the building could be divided into three sections, the 1st floor's height is 3.9m, story height from 2nd to 5th floor is 3.6m, story height of the 6th floor and above is 3m, total height is 33.3m,length of the structure from east to west is 42.8m, width from north to south is 23.4m, plane layout is in the form of letter L, belonging to the irregular building, the overall plan is as shown in Figure.1, main sectional dimensions of structural components and the corresponding strength grades of concrete are shown in Table 1. Original earthquake fortification intensity was 7 degrees, designed fundamental acceleration was 0.15g. As earthquake fortification intensity was enhanced to 8 degrees, designed fundamental acceleration was changed to 0.20g; site classification is Ⅱ class, design earthquake group is the 2nd group. Figure.1 Overall Plan

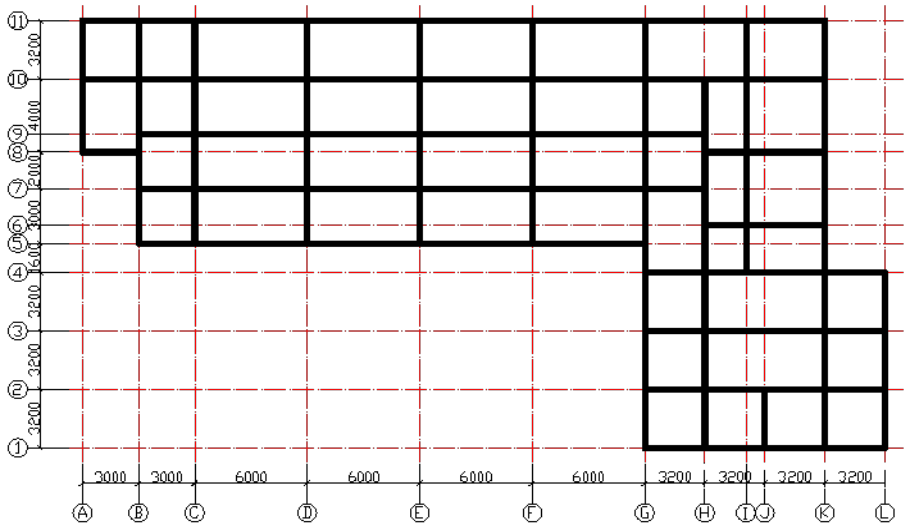


Figure 1. Overall Plan

Table 1. Sectional Dimensions of Components and Strength Grades of Concrete

Component	Floor	Sectional Dimensions	Concrete Strength Grades	Steel Strength Grades
Side Column in Frame	1～5F	700×700	C35	HRB400
	5～10F		C30	
Center Column in Frame	1～5F	600×600	C35	HRB400
	5～10F		C30	
Main Beam in Frame	1～5F	300×500	C35	HRB400
	5～10F		C30	
Secondary Beam in Frame	1～5F	200×400	C35	HRB400
	5～10F		C30	

2.2. MODELING AND SEISMIC PERFORMANCE ANALYSIS

SAP2000[6] was used to model and analyze the original frame. linear bar element was adopted to simulate both beams and columns in the frame, shell element was adopted to simulate floorboard. To rationally reflect overall stiffness of the frame, floorboard of each floor was uniformly set to be rigid clapboard. Overall model of the original frame is as shown in Figure.2, constitutive relations of steel and concrete used are as shown in Figure. 3 and Figure. 4.

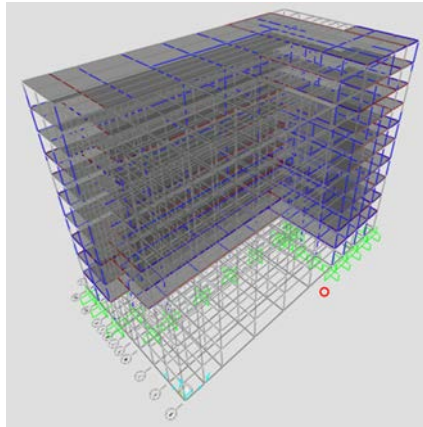


Figure 2. Overall Model of the Original Frame

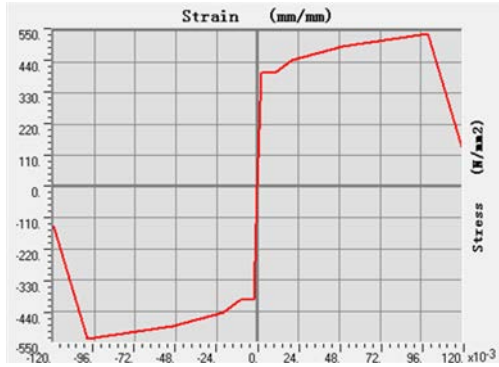


Figure 3. Constitutive Relation of Steel

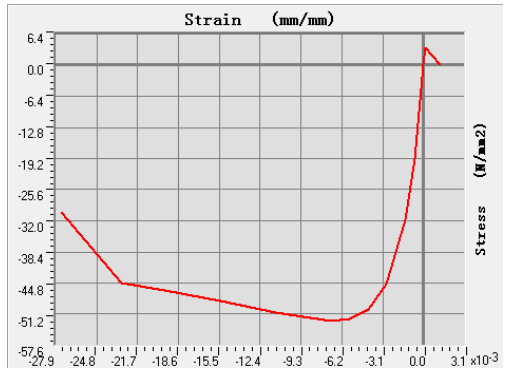
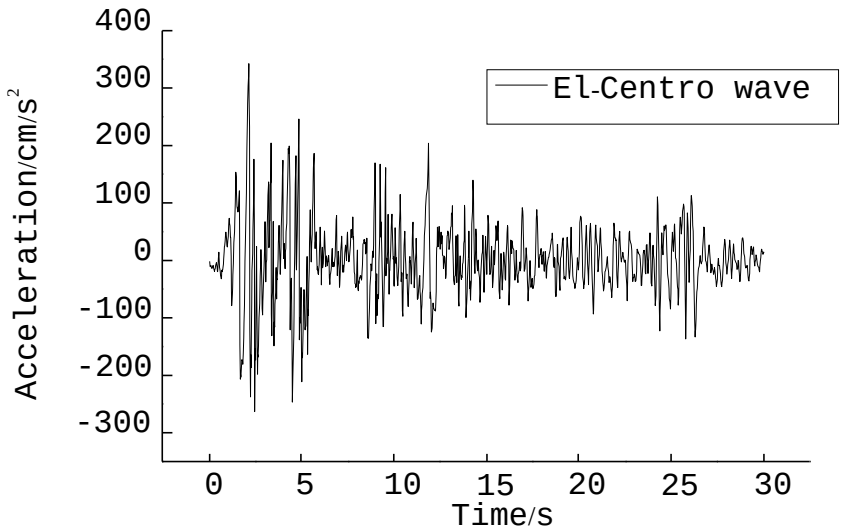


Figure 4. Constitutive Relation of Concrete

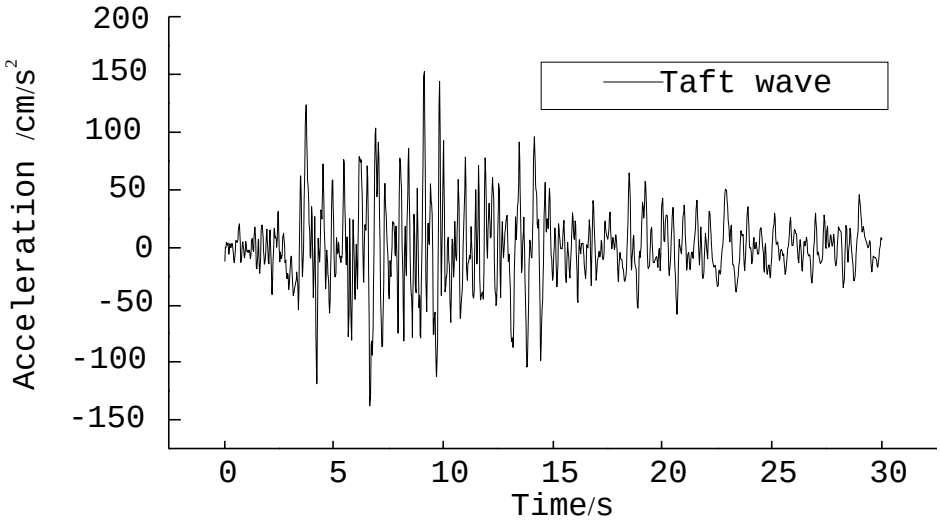
According to requirements of "Code for seismic design of building" (GB 50011-2016)[5], El-Centro wave and Taft wave, as well as an artificial simulated seismic wave were selected for time-history analysis under 7 degrees frequent earthquake, 8 degrees frequent earthquake and 8 degrees rarely occurred earthquake[7]. Three kinds of seismic wave acceleration time-history curve are shown in Figure.5. According to the Code, acceleration peak values of the three seismic waves were adjusted to a certain extent, and the adjustment coefficients are shown in Table 2.

Table 2. Adjustment Coefficients of Acceleration Peak Values of the Three Seismic Waves

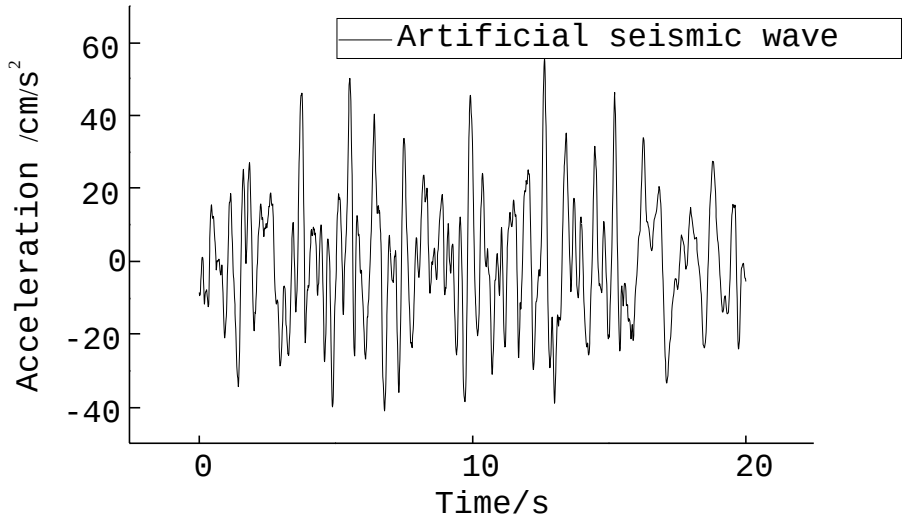
	El-Centro Wave	Taft Wave	Artificial Seismic Wave
Frequent earthquake (7 degrees)	1.02	2.23	6.31
Frequent earthquake (8 degrees)	2.05	4.47	12.62
Rarely occurred earthquake (8 degrees)	11.71	26.20	72.09



(a) Acceleration time-history curve of El-Centro wave



(b) Acceleration time-history curve of Taft wave



(c) Acceleration time-history curve of artificial seismic wave

Figure 5. Three kinds of seismic wave acceleration time-history curves

2.3. RESULTS OF THE ORIGINAL FRAME

The former six order modes of the original frame were chosen for modal analysis, the original frame Tl =1.498s, taking translation in Direction Y as principal; while T2=1.378s, taking translation in Direction X as principal; T3=1.265s, taking torsion as principal; period taking the first torsion as principal Tt=1.265s, then: Tt/Tl =1.265/1.498=0.84<0.90, meeting the requirements of seismic code.

Interlayer displacement angles of part of the original frame floors under El-Centro wave and Taft wave, as well as artificial seismic wave during 8 degrees frequent earthquake were showed in Table 3. The interlayer displacement angles from 1st to 6th floor of the original frame under the action of 8 degrees frequent earthquake obviously exceeded the required 1/550; although torsional displacement ratio of the original frame under the action of 8 degrees frequent earthquake was smaller than the limiting value 1.5 of “Technical specification for concrete structures of tall building”(JGJ3-2010)[8], it’s nearly greater than the suggestive value 1.2 of “Technical specification for concrete structures of tall building”.

Table 3. Inter-layer displacement angles of part of the original frame floors under 8 degrees frequent earthquake

Floor	El-Centro wave		Taft wave		Artificial Seismic Wave	
	X	X	Y	X	X	Y
1	1/620	1/652	1/616	1/652	1/652	1/616
2	1/466	1/519	1/509	1/519	1/519	1/509
3	1/475	1/537	1/511	1/537	1/537	1/511
4	1/503	1/549	1/516	1/549	1/549	1/516
5	1/559	1/594	1/548	1/594	1/594	1/548
6	1/730	1/777	1/705	1/777	1/777	1/705

3. REINFORCEMENT SCHEMES SELECTION AND DESIGN

It is necessary to reinforce the original frame as the interlayer displacement angles from 1st to 6th floor of the original frame did not meet the requirements of the specification, while torsional displacement ratio exceeded suggestive value of the specification,. As the project is a comprehensive office building, as long as the building process equipment layout was determined, there would be hardly any room for changing the body type and structural arrangement, it’s not suitable to arrange shear walls either in the north or in the east; as for enhancing weakness part of the frame through increasing sectional size of the beams and columns, although seismic performance of the original frame could meet the specification requirements, the caused "large beams and large columns" would not only bring inconvenience to building use, but also lead to brittle failure of the frame on account of oversized stiffness; although the addition of conventional braces could achieve the purpose of seismic strengthening under the action of frequent earthquake, the braces would be extremely easy to be compressed and buckled under the action of rarely occurred earthquake, and be unable to give full play to tensile behavior of the steel. To sum up, BRB is the best choice for this project, which could not only improve lateral stiffness of the frame, but also adjust torsional deformation of the frame, as well as reduce brace section and shear force of the node area.

In order to give full play to BRB, the brace should be arranged as far away from rigidity center as possible, to increase torque and improve torsional rigidity. The arrangement form is as shown in Figure. 6: arrange totally 33 BRBs at 8-11 of Axle A and 10-11 of Axle K from 1st to 6th floor, G-H and J-K of Axle 1 and J-K of Axle 11 from 1st to 5th floor.

Wen element was adopted to simulate BRB. Q235 cross section steel was applied, the elasticity modulus of which was E=200GPa, the length was 5000mm, the cross sectional area of each floor was equal, which is 3.96×10-2m2, and the yield bearing capacity was estimated to be 3500kN. The damping coefficient was 2000kN•s/m, the damping exponent was 0.5, Poisson's ratio was 0.3, with the connection type of Multilinear-plastic. The connecting format was hinge joint, diagonal bracing was used for arrangement.

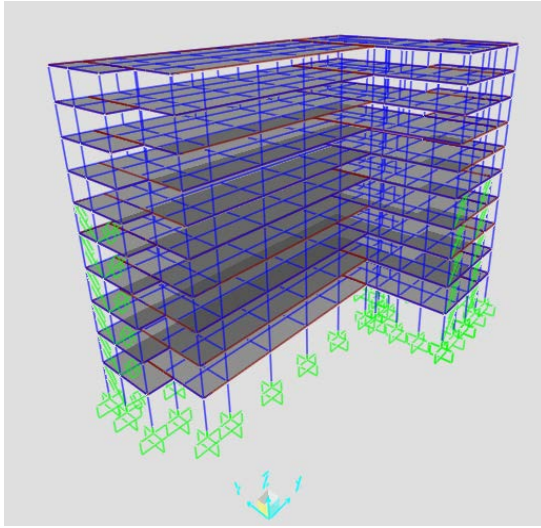


Figure 6. Arrangement Form of BRB

4. STRUCTURAL SEISMIC PERFORMANCE ANALYSIS UNDER THE 8 DEGREES FREQUENT EARTHQUAKE

4.1. RESULTS OF THE ORIGINAL FRAME

The former six order modes of BRB frame were chosen for modal analysis, the results are shown in Table 4.

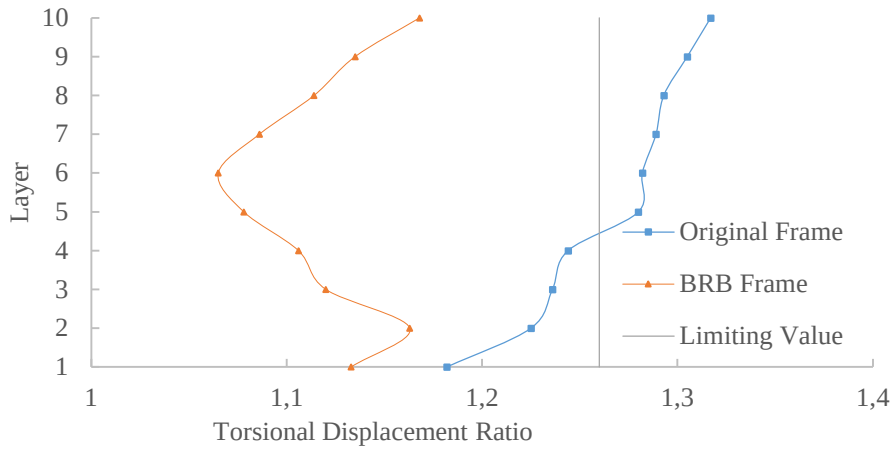
Table 4. Structural Periods of BRB Frame

Mode No.	BRB Frame	Type
1	1.1829	X
2	0.8680	Y
3	0.8330	T
4	0.4515	X
5	0.3268	Y
6	0.2813	T
Torsional Period Ratio	0.7	

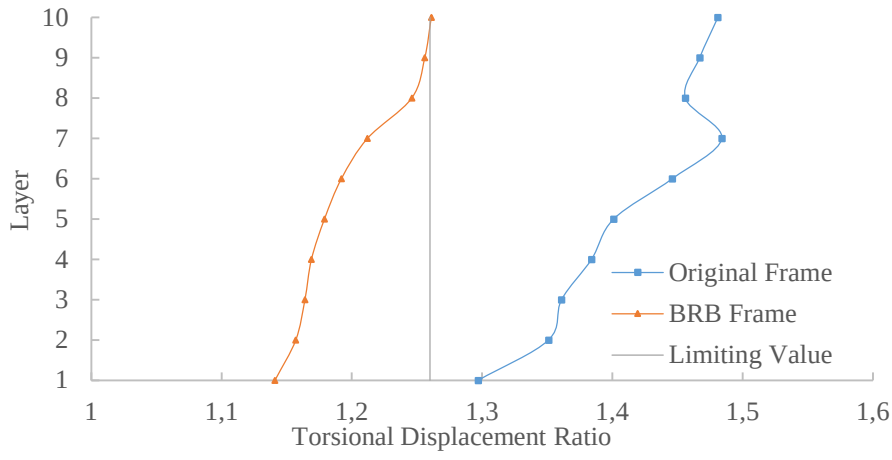
As shown in Table 4, the BRB frame T1=1.1829s, Tt=0.8330s, and the period ratio is only 0.70, which is decreased by 26.3% compared with the original frame. In addition, period of each order of vibration mode of BRB frame decreases, indicating that the lateral stiffness of the frame is improved, and the torsion phenomenon is controlled.

4.2. TORSIONAL DISPLACEMENT RATIO

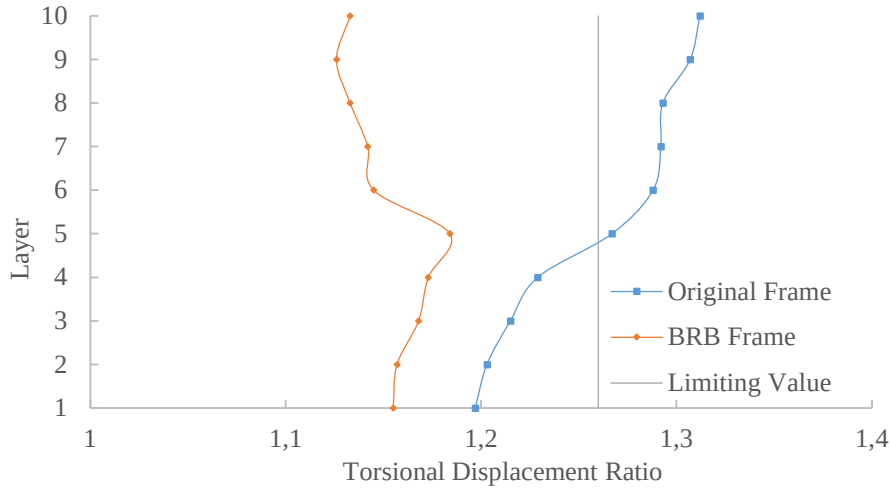
Torsional displacement ratio should also be controlled for the torsional irregular structure, as torsional displacement ratio could directly reflect the torsional linearity of the frame, in addition to the control of period ratio[9]. Figure. 7 shows torsional displacement ratios of both the original frame and BRB frame under three kinds of seismic wave.



(a) under the action of El-Centro wave



(b) under the action of Taft wave



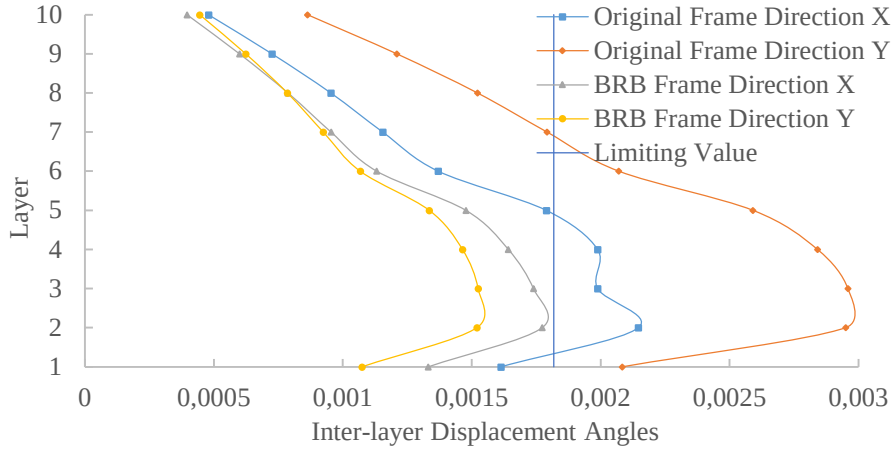
(c) under the action of artificial seismic wave

Figure 7. Torsional displacement ratios under the 8 degrees frequent earthquake

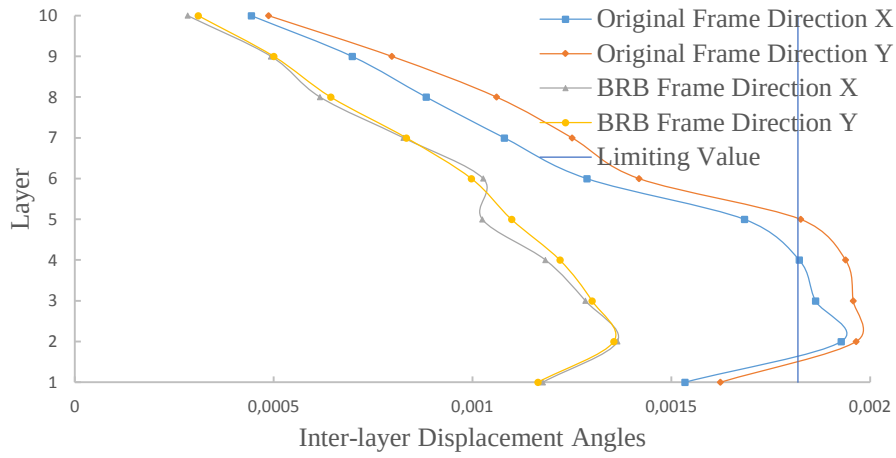
As shown in Figure. 7, torsional displacement ratio of BRB frame is 11% lower than that of the original frame under the action of El-Centro wave, while 15% under the action of Taft wave, and 15% under the action of artificial seismic wave, indicating that displacement ratio could be decreased through reasonable layout of BRB, while the uneven rigidity distribution of the original frame could be improved.

4.3. COMPARISON OF INTER-LAYER DISPLACEMENT ANGLES

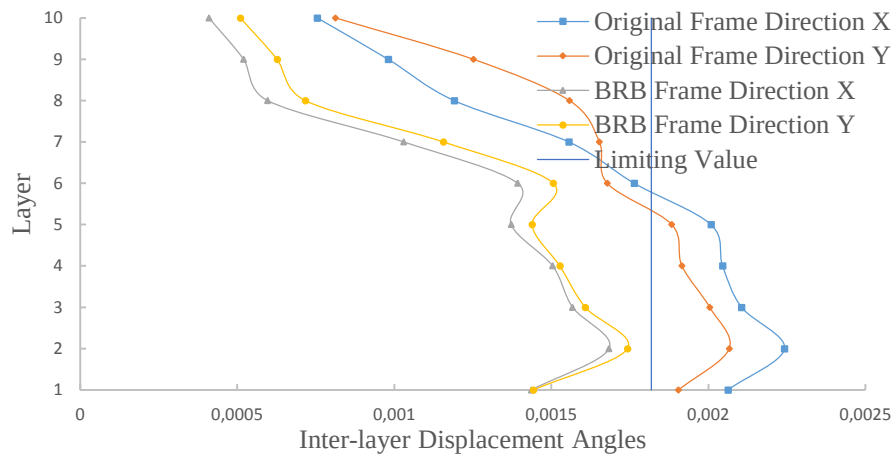
The differences of interlayer displacement angle was shown in Figure8 between the original frame and BRB frame under the action of 8 degrees frequent earthquake through time-history analysis.



(a) under the action of El-Centro wave



(b) under the action of Taft wave



(c) under the action of artificial seismic wave

Figure 8. Inter-layer displacement angles under the action of 8 degrees frequent earthquake

Interlayer displacement angles is obviously non-conforming to the required 1/550 in "Technical specification for concrete structures of tall building" from 1st to 6th floor of the original frame under the action of 8 degrees frequent earthquakeAs for the BRB frame, horizontal displacement of the floors is greatly decreased compared to that of the original frame, and the rigidity changing among floors is more even. Thereinto, interlayer displacement angle decreases by 16% in Direction X under the action of El-Centro wave, interlayer displacement angle decreases by 28% in Direction Y, interlayer displacement angle decreases by 29% in Direction X under the action of Taft wave, interlayer displacement angle decreases by 31% in Direction Y, interlayer displacement angle decreases by 25% in Direction X under the action of artificial seismic wave, interlayer

displacement angle decreases by 16% in Direction Y, which all meet the requirements of the specification.

5. STRUCTURAL SEISMIC PERFORMANCE ANALYSIS UNDER THE 8 DEGREES RARELY OCCURRED EARTHQUAKE

According to the requirements of “Code for seismic design of building”and “Techinical specification for concrete structures of tall building”, plasticity development of the frame should be analyzed through elasto-plastic time-history analysis under the action of 8 degrees rarely met earthquake. El-Centro wave,Taft wave, and artificial seismic wave should be input the same as in the case of 8 degrees frequent earthquake to simulate seismic action during the elasto-plastic time-history analysis under the action of 8 degrees rarely met earthquake,

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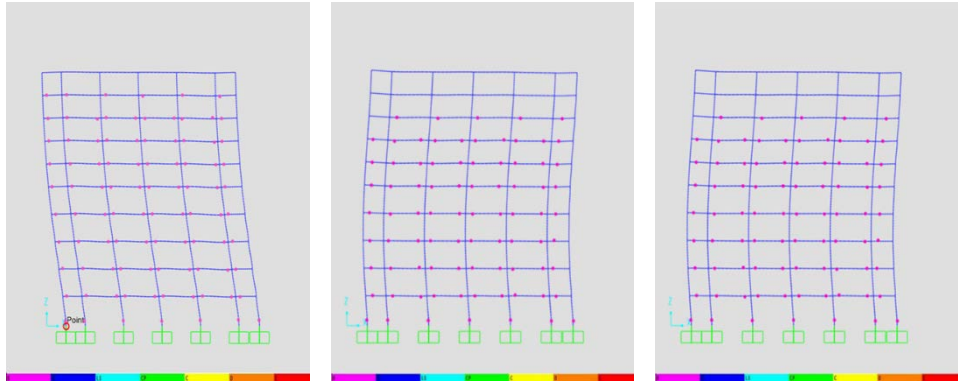
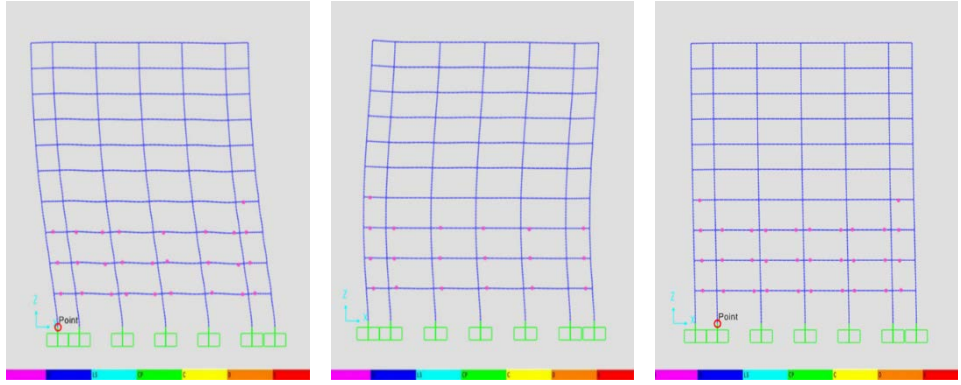
5.1. PLASTIC HINGES DISTRIBUTION

Plastic hinge development of the original frame and BRB frame is shown in Fig.9 and Fig.10 under the action of 8 degrees rarely met earthquake respectively.



(a) under the action of El-Centro wave *(b) under the action of Taft wave* *(c) under the action of artificial seismic wave*

Figure 9. Plastic hinges forming diagram of the original frame under the action of 8 degrees rarely occurred earthquake



(a) under the action of El-Centro wave *(b) under the action of Taft wave* *(c) under the action of artificial seismic wave*

Figure 10. Plastic hinges forming diagram of the BRB frame under the action of 8 degrees rarely occurred earthquake

Compared plastic hinge forming diagram of the original frame with that of the BRB frame, it could be found that: under the effect of three kinds of seismic wave, plastic hinge of BRB frame basically appeared on the beams, hardly on the columns, which verified that BRB frame conforms to seismic requirements of "strong column and weak beam". Moreover, the number of hinge of BRB frame was obviously smaller than that of the original frame, which indicated that BRB frame fully exerted the characteristics of good dissipation capacity under the action of 8 degrees rarely met earthquake.

5.2. TOP DISPLACEMENT COMPARISON

The top displacement could more visually describe the damping and anti-torsional effect of the original frame after adding BRB.The top displacement values of the original frame and BRB frame is shown in Table 5 under three kinds of seismic wave.

From Table 5,the top maximum displacement value of the BRB frame is significantly smaller than that of the original frame under the action of 8 degrees rarely occurred earthquake, and the overall changing trend is obvious. Interlayer displacement angle of the original frame under the action of El-Centro wave, Taft wave, and artificial seismic wave exceeded the required 1/50, while interlayer displacement angle of BRB frame under the action of three kind of seismic wave could not only be controlled within 1/50, but also be controlled within the suggested 1/80 in literature [10], indicating that compared to the original frame, seismic performance of BRB frame could be greatly improved during the phase of rarely met earthquake.

Table 5. Top maximum displacement under the action of 8 degrees rarely occurred earthquake

Seismic Wave	Top Maximum Displacement in Direction X		Inter-layer Displacement Angles of Original Frame	Inter-layer Displacement Angles of BRB Frame	Top Maximum Displacement in Direction Y		Inter-layer Displacement Angles of Original Frame	Inter-layer Displacement Angles of BRB Frame
	Original Frame	BRB Frame			Original Frame	BRB Frame		
El-Centro Wave	66.51	11.02	1/45	1/272	46.21	13.11	1/65	1/229
Taft Wave	69.76	17.65	1/43	1/170	52.34	20.87	1/57	1/143
Artificial Seismic Wave	26.92	9.68	1/111	1/310	17.56	8.67	1/171	1/346

6. CONCLUSIONS

(1) As for irregular plane frame, BRB could be the dissipative members to reduce structural seismic response, and enhance structural rigidity, while further reduce structural torsional effect through rational plane layout, to protect the main structure well.

(2) As for irregular plane frame in high intensity area, BRB could be used for reinforcement of the original frame, on the basis of meeting requirements of aseismic design, which could provide a simple and effective approach for seismic reinforcement of similar structures without changing the original building outline.

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04| Оригинални научни рад
Research paper
doi 10.7251/STP1813078L ISSN 2566-4484

ЕКСПЕРИМЕНТАЛНА И НУМЕРИЧКА АНАЛИЗА ЈЕДНОСТАВНОГ МОДЕЛА РАМОВСКЕ КОНСТРУКЦИЈЕ СА ПРИГУШИВАЧЕМ СА УСКЛАЂЕНИМ КРЕТАЊЕМ ВОДЕ

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Резиме:

У овом раду је укратко дат осврт на врсте, принципе рада и анализе система за пригушивање вибрација инжењерских конструкција, са акцентом на усклађеним пригушивачима. Изложени су резултати експерименталне и нумеричке анализе алуминијумске скелетне конструкције побуђене заданим почетним помјерањем. Динамички параметри (сопствене фреквенције и пригушења), добијени мјерењима на основном експерименталном моделу, поређени су са нумеричким моделом, а затим су вршена међусобна поређења параметара различитих варијанти експерименталног модела. Анализирани су и упоређени одговори модела са и без система за пригушивање. Као пригушивач је кориштена посуда са водом постављена на врх конструкције. Вариран је ниво воде у посуди, као и положај резервоара у односу на правац побуде. За све варијанте модела, приказане су вриједности прве и друге сопствене фреквенције у правцу побуђивања те су процијењене вриједности пригушења.

Кључне ријечи: експериментална динамичка анализа, пригушење, усклађено кретање воде

EXPERIMENTAL AND NUMERICAL ANALYSIS OF A SIMPLE FRAME STRUCTURAL MODEL WITH TUNED LIQUID DAMPER

Abstract:

In this paper, a brief overview of damping systems and their operation and analysis principles is provided, with emphasis on tuned damping systems of engineering structures. The results of the experimental analysis are presented for an aluminum frame structure excited with initial displacement. The measured dynamic parameters (eigenfrequencies and dumping factors) of the basic experimental model are compared with the numerical model values. Furthermore, the comparison of the results obtained for

different variants of the experimental model are shown. Responses of models with and without the damping device are considered. A water reservoir placed on top of the structure is utilized as a damping device. The water level in the reservoir and orientation of the reservoir with respect to the direction of excitation force are varied. For all model variants, the values of the first and the second eigenfrequencies in the direction of excitation are shown and the corresponding damping values are estimated.

Keywords: experimental dynamic analysis, damping, tuned liquid movements

1. INTRODUCTION

Contemporary skyscrapers are extremely flexible structures whose dynamic analysis is of extreme importance. The swaying of a building can be disturbing for inhabitants and many devices are introduced to diminish its effect. These devices are called dampers and their main purpose is to control earthquake and wind-induced vibrations in buildings. However, they can meliorate the behavior of the building in response to other types of dynamic excitations, too.

Earthquakes can cause excessive random oscillations for many types of buildings. Nevertheless, the wind, in some regions, is a dominant load for the design of flexible high-rise buildings because of their high oscillation period.

The influence of the damper on structural response is often analyzed in literature. One of the most comprehensive research is given by Koščak and Turkalj in [1]. They experimentally analyzed the dynamical characteristics of a multistory frame structure model and compared it with a numerical model. Additionally, the influence of a water reservoir and pendulum with corresponding mass is examined.

Also, a study of tuned liquid mass dampers performance test is given in [2]. Authors of this study focused on reduction of a bi-directional response of a building. Firstly, they tested a small-scale model of tuned liquid mass dampers using a shaking table. By changing direction of a damper, relative to the direction of excitation, they simulated behavior of a tuned liquid column damper and a tuned mass damper. After detail analysis of obtained results, they manufactured a full-scale damper and performed testing on a five story steel building. Interesting study is given in [3], where authors developed a 3.7-ton transmission system with one degree of freedom. It had adjustable dynamic characteristics in order to simulate structures natural frequencies between 0.7 and 2 Hz and to validate tuned liquid dampers' properties.

The paper is organized as follows. Next section deals with some basic concepts of structural damping devices. The third section gives brief description of physical and numerical model and it is followed by concise explanation of experiment setup. Results and discussion are given in fifth section, while the conclusions are made at the end section.

2. STRUCTURAL DAMPERS

When structural damping devices are considered, we can distinguish passive damping devices and tuned systems. Passive damping devices include metallic, friction, viscous and viscoelastic dampers. Tuned systems include mass dampers and they are also called tuned dampers because the natural frequencies of these devices are tuned to be equal or similar to the natural frequencies of the structure to which they are attached. Herein, the focus is on this type of dampers, but few words are also given about passive damping devices.

Friction dampers are devices for which the accumulated energy is spent on overcoming friction at the contact surfaces, Fig. 1a. In metallic dampers, energy is spent on inelastic deformation of components, Fig. 1b. For passive visco-elastic dampers, materials used are usually polymers that dissipate energy by shear strain. An example is displayed on the Fig. 1c, where the visco-elastic material is located between steel plates. The relative displacement of the outer plates in relation to the center plate results in a dissipation of energy in the layer of highly elastic material. Dry or visco-elastic friction-

based dampers use solid body properties to dissipate energy, but fluids can also be used. When fluids are utilized, dissipation depends on the viscosity of the fluid – viscous pot dampers, or density of the fluid – viscous orifice dampers, Fig. 1d, [4].

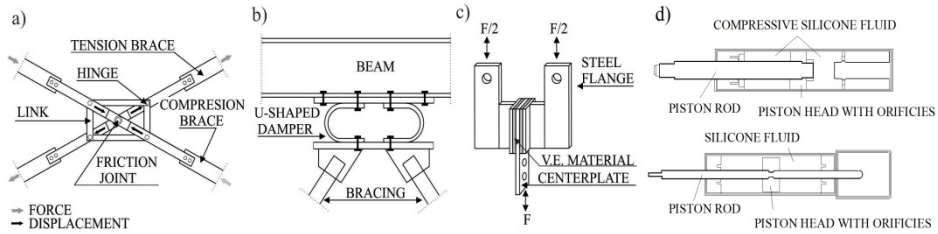

Figure 1. a) Friction damper, b) Metallic damper, c) Viscoelastic damper, d) Viscous pot and orifice damper

Unlike passive damping devices that are placed on structural elements in order to dissipate energy, tuned dampers are devices that must be allowed to move with respect to the building. There are various types of tuned dampers: tuned mass dampers (TMD), tuned liquid dampers (TLD) in containers or tuned liquid dampers with liquid in column, Fig. 2.

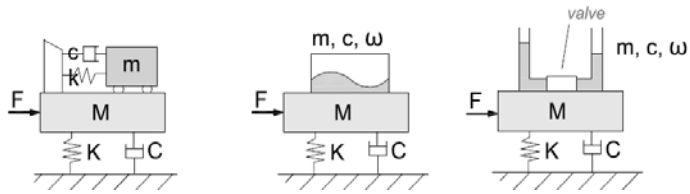

Figure 2. Tuned mass damper, tuned liquid dampers with liquid in a container and in a column

If we consider oscillator with one degree of freedom, subjected to harmonic force, the response of this oscillator may be reduced in amplitude by adding a secondary mass that has a relative movement with respect to the primary oscillator. This added mass is connected to the construction by a spring, or in a form of pendulum, and by a damper, Fig. 3a.

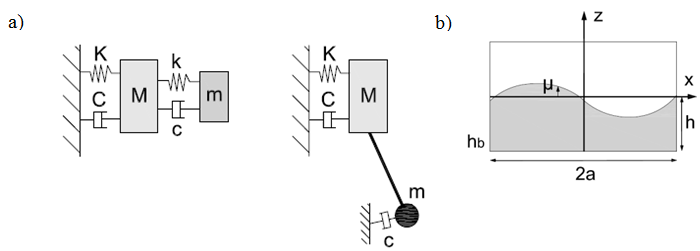

Figure 3. a) Tuned mass dampers with a spring or pendulum b) Schema of container filled with water

When construction vibrates, it excites the damper mass simultaneously. The kinetic energy transferred from the structure to the TMD gets absorbed by a damping component of the device.

Relative displacement of the primary oscillator with respect to the TMD can be described by following equations [5]:

$$M\ddot{y}_1(t) + C_1\dot{y}_1(t) + Ky_1(t) = c\dot{y}_2(t) + ky_2(t) + f(t) \quad (1)$$

$$m\ddot{y}_2(t) + c\dot{y}_2(t) + ky_2(t) = -m\ddot{y}_1(t) \quad (2)$$

Analysis of these equations enables sizing (tuning) of a mass damper in order to get maximum damping. Since added mass introduces another degree of freedom in construction, in diagram of movement/frequency two peaks are seen, where without damping mass there was only one peak. The minimum amplitude of the resonance is thus obtained by choosing the optimum tuning, mass and damping ratio. Tuning ratio is defined as ratio of fundamental frequency of construction to the one of damper. Mass ratio relates masses of a damper and construction. [6]

Recently, a new system that consists of multiple mass dampers (MMD) is in use. These devices can be more efficient than TMD, because they can be adjusted to damp much wider frequency spectrum. [5]

Another category of mass dampers consists of replacing a mass and a damper by a container filled with liquid. In this case, the liquid is the secondary mass, and the damping is provided by a friction between the liquid and the container walls - sloshing effect. The most often utilized liquid is water.

In fluid dynamics, slosh refers to the movement of a liquid inside another oscillating object. When container starts to oscillate, waves on the water surface move to different directions due to fluid inertia. Energy needed for moving of the wave diminishes the oscillation energy of construction, which reduces the amplitude of oscillation. Standing wave induced in this manner has its own frequency, which is a function of water depth and container shape, [1]. For rectangular container, according to the linear theory of the boundary layer, frequencies of natural modes can be determined by the equation:

$$f_n = \frac{\omega_n}{2\pi} = \sqrt{\frac{2n-1}{2a}\pi g \tanh\frac{\pi h}{2a}} \quad (3)$$

where ω_n is circular frequency of mode n, a is length of container in the direction of oscillation, g gravity acceleration, and h is depth of water in container. For n=1, natural frequency of the first mode is obtained and this mode has dominant effect in relation to the other modes. Therefore, TLD is designed in such a way that the frequency of the first mode of water surface oscillation is close to the first frequency of considered structure, [1]. In case of a column liquid damper, the vibration frequency in $\sqrt{(2g/l)}$, where l is column length. [6]

Liquid in container can be modeled with multiple masses, where one of them is connected to container walls by rigid connection, while the others are connected with springs. This shows analogy that can be established between a TMD and a TLD. Equations of this system can be written in exactly the same way as equations (1) and (2), with $m = \rho 2bh,\ c = 2m\xi\omega,\ k = m\omega^2$. [5]

The principle used for sizing of the TMD can also be applied to TLD. Although the parameters of a TMD can be optimized and analytical solution provided, the nonlinear response of the moving fluid in a container makes such optimization very difficult.

Behavior of TLD can be modeled by equivalent linear elastic system, when vibration amplitudes are small. Because the damping radio of water is small, 1-5 %, approximation with linear model is feasible. When vibration amplitudes are large, TLD behavior becomes nonlinear and parameters k and c become nonlinear, too. For equivalent TMD, they are determined experimentally. [2]

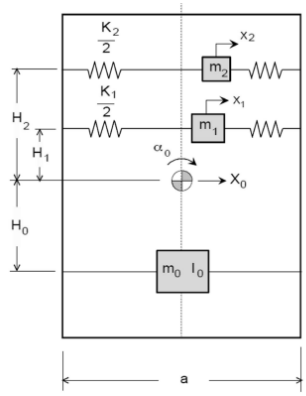

Figure 4. Equivalent mechanical model of a TLD [2]

3. PHYSICAL AND NUMERICAL MODEL

3.1. PHYSICAL MODEL

Figure 5. Experimental setup

For physical model, main structural material is aluminum, which is more favorable than structural steel due to two reasons. It is more convenient for crafting while the lower modulus of elasticity results with more flexible structure. Floor slabs are made with plywood with additional stainless-steel sheets bolted on the lower side of the slab. Foundation structure is made of steel.

Besides the main model, additional structure with purpose of application of initial displacement is constructed. It consists of wooden stand and weight.

Construction of static system is considered to ensure that model oscillates in the first mode in XZ plane, and torsional oscillations are avoided in order to simplify analysis of the results.

Disposition and details of basic experimental model are given in Fig. 6. For different variants of model, weights are added on the upper floor as well as plastic container (203x135mm) that served as TLD.

Beams and columns connections are made with one M3 bolt per connection. In direction X, in which the construction is set to vibrate and the measuring of response is made, joint (pin) connections are simulated in a way that nuts are left loose and the beam connection are set free to rotate around the bolt. All connections are lubricated to reduce

friction as much as possible. Thus, free moment connections are achieved in X direction. In Y direction, bolts are tightened with full tightening force. Since the excitation force is relatively weak, beam-columns connections didn't slip or rotate (intensive micro and macro slipping didn't occur) and they remained in linear damping region. This can be seen from acceleration response of the tested construction. Considering all mentioned above, connections in Y direction can be taken as approximately rigid.

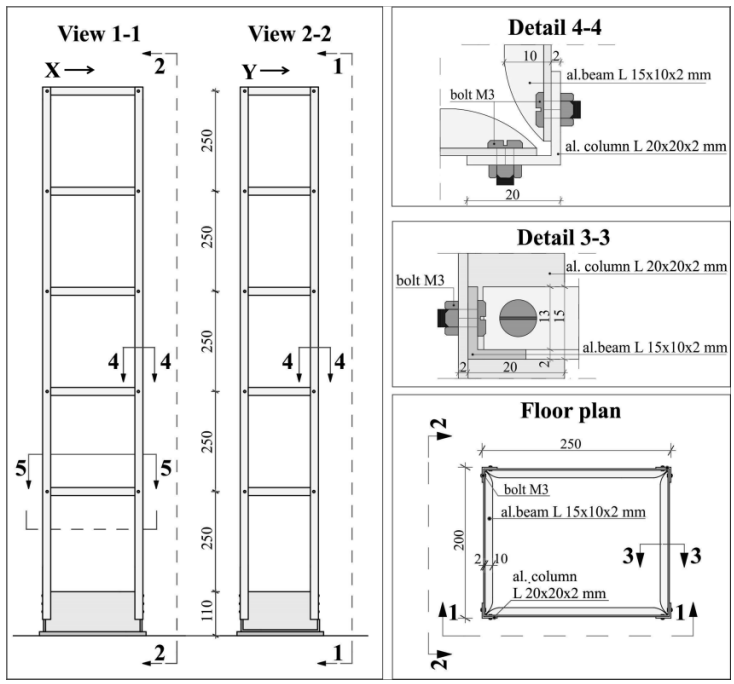

Figure 6. Disposition and characteristic details of physical model

Characteristic of the beam-column connection in X direction could be changed during multiple tests, due to the relatively large displacement of upper floors. This could lead to situation where the model would not remain the same before and after testing. Periods of oscillations before and after the test would be different, which would lead to difficulty in comparing the results. This effect of structure softening after the excitation, where we have different periods of structure oscillation before and after the application od dynamic force is extensively discussed in [7]. In experiment discussed herein, softening can be neglected since the excitation force is relatively small, and in order to set connections, several previous trial tests were performed.

Floor slabs are freely supported on beams placed in X direction, and they do not touch beams along Y direction. In this way, rigidity in X direction is not affected. Besides, plywood floor slabs are much thicker than the rest of the construction, so it is achieved that the floor slabs together with beams placed in X direction can be considered as rigid plates hinged with two frames, Fig 6. This is important because of defining connections in numerical model. Otherwise, the rigidity between floor slabs and truss structure would be unknown.

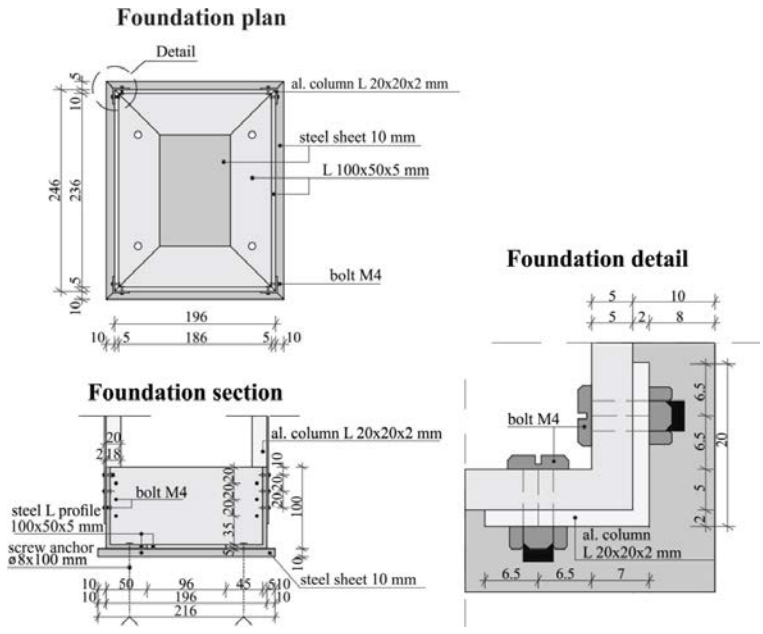

Figure 7. Foundation plan and section, column-foundation connection detail

Model columns are connected on external side of steel foundation structure and joined to it, each with six M4 bolts. Steel foundation is anchored into the concrete floor with four 8 mm diameter anchors, of 100 mm length, Fig. 7. Thus, connections between columns and foundations in numerical model are meant to be considered as full moment connections. After test result analysis and comparison with numerical results, where columns are fully fixed (model variants M0, N2, Table 1), it is concluded that this connection, although made with six bolts for each column, could not be considered as full moment connection. Hence, connections are set as partially rigid in numerical model, concerning bending moment. They are calibrated in a way that numerical model gives results with minimum deviations from experimental results (model variant N1).

Considering above said, tested model can be observed as a vertical console with discontinues rigidity in column connection zone. Dimensions of box profiles of foundation structure are chosen in a way that its rigidity is considerably higher than the truss part of the structure. This minimized its influence on model response.

In experimental results processing, in order to gain damping values, model is seen as one degree of freedom dynamic system.

3.2. NUMERICAL MODEL

Numerical model was made in program SAP2000. Model was made only for basic experimental structure M0, in order to compare the frequency response of experimental and numerical setup, Fig 8.

Two variants of numerical model were made: N1 and N2. N1 variant considers full moment connections of columns restraints, while N2 variant is with a calibrated stiffness of restraints. This calibration is made with respect to the experimentally obtained frequency. Concretely, stiffness of moment connection is modified until the first frequency approximately matched the first frequency obtained in the experiment for base model. Since it is concluded that floors have no influence on the rigidity of construction

as a whole in XZ plane, influence of floors mass is distributed evenly in joints of numerical model.

Figure 8. 3D view of numerical model

All variants of physical and numerical models are given in Table 1.

Table 1. Variants of physical and numerical model

Mark	Model variant	Mass (Kg)
M0	Basic model	6.792
M1	330g of added mass on the upper floor	7.122
M2	660g of added mass on the upper floor	7.452
M3	990g of added mass on the upper floor	7.782
M4	1320g of added mass on the upper floor	8.112
V1P1	135mm water tank in 'X' direction Mass of water and the tank combined is 330g	7.122
V2P1	135mm water tank in 'X' direction Mass of water and the tank combined is 660g	7.452
V3P1	135mm water tank in 'X' direction Mass of water and the tank combined is 990g	7.782
V4P1	135mm water tank in 'X' direction Mass of water and the tank combined is 1320g	8.112
V2P2	203mm water tank in 'X' direction Mass of water and the tank combined is 660g	7.452
V3P2	203mm water tank in 'X' direction Mass of water and the tank combined is 990g	7.782
V4P2	203mm water tank in 'X' direction Mass of water and the tank combined is 1320g	8.112
N1	Numerical model (basic model) – tunned spring restraints	
N2	Numerical model (basic model) – fixed restraints	

4. EXPERIMENT SETUP

4.1. ACQUISITION SYSTEM

Free decay responses of vibration were measured using the four-channel acquisition system Portable Pulse of type 3560C, manufactured by Bruel&Kjaer and accelerometer,

of type 4570, also made by Bruel&Kjaer. The root mean square (r.m.s.) values of structure acceleration response were measured using the Fast Fourier Transform (FFT) analyzer integrated into the acquisition system Portable Pulse.

The FFT analyzer set-up was as follows:

- the frequency span: 0-25 Hz
- number of measured lines: 200
- the frequency resolution: 0.125 Hz;
- number of linear averaging of r.m.s. values of acceleration amplitude: 10.

Time-response functions and autospectrum functions were recorded in the Data Recorder of the Pulse LabShop software.

4.2. EXPERIMENT COURSE

Experimental tests consisted of multiple acceleration measurements, with an accelerometer placed on the top of the structure. Excitation mechanism is shown in Fig. 9. The response is measured on basic model, model with additional stationary mass added on the top floor, and model with water reservoir on top, with dimensions 135x203 mm. Detail description of model variations is given in Table 1. For each variant, results from three measurements are obtained, and then averaged.

Accelerometer is placed on the middle of the beam in Y direction, on the top of the model, so it could measure excitations along X direction. For each measurement, the excitation was induced by placing the weight of 1042 g, suspended by the rope fastened at the structure's upper floor. Weight forced the structure to take new equilibrium position, and after the rope that held the weight was cut, the structure started to vibrate.

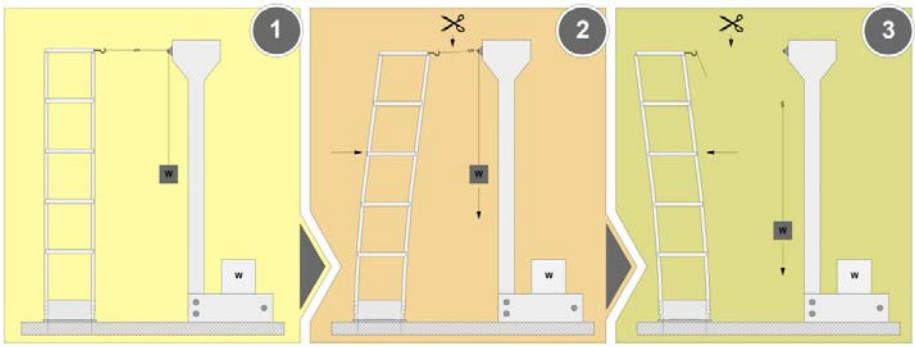

Figure 9. Model excitation scheme

5. RESULTS AND DISCUSSION

5.1. EIGENFREQUENCIES

Eigenfrequencies of tested model are determined by processing data obtained from accelerometer and data acquisition equipment, using Microsoft Excel. Results are shown in a form of graphs. By spotting characteristic peak on graph, and reading its abscissa value, dominant frequency is obtained. It is the frequency of the first eigenmode.

Also, it is possible to note the second eigenfrequency in XZ plane, Fig 10. Regarding data obtained from models which contained reservoir with high level of water, eigenfrequencies of oscillating water can also be noted, Fig 10.

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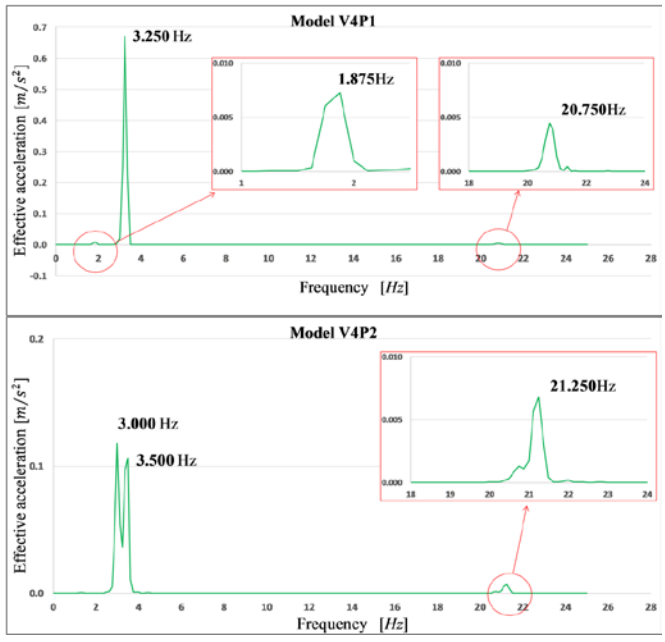

Figure 10. Eigenfrequencies determination, models V4P1 and V4P2

Frequencies obtained experimentally, for all model variations, and also their averaged values, are given in Tab. 2.

The lowest three eigenfrequencies of oscillating water are calculated using the expression (3) and these values can be compared with the experimental results. Calculated values are given in Tab. 3.

Table 2. Experimentally obtained eigenfrequencies of all model variations

Model mark		1st natural frequency, XZ plane f[Hz]				2nd natural frequency, XZ plane f[Hz]			
		Measurement number			Average	Measurement number			Average
		1	2	3		1	2	3	
Experimental	M0	3.375	3.375	3.375	3.375	21.750	21.750	21.750	21.750
	M1	3.125	3.125	3.125	3.125	21.125	21.125	21.125	21.125
	M2	3.000	3.000	3.000	3.000	20.750	20.750	20.625	20.588
	M3	2.875	2.875	2.875	2.875	20.375	20.375	20.375	20.375
	M4	2.750	2.750	2.875	2.792	20.000	20.250	20.000	20.083
	V1P1	3.250	3.250	3.250	3.250	21.375	21.375	21.375	21.375
	V2P1	3.250	3.250	3.250	3.250	21.250	21.250	21.250	21.250
	V3P1	3.250	3.250	3.250	3.250	21.000	21.000	21.000	21.000
	V4P1	3.250	3.250	3.250	3.250	20.750	20.875	20.750	20.792
	V2P2	3.250	3.375	3.250	3.292	21.375	21.375	21.250	21.333
	*V3P2	3.375	3.375	3.375	3.375	21.375	21.375	21.375	21.375
	*V4P2	3.000	3.000	3.000	3.000	21.250	21.250	21.250	21.250
Numerical	N1	/	/	/	3.375	/	/	/	20.007
	N2	/	/	/	3.654	/	/	/	23.614

Table 3. Calculated natural frequencies of water depending on tank length and water depth

Model mark	Water tank lenght l[mm]	Water depth h[mm]	Natural frequency f[Hz]		
			1	2	3
V1P1	135	5	0.826	1.432	1.848
V2P1	135	17	1.483	2.568	3.315
V3P1	135	29	1.849	3.202	4.134
V4P1	135	41	2.073	3.591	4.637
V2P2	203	17	1.001	1.732	2.236
V3P2	203	29	1.276	2.210	2.853
V4P2	203	41	1.471	2.549	3.291

5.2. DAMPING

By experimental measurements, using accelerometer and data acquisition software, accelerations of model top in time domain and along X direction are obtained. Graphical representation of these accelerations is processed in Microsoft Excel. Envelope is obtained following equations of a system with one DOF. The equation of motion of free damped vibrations of this system, for damping less than the critical, is as follows:

$$y = Ce^{-\xi\omega t}\sin(\omega_d t) \tag{4}$$

where the phase angle equals zero.

Acceleration is obtained after derivation of this equation with respect to time:

$$\ddot{y} = Ce^{-\xi\omega t}[\xi^2\omega^2\sin(\omega_d t) - 2\xi\omega\cos(\omega_d t)\omega_d - \sin(\omega_d t){\omega_d}^2] \tag{5}$$

Terms $\xi^2\omega^2\sin(\omega_d t)$ and $2\xi\omega\cos(\omega_d t)\omega_d$ can be neglected, because they do not affect result significantly, and also damping estimation is much easier. After neglecting these two terms the equation remained is following:

$$\ddot{y} = Ce^{-\xi\omega t}[-\sin(\omega_d t){\omega_d}^2] \tag{6}$$

For $\sin(\omega_d t)$= ±1 envelopes are obtained:

$$\ddot{y} = -Ce^{-\xi\omega t}{\omega_d}^2,\ \ddot{y} = Ce^{-\xi\omega t}{\omega_d}^2 \tag{7}$$

Unknown values are initial amplitude C and damping ratio ξ. By varying these values and harmonization of envelope with acceleration graph, calibrated estimated values of initial amplitude and damping factor are obtained, Fig. 11.

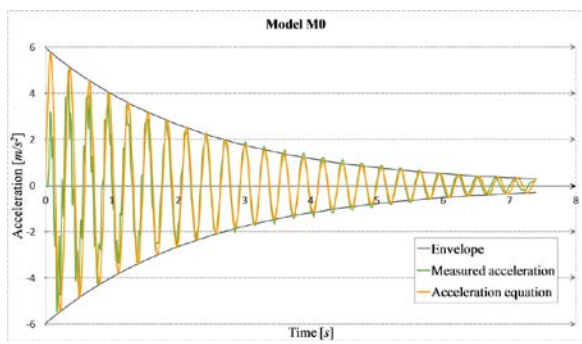

Figure 11. Model M0 response compared to acceleration equation and its envelopes

Estimated values of initial amplitude and damping are given in Table 4, where asterisk denotes models for which damping cannot be precisely estimated due to beating.

Graphical presentation of individual responses with envelopes, regarding different variants of model are given on Fig. 12.

Table 4. Estimated values of initial amplitude and damping for all model variants

Model mark	First amplitude C[m]				Damping ξ			
	Measurement number			Average	Measurement number			Average
	1	2	3		1	2	3	
M0	0.013	0.012	0.013	0.0127	0.0190	0.0185	0.0190	0.0188
M1	0.013	0.013	0.012	0.0127	0.0190	0.0185	0.0190	0.0188
M2	0.011	0.011	0.011	0.0110	0.0180	0.0175	0.0170	0.0175
M3	0.011	0.011	0.011	0.0110	0.0175	0.0175	0.0175	0.0175
M4	0.011	0.012	0.011	0.0113	0.0185	0.0175	0.0170	0.0177
V1P1	0.012	0.013	0.014	0.0130	0.0270	0.0280	0.0270	0.0273
V2P1	0.011	0.011	0.010	0.0107	0.0240	0.0240	0.0230	0.0237
V3P1	0.010	0.010	0.012	0.0105	0.0210	0.0220	0.0230	0.0220
V4P1	0.010	0.009	0.010	0.0097	0.0200	0.0210	0.0210	0.0207
V2P2	0.012	0.012	0.012	0.0120	0.0390	0.0370	0.0380	0.0380
*V3P2	0.010	0.010	0.011	0.0103	0.0320	0.0300	0.0310	0.0310
*V4P2	0.011	0.011	0.011	0.0110	0.0260	0.0260	0.0260	0.0260

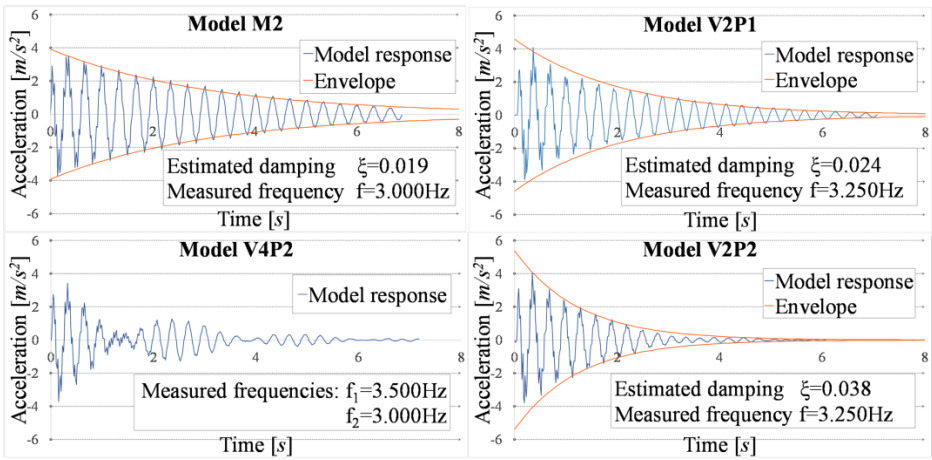

Figure 12. Examples of model responses with envelopes

5.3. DISCUSSION

Obtained results enable comparison of different model variations responses:

- Models with no damping device and different mass on top: M0, M1, M2, M3, M4;
- Models with the same mass with and without damping device: M2, V2P1, V2P2; M3, V3P1, V3P2;
- Models with TLD with different water levels: V1P1, V2P1, V3P1,V4P1; V2P2, V3P2, V4P2;
- Basic physical and numerical models: M0, N1.

Based on the comparison of the results obtained on model without damper, with different masses on the highest level, it is concluded that the frequencies of oscillations decrease when mass increases, which is expected. Additionally, it can be concluded that the added mass on the highest level of the model does not have much impact on the change of damping, Fig. 13, Tab. 5.

Table 5. Comparison of eigenfrequencies and estimated damping (Fig. 13, Fig.14)

Model mark	Average frequency f[Hz]	Δf (%)	Average damping ξ	Δξ (%)
M0	3.375	/	0.0188	/
M2	3.000	-11.11	0.0175	-6.91
M4	2.792	-17.27	0.0177	-5.85
Δf (%); Δξ (%) expressed relative to **M0**				
M2	3.000	/	0.0175	/
V2P1	3.250	8.33	0.0237	35.43
V2P2	3.292	9.73	0.0380	117.14
Δf (%); Δξ (%) expressed relative to **M2**				
M3	2.875	/	0.0175	/
V3P1	3.250	13.04	0.0220	25.71
V3P2	3.375	17.39	0.0310	77.14
Δf (%); Δξ (%) expressed relative to **M3**				

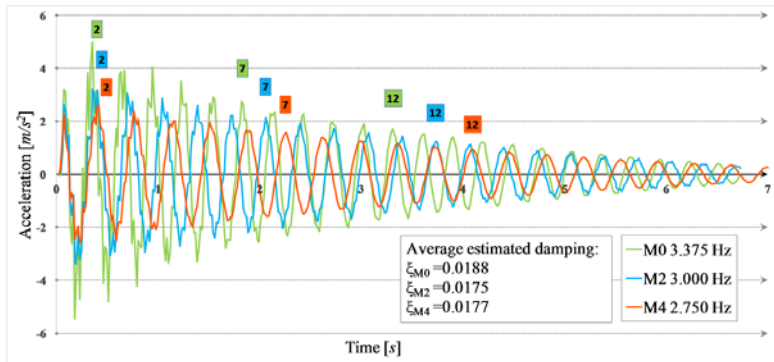

Figure 13. Response comparison, models M0,M2,M4

By comparison of responses of the models with the same mass, with and without a damper, it can be concluded that the water reservoir significantly increases damping. Model with the reservoir set in direction 2 (P2, reservoir length 203 mm) gave higher damping values than the ones when a reservoir in placed in direction 1 (P1, reservoir length 135 mm), Tab 6, Fig 15. Reason for this difference in model responses we can seek in oscillation synchronization of active (moved) part of liquid in reservoir and oscillation of model. In second direction beating phenomenon is observed. Its influence can be related with higher damping values. Beating is phenomena which occurs when two oscillations of the same amplitude interact creating specific pattern [8], [9].

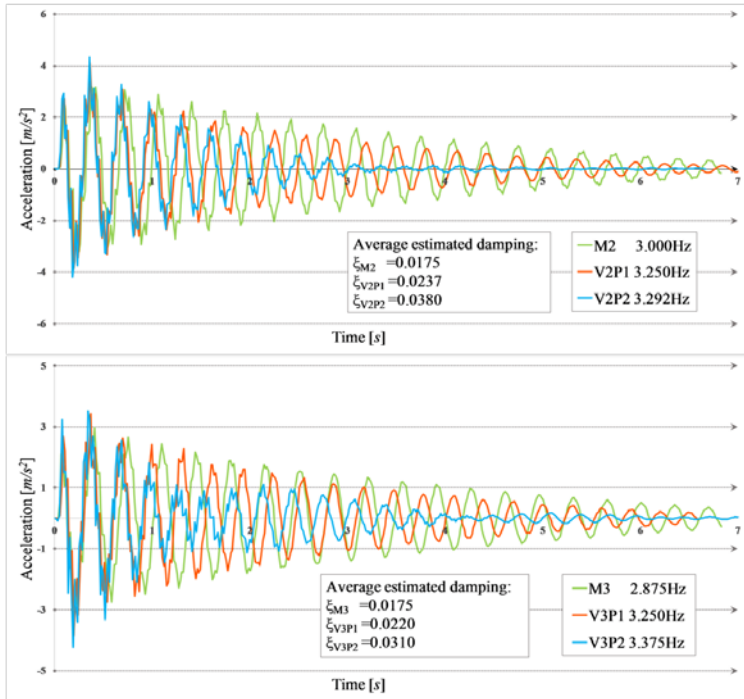

Figure 14. Acceleration response comparisons

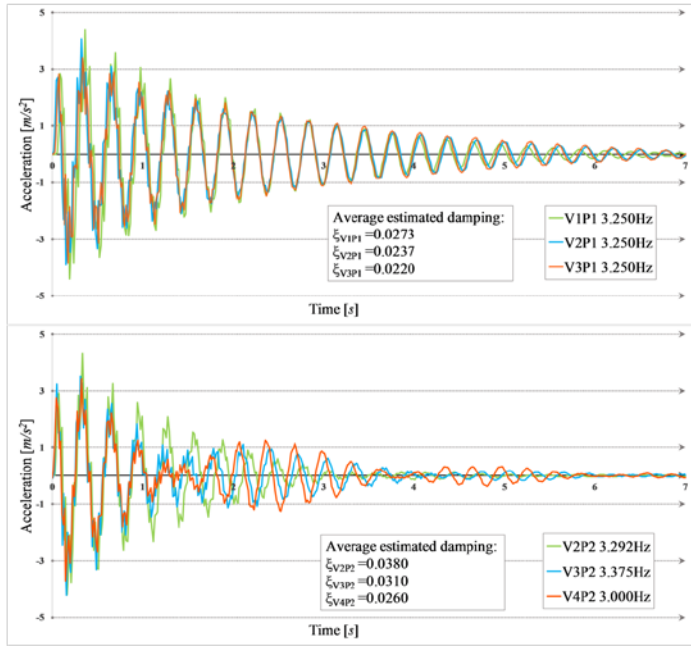

Figure 15. Acceleration response comparisons

Table 6. Comparison of eigenfrequencies and estimated damping (Fig. 15)

Model mark	Average frequency f[Hz]	Δf (%)	Average damping ξ	Δξ (%)
V1P1	3.250	/	0.0273	/
V2P1	3.250	0.00	0.0237	-13.19
V3P1	3.250	0.00	0.0220	-19.41
Δf (%); Δξ (%) expressed relative to **V1P1**				
V2P2	3.292	/	0.0380	/
V3P2	3.375	-2.52	0.0310	-18.42
V4P2	3.000	-8.87	0.0260	-31.58
Δf (%); Δξ (%) expressed relative to **V2P2**				

By the increase of the water level in the reservoir, damping factor decreases. With higher water level, the influence of water mass which stays still is greater, and this still water acts as mass attached to the system. This mass does not affect damping factor, so it is expected that damping decreases when water level rises, Fig. 15, Tab. 6.

On models V3P2 and V4P2 beating is obvious, Fig 15, which is clearly indicated on graphical representations of model responses. Most obvious beating is on model V4P2. Since water mass in reservoir is significant in comparison to model mass (water mass in reservoir is 1,132 kg, and the mass of total model is 6,792 kg) amplitude ratio is approximately equal, and beating is clearly indicated. That is the reason why, for variants V3P2 and V4P2, values of estimated damping and indicated frequency should be taken with uncertainty.

Comparison of accelerations of numerical model N1 and corresponding physical model M0, it can be seen that their responses are slightly out of phase. However, well compliance is achieved, Fig 16. Main reason for this compliance is adjustment of experimental model to avoid the influence of damping in connection joints. This damping can be very significant and it could lead up to 30% differences in experimental and numerical results using wire finite elements, [8]. The influence of the intensity of the perturbation on the construction's response also should not be neglected. In performed experiment, as mentioned earlier, because of the small intensity of the perturbation, there has been no friction activation and slipping into column-beam joints.

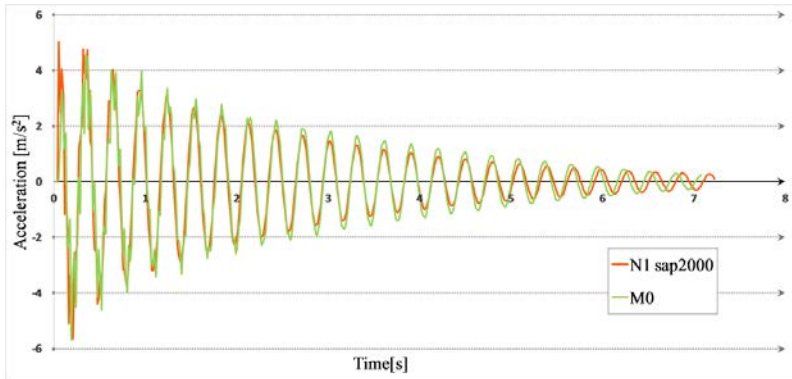

Figure 16. Acceleration response comparisons

6. CONCLUSIONS

TMD is an effective solution for reduction of vibrations induced by dynamic forces. Herein, an influence of TLD on simple frame model is demonstrated. Due to many restrictions, simple model is created using available resources. It is calibrated in such a way that its response can be modeled with one degree of freedom system. Experimental analysis revealed some interesting facts considering changes in frequencies, as well as damping and beating phenomena occurrence. It can be concluded that the highest level of damping occurs when water reservoir is placed longitudinally with respect to excitation direction. This case is also related to the occurrence of beating.

Further research is required in order to draw more firm conclusions. It should consist of testing various TLD, in order to get better tuning between the first eigenfrequency of a model and a damper. Also, it may be useful to try to lower the first mode frequency of the model to match values around 1 Hz, since dominant modes of real buildings are in that range.

LITERATURE

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05| Оригинални научни рад
Research paper
doi 10.7251/STP1813096M ISSN 2566-4484

ULTIMATE STRENGTH OF COMPRESSED SLABS AND BOX GIRDERS

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Abstract: A theoretical investigation into the effectiveness of a plate thickness against the ultimate strength of a compressed slabs and box girders is carried out. Series of the buckling analyses, the elastic, the viscoplastic and the ultimate strength are performed by the rheological-dynamical inelastic theory and the finite strip method on a slabs and box girders under thrust. In the analytical method, rheological-dynamical analogy (RDA) is introduced to express the critical stresses of slabs and box girders in the range of viscoplastic strains and strain hardening. Applying the finite strip method (FSM) as a semi-analytical method, the fundamental equilibrium equations are derived based on the principle of minimum total potential energy. Apart from the quantitative research the qualitative research is presented to demonstrate the capabilities of the present theory.

Keywords: slabs; box girders; elastic buckling; viscoplastic buckling; ultimate strength; FSM; RDA.

ГРАНИЧНА НОСИВОСТ ПРИТИСНУТИХ ПЛОЧА И САНДУЧАСТИХ НОСАЧА

Резиме: Извршено је теоријско истраживање утицаја промјене дебљине код притиснутих плоча и сандучастих носача на граничну носивост. Низ анализа извијања је спроведен. Реолошко-динамичком аналогијом и методом коначних трака одређена је еластична, вископластична и гранична носивост на притиснутим плочама и сандучастим носачима. Реолошко-динамичка аналогија (РДА) је кориштена у аналитичким изразима за добијање критичних напона анализираних носача у области вископластичних деформација и ојачања материјала. Употребом методом коначних трака (МКТ) као полуаналитичког метода изведене су једначине равнотеже на основу принципа минимума укупне потенцијалне енергије. Поред квантитативне анализе дат је и квалитативан приказ са циљем да се истакну могућности дате теорије.

Кључне ријечи: плоче; сандучасти носачи; еластично извијање; вископластично извијање; гранична носивост; МКТ; РДА

1. INTRODUCTION

In general, many structures are constructed by using slabs to reduce their weight and costs, and box girders to improve their rigidity and strength. The buckling strength of slabs and box girders increases with the increase of a plate thickness, but reaches its maximum limiting value when the ultimate strength reached. However, the investigation of the stability of structural elements under compressive loading incorporating in the analysis the inelastic material behavior is undoubtedly a complex subject [1-3].

The thin-walled structures are structures which are generally made by joining flat plates at their edges. An important sub-set of these structures, which are the main concern of this paper are essentially prismatic forms, such as slabs and box girders. The analysis of the behavior of these structures is done using the semi-analytical FSM. The FSM is based on the basis functions (or eigenfunctions), which are derived from the solution of the beam differential equation of transverse vibration, and proved to be an efficient tool for analysis a great deal of structures for which both geometry and material properties can be considered as constant along a main direction. This method was pioneered by Cheung [4], who combined the plane elasticity and the Kirchhoff plate theory. Wang and Dawe [5] have applied the elastic geometrically non-linear FSM to the large deflection and post-overall-buckling analysis of diaphragm-supported plate structures. The geometrically non-linear harmonic coupled finite strip method (HCFSM) is also one of the many procedures that can be applied to analyze the large-deflection and post-buckling behavior of slabs and box girders [6].

If uniformly compressed thin-walled structures undergo inelastic deformations, these structures generally sustain two sources of non-linearity (geometrical non-linearity due to large deflection and material non-linearity due to inelastic behavior). Due to the slender nature of the cross-sections, their behavior is inevitably complex, with several parallel buckling phenomena influencing performance and limit states. The analysis presented in this paper is based on the RDA [7, 8]. The RDA is a type of inelastic analysis, which transforms one category of very complicated material non-linear problems to simpler linear dynamic problems by using modal analysis [9]. In this paper, we present a new approach in which the ultimate strengths of slabs and box girders are investigated by RDA. For the analysis of these structures using FSM, an inelastic isotropic 2D constitutive matrix is derived in [10].

2. METHODS OF THEORETICAL ANALYSES

It is well known that an initially flat slab undergoes a primary buckling from an initially flat equilibrium state under external loads, if the loads are applied non-eccentrically. When the load is eccentrically applied, lateral deflection increases from the beginning of the loading, but the increase in deflection is small until the load is near to the buckling load. Furthermore, the interaction of two types of column buckling (failure) in box girders, local and global (Euler) column buckling, may generate an unstable coupled mode, rendering the structure highly sensitive to imperfections. To analyze such behavior, the geometrical non-linearity must be taken into account.

For a further increase of the load, plastification gradually takes place, and structure (flat slab or box girder) reaches its ultimate strength. For the analysis of this stage, the material non-linearity as well as the geometrical non-linearity must be taken into account.

2.1. BUCKLING ANALYSIS BY FSM

The non-linear strain-displacement relations in FSM can be predicted by combination of plane elasticity and the Kirchhoff plate theory. This has been accomplished in [6], by using the second-order terms of Green-Lagrange strains. However, since longitudinal loading is assumed here (see Fig. 1), the second-order terms are only necessary for the longitudinal normal strain

$$\varepsilon_y = \frac{\partial v_0}{\partial y} + \frac{1}{2}\left[\left(\frac{\partial u_0}{\partial y}\right)^2 + \left(\frac{\partial v_0}{\partial y}\right)^2 + \left(\frac{\partial w}{\partial y}\right)^2\right] - z\frac{\partial^2 w}{\partial y^2}, \tag{1}$$

where u_0 and v_0 are, respectively, displacements in the middle surface in x and y directions, and w is displacement in z direction.

In FSM, which combines elements of the classical Ritz method and the finite element method (FEM), the general form of the displacement function can be written as a product of polynomials and trigonometric functions [4]

$$f = \mathbf{Aq} = \sum_{m=1}^{r} Y_m(y) \sum_{k=1}^{c} \mathbf{N}_k(x)\mathbf{q}_{km}, \tag{2}$$

where $Y_m(y)$ are functions from the Ritz method, $N_k(x)$ are interpolation functions from FEM [4] and $\mathbf{q}_{km}$ is a vector representing the m-th term nodal displacements. r is an integer specifying the number of series terms chosen for approximation and c represents the number of nodal lines of a strip.

The most commonly used series are the basis functions (or eigenfunctions) which are derived from the solution of the beam vibration differential equation

$$\frac{\partial^4 Y}{\partial y^4} = \frac{\mu^4}{a^4} Y, \tag{3}$$

where a is the length of the strip and μ is a parameter.

The general form of the basis functions is

$$Y(y) = C_1 \sin\left(\frac{\mu \cdot y}{a}\right) + C_2 \cos\left(\frac{\mu \cdot y}{a}\right) + C_3 \sinh\left(\frac{\mu \cdot y}{a}\right) + C_4 \cosh\left(\frac{\mu \cdot y}{a}\right), \tag{4}$$

with the coefficients C_1, etc., to be determined by the boundary conditions. This has been worked out in the ref. [4] for various boundary conditions and is listed below for a simply supported strip only

$$Y_m(y) = \sin\left(\frac{\mu_m \cdot y}{a}\right), \quad (\mu_m = \pi, 2\pi, 3\pi, ...m \cdot \pi). \tag{5}$$

We define the local Degrees Of Freedom (DOFs) as the displacements u_0, v_0 and w, and the transverse slope amplitude $\varphi = \left(\frac{\partial w}{\partial x}\right)$ of a nodal line (DOFs=4), as shown in Fig. 1. The DOFs are also called generalized coordinates.

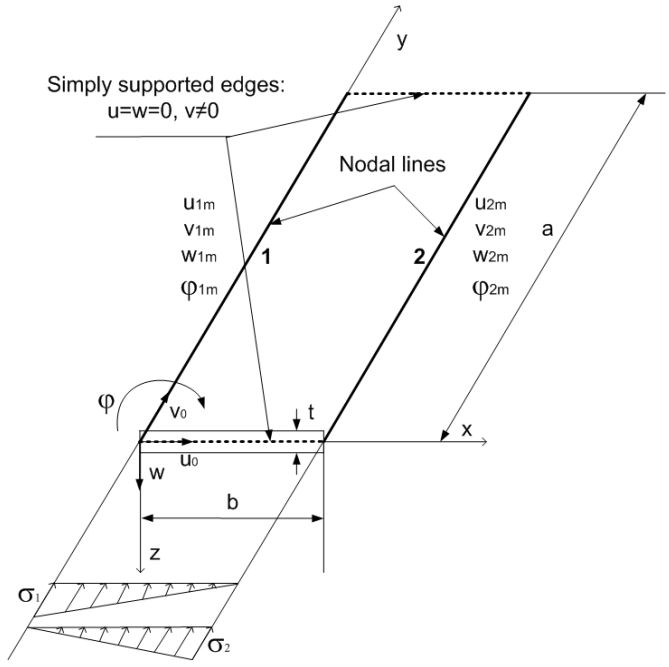

Figure 1. A simple supported strip with initial stresses.

The total potential energy of a strip is designated Π and is expressed with respect to the local DOFs [6]

$$\Pi = U + W = \left(U_m + U_b\right) + W =$$
$$= \left(1/2 \int_A \mathbf{q}_u^T \mathbf{B}_{u1}^T \mathbf{D}_m \mathbf{B}_{u1} \mathbf{q}_u dA + 1/2 \int_A \mathbf{q}_w^T \mathbf{B}_{w3}^T \mathbf{D}_b \mathbf{B}_{w3} \mathbf{q}_w dA \right) - \int_A \mathbf{q}^T \mathbf{A}^T \mathbf{p} dA. \tag{6}$$

The conventional stiffness block matrices are, respectively [6]

$$\hat{\mathbf{K}}_{uu} = \int_A \mathbf{B}_{u1}^T \mathbf{D}_m \mathbf{B}_{u1} dA, \quad \hat{\mathbf{K}}_{ww} = \int_A \mathbf{B}_{w3}^T \mathbf{D}_b \mathbf{B}_{w3} dA, \tag{7}$$

where we introduce matrices, which are referred to as the strain matrices

$$\mathbf{B}_{u1} = \mathbf{L}_1 \mathbf{A}_u, \ \mathbf{B}_{w3} = \mathbf{L}_3 \mathbf{A}_w, \tag{8}$$

where

$$\mathbf{L}_1 = \begin{bmatrix} \partial/\partial x & 0 \\ 0 & \partial/\partial y \\ \partial/\partial y & \partial/\partial x \end{bmatrix}, \mathbf{L}_3 = \begin{bmatrix} -\partial^2/\partial x^2 \\ -\partial^2/\partial y^2 \\ -2 \cdot \partial^2/\partial x \partial y \end{bmatrix}, \tag{9}$$

and

$$\mathbf{A}_u = \begin{bmatrix} \mathbf{A}_u^u & \mathbf{0} \\ \mathbf{0} & \mathbf{A}_u^v \end{bmatrix}, \mathbf{q}_u = \begin{bmatrix} \mathbf{q}_u^u \\ \mathbf{q}_u^v \end{bmatrix}. \tag{10}$$

$\mathbf{A}_u^u$, $\mathbf{A}_u^v$ and $\mathbf{A}_w$ are the corresponding approximate functions, while $\mathbf{q}_u^u$, $\mathbf{q}_u^v$ and $\mathbf{q}_w$ represent vectors of displacement parameters in the nodal lines. The potential energy due to external surface loads **p** can be written simply as

$$W = -\int_A \mathbf{q}^T \mathbf{A}^T \mathbf{p} dA. \tag{11}$$

In order to obtain the equilibrium equations, the principle of minimum total potential energy is invoked

$$\frac{\partial \Pi}{\partial \mathbf{q}_m^T} = \mathbf{0}. \tag{12}$$

Eq. (12) gives a linear set of algebraic equations

$$\left(\hat{\mathbf{K}}_{uu}\mathbf{q}_u + \hat{\mathbf{K}}_{ww}\mathbf{q}_w\right) - \mathbf{Q} = \hat{\mathbf{K}}\mathbf{q} - \mathbf{Q} = \mathbf{0}, \tag{13}$$

where $\mathbf{Q}$ are the nodal forces.

Well known elements of the property matrices $\mathbf{D}_\mathrm{m}$ and $\mathbf{D}_\mathrm{b}$ for the orthotropic elastic material are

$$\begin{aligned} &K_x = \frac{E_x}{1-\mu_x\mu_y}, K_y = \frac{E_y}{1-\mu_x\mu_y}, K_1 = \frac{\mu_y E_x}{1-\mu_x\mu_y} = \frac{\mu_x E_y}{1-\mu_x\mu_y}, K_{xy} = G \\ &D_{m11} = K_x t, D_{m22} = K_y t, D_{m12} = K_1 t, D_{m66} = K_{xy} t \\ &D_{b11} = K_x \frac{t^3}{12}, D_{b22} = K_y \frac{t^3}{12}, D_{b12} = K_1 \frac{t^3}{12}, D_{b66} = K_{xy} \frac{t^3}{12}, \end{aligned} \tag{14}$$

where t is the thickness of a strip, Fig. 1.

Consider the simply supported flat strip shown in Fig. 1. The strip is subjected to an initial stress σ, which varies linearly from side 1 to side 2, but is constant along the longitudinal axis

$$\sigma_{ij} = \sigma_{22} = \sigma_y = \left(1 - \frac{x}{b}\right)\sigma_1 + \frac{x}{b}\sigma_2. \tag{15}$$

Considering the assigned stress distribution, from the non-linear strain tensor we include only the term given by Eq. (1). It is well known that the total potential energy of a strip is defined as the sum of its strain energy, potential energy due to nodal line forces, as well as the additional potential energy due to the initial stress.

As far as linear stability is concerned, the nodal forces $\mathbf{Q}$ are zero and it's therefore possible to derive the eigenvalue equation [6]

$$\left(\hat{\mathbf{K}} - \lambda \mathbf{K}_\sigma\right)\mathbf{q} = \mathbf{0}, \tag{16}$$

where $\hat{\mathbf{K}}$ is the conventional stiffness matrix, $\mathbf{K}_\sigma$ is the geometric stiffness matrix, λ is the eigenvalue (the load factor is compression positive), and $\mathbf{q}$ is the eigenvector (buckling mode). Based on Eq. (16) for one finite strip we can form the eigenvalue equations for a system of finite strips (mesh). The eigenvalue problem is to extract the solution pairs λ_{im} and $\mathbf{q}_{im}$ for all DOFs i, and all series terms m = 1,...,r. The buckling stresses are

$$\sigma_{im} = \frac{\lambda_{im}}{2 \cdot t}. \tag{17}$$

2.2. INELASTIC BUCKLING ANALYSIS BY FSM AND RDA

This section can be thought as an extension to Section 2.1. The purpose of developing a mathematical model for the rheological behavior of solids is to permit realistic results to be obtained from mathematical analyses of damaged structure under various conditions, such as micro cracking, which leads to its visco-plastic (VP) deforming and failure.

The FSM equilibrium equations (see Eq. 16) for a system exhibiting non-linear behavior can be written as

$$\left(\hat{\mathbf{K}}(\mathbf{C}) - \lambda \mathbf{K}_\sigma\right)\mathbf{q} = \mathbf{0}. \tag{18}$$

The non-linear term is the conventional stiffness matrix $\hat{\mathbf{K}}(\mathbf{C})$ of the system, which depends on the inelastic constitutive matrix **C**, according to the RDA. 2D compliance matrix $\mathbf{C}^{-1}$ is 'degenerated' directly from 3D theory [10] as follows

$$\begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{bmatrix} = \mathbf{C}^{-1} \begin{bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{bmatrix}, \ \mathbf{C}^{-1} = \begin{bmatrix} 1/E_{Rx} & -e_{xy}/E_{Rx} & 0 \\ -e_{xy}/E_{Rx} & 1/E_{Ry} & 0 \\ 0 & 0 & 1/G_{Rxy} \end{bmatrix}, \tag{19}$$

where

$$\begin{aligned} &E_{Ry} = \frac{3E_H}{5-4\mu+2(1+\mu)\varphi_y}, \ E_{Rx} = \frac{3E_H}{5-4\mu+2(1+\mu)\varphi_x}, \ G_{Rxy} = \frac{G_H}{1+\sqrt{\varphi_x \varphi_y}}, \\ &e_{xy} = \frac{(7\mu-2)+(1+\mu)\varphi x}{5-4\mu+2(1+\mu)\varphi_x}, \ \varphi_x = \sigma_x K_E, \ \varphi_y = \sigma_y K_E. \end{aligned} \tag{20}$$

The RDA modulus iteration starts with the elastic constitutive matrix **D** (see $\mathbf{D}_m$ and $\mathbf{D}_b$)

$$\left(\hat{\mathbf{K}}(\mathbf{D}) - \lambda \mathbf{K}_\sigma\right)\mathbf{q} = \mathbf{0}. \tag{21}$$

This is a transcendental eigenvalue problem. Solving these equations, critical stresses $\sigma_{cry}^{(0)}$ can be obtained.

The corresponding VP slope is RDA modulus, which is the input parameter for the next iteration

$$E_{Ry}^{(1)} = \frac{3E_H}{5-4\mu+2(1+\mu)\sigma_{cry}^{(0)} \cdot K_E}, \tag{22}$$

where

$$K_E = \varphi \frac{3\left(1-\mu^2\right)}{\pi^2 E_H}\left(\frac{b}{t}\right)^2. \tag{23}$$

The first iteration gives the critical VP stress. The iterative procedure must be performed until there is convergence to the critical failure stress. The scheme of the modulus iterative method is illustrated in Fig. 2.

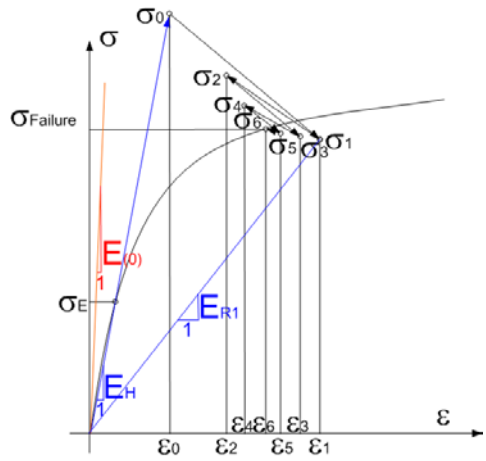

Figure 2. Scheme of the modulus iterative method.

3. NUMERICAL APPLICATIONS

Two examples are analyzed in this paper, compressed steel slab and box girder. The theoretical investigation into the effectiveness of the thickness against the ultimate strength is carried out. The transition from the various buckling modes by changing the lengths and thicknesses are examined and the elastic, VP and failure (ultimate strength) buckling curves are given.

3.1. SLABS

Consider the uniformly compressed rectangular steel slabs ($4.0 \geq a / b \geq 0.5$) depicted in Fig. 3, whose all edges are simply supported. Slabs of the following geometrical and elastic properties t = 16 mm, b = 1000 mm, E_H = 210 GPa and $\mu = 0.3$ were investigated using the FSM and RDA. The slab is divided into 6 finite strips with 7 nodal lines. Five series terms were included in the analysis.

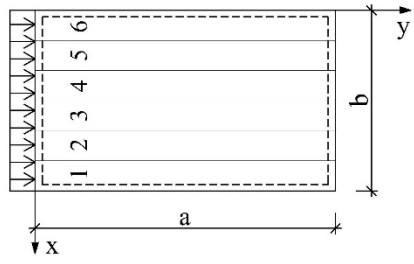

Figure 3. Uniformly compressed rectangular slab and finite strip idealization.

Fig. 4 shows the elastic buckling curve (critical stress versus a/b ratio). Critical stresses for three observed slab lengths of a = 1, 2 and 4 m are highlighted. As can be seen the same elastic critical stresses are obtained for different modes.

In order to obtain the inelastic quasi-static critical stresses, the Euler formula for buckling of an isolated plate strip was employed to find the structural-material constant K_E of plate, Eq. (23). The convergence of failure stress or ultimate strength for all *a*/*b* ratios is obtained using only six or seven iterations. The first iteration gives the VP yield stress.

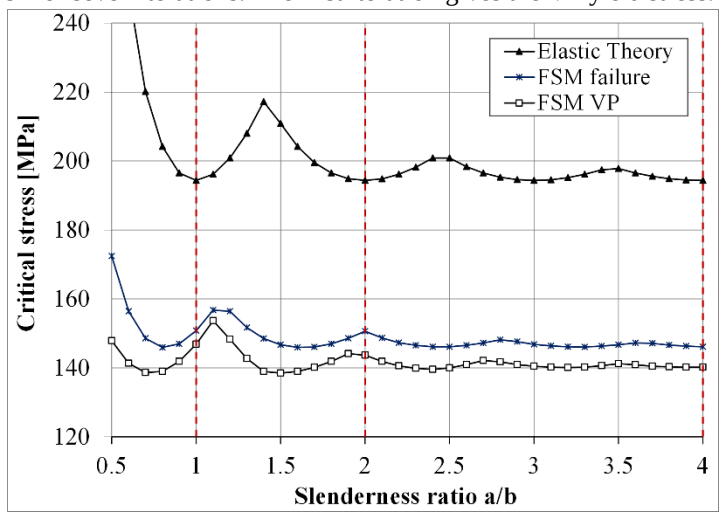

Figure 4. Elastic, VP and failure buckling curves for steel slab.

Inelastic critical stresses lag behind the elastic critical stresses across all modes, which is a consequence of the VP behavior of material that characterized by the delay time T^D [7]. As the length of slab is larger, the observed lag increases. Due to lag, the same slab length does not always correspond to the same mode at the elastic, VP and failure stresses. This phenomenon is named as mode interaction.

Fig. 5 shows critical stresses versus thickness for three observed slab lengths. It can be noticed that all stresses increase non-linear with increases of thickness.

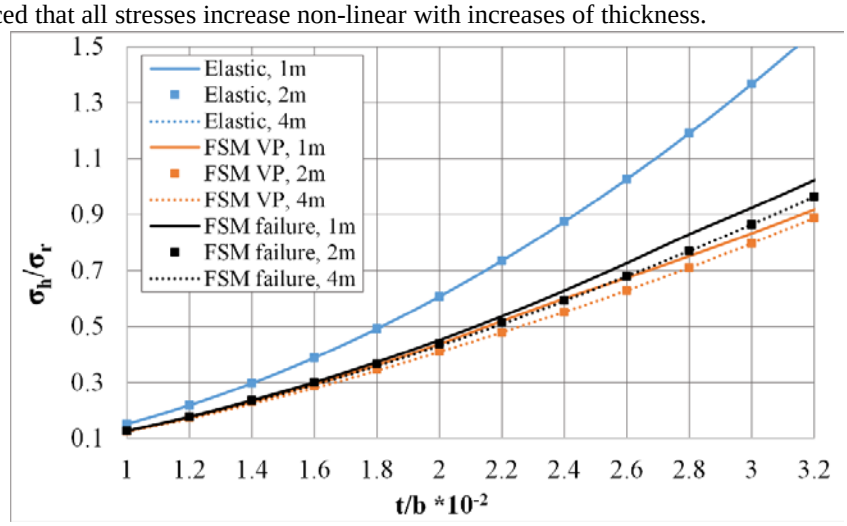

Figure 5. Critical stresses vs. thicknesses for three observed slab lengths.

Fig. 6 shows the load capacity or ultimate strength of slabs, as the 3D surface.

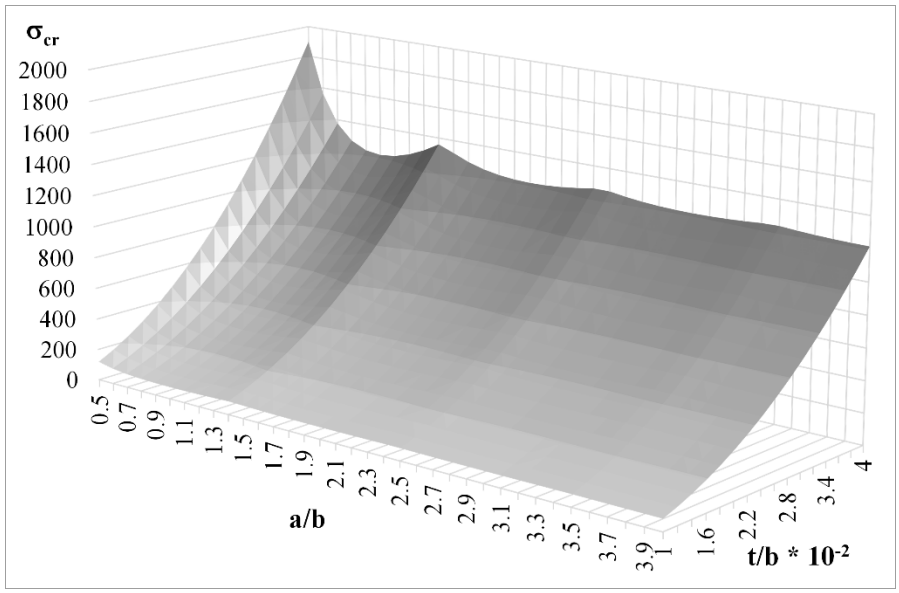

Figure 6. 3D surface of ultimate strength of slabs.

3.2. BOX GIRDERS

Simply supported ideally straight thin-walled box girder that consists of two webs of 100 mm and two flanges of 60 mm has been analyzed in details and results are compared with other theories for thickness of t = 2 mm [10, 11]. The girder is compressed axially. The elastic material properties are given in Fig. 7. In this paper the theoretical investigation into the effectiveness of the thickness against the ultimate strength is carried out.

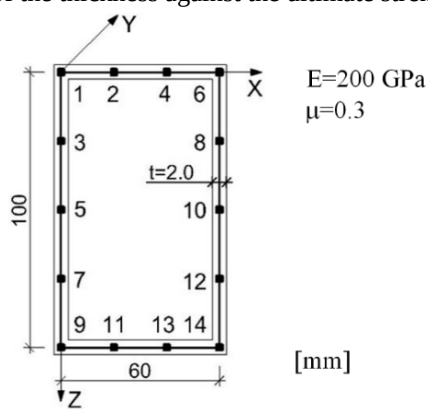

Figure 7. Thin-walled box girder and finite strip idealization.

The FSM elastic critical stresses computed with 14 finite strips and 8-35 series terms are shown in Fig. 8. Critical stresses for three observed girder lengths of a = 80, 120 and 400

mm are highlighted. Due to lag, the same girder length does not always correspond to the same mode at the elastic, VP and failure stresses. Consequently, the phenomenon of mode interaction is appeared again.

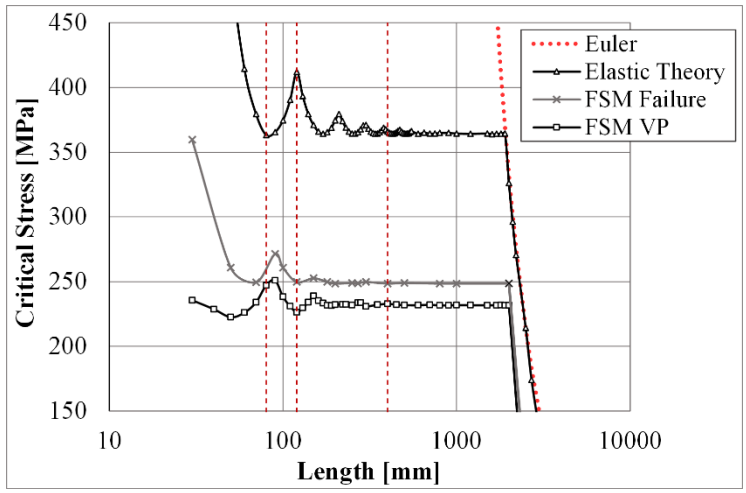

Figure 8. Elastic, visco-plastic and failure buckling curves for box girder.

Fig. 9 shows the change of stresses due to the change of thicknesses for three observed girder lengths. As can be seen, the non-linear changes of stresses are appeared up to a certain thickness, when the stresses stop to rise. This reduction of stresses is different for the elastic, VP and failure behavior of girders with strong dependents from the girder lengths.

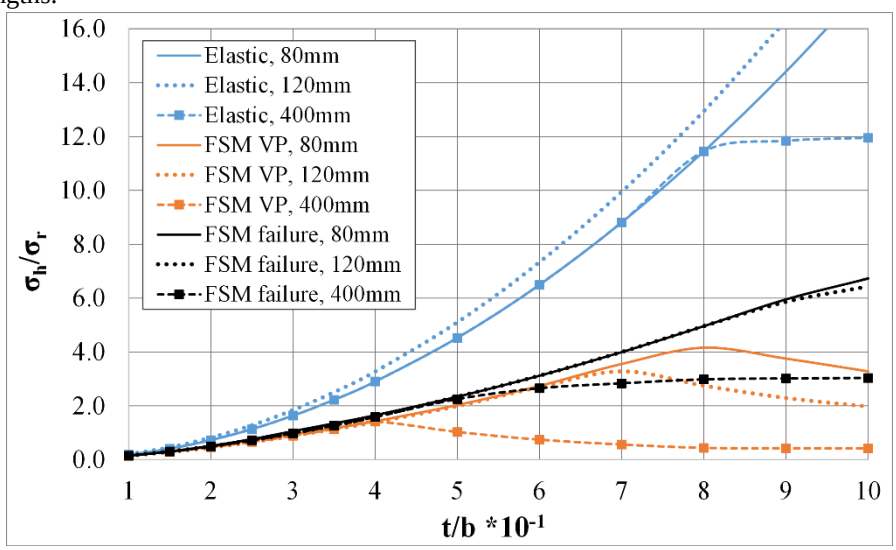

Figure 9. Critical stresses vs. thicknesses for three observed box girder lengths.

Results from the numerical studies for observed girder length of 400 mm that represent the influence of mode interactions on the buckling stresses are shown in Figs. 10 and 11.

Elastic interaction between local-global modes occurs in intermediate length of girders with near coincident critical stresses. The girders have the same lengths, but do not have all elastic characteristics in the same mode for small change of thickness. Because of that the girder loss of stability by local buckling for less thickness (t = 8 mm), while for higher thickness (t = 8.1 mm) the girder loss of stability by global buckling.

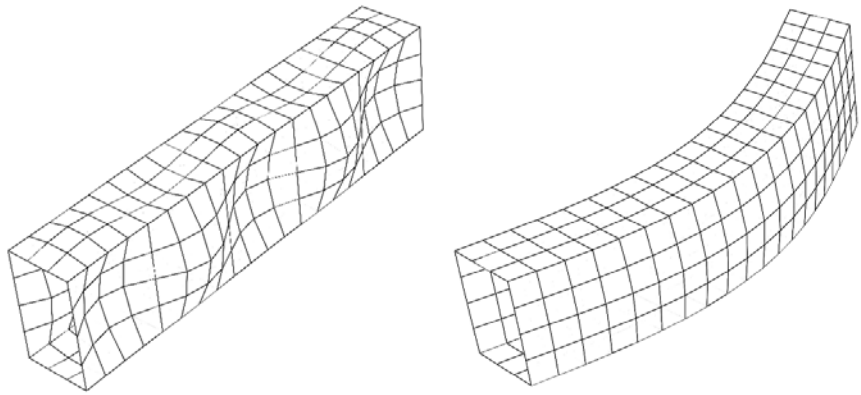

Figure 10. Buckling modes for length of 400 mm by FSM: local buckling (left - thickness of 8.0 mm) and global buckling (right - for thickness of 8.1 mm).

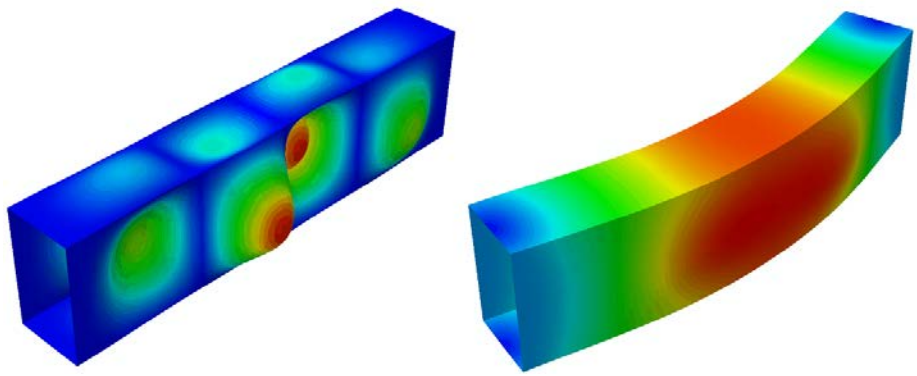

Figure 11. Buckling modes for length of 400 mm by Abaqus: local buckling (left - thickness of 8.6 mm) and global buckling (right - for thickness of 8.7 mm).

However, if we chose the thickness t = 2 mm, the above mentioned phenomena of elastic mode interaction appears on the girder length of 1900 mm in the global mode, Fig. 12, while the local mode defined the ultimate strength on the length of 1890 mm.

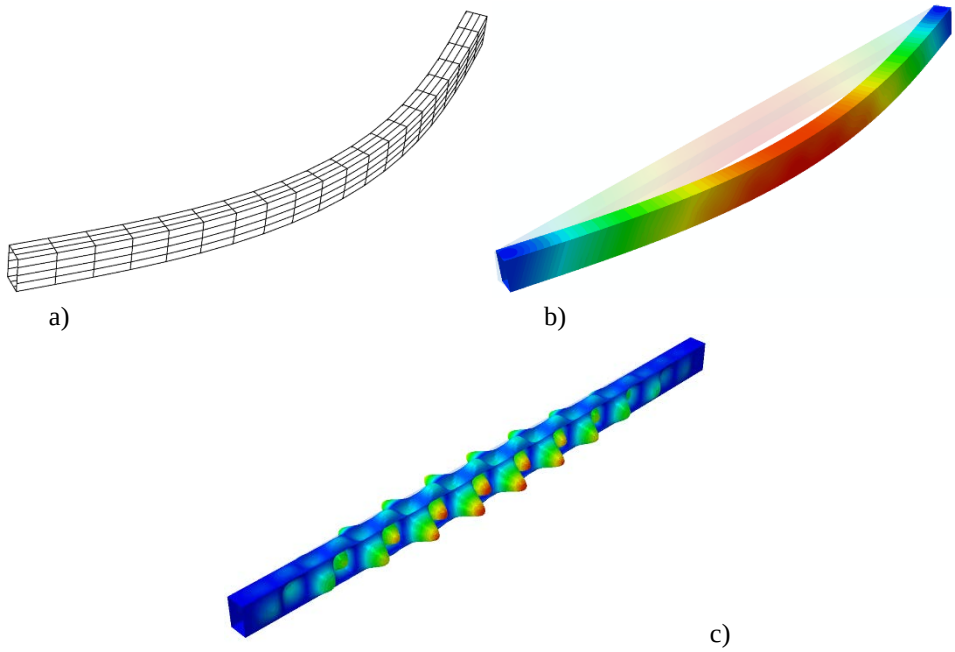

Figure 12. Global buckling modes for length of 1900mm: FSM (a), Abaqus (b) and local buckling mode for length of 1890mm with thickness of 2mm (c).

4. CONCLUSIONS

A theoretical investigation into the effectiveness of a plate thickness against the ultimate strength of a compressed slabs and box girders is carried out. The interaction between modes in the inelastic range of strains is analyzed taking into account the governing dynamic RDA modulus. The semi-analytical FSM eigenvalue analysis of slabs and box girders is used. The main indicators of capacity or collapse behavior are both the mode and the load (critical stress). Also the great influences on ultimate strength have both the length and thickness of slabs and box girders.

ACKNOWLEDGEMENTS

The work presented in this paper is a part of the investigation conducted within the research projects ON 174027 "Computational Mechanics in Structural Engineering" and TR 36017 "Utilization of by-products and recycled waste materials in concrete composites for sustainable construction development in Serbia: investigation and environmental assessment of possible applications", supported by the Ministry of Science and Technology of the Republic of Serbia. This support is gratefully acknowledged.

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06| Оригинални научни рад
Research paper
doi 10.7251/STP1813110B ISSN 2566-4484

SOME NUMERICAL ASPECTS OF A LINEAR STATIC ISOGEOMETRIC ANALYSIS OF AN ARBITRARILY CURVED PLANE BERNOULLI-EULER BEAM

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Abstract:

Linear static analysis of arbitrarily curved beams is considered. Metric of a Bernoulli-Euler beam is rigorously defined and the weak form of the corresponding boundary-value problem is solved using isogeometric approach. Driving force behind present research is detail numerical analysis of recently developed model of an arbitrarily curved beam. This is obtained via in-depth analysis of convergence properties, as well as by comparison with other numerical models. Excellent agreement of results is obtained and improved accuracy of the model with the highest continuity is proved to be valid for most cases.

Keywords: arbitrarily curved beam; isogeometric analysis; structural modeling

НЕКИ НУМЕРИЧКИ АСПЕКТИ ЛИНЕАРНЕ СТАТИЧКЕ ИЗОГЕОМЕТРИЈСКЕ АНАЛИЗЕ ПРОИЗВОЉНО КРИВЕ БЕРНУЛИ-ОЈЛЕРОВЕ ГРЕДЕ

Резиме:

У раду је размотрена линеарна статичка анализа произвољно кривих греда. Метрика Бернули-Ојлерове греде је строго дефинисана, након чега је, примјеном изогеометријског приступа, ријешена слаба форма одговарајућег граничног проблема. Основни мотив за провођење датог истраживања слиједи из уочене потребе за детаљном нумеричком анализом недавно развијеног модела произвољно криве греде. Ова анализа је извршена пажљивим разматрањем особина конвергенције посматраног модела, као и кроз поређење са другим нумеричким моделима. Добијено је одлично поклапање резултата при чему је потврђена чињеница да модели са највишим континуитетом често имају побољшану тачност.

Кључне ријечи: произвољно крива греда, изогеометријска анализа, моделирање конструкција

1. INTRODUCTION

Curved beams are increasing in popularity as structural elements. They have significant aesthetical value and great versatility when it comes to free-form modeling. Introduction of contemporary materials with improved mechanical properties enabled development of structural forms not previously imaginable. Consequently, there is an increase in necessity for development of efficient computational models for these structures. Besides standard isoparametric finite element (FE) method, during past decade we have witnessed an extensive growth of so-called isogeometric analysis (IGA), which is ideally suited for analysis of curved structures, [1]. The logic of IGA approach is reverse in comparison with isoparametric concept, [2]. Namely, isogeometric approach defines the structural geometry primarily and, most often, exactly. This is enabled due to versatility of basis functions, non-uniform rational basis spline (NURBS) being the most prominent one. Afterwards, the same adopted basis functions are utilized for description of kinematics. IGA is developed as a tool which could bridge gap between design and analysis, which it partially succeeded but more research is in front of us. Some of the actual topics are trimmed geometries, optimal quadrature rules etc. [3].

Analysis of curved beams in the frame of IGA is frequent, especially regarding Timoshenko beam model, see for example [4]. However, especially attractive feature of Bernoulli-Euler (BE) beam model is potential to introduce rotation-free models, since, for this theory, the rotation of a cross section is a function of translations of beam axis.

Aim of this paper is to investigate some numerical aspects of rotation-free IGA of an arbitrarily curved BE beam following recent findings given in [5], [6] and [7]. Detail analysis of influence of NURBS order and continuity on convergence properties is performed.

Paper is organized in five sections. After this brief introduction, some basic concepts regarding NURBS-based IGA modeling is presented. Numerical model is given in third section where abbreviated derivation of beam metric is given and followed with finite element formulation. Numerical analysis of two examples is performed in fourth section after which brief conclusions are drawn.

2. NURBS-BASED ISOGEOMETRIC MODELING

Brief consideration of NURBS functions is given. For more detailed discussion on this topic, refer to [8] and [9].

2.1. Non-uniform B-spline

B-splines are piecewise polynomial curves defined as:

$$\mathbf{r}(\xi) = \sum_{i=1}^{N} B_{i,p}(\xi)\mathbf{P}_i, \tag{1}$$

where $\mathbf{P}_i \in \mathbb{R}^d$ are control points and $B_{i,p}(\xi)$ are the pth order B-spline basis functions. Line segments that connect consecutive control points form the so-called control polygon. The B-spline basis functions are defined by a knot vector $\boldsymbol{\xi} = \{\xi_1, \xi_2, ..., \xi_{N+p+1}\}$, a non-decreasing sequence of real numbers, called knots. The same knot value may appear in a knot vector more than once and it is called a multiple knot. The knots partition the parameter space into knot spans, which also have representations in a physical space and parent domain, Fig. 1. Each non-zero knot span represents an isogeometric finite element.

If the first and the last knot have multiplicity $p+1$, the knot vector is said to be open. In this research, we employ only open knot vectors. Depending on whether the knot spans are equal or not, knot vectors may be uniform or non-uniform.

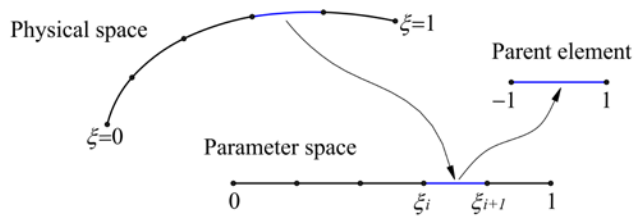

Figure 1. Physical space, parameter space and parent element

With a given knot vector, the B-spline basis functions are defined by the Cox-de Boor recursion formula, starting with piecewise constants ($p=0$):

$$B_{i,0}(\xi)=\begin{cases}1 & \text{if } \xi_i \le \xi < \xi_{i+1} \\ 0 & \text{otherwise}\end{cases},$$
$$B_{i,p}(\xi)=\frac{\xi-\xi_i}{\xi_{i+p}-\xi_i}B_{i,p-1}(\xi)+\frac{\xi_{i+p+1}-\xi}{\xi_{i+p+1}-\xi_{i+1}}B_{i+1,p-1}(\xi). \tag{2}$$

Some of the important properties of basis functions are that they constitute a partition of unity and they are non-negative for any value of parameter ξ. In each knot span, at most $p+1$ basis functions are non-zero, which is referred as a local support property. B-spline basis function is C^{p-m} continuous at knots of multiplicity m. Basis functions formed from open knot vectors are interpolatory at the ends of parametric interval and also at knots whose multiplicity is equal to a polynomial order. The properties of B-spline curves follow directly from those of their basis functions.

Non-Uniform Rational B-spline (NURBS) is a generalization of B-spline functions that allows us to exactly represent a wide range of objects that cannot be represented with simple polynomials, such as conic sections. Rational B-spline is obtained by a projective transformation of higher dimensional B-spline and can be defined as:

$$\mathbf{r}(\xi)=\sum_{i=1}^{N}B_{i,p}(\xi)w_i\mathbf{P}_i \Big/ \sum_{j=1}^{N}B_{j,p}(\xi)w_j=\sum_{i=1}^{N}R_{i,p}(\xi)\mathbf{P}_i, \tag{3}$$

where w_i are the weights and $R_{i,p}$ are the rational basis functions. Rational basis functions share the same main properties with the B-spline basis. If all weights are set to be equal, the NURBS curve becomes B-Spline.

An example of a cubic NURBS curve and corresponding rational basis is presented in Fig. 2. The curve is interpolatory and tangent to the control polygon at first and last control point and also at the sixth control point, since the multiplicity of the knot $\xi=3$ is $m=3$. Increasing the weight w_5 affects the curve shape only in the interval (1,3), where associated basis function is non-zero and a curve is pushed toward the control point. At the location of repeated knot, the curve is C^0 continuous.

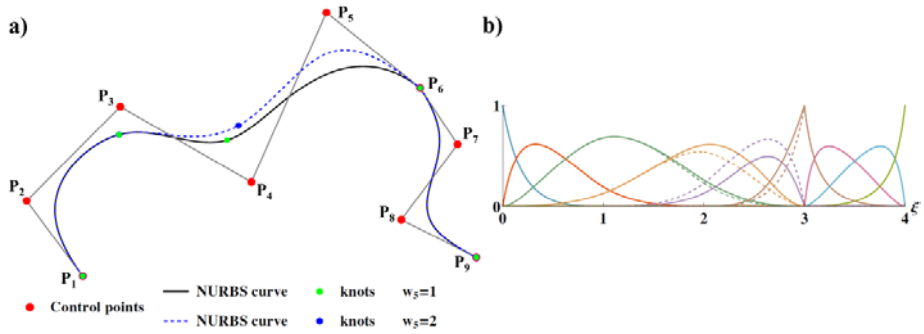

Figure 2. (a) NURBS curve with modification of w_5 *(b) Cubic rational bases defined with knot vector* $\boldsymbol{\xi} = \{0,0,0,0,1,2,3,3,3,4,4,4,4\}$ *and weights* $\mathbf{w} = \{1,2,3,2,1,1,3,3,1\}$ *(solid line). For* $w_5 = 2$ *, corresponding rational basis are changed (dashed line).*

2.2. Mesh refinement

The knot insertion (h -refinement) consist in adding new knots in a knot vector while the geometry and parameterization of the original curve stay intact. Inserting new knot values result in splitting the existing elements into smaller ones. If inserted knot was already present in a knot vector, the continuity of basis functions will be reduced and no new elements will be created. In this research, h -refinement implies increasing the number of elements while polynomial order and continuity remain fixed.

The p -refinement (i.e. order elevation) strategy involves increasing the polynomial order of basis functions without changing the curve geometrically or parametrically. During the order elevation, continuity of basis functions is preserved by increasing the multiplicity of knots. The number of elements remains unchanged since no new knot values are added.

The fact that the knot insertion and order elevation processes do not commute, allows us to elevate an order on a coarsest mesh and than perform knot insertion. As a result, the continuity of basis functions can be increased. This is referred to as k -refinement strategy. Pictorial representation of p - and k -refinement procedures, applied on a patch with three elements, is displayed in Fig. 3.

3. THEORETICAL CONSIDERATIONS

Present derivations are based on the classic BE assumption: cross sections are absolutely rigid and orthogonal to the deformed beam axis. Consequence of this assumption is the degeneration of a 3D beam model into its 1D counterpart, Fig 4. The convective frame of reference (ξ,η,ζ) is utilized with appropriate base vectors $(\mathbf{g}_1,\mathbf{g}_2,\mathbf{g}_3)$. At the centroid, curvilinear coordinate axis ξ correspond to the beam axis while η and ζ are aligned with the principal axes of the second moment of area of a cross section, Fig 4. Due to introduced assumption, ξ is the only independent variable for the analysis of plane BE beams. Notice that base vectors $(\mathbf{g}_2,\mathbf{g}_3)$ remain unit for all configurations. Present derivations are compact version of the ones given in [7] and [5].

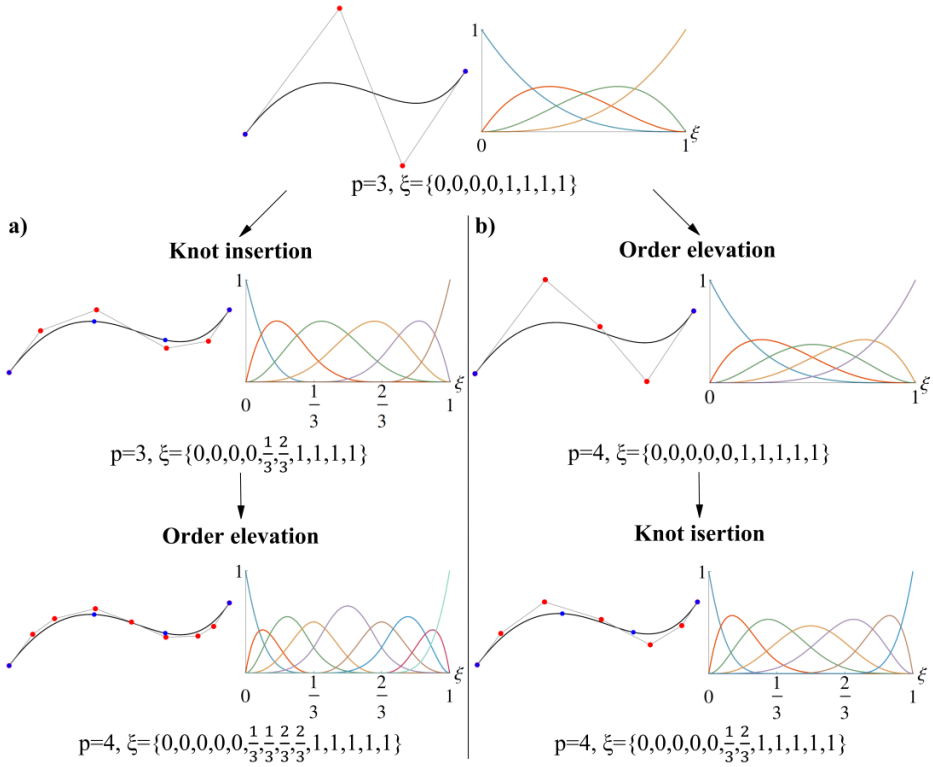

Figure 3. Higher-order meshes for: (a) p-refinement (b) k-refinement

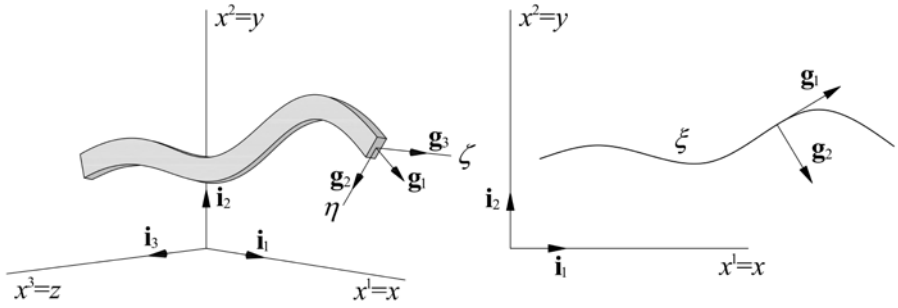

Figure 4. Degeneration of 3D beam into 1D; Coordinate systems and base vectors

3.1. REFERENCE CONFIGURATION OF BEAM AXIS

Position vector of the beam axis is $\mathbf{r} = \mathbf{r}(\xi)$ while its Cartesian coordinates are $x^{\alpha} = x^{\alpha}(\xi)$, $\alpha = 1,2$. Hence, the position vector of beam axis and its base vector are:

$$\mathbf{r} = x^{\alpha}\,\mathbf{i}_{\alpha}, \qquad \mathbf{g}_1 = \mathbf{r}_{,1} = \frac{d\,\mathbf{r}}{d\xi} = x^{\alpha}_{,1}\,\mathbf{i}_{\alpha}, \tag{4}$$

where $()_{,k}$ designates differentiation with respect to the kth coordinate of the system (ξ,η). $\mathbf{i}^{\alpha}$ are the unit base vectors of the Cartesian coordinate system, Fig. 4.

Classic relation of convective and arc-length coordinates is:

$$ds^2 = (x^\alpha_{,1})^2 d\xi^2 = g_{11}\, d\xi^2 \Rightarrow \; ds = \sqrt{g_{11}}\, d\xi, \tag{5}$$

where g_{11} is the component of the metric tensor of a beam axis:

$$g_{\alpha\beta} = \begin{bmatrix} g_{11} & 0 \\ 0 & 1 \end{bmatrix} \Rightarrow \det g_{\alpha\beta} = g_{11}. \tag{6}$$

Base vector $\mathbf{g}_1$ is collinear with tangent and its first derivative with respect to ξ is:

$$\mathbf{g}_1 = \sqrt{g_{11}}\,\mathbf{t}, \qquad \mathbf{g}_{1,1} = \Gamma^1_{11}\mathbf{g}_1 + \bar{K}\mathbf{g}_2, \qquad \bar{K} = g_{11}K, \qquad \Gamma^1_{11} = x^\alpha_{,1}\, x_{\alpha,11} g^{11}. \tag{7}$$

where K is the modulus of curvature vector with respect to the Frenet-Serret frame of reference, while $\bar{K}$ is its counterpart but with respect to the convective frame of reference. Γ^1_{11} is the Christoffel symbol of the second kind while the determinant of the contravariant metric tensor of the beam axis is $g_{11} = g^{11}$. The base vector of η coordinate follows from (7):

$$\mathbf{g}_2 = x^\alpha_{,2}\,\mathbf{i}_\alpha, \quad \mathbf{g}_2 = \frac{1}{\bar{K}}(\mathbf{g}_{1,1} - \Gamma^1_{11}\mathbf{g}_1) \Rightarrow \; x^\alpha_{,2} = \frac{1}{\bar{K}}(x^\alpha_{,11} - \Gamma^1_{11} x^\alpha_{,1}). \tag{8}$$

3.2. METRIC OF DEFORMED BEAM AXIS AND REFERENCE STRAINS

The position vector of the beam axis in the deformed configuration is:

$$\mathbf{r}^*(\xi) = \mathbf{r}(\xi) + \mathbf{u}(\xi), \tag{9}$$

where $\mathbf{u}(\xi)$ is its displacement vector while tangential base vector of the beam axis is:

$$\mathbf{g}_1^* = \mathbf{r}^*_{,1} = (x^\alpha_{,1} + u^\alpha_{,1})\mathbf{i}_\alpha = x^{*\alpha}_{,1}\,\mathbf{i}_\alpha. \tag{10}$$

Notice the determinant of the metric tensor of the deformed beam axis:

$$g^*_{11} = x^{*\alpha}_{,1} x^*_{\alpha,1}. \tag{11}$$

Additionally, normal base vector of the deformed beam axis is:

$$\mathbf{g}_2^* = \mathbf{g}_2 + \mathbf{u}_{,2}, \qquad \left|\mathbf{g}_2^*\right| = \left|\mathbf{g}_2\right| = 1. \tag{12}$$

where:

$$\mathbf{u}_{,2} = -\left(\mathbf{g}_2 \cdot \mathbf{u}_{,1}\right)\mathbf{g}^1 = -\frac{1}{g_{11}}\left(\mathbf{g}_2 \cdot \mathbf{u}_{,1}\right)\mathbf{g}_1, \quad u_{,2} = -B^\beta_\alpha u_{\beta,1}, \quad B^\beta_\alpha = \frac{1}{g} x^\beta_{,2} x_{\alpha,1}. \tag{13}$$

The modulus of curvature of the deformed beam axis follows, analogous to (7):

$$\mathbf{g}^*_{1,1} = \Gamma^{*1}_{11}\mathbf{g}^*_1 + \bar{K}^*\mathbf{g}^*_2 \Rightarrow \; \bar{K}^* = \mathbf{g}^*_{1,1}\cdot\mathbf{g}^*_2. \tag{14}$$

Only Lagrange component of strain for linear BE theory is:

$$\varepsilon_{11} = \frac{1}{2}(g^*_{11} - g_{11}) \;\Rightarrow\; \varepsilon_{11} = x^\alpha_{,1} u_{\alpha,1}. \tag{15}$$

Additionally, the flexural strain of the beam axis is introduced as:

$$\kappa = \bar{K}^* - \bar{K} = \mathbf{g}^*_{1,1}\cdot\mathbf{g}^*_2 - \mathbf{g}_{1,1}\cdot\mathbf{g}_2. \tag{16}$$

Using the BE conditions, as well as neglecting higher order terms of displacement gradients, we can obtain following relation:

$$\kappa = \mathbf{u}_{,11}\cdot\mathbf{g}_2 - \Gamma^1_{11}\mathbf{u}_{,1}\cdot\mathbf{g}_2 = (\mathbf{u}_{,11} - \Gamma^1_{11}\mathbf{u}_{,1})\cdot\mathbf{g}_2, \quad \kappa = (u_{\alpha,11} - \Gamma^1_{11}u_{\alpha,1})x^\alpha_{,2}. \tag{17}$$

3.3. STRAIN AT AN ARBITRARY POINT

If we define position vectors of an arbitrary point in the reference and deformed configurations as:

$$\mathbf{r}(\xi,\eta)=\overline{\mathbf{r}}=\mathbf{r}(\xi)+\eta\ \mathbf{g}_2, \qquad \overline{\mathbf{r}}^*(\xi,\eta)=\overline{\mathbf{r}}^*=\mathbf{r}^*(\xi)+\eta\ \mathbf{g}_2{}^*, \tag{18}$$

the base vector at an arbitrary point of a cross section with respect to ξ coordinate is:

$$\overline{\mathbf{g}}_1=\mathbf{g}_1+\eta\ \mathbf{g}_{2,1}. \tag{19}$$

Using the expression for the first derivative of normal base vector:

$$\frac{d\,\mathbf{g}_2}{d\xi}=-K\,\mathbf{g}_1, \tag{20}$$

base vector $\overline{\mathbf{g}}_1$ with respect to the reference and deformed configurations is:

$$\begin{aligned}&\overline{\mathbf{g}}_1=\mathbf{g}_1-\eta K\,\mathbf{g}_1=(1-\eta K)\,\mathbf{g}_1=g_0\,\mathbf{g}_1, \qquad g_0=1-\eta K,\\ &\overline{\mathbf{g}}_1^*=(1-\eta K^*)\,\mathbf{g}_1^*\Rightarrow\ \overline{\mathbf{g}}_1{}^*=g_0^*\,\mathbf{g}_1^*, \qquad g_0^*=1-\eta K^*.\end{aligned} \tag{21}$$

Now, strain at an arbitrary point of a cross section reduces to:

$$\varepsilon_{11}(\eta)=\overline{\varepsilon}_{11}=\frac{1}{2}(\overline{g}_{11}{}^*-\overline{g}_{11})=\frac{1}{2}\left(g_0{}^{*2}g_{11}{}^*-g_0{}^2g_{11}\right). \tag{22}$$

which, after insertion of XX and neglecting higher order terms of strain, transforms to:

$$\overline{\varepsilon}_{11}=g_0\left[(1+\eta K)\,\varepsilon_{11}-\eta\kappa\right]. \tag{23}$$

This expression is derived rigorously, without any additional geometric assumptions besides the BE hypothesis and the ones regarding finite (but small) strain theory, [5].

3.4. FINITE ELEMENT FORMULATION

Stress-strain relation for linear elastic material, at an arbitrary point, is:

$$\overline{\sigma}^{11}=E(\overline{g}^{11})^2\,\overline{\varepsilon}_{11}, \tag{24}$$

where E is the modulus of elasticity, while $\overline{g}^{11}$ is the determinant of the contravariant metric tensor at an arbitrary point. Now, the internal virtual work can be written as:

$$\delta W_{\text{int}}=\int_V(\overline{g}^{11})^2\,\overline{\varepsilon}_{11}E\delta\overline{\varepsilon}_{11}dV. \tag{25}$$

If we recall basic relations:

$$dV=\sqrt{\overline{g}_{11}}\,d\xi d\eta d\zeta, \quad \sqrt{\overline{g}_{11}}=g_0\sqrt{g_{11}}, \quad \overline{g}^{11}=\frac{1}{g_0{}^2}g^{11}, \tag{26}$$

and introduce (23) into (25), the internal component of the virtual work reduces to:

$$\delta W_{\text{int}}=\int_\xi(\overline{N}\,\delta\varepsilon_{11}+\overline{M}\,\delta\kappa)\sqrt{g_{11}}\,d\xi, \tag{27}$$

where $\overline{N}$ and $\overline{M}$ are section forces energetically conjugated to the reference strains of the beam axis:

$$\overline{N}=\int_A(1+\eta K)g_0{}^2\overline{\sigma}^{11}d\eta d\zeta, \qquad \overline{M}=-\int_A\eta g_0{}^2\overline{\sigma}^{11}d\eta d\zeta. \tag{28}$$

which differ from the standard section forces. After integration, we obtain:

$$\overline{N} = E(g^{11})^2 (A\varepsilon_{11} - \overline{I}\,\kappa), \qquad \overline{M} = E(g^{11})^2 (-\overline{I}\,\varepsilon_{11} + I\,\kappa), \tag{29}$$

where the appropriate cross section geometric properties are introduced:

$$A = \int_A \frac{(1+\eta K)^2}{g_0} d\eta d\zeta, \quad \overline{I} = \int_A \frac{\eta(1+\eta K)}{g_0} d\eta d\zeta, \quad I = \int_A \frac{\eta^2}{g_0} d\eta d\zeta = \frac{\overline{I}}{2K}. \tag{30}$$

The matrix form of the equation (29) can be written as:

$$\begin{bmatrix} \overline{N} \\ \overline{M} \end{bmatrix} = E(g^{11})^2 \begin{bmatrix} A & -\overline{I} \\ -\overline{I} & I \end{bmatrix} \cdot \begin{bmatrix} \varepsilon_{11} \\ \kappa \end{bmatrix} \quad \Leftrightarrow \quad \overline{\mathbf{R}} = \overline{\mathbf{D}}\boldsymbol{\varepsilon}. \tag{31}$$

For the isogeometric finite element with control points $I = 1, 2, 3 ... N$, the relation between the vector of the reference strains of the beam axis and the vector of displacements of control points is introduced:

$$\boldsymbol{\varepsilon} = \mathbf{B}\mathbf{q}, \qquad \boldsymbol{\varepsilon}^{\mathrm{T}} = \begin{bmatrix} \varepsilon_{11} & \kappa \end{bmatrix}, \tag{32}$$

where the appropriate vectors and matrices are defined:

$$\mathbf{B} = \begin{bmatrix} \mathbf{B}_1 & \mathbf{B}_2 & \cdots & \mathbf{B}_I & \cdots & \mathbf{B}_N \end{bmatrix}, \qquad \mathbf{q}^{\mathrm{T}} = \begin{bmatrix} \mathbf{q}_1 & \mathbf{q}_2 & \cdots & \mathbf{q}_I & \cdots & \mathbf{q}_N \end{bmatrix},$$

$$\mathbf{B}_I = \begin{bmatrix} x_{1,1} R_{I,1} & x_{2,1} R_{I,1} \\ x_{1,2}\left(R_{I,11} - \Gamma_{11}^1 R_{I,1}\right) & x_{2,2}\left(R_{I,11} - \Gamma_{11}^1 R_{I,1}\right) \end{bmatrix}, \ \mathbf{q}_I = \begin{bmatrix} u_I^1 & u_I^2 \end{bmatrix}. \tag{33}$$

These designations enable us to represent the internal component of the virtual work as:

$$\delta R_u = \mathbf{q}^{\mathrm{T}} \int_\xi \mathbf{B}^{\mathrm{T}} \overline{\mathbf{D}} \mathbf{B} \sqrt{g_{11}}\, d\xi \delta \mathbf{q}, \tag{34}$$

where:

$$\mathbf{K} = \int_\xi \mathbf{B}^{\mathrm{T}} \overline{\mathbf{D}} \mathbf{B} \sqrt{g_{11}}\, d\xi \tag{35}$$

is the linear stiffness matrix of a rotation-free BE isogeometric finite element, [7].

4. NUMERICAL STUDY

Two examples are studied: circular and a free-form cubic beam. Convergence analysis is performed in such a way that the order of convergence is observed as a function of a number of elements n_{el} , analogously to [10]. Expected values are $p+1$ for displacements, p for normal force and $p-1$ for bending moment, [11]. The order of convergence, for a mesh with n_{el} elements, is here determined as:

$$\left| \log_{10} \frac{\left| S_{n_{el}}^h - S^{ex} \right|}{\left| S_{n_{el}-1}^h - S^{ex} \right|} \right| \Big/ \log_{10}\left(\frac{n_{el}}{n_{el}-1} \right)$$

where S^{ex} is the reference solution while S_i^h is an approximate solution for a mesh with i elements. Results obtained with very dense meshes are utilized as the reference values, except for the quantities for which these solutions are analytically defined. Since it is noticed that the order of convergence significantly oscillates for some variables and meshes under considerations, these parts graphs are truncated to enable readability.

4.1. CIRCULAR ARCH

Fig. 5 shows disposition and properties of a clamped circular arch. Prominent feature of this example is concentrated force at the middle of structure. Due to this load, model does not have C^3 at this section. Therefore, it is interesting to observe the behavior of quartic NURBS using this interelement continuity.

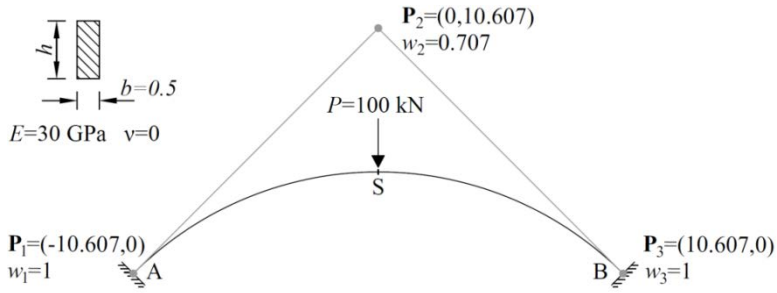

Figure 5. Clamped circular arch under concentrated load.

Convergence properties for $Kh = 0.067$ are represented in Fig. 6, Fig. 7, Fig. 8, Fig. 9 and Fig. 10. Convergence of deflections is fast, especially for quartics, Fig. 6. Quadratic NURBS returns the order of convergence which is lower than expected value of 3. For cubics, this order converges to predicted value. Regarding quartic NURBS, model with C^3 continuity returns extremely low order of convergence, while solutions for models with lower continuities converge with very high orders.

Regarding convergence of normal force at the section S, it is noticed that all models return expected orders of convergence, Fig. 7. Exception is quartic NURBS with C^3 continuity, which returns lower accuracy. This is due to the coupling of normal force with flexural strain. Notice that similar results are obtained at the support, disregarding the mentioned phenomenon of the highest continuity for quartic elements, Fig. 9.

Generally, convergence properties of bending moments are in line with analytical predictions. Fig. 8 reveals that the orders of convergence for models with quartic NURBS is oscillatory. Again, model with C^3 continuity has very low accuracy. Note that the orders of convergence for both models with cubic NURBS converge to the same value $p-1=2$. However, it is evident that model with C^2 continuity has average higher order of convergence, which results with better accuracy per DOF, compared to the C^1 model. At the support, quadratics and cubics behave similarly as at S. Nevertheless, quartics have very high accuracy while their orders of convergence could not be detected, Fig. 10.

Fig. 11 shows excellent correspondence of distribution of bending moments and normal forces along beam. Although not presented, straight BE beam element in Abaqus, B23, requires dense meshes for convergence of section forces.

Fig. 12 displays relative error of considered beam models with respect to 2D isotropic and 2D orthotropic model. 2D models are created using dense meshes of CPS3 elements in Abaqus. Orthotropic material model is made by multiplication of modulus of elasticity along η direction and shear modulus with an empirically determined factor of $100Kh$, [10]. This calibrated orthotropic material model is introduced in order to artificially introduce BE assumptions into general 2D model. Result is evident from Fig. 12b, where excellent correspondence of present and calibrated orthotropic 2D model is noticed, even

for high values of curviness *Kh*. For more detail discussion on influence of curviness on beam models, see [7] and [10].

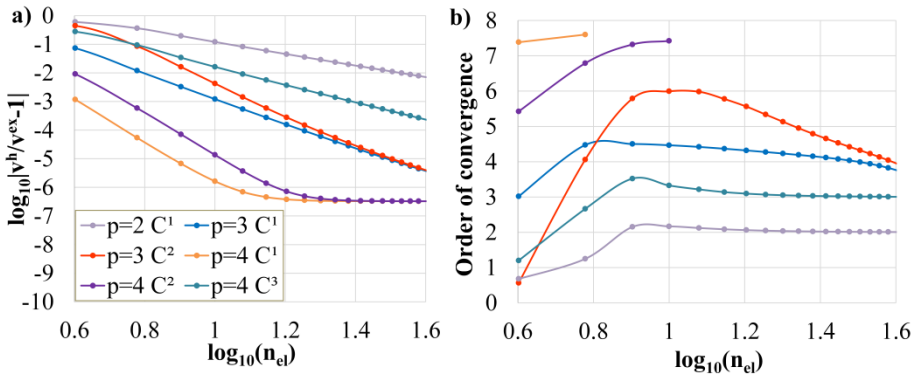

Figure 6. Convergence properties for the deflection at S using the h-refinement with different NURBS orders and continuities: a) relative error; b) order of convergence.

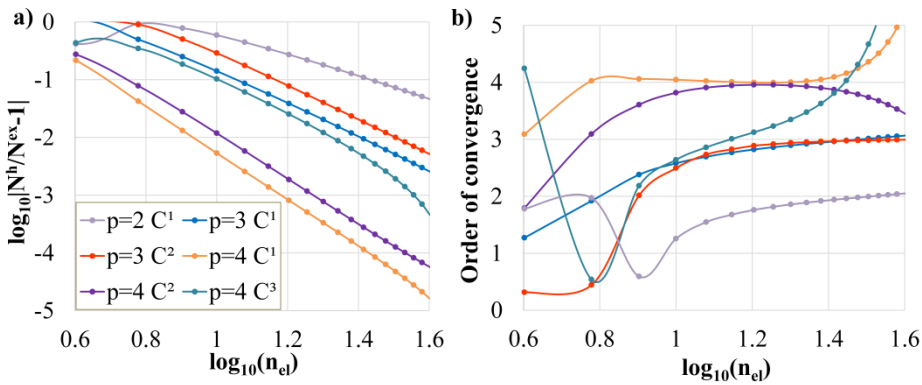

Figure 7. Convergence of the normal force at S using the h-refinement with different NURBS orders and continuities: a) relative error; b) order of convergence.

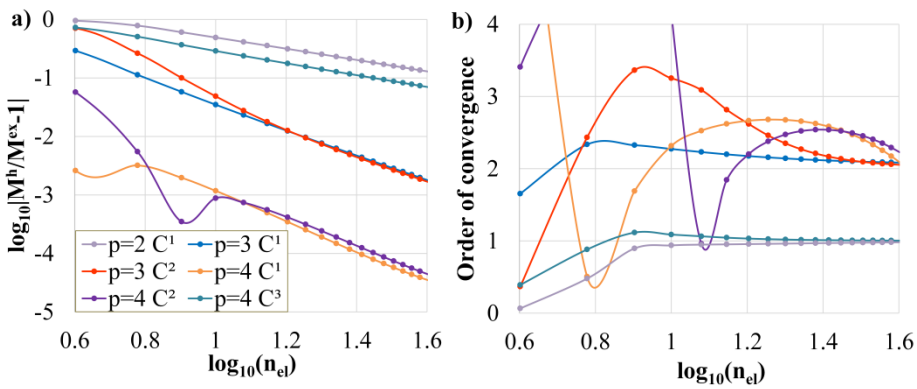

Figure 8. Convergence of the bending moment at S using the h-refinement with different NURBS orders and continuities: a) relative error; b) order of convergence.

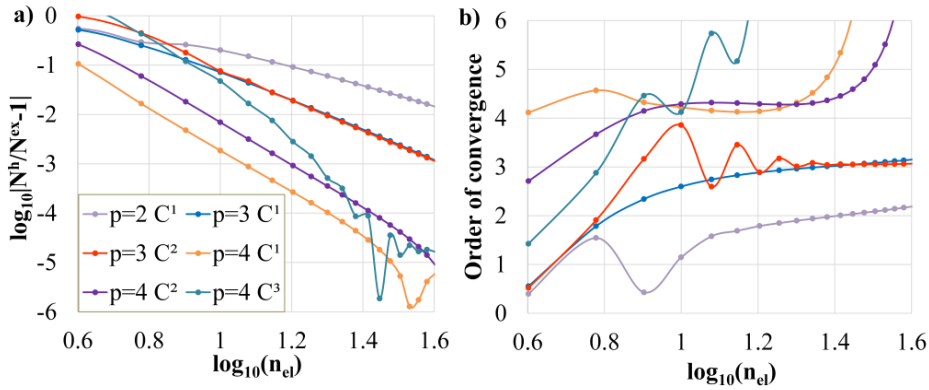

Figure 9. Convergence of the normal force at A using the h-refinement with different NURBS orders and continuities: a) relative error; b) order of convergence.

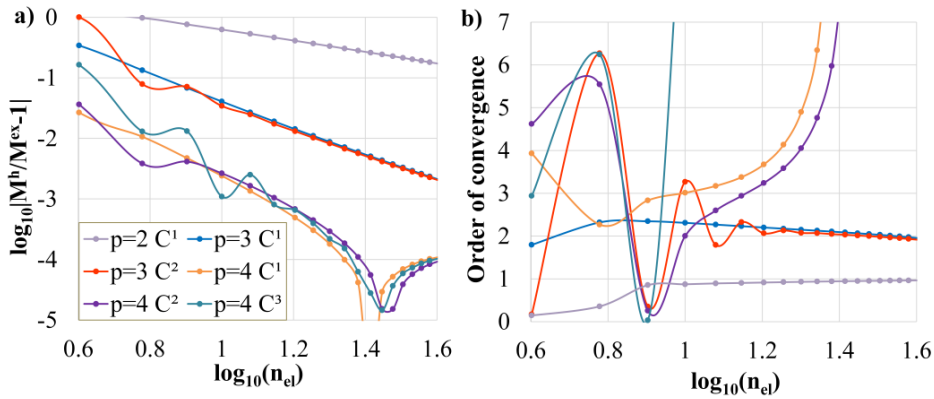

Figure 10. Convergence of the bending moment at A using the h-refinement with different NURBS orders and continuities: a) relative error; b) order of convergence.

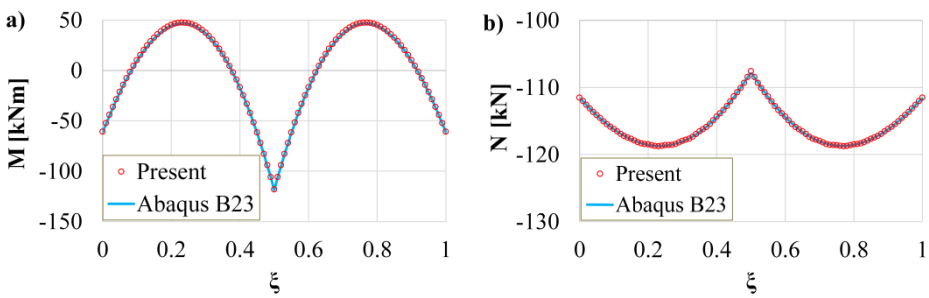

Figure 11. Distribution of: a) bending moment, b) normal force.

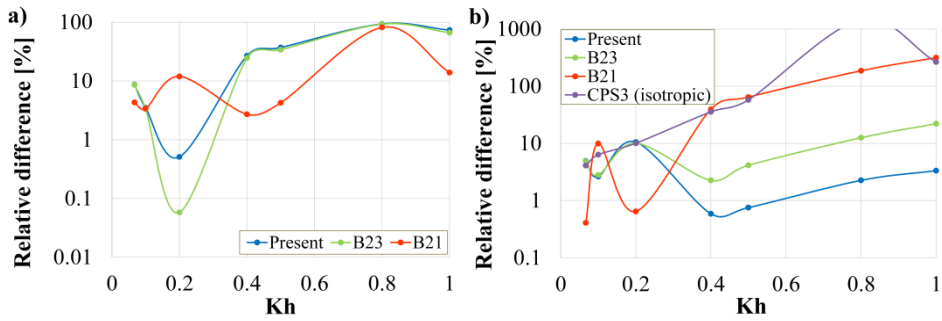

Figure 12. Relative difference of deflection at S: a) vs. isotropic 2D CPS3 model, b) vs. orthotropic 2D CPS3 model.

4.2. CUBIC ARCH

This example deals with cubic arch presented in Fig. 13. Half of the structure is analyzed using symmetry. This example does not suffer from the problem of discontinuity, as the previous one, since the external load acts at the end point, due to symmetry. However, 2D model is created in Abaqus for comparison and it has well-known issues with pinned support due to stress and strain concentration.

Convergence properties are given in Fig. 14, Fig. 15, Fig. 16, Fig. 17 and Fig. 18. Fig. 14 shows that all models yield very high orders of convergence for deflection, where only those for cubics are well-defined and converge to the expected value of $p+1=4$. Results in Fig. 15 suggest that some polynomial degrees return analytical values of the order of convergence for normal force at S but this is not true for all. Cubics with C^1 have improved accuracy and their orders of convergence could not be determined, as well as those for C^3 quartics and quintics. The same section force at the support has highly oscillatory behavior of the orders of convergence, Fig. 17. Interestingly, cubic and quartic NURBS with highest continuity return orders which are in line with expectations. It is not straightforward to make conclusion regarding relation of accuracy and continuity since for cubics, improved accuracy is evident for model with higher continuity, while it is contrary for quintics.

Convergence of bending moments reveals some expected properties. For the section at S, all models converge to the predicted value, except for the quintics with C^4 continuity, Fig. 16. Here, improved accuracy of models with highest continuity is evident. Highly oscillatory behavior of the order of convergence for bending moment at the support is observed in Fig. 18b and some parts of graphs had to be truncated. Close inspection suggests that cubic and quartics behave closely to predictions, and improved accuracy per DOF for models with the highest continuity is observed. Quintics return great accuracy while their orders of convergence are not detectable.

In Fig. 19, nearly full compliance of distributions of section forces is obtained via comparison with B23 element from Abaqus. Detail comparison of relative error of beam models with respect to the isotropic model, made of general S3 shell elements in Abaqus, is given in Fig. 20 for different values of curviness. It is evident that present model returns the worst compliance with general shell model. Concretely, present model is the stiffest of all four. This is due to the strictly defined metric of a beam, not present for straight B21 and B23 elements, and BE hypothesis.

Finally, distribution of stresses for two values of curviness is presented in Fig. 21. In Abaqus S3 model, maximum principle stress is displayed. For lower values of curviness, uniaxial stress/strain assumption of BE theory yields good estimate. Still, for extremely large values of curviness, all stress and strain components are significant. Additionally, stress concentration at the pinned support for S3 shell model becomes more prominent as the value of curviness increase. These extreme ranges of stress are marked with gray and black in legend for $K_{max}h = 1$ and they are hardly visible in given contour plot.

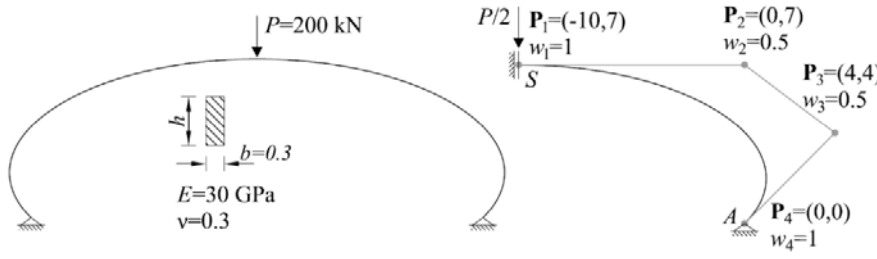

Figure 13. Simply supported free-form cubic arch under concentrated load.

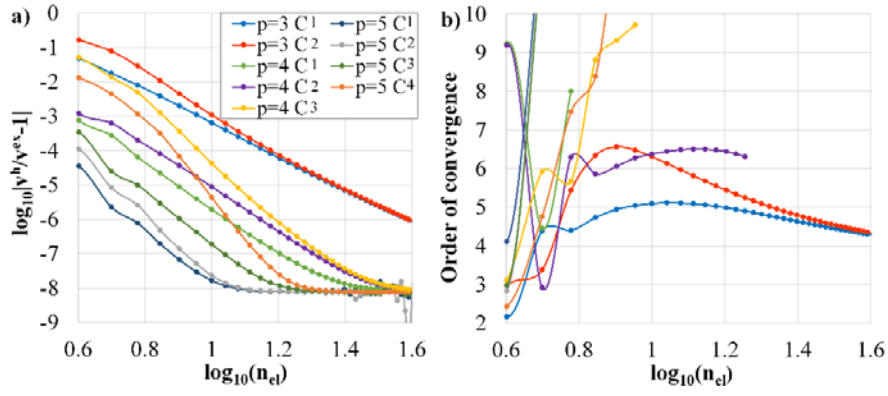

Figure 14. Convergence of the deflection at S using the h-refinement with different NURBS orders and continuities: a) relative error; b) order of convergence.

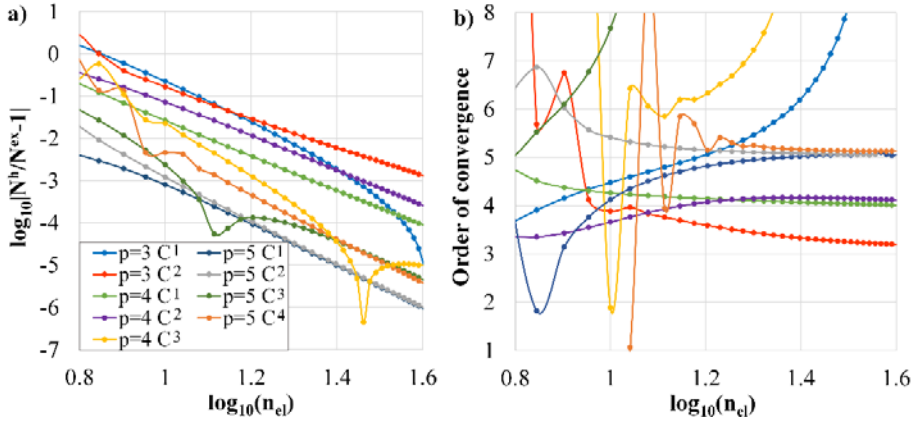

Figure 15. Convergence of the normal force at S using the h-refinement with different NURBS orders and continuities: a) relative error; b) order of convergence.

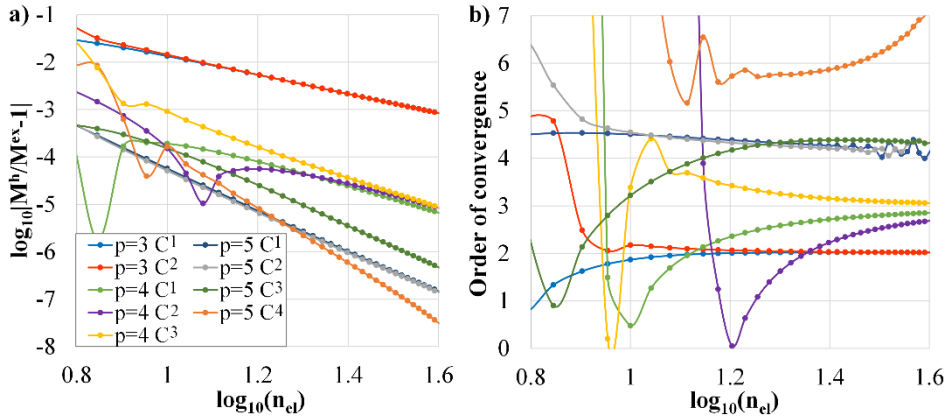

Figure 16. Convergence of the bending moment at S using the h-refinement with different NURBS orders and continuities: a) relative error; b) order of convergence.

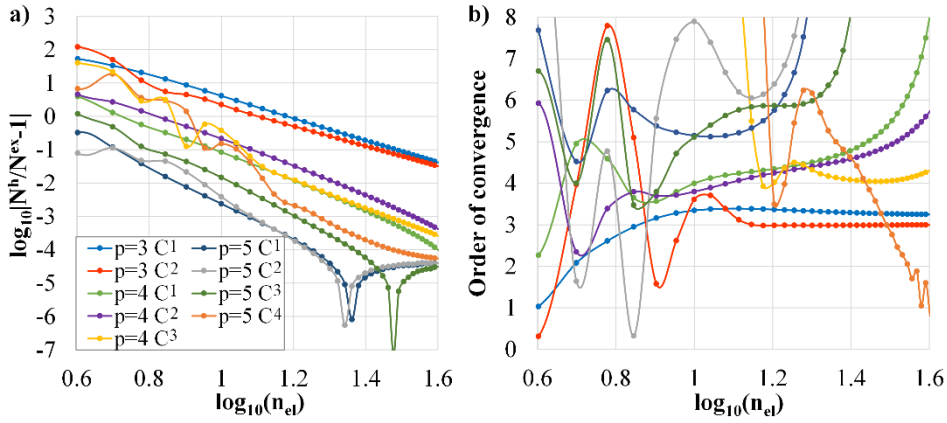

Figure 17. Convergence of the normal force at A using the h-refinement with different NURBS orders and continuities: a) relative error; b) order of convergence.

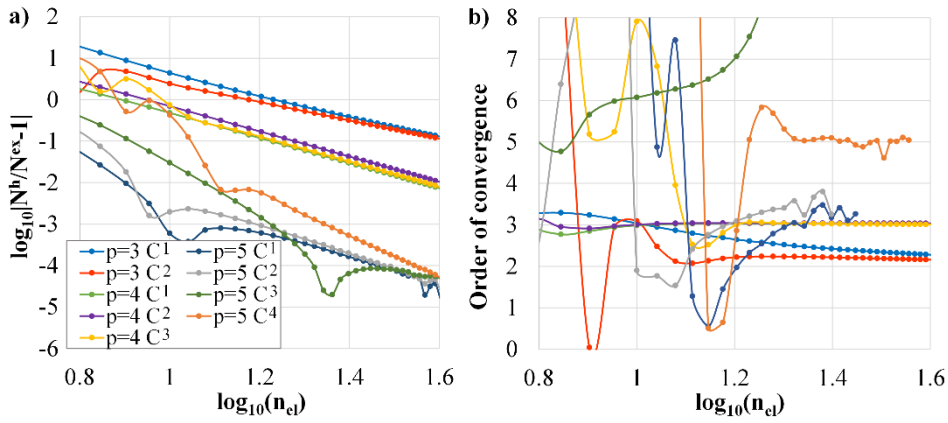

Figure 18. Convergence of the bending moment at A using the h-refinement with different NURBS orders and continuities: a) relative error; b) order of convergence.

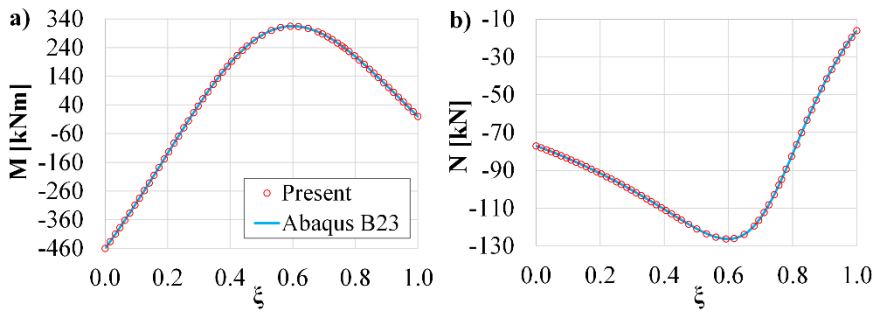

Figure 19. Distribution of: a) bending moment, b) normal force.

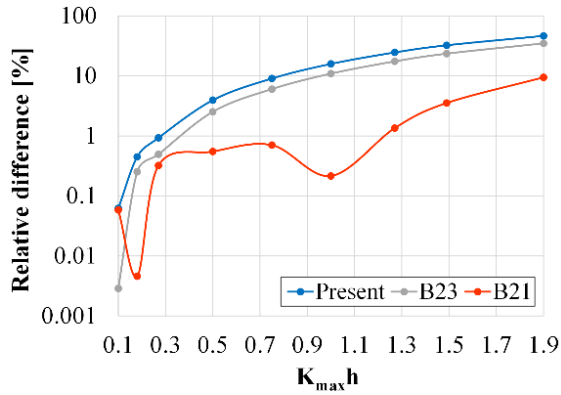

Figure 20. Relative differences of deflections at S with respect to 2D model vs. $K_{\max}h$.

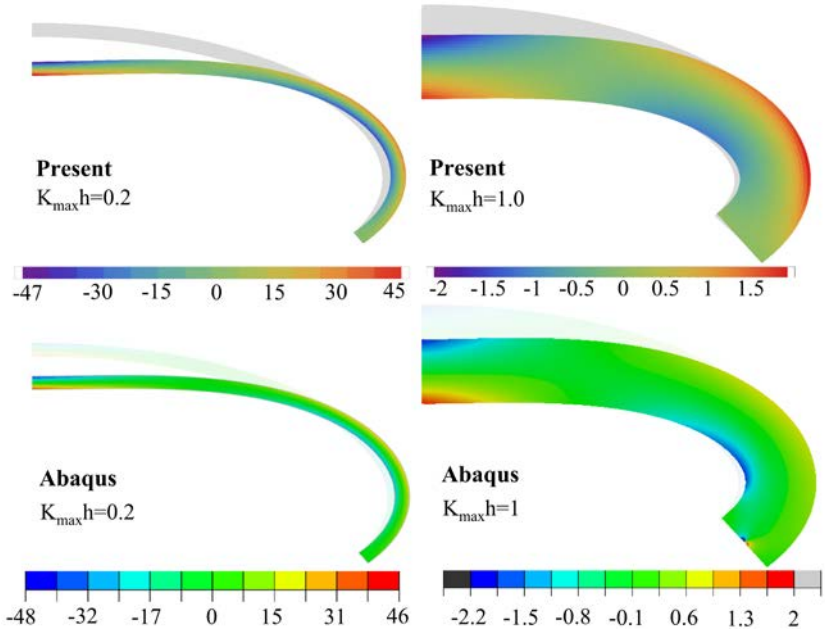

Figure 21. Stress distribution on deformed configuration for two values of curviness

5. CONCLUSIONS

Thorough numerical analysis of recently developed computational model of an arbitrarily curved beam is performed via two examples. Due to rigorously defined metric and BE assumptions, present model is stiffer than standard beam models. It is concluded that the order of convergence is improved for the most meshes with highest continuity. However, for models that have interelement discontinuity of some order, increase in continuity must be considered carefully, since it could result with reduced accuracy.

Further research will be focused on a finite rotation and finite strain dynamic analysis of plane and spatial beams.

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07| Оригинални научни рад
Research paper
doi 10.7251/STP1813127R ISSN 2566-4484

UTICAJ PRIMENE SITNOG AGREGATA OD RECIKLIRANOG BETONA NA KARAKTERISTIKE ASFALTNIH MEŠAVINA

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Rezime:

Cilj ovog rada je procena mogućnosti upotrebe sitnog agregata od recikliranog betona (RCA) u asfaltnim mešavinama. Eksperimentalna ispitivanja su obuhvatila projektovanje i ispitivanje četiri asfaltne mešavine sa delimičnom zamenom sitnog (0/4 mm) prirodnog agregata recikliranim, u količini od 0% (etalon), 15%, 30% i 45%, maseno. Sve asfaltne mešavine su projektovane za noseće slojeve kolovozne konstrukcije. Modul krutosti asfaltnih mešavina sa recikliranim agregatom niži je u odnosu na kontrolnu mešavinu. Dodatak sitnog RCA nema bitan uticaj na otpornost asfaltnih mešavina na dejstvo vode i kreće se u granicama od -2.4% do +1.7% u odnosu na kontrolnu mešavinu. Otpornost na trajnu deformaciju se povećava sa dodatkom do 30% sitnog RCA.

Ključneriječi:asfalt, recikliraniagregat, krutost, dejstvovode, trajnadeformacija.

INFLUENCE OF FINE RECYCLED CONCRETE AGGREGATE ON THE PROPERTIES OF ASPHALT MIXTURES

Abstract:

The objective of this paper was to assess the possibility of using fine recycled concrete aggregate (RCA) in asphalt mixtures. The experimental research included four asphalt mixtures with partial natural aggregate substitution by fine RCA (0/4 mm), in the amount of 0% (control mixture), 15%, 30% and 45%, by mass. All asphalt mixtures were designed for the base course. The stiffness modulus of asphalt mixtures with RCA was lower compared with the control mixture. The use of fine RCA had no significant influence on the water sensitivity and ranged from -2.4% to +1.7% relative to the control mixture. Resistance to permanent deformation increases with the addition of up to 30% fine RCA.

Keywords: asphalt, recycled aggregate, stiffness, water sensitivity, permanent deformation.

1. INTRODUCTION

In the last two decades the world tendencies are turned to reduction of environmental pollution and exploitation of natural aggregates byusing recycled concrete aggregate(RCA) [1-2]. Researchespublished so far have shown that recycled concrete has been used as coarse aggregate for embankments, for the unbound base and sub-base layers in road pavement construction and as a component in cement concrete mixtures.Although, fine recycled concrete aggregate makes 30% to 60% of produced RCA, it was rarely applied because of the high content of very fine particles (filler). Having in mind that fine particles present an obligatory component of asphalt concrete mixtures, it should be expected that the application of both fine and coarse RCA in these mixtures is possible.

RCA produced by milling of old concrete, consists of natural aggregate combined with residual cementitious mortar. The presence of mortar,generally more porous than natural aggregate, influences degradation in the properties of RCA compared to natural aggregates such as: higher water absorption, lower strength, lower density and abrasionresistance [3-5]. Nevertheless, when applied in asphalt concrete production, RCA shows some advantages. Thepresence of residual cementitious mortar makes the surface texture of the RCA exceptionally rough, with sharp edges andfavorably shaped particles. These properties are result of the crushing technology of concrete in production of RCA, contributing to theinteraction and higher surface friction between the aggregate particles. However, the main advantages of possible RCA application are based onthe principles of sustainable development: waste quantities reduction, aesthetic impact on the environment, preservation of natural resources, collection of metal debris during concrete recycling and reduction of C&D waste disposal costs.

Water resistance presents one of the most important tests for asphalt mixtures with recycled concrete aggregates, due to the porosity of this type of aggregates. The importance of this condition is proved by the number of the experiments performed on this subject. Pasandini and Perez [6] presented a thorough review of the waterresistance test results in these kinds of asphalt mixtures. Most of the tests were conducted on the mixtures where both fine and coarse natural aggregate were partially replaced with RCA. Results presented by Shen and Du [7], Perez et al. [8], Bushal and Wen [9] and Mills-Beale & You [10] show that with increase of the RCA content sensitivity of these mixtures to water increases.

Permanent deformation presents one of the most important deterioration mechanisms in flexible road constructions [11]. Results gained in dynamical creep test, conducted by Wong et al. [12], Arabani & Azarhoosh [13] and Arabani et al.[14], show that asphalt mixture containing only fine recycled aggregates ($\leq$ 4.75 mm) had higher permanent deformation resistance than control mixture made with natural aggregate.

Stiffness of asphalt mixtures presents their basic property for determination of the response of the road structure (both stress and strain) to the traffic loads, during the design process. Similarly, asstiffnessdescribes the ability of one asphalt layer to transfer the loads to lower layers, deformation levels at the contact of two different layers are defined for different load levels, and therefore indirectly influence development of the fatigue induced cracks [15]. Higher values of stiffness make the placing of thinner asphalt layers possible, lowering costs of construction. Still, extremely high stiffness values, due to lowering of flexibility of asphalt layers, can lead to formation of thermal cracks. Result analysis of asphalt mixtures with partial or complete replacement of

natural aggregates with recycled concrete aggregates, showed that the grain size of the RCA used had the major impact on the stiffness of tested asphalt mixtures. Several research results showed that mixtures with 100% of fine RCA (≤ 4.75 mm) replacing the natural aggregate had higher stiffness moduli thancontrol mixture [12-14].

Main objective of research presented in this paper was to estimate the possibilities of application of fine RCA in asphalt mixtures. The tests were performed on asphalt mixtures for base course,AC 22 BASE, because of the higher possible consumption of RCA and lower bitumen content in comparisonto wearing courses. In addition, due tothe lower mechanical properties of RCA, compared with natural crushed aggregate, it is more appropriate to use it in base courses, which are not directly exposed to traffic loading and environmental conditions, and therefore demand less severe technical requirements.

2. MATERIALS AND METHODS

Results of physical and mechanical tests on asphalt mixtures with different RCA content are presented in the paper. These results were compared with properties of control mixture made with natural crushed aggregate.

The maximum RCA content in the mixture was limited to 45% due to the concerns that its lower mechanical characteristics would influence the performance of the asphalt mix, and in order to avoid the need for an excessive increase in the bitumen content. One control and three asphalt mixtures with partial replacement of fine natural aggregate (0/4 mm) with RCA in amount of 15%, 30% and 45% by mass, were prepared. For example, the mark S-30 indicates a mixture in which 30% of fine natural aggregate was replaced by recycled aggregate.

In all mixtures aggregate gradation was kept the same. Targeted air voids volume was set to 5.2%. Mixtures design was determined using the Marshal method. The mixtures were then prepared and placed in different molds. Finally, water resistance, stiffness and permanent deformation resistance were determined.

2.1. COMPONENT MATERIALS

Basic physical and mechanical properties of the component materials were performed in order to design the mixtures and to determine potential influence that each of the materials used (natural aggregate, recycled aggregate, bitumen and filler), could have on the properties of asphalt mixtures. Presented research was conducted in Laboratory of pavement and Laboratory of materials at the Faculty of Civil Engineering, University of Belgrade.

Natural crushed limestone aggregate, produced by "Ravnje" – Valjevo, separated into following fractions: 0/4 mm, 4/8 mm, 8/16 mm and 16/22.4 mm was used in all the mixtures. Natural aggregate was taken from the asphalt base STRABAG in Obrenovac. The RCA used in this study was obtained by crushing cementitious concrete slabs that previously served as the sub-structure for tram rails in Belgrade, Serbia. The concrete was, during exploitation, covered with an asphalt layer, and was not directly exposed to environmental effects. At the time of removing and recycling, the concrete was more than 30 years old. The data about the quality of the concrete in question were not available. This is why three cylindrical samples (diameter 65 mm and height 65 mm) were taken out of the largerpieces of concrete for compressive strength (f_p,c) and bulk density (γ) testing. Based on the test results, presented in Table 1, it can be concluded

that the class of the original concrete in the moment of placement satisfied conditions for the class C35/45.After visual examination of recycled aggregate it was concluded that the original concrete was made with three fractions of natural aggregate. In addition to RCA (98%), the used material also contained 1.2% of asphalt and 0.8% of brick debris.

Table 1. Original concrete properties

Sample	γ(g/cm^3)	f_p,c(MPa)
1	2.394	56.3
2	2.334	41.8
3	2.339	49.9

Grading curves of natural and recycled aggregate used in this study are shown in Figure 1. It can be seen that the fine fraction of RCA (0/4 mm) is finer than the same fraction of natural aggregate.

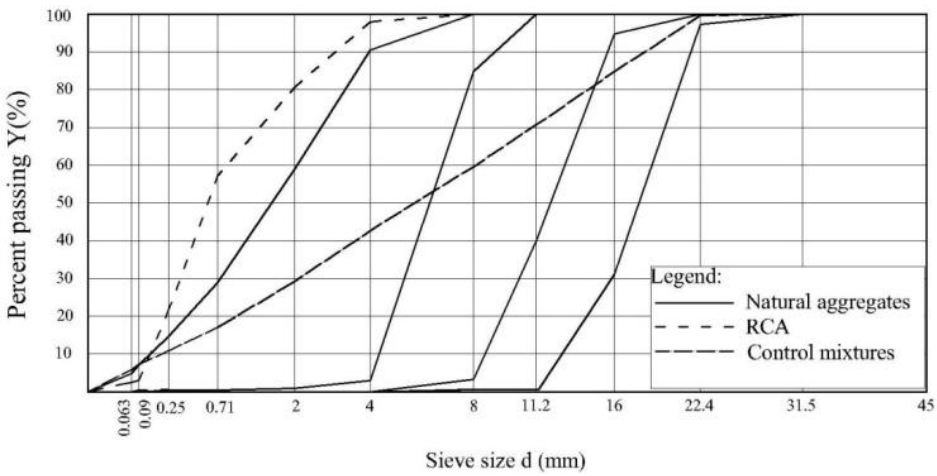

Figure1. Grading curves of natural and recycled aggregates

The main properties of the aggregates used are shown in Table 2. The RCA had a lower density compared with natural crushed aggregate, because of the residual cementitious mortar. Also, because of the higher porosity of the cementitious mortar, the RCA was characterized by higher water absorption. A decreased resistance to crushing compared with natural aggregate, expressed by a lower value of the Los Angeles (LA) coefficient, points to the inferior RCA toughness and abrasion characteristics. However, the equivalent value of LA for the mineral mixture, even with a high RCA content, was still lower than 30, satisfying the technical requirements for material classes Z3, Z4 and Z5. These materials can be applied in bituminous base and binder layers for all traffic load categories [16].

Table 2. Physical and mechanical properties of aggregate

Parameter	Units	Standard	RCA	Natural aggregate
ρ_a	(kg/m^3)	EN 1097-6	2645	2717
ρ_{ssd}	(kg/ m^3)		2512	2650
ρ_{rd}	(kg/ m^3)		2430	2580
WA	(%)		3.4	0.4

Following marks were used in table 2:

ρ_a - apparent specific gravity,

ρ_{ssd} - bulk specific gravity SSD,

ρ_{rd} - bulk specific gravity of samples dried in the oven,

WA -water absorption.

Limestonefiller produced by "Rujevac" – Ljig and asphalt binderB50/70 produced in Oil refinery in Pancevo were used in all the mixtures. The gradation of the filler is shown in Table 3.

Table 3. Filler gradation

d (mm)	0.063	0.09	0.25	0.71
Y (%)	75.9	84	97.2	100

Basic bitumen propertieswere determined through standard tests: penetration, apparent specific gravity and softening point. Results from these tests are presented in Table 4.

Table 4. Properties of asphalt binder

Test	Units	Standard	Value
Penetration	(25°C, 0.1 mm)	EN 1426	53.4
Specific gravity	(kg/m^3)	EN 15326	1004
Softening point	(°C)	EN 1427	50.5
Penetration index	(-)	EN 12591	-0.9

2.2. ASPHALT MIXTURES

Preparation of the mixtures was performed using the Marshal procedure at a temperature of 150°C, with compacting energy of two times 50 blows. Mineral mixtures were composed of: limestone filler (5%) and aggregate made of following fractions: 0/4 mm (41%), 4/8 mm (15%), 8/16 mm (24%) and 16/22.4 mm (15%). In order to provide comparison between the results gained with different mixtures, optimal bitumen content (OBC)in all mixtures was adopted for a target air voids (AV) volume of 5.2%. Table 5 presents values of OBC, AV, voids in mineral aggregate (VMA), percentage of voids

filled with bitumen (VFB), density (G), maximum density (G_max), as well as Marshall stability and flow for each mixture.

Table 5 Volumetric properties of asphalt mixtures

Mix	OBC	AV	VMA	VFB	G	G_max	Stability	Flow
	(%)	(%)	(%)	(%)	(kg/m3)	(kg/m3)	(kN)	(mm)
Control (E)	3.4	5.2	13.5	61.0	2419	2553	12.0	3.3
S-15	3.5	4.9	13.4	63.2	2418	2543	12.5	3.0
S-30	3.5	4.6	13.0	64.9	2410	2525	12.8	3.4
S-45	3.6	5.4	14.0	61.1	2379	2516	12.4	3.2
Specification		5-9	NR	55–74	NR	NR	min 6	NR
* NR – not defined								

Influence of RCA on the properties of asphalt mixtures was determined on the samples prepared in a way that realistically simulates the behavior of asphalt concrete in the road structure.

2.3. SAMPLE PREPARATION

For the purposes of stiffness modulus testing, a special polygon with three 500×500×70 mm fields was prepared. After mixing, each asphalt mixture was cured for 1.5 h at a temperature of 170°C, and then laid and compacted using a roller compactor with a weight of 1000 kg. Figure 2 shows the procedure of asphalt mixture laying and compaction. In the final step, 18 beams, 50×60×400 mm in size, were cut from three slabs. Five out of these 18 beams for each mixture was used for stiffness testing.

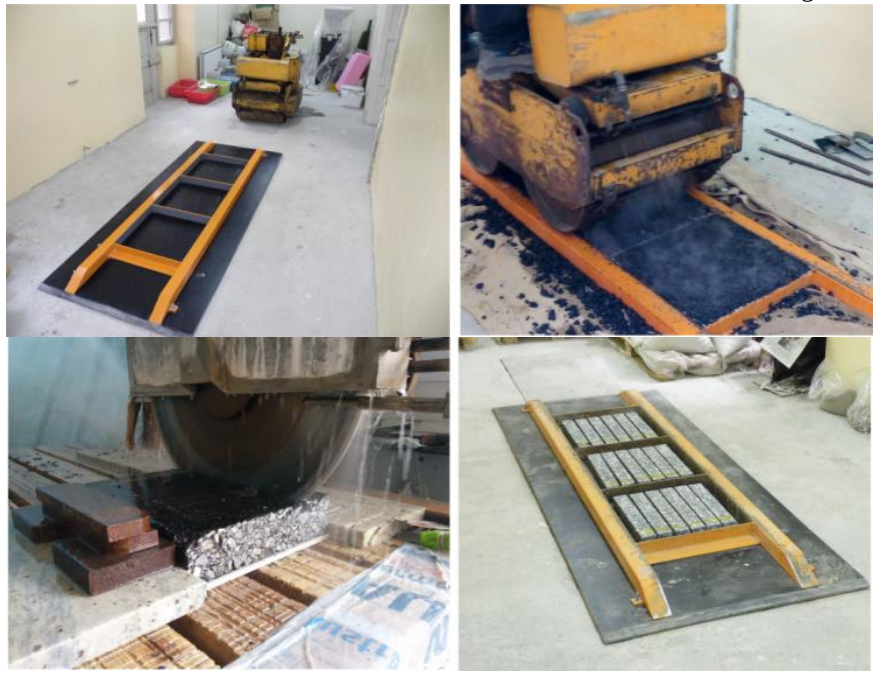

Figure 2. The procedure of beam production

During preparation of the samples used for testing of resistance to permanent deformation, in order to simulate the conditions in the asphalt plant and in situ, the asphalt mixture was conditioned before compaction at a temperature of 135°C for 4h. Two 320×260×70 mm slabs were compacted using a segment compactor, in accordance with EN 12697-33, for each asphalt mixture.

Testing of water resistance of asphalt mixtures was conducted on the Marshal samples Ø/H=101.6/63.5 mm, compacted with two times 35 blows.

3. RESULTS AND DISCUSSION

3.1. WATER RESISTANCE OF ASPHALT MIXTURES

Water resistance of asphalt mixtures was tested by measuring indirect tensile strength (ITS) of dry and wet samples, in accordance toEN 12697-12, method A. Six Marshal cylindrical samples were prepared for each of the mixtures and separated into two groups. Each group contained three samples with similar densities. The first group was kept in dry conditions,at the room temperature of 20°C.The second group was placed into water at pressure of 6.7 kPafor 30 min, and afterwards conditioned in water at temperature of 40°C during next 72 hours. Before testing, samples were held at the temperature of 25°C for 2 hours. ITS testing was conducted on the universal compression machine UTM-25 according to EN12697-23. The calculation of indirect tensile strength is shown in the following expression:

$$ITS = \frac{2 \cdot P}{\pi \cdot h \cdot d_s}$$

where:

P - maximum force(kN),

h - sample height(mm),

d_s- sample diameter (mm).

Water resistance of asphalt mixtures (ITSR) is defined as ratio between measured indirect tensile strengths of samples conditioned in wet and dry environment:

$$ITSR = \frac{ITS_{wet}}{ITS_{dry}} \cdot 100$$

Table 6 presents average values of all indirect tensile strengths of dry (ITSdry) and wet (ITSwet) samples for each of the tested mixtures, together with their ratio (ITSR).

Table 6. Average values of ITS and of ITSR

Mix	ITSdry (MPa)	ITSwet (MPa)	ITSR (%)
E	937.2	692.9	73.9
S-15	851.6	609.2	71.5
S-30	921.7	696.6	75.6
S-45	963.3	719.5	74.7

Measured values of ITS, for asphalt mixtures made with RCA, increased with higher RCA content, independently of the way of conditioning (dry or wet). These results are consequence of the better interaction and higher friction between the RCA particles, due to their rough surface and sharper edges.

Indirect tensile strength ratio (ITSR), that presents measure of water resistance of asphalt mixtures, was higher for two out of three mixtures with RCA when compared to control mixture.

3.2. RESISTANCE TO PERMANENT DEFORMATION

Testing of the resistance to permanent deformation was performed using the small wheel tracking device in air, at a temperature of 60°C, after 10000 cycles (20000 passes), all in accordance with EN 12697-22, Annex B, small appliance. Wheel load of 700 N is transferred over contact surface of 1900 mm^2 with frequency of 0.88 Hz. According to this method, resistance of asphalt mixtures to permanent deformation is determined by measuring of the depth of the track that is formed after each wheel loading cycle. Figure 3 presents the laboratory WTT (Wheel tracking test)machineproduced by INFRATEST 20-4000, that was used for this test.

Figure 3. Wheel tracking test machine

Wheel tracking test results, as a function of number of loading cycles, are presented in Figure 4.

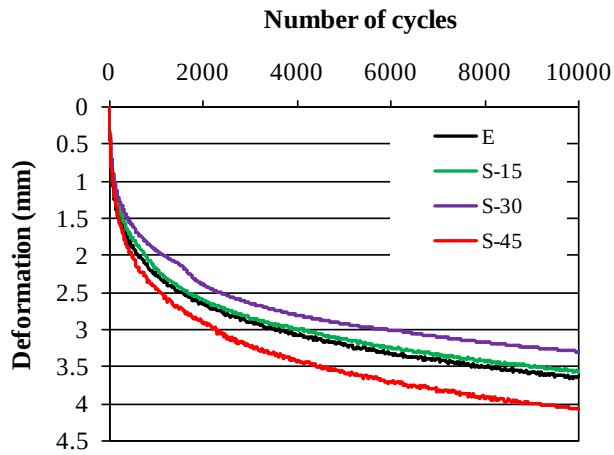

Figure 4. Permanent deformation of mixtures made with fine RCA

It can be concluded, based on the presented diagram, that partial replacement of natural with recycled aggregate did not lead to greater changes in the measured track depth. Addition of RCA in amounts lower than 30% improves the resistance of mixture to permanent deformation. This behavior can be explained by the structure and the texture of RCA. Surfaces of RCA are rough, with sharp edges as a result of being crushed multiple times, which increases the specific surface area and the friction between the aggregate particles. This provides well compaction of the grains that prevents their movement during traffic loading. Bitumen softens on higher temperatures, which causes the decrease in the bond properties and shear strength. This is why aggregate structure is the most important parameter in the resistance of asphalt mixtures to permanent deformation. Still, addition of 45% of fine RCA has led to greater permanent deformations compared to the control mixture.Nevertheless, they did not exceed 7%, the upper limit for proportional track depth according to Technical requirements for road construction in Republic of Serbia [16].Measured track depth for mixture S-45, after 10.000 cycles of traffic load was 4 mm, or 5.5% (proportional track depth).

3.3. STIFFNESS MODULUS

Stiffness modulus of asphalt concrete was tested using a four point bending beam test, in accordance with EN 12697-26, Annex B. The test was carried out at temperatures of 5°C, 15°C and 25°C, at frequency of 8 Hz. The dynamic load took the form of a sinusoidal function ("haversine") with controlled strain of 50 με, to avoid the possibility of fatigue damage. Differently to ordinary sinusoidal function, "haversine" sinusoid creates only tension induced strain on one side, and only compression induced strain on the other side of the sample. In this way, strain control is performed with no transition of the beam through neutral position thatwould lead to probable relaxation of the material. Test duration was limited to 100 cycles, to prevent the occurrence of the permanent deformations and change in the stress state in beams. Disposition of the stiffness modulus test is shown in Figure 5.

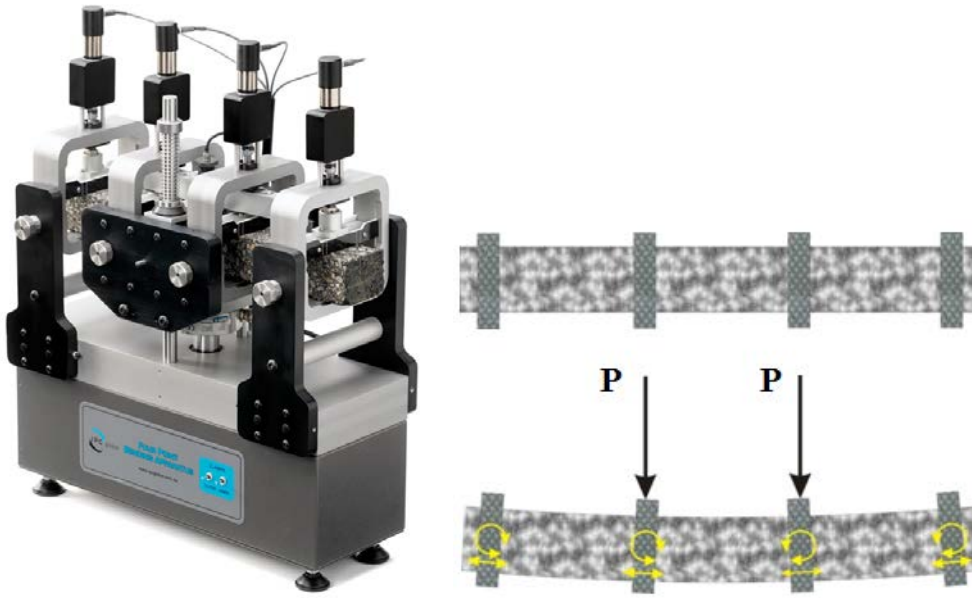

Figure 5. Disposition of the stiffness modulus test

Figure 6 presents average values of stiffness modulus (absolute values of the complex modulus |E*|) at frequency of 8 Hz after 100 load cycles, in accordance with EN 13108-20:2006 (Annex D).

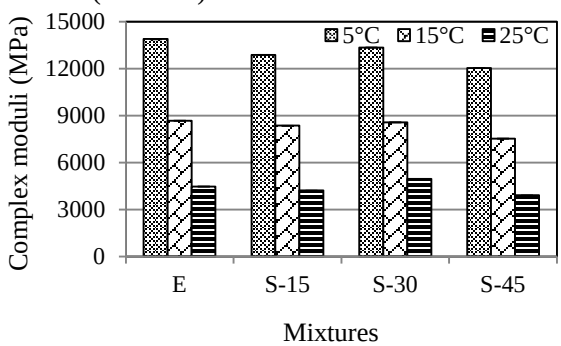

Figure 6. Stiffness modulus at all three testing temperatures at a frequency of 8 Hz

The average stiffness moduli of all mixtures with RCA were lower than the modulus of the control mixture. Still, the strong dependence between the amount of the RCA used and the stiffness moduli values could not be determined. This is consequence of the complex behavior of the asphalt mixtures with RCA. Due to the lower mechanical properties of RCA compared to natural aggregate, it was expected that the stiffness decreases with the increase of the amount of RCA in the mixture. However, because of the rough surface and sharp edges of the RCA interaction and friction between grainsare increased, sothat the load induced movements of the grains are prevented. RCA is more porous and has greater specific surface area when compared to natural aggregate grain, which impliesthinner layer of bitumen around aggregate particles [17].

4. CONCLUSION

In order to support implementation and promotion of sustainable development in civil engineering, wide range of tests were conducted on RCA and asphalt mixtures with RCA. The main objective of the research presented was to evaluate the possible application of RCA in asphalt mixtures, in accordance with the official technical requirements. Tests were performed on asphalt mixtures for base course, AC 22 BASE. The following conclusions can be made, based on the presented results:

- When compared to the natural crushed (stone) aggregate, RCA has lower density, due to remaining cement mortar and higher water absorption related to the higher porosity of cement mortar.
- Differences between water resistance of mixtures with RCA and control mixture were between-2.4% and +1.7%. that is negligible from the point of the potential application in asphalt mixtures. As Technical requirements for road construction in the Republic of Serbia [16] do not prescribe minimal conditions for water resistance of asphalt mixtures, it can be concluded that from this aspect there are no obstacles for partial replacement of natural aggregate with RCA in amount of 45%.
- Partial replacement of natural aggregate with RCA in amount of 45%, does not substantially affect the tracks depth during the permanent defomation resistance determination. Addition of up to 30% of RCA increases the mixture resistance to permanent deformation. Highest measured proportional track depth was 5.5% which is lower than 7% (allowed limit according to Technical requirements for road construction in the Republic of Serbia) [16].
- Although, asphalt concrete mixtures with recycled aggregate had lower stiffness modulus than control mixture,these differences were not substantial. Similarly as in case of water resistance, Technical requirements [16] do not define minimal values for stiffness modulus. It can be concluded that it is possible to use fine recycled aggregate in asphalt mixtures in amounts up to 45%.

Acknowledgements

The presented study is a part of the research financially supported by the Ministry of Education, Science, and Technological Development of the Republic of Serbia under the research project TR 36048: "Research on condition assessment and improvement methods of civil engineering structures in view of their serviceability, load-bearing capacity, cost effectiveness and maintenance" and TR 36017: "Utilization of by-products and recycled waste materials in concrete composites in the scope of sustainable construction development in Serbia: investigation and environmental assessment of possible applications".

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08| Оригинални научни рад
Research paper
doi 10.7251/STP1813139B ISSN 2566-4484

УТИЦАЈ ВРСТЕ И ПРИМЈЕНЕ КОМПОНЕНТНИХ МАТЕРИЈАЛА НА САДРЖАЈ ХЛОРИДА У САМОУГРАЂУЈУЋЕМ БЕТОНУ

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Резиме: Обзиром да су, један од најчешћих узрочника корозије арматуре, а тиме и деградације бетонских конструкција, хлор јони, од изузетне је важности познавање њихове концентрације у бетону. У раду су приказана ограничења садржаја хлор јона у бетонима и класе према европској регулативи, те спроведено експериментално истраживање о величини утицаја примијењених компонентних материјала на садржај хлор јона у различитим врстама самоуграђујућих бетона. Истраживањем се показало да на повећање садржаја хлор јона у бетону доминантан утицај има цемент, а затим и примјена рециклираног агрегата, произведеног од отпадног бетона. Примјена минералних додатака – кречњачког филера и електрофилтерског пепела и ријечног агрегата утиче на смањење концентрације хлорида у бетону.
Путем факторијалне анализе, извршено је моделирање фунционалне зависности садржаја хлорида и примјене различитих врста компонентних материјала.

Кључне ријечи: хлориди, самоуграђујући бетон, експериментална истраживања.

THE INFLUENCE OF COMPONENT MATERIALS TYPES AND APLICATION ON THE CHLORIDE ION CONTENT IN SELF-COMPACTING CONCRETE

Abstract: Considering that one of the most common causes of reinforcement corrosion, and consequently degradation of concrete structures, are chloride ions, it is of utmost importance to know their concentration in concrete. This paper presents the limitations of the chloride ions content in concrete and classes according to European regulations, and the experimental research on the magnitude of the influence of applied component materials on the chloride content in various types of self-compacting concrete.
The research presented that the dominant influence in respect of the increase of the chloride ions content in concrete, is of cement and then of a recycled concrete aggregate. The application of additions - limestone filler and fly ash and river aggregate results in the reduction of the chloride concentration in the concrete.
Through factorial analysis, modeling of the functional dependence of chloride content and application of different types of component materials was performed.

Keywords: chloride, self-compacting concrete, experimental research.

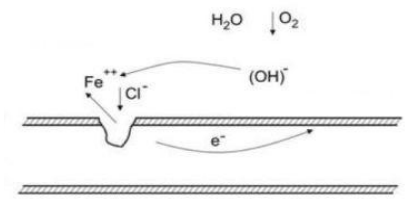
1. INTRODUCTION

When designing concrete constructions, in accordance with the European regulations, it is necessary to consider the environmental conditions which are expected to occur during constructions working life (XO, XC, XD, XS, XF, XA), as well as possible special forms of aggressive or indirect effects, which may exist at the site of application. These special effects imply:

- chemical attack, arising from, for example: the use of the construction (storage of aggressive liquids etc), solutions of acid or sulfate salts (EN 206, ISO 9690), chlorides contained in concrete (the class of the chloride content in the concrete Cl - Table 1, according to EN 206) and alkaline-silicate reaction of aggregates (EN 206, SRPS B.B2.009);
- physical attack, arising from, for example: temperature changes, abrasion (class of abrasion of concrete XM according to EN 1992-1-1) and water penetration (EN 206) [1,2,3].

Researches [4,5,6,7,8,9] have shown that a significant cause of many degradations of concrete constructions is a reinforcement corrosion, which may be result of various chemical and electrochemical processes. It has been shown that an excessive amount of chloride ions, which can be found in the composition of concrete mix-design components, by many researches, is a significant and frequent cause of depassivization of the reinforcement, and thus its corrosion. Hence, their content in concrete, by applying new European regulations, is determined and limited, as shown in the Chapter 2.

When due to the presence of chloride ions, depassivization of the reinforcement is present, locally activated surface of the steel, in the presence of water and oxygen, behaves as an anode, while the entire remaining reinforcement may be a corrosion cell cathode (Picture 1).



Picture 1. Schema of electrochemical corrosion due to chloride effects

The cathodic reaction is reduction of oxygen passing through the concrete layer. Due to the large difference between the surfaces of the electrodes (small anode, and a large cathode) corrosion is extremely intense on anode. Metal ions, which are generated by the dissolution of metals in an anode reaction, make corrosion products, so called rust, which occupies considerably larger volume than the original metal [10,11].

The appearance of degraded concrete, on which the cover layer has ruptured due to pressure from reinforcement corrosion products, is shown in the Picture 2.

Picture 2. Degradation of concrete due to excessive chloride content

In order to prevent a degradation of concrete constructions due to the subject aggression, it is important to determine the influence of the application, and the magnitude of this influence, of component materials on the chloride ions content in self-compacting concrete - as shown in the experimental study given herein. Also, it is of great importance that in this experimental research are applied recycled materials and by-products of thermal power plants, in addition to component materials from the domestic resources used for making self-compacting concrete (still a contemporary concrete composite on the domestic market).

According to research of *B. Beeralingegowd-a* and *V. D. Gundakalle* [12], the content of chlorides in self-compacting concrete depends on the type of additions used and their mutual ratio. In this respect, it has been demonstrated that by application of limestone filler, in relation to the application of fly ash, the concrete with lower chloride content are gained. In doing so, research by *K. Audenaert* and *G. De Schutter* [13], *P. R. da Silva* and *J. de Brito* [14], show that self-compacting concrete, because of the generally better compactness of the cementitious stone, has better resistance to the aggressive effect of chloride ions, compared to conventional concrete, which is compacted by vibration.

2. CHLORIDE CONTENT IN CONCRETE

The chloride content in concrete, which is expressed as the percentage of chloride ion relative to the mass of cement, is determined as the sum of the individual contributions of chlorides from component materials, by one of the following methods or their combination:

- calculation based on the maximum content of chloride in component materials, either as permitted by the standard for that material or as the one declared by the manufacturer of each component and
- calculation based on chloride content in component materials, calculated monthly from mean value for the last 25 determination of chloride content in sum with product of 1.64 times calculated standard deviation for each component material.

The second method is particularly applicable in the case of aggregates extracted from the sea, as well as in cases where no declared or standardized maximum value is available.

Table 1 shows the classes of chloride content in concrete, according to EN 206: 2013, with the maximum permissible percentage of chloride ion in relation to cement mass, as well as examples of particular concrete class application.

Table 1. Classes of chloride content in concrete, EN 206:2013 [1]

Chloride content class[1)]	Maximum content of Cl^- by mass of cement [2)]	Concrete use
Cl 1,0	1,0 %	Not containing steel reinforcement or other embedded metal, with the exception of corrosion resistant lifting devices
Cl 0,20	0,20 %	Containing steel reinforcement or other embedded metals
Cl 0,40	0,40 %	
Cl 0,10	0,10 %	Containing prestressing steel for reinforcement in direct contact with concrete
Cl 0,20	0,20 %	

[1)] For the specific concrete use, the class to be applied depends on the provisions valid in the place of us of concrete.
[2)] If type II additions are used and if they are taken into account in determening the amount of cement, the chloride content is expressed as the percentage chloride ion by mass of cement plus total mass of additions.

Calcium chloride and admixtures based on chloride should not be added to concrete containing steel reinforcement, prestressed steel reinforcement or other embedded metal.

3. AUTHORIZED EXPERIMENTAL RESEARCH

3.1. EXPERIMENTAL RESEARCH PROGRAM

Experimental research, which includes laboratory tests on several different types of self-compacting constructive concrete, is realized in two laboratories:

- Laboratory for testing of building materials, Department of Civil Engineering and Geodesy, Faculty of Technical Sciences, University of Novi Sad and
- Laboratory of the Institute for Urbanism, Civil Engineering and Ecology of Republic of Srpska, in its business unit the Institute for Material and Construction Testing of the Republic of Srpska, Banja Luka.

Eight mixtures of self-compacting concrete were designed, with different types of aggregates (river and recycled concrete aggregate), with or without the use of different types of additions. All concrete mixtures are made of a threefraction aggregate, with nominally largest grain of 16 mm, with a continuous granulometric curve. From additions, limestone filler was used (addition type I), fly ash (addition type II), as well as their combination. Portland-composite high-strength cement was used as the basic binder, and a new generation superplasticizer was used as an admixture. Water used is potable water.

The starting criteria for all mix design, as it is customary for all self-compacting concrete, were chosen regarding the characteristics of the fresh concrete, and they were as follows:

- achieving "complete compactness", without the use of mechanical means for embedding, shaking or vibration; the entrapped air in fresh concrete is limited to a value of 3 to 5%,
- achievement of the consistency class SF2, for which the slump flow value ranges from 660 to 750 mm; according to this request, the amount of superplasticizer is determined, but also according to the manufacturer's recommendation.

Additional common features of the concrete mixtures were:

- concrete mixtures contain, in average, large amount of powder component (for self-compacting concrete it is within the range from 450 to 550 kg/m^3),
- approximately the same total amount of cement and addition for all mixtures is applied, in amount of 483,5 ± 7,4 kg/m^3, i.e. approximately the same amount of powder component: cement, addition and aggregates with grains of less than 0,125 mm, in the amount of 497,9 ± 8,1 kg/m^3, with different combinations of additions being applied, namely:
    - concrete mixtures B-1 and B-2, without additions,
    - concrete mixtures B-3 and B-4, with limestone filler,
    - concrete mixtures B-5 and B-6, with fly ash and
    - concrete mixtures B-7 and B-8, with a mixture of limestone filler and fly ash in equal amount,
- the total amount of aggregate is 1571,6 ± 99,4 kg/m^3, where aggregates of different origin are used:
    - concrete mixtures B-1, B-3, B-5 and B-7, with a river aggregate and
    - concrete mixtures B-2, B-4, B-6 и B-8, with a mixture of river sand and coarse recycled concrete aggregate.
- the amount of superplasticizer is 0,0060 ± 0,0007 m^3 in 1 m^3 of concrete,
- water-cement ratio 0,487 ± 0,075.

For the above-mentioned concretes, labels with a brief description are given as follows:

- B-1 self-compacting concrete with a river aggregate, without the use of additions,
- B-2 self-compacting concrete with a mixture of river sand and coarse recycled concrete aggregate, without additions,
- B-3 self-compacting concrete with a river aggregate and limestone filler,
- B-4 self-compacting concrete with a mixture of river sand and coarse recycled concrete aggregate and limestone filler,
- B-5 self-compacting concrete with a river aggregate and fly ash,
- B-6 self-compacting concrete with a mixture of river sand and coarse recycled concrete aggregate and fly ash,
- B-7 self-compacting concrete with a river aggregate, limestone filler and fly ash and

- B-8 self-compacting concrete with a mixture of river sand and coarse recycled concrete aggregate, limestone filler and fly ash.

The following characteristics were tested on the designed concretes:

- the air entrapped, according to SRPS U.M1.031:1982 [15] (SRPS ISO 4848:1999) and EN 12350-7:2009 [16],
- bulk density of fresh concrete, according to SRPS U.M1.030:1982 [17],
- consistency – slump-flow test, according to EN 12350-8:2010 [18],
- bulk density of hardened concrete, according to SRPS U.M1.009:1993 [19],
- compressive strength determination after 28 days, according to SRPS U.M1.020:1992 [20] and EN 12390-3:2009 [21] and
- chloride content, according to EN 206:2013 [1].

For all concrete mixtures, concrete preparation, making and curing specimens was carried out in the same way and under the same thermohygrometric conditions.

3.2. CHARACTERISTICS OF COMPONENT MATERIALS AND COMPOSITION OF CONCRETE MIXTURES

3.2.1. Characteristics of component materials

For the design of self-compacting concrete, the following components were used:

- portland-composite cement with moderate portland-cement clinker content, of high class with ordinary early strength, marked as CEM II/B-M (S-LL) 42,5 N, "Dalmacijacement", of manufacturer "Св. Jypaj" from Split (Kaštel Šućurac); specific and bulk density, in loose and compacted state, are respectively, 3140, 1100 and 1480 kg/m^3,
- limestone filler of manufacturer "Japra" ldt. Novi Grad; with specific density of 2780 kg/m^3,
- fly ash of thermal power plant "Nikola Tesla B" from Obrenovac, with the original composition, obtained as a by-product from the thermal power plant (fly ash was not sieved before use, so that grains larger than 0.125 mm contribute to the fine fraction of concrete aggregate); specific density is 2400 kg/m^3,
- aggregate from Sava river, from manufacturer "RTC Luka LEGET" from Sremska Mitrovica, washed and separated into fractions: 0/4, 4/8 and 8/16 mm (when making concrete B-1, B-3, B-5, B-7 all three mentioned fractions are used, while for concrete B-2, B-4, B-6 and B-8 only the first fraction was used); specific density is 2700 kg/m^3, while the bulk density of the grain, for fractions I, II and III are, respectively, 1608, 1555 and 1535 kg/m^3,
- recycled concrete aggregate labeled as RA-N obtained by crushing of wasted concrete MB30 and MB40 (raw materials for the aggregate concerned were concrete cubes, previously used for pressure strength testing and a prefabricated reinforced concrete pillar made with inadequate dimensions); crushing is realized in two phases – the first was the so-called primary crushing, where the elements mentioned above are roughly crushed, using a pneumatic hammer, then, so-called, secondary crushing, or fine shredding, using a rotary crusher was performed; the aggregate is separated into standard

fractions, whereby for the subject research, fractions II and III were used, i.e. fractions of coarse aggregate 4/8 and 8/16 mm); the specific density is 2500 kg/m^3, while the bulk density of the grain, for fractions II and III are, respectively, 1359 and 1309 kg/m^3,

- new generation superplasticizer admixture "Cementol®Zeta Super S", of manufacturer "TKK", Srpenica, Slovenia, based on a modified polycarboxylic ether polymer, declared as a high ranged water reducing admixture HRWRA, according to EN 934-2:2009+A1:2012,
- potable water.

For concrete B-1, B-3, B-5 and B-7, fully designed with a river aggregate, a mixture of aggregates M-1 is applied, whose granulometric composition is shown in the Table 2.

For concrete B-2, B-4, B-6 and B-8, designed using the river aggregate in first fraction and the recycled concrete aggregate in the second and third fraction, a mixture of aggregates M-2 is applied, whose granulometric composition is shown in the Table 3.

Table 2. – Particle size distribution of aggregate mixture M-1

Fraction		Sieve opening d [mm]									
		дно	0,125	0,25	0,5	1	2	4	8	16	31,5
Passing Y [%]	0/4	0	2,1	25,4	65,4	76,9	85,5	94,5	100	100	100
	4/8	0	0	0,1	0,2	0,3	0,8	9,5	92,2	100	100
	8/16	0	0	0	0	0	0	0	4,4	90	100
$Y_i \cdot x_i$ [%]	0/4	0	0,9	10,9	28,1	33,1	36,8	40,6	43,0	43	43
	4/8	0	0	0	0	0,1	0,2	2,1	20,3	22	22
	8/16	0	0	0	0	0	0	0	1,54	31,5	35
M-1 [%]		**0**	**0,9**	**10,9**	**28,2**	**33,1**	**36,9**	**42,7**	**64,8**	**96,5**	**100**

Table 3. – Particle size distribution of aggregate mixture M-2

Fraction		Sieve opening d [mm]									
		дно	0,125	0,25	0,5	1	2	4	8	16	31,5
Passing Y [%]	0/4	0	2,1	25,4	65,4	76,9	85,5	94,5	100	100	100
	4/8	0	0	0	0	0	0,5	21,1	100	100	100
	8/16	0	0	0	0	0	0	0,2	23,7	100	100
$Y_i \cdot x_i$ [%]	0/4	0	0,9	11,2	28,8	33,8	37,6	41,6	44	44	44
	4/8	0	0	0	0	0	0,1	2,1	10	10	10
	8/16	0	0	0	0	0	0	0,1	10,9	46	46
M-2 [%]		**0**	**0,9**	**11,2**	**28,8**	**33,8**	**37,7**	**43,8**	**64,9**	**100**	**100**

3.2.2. Concrete mix-design

Concrete mix-design and concrete bulk density are given in table 4.

Table 4. – Concrete mix-design

Concrete mixture				B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8
Cement			[kg/m³]	490,9	483,6	403,6	404,2	391,8	393,1	394,1	394,5
Limestone filler			[kg/m³]	–	–	85,6	85,7	–	–	42,2	42,2
Fly ash			[kg/m³]	–	–	–	–	84,2	84,5	42,2	42,2
Aggregate	River	0/4 mm	[kg/m³]	718,5	697,3	715,3	702,0	659,6	647,8	689,8	676,4
		4/8 mm	[kg/m³]	367,6	–	366,0	–	337,4	–	352,9	–
		8/16 mm	[kg/m³]	584,8	–	582,2	–	536,9	–	561,5	–
	Recycled	4/8 mm	[kg/m³]	–	158,5	–	159,6	–	147,2	–	153,7
		8/16 mm	[kg/m³]	–	729,0	–	733,9	–	677,2	–	707,2
HRWRA			[kg/m³]	7,36	7,29	6,05	6,06	5,88	5,9	5,91	5,92
Water			[kg/m³]	202,2	200,3 +17,1	201,8	202,1 +17,0	220,2	220,9 +16,9	201,8	202,0 +16,9
Bulk density			[kg/m³]	2371,4	2295,8	2360,6	2310,6	2236,0	2193,5	2290,4	2241,0

3.2.3. Results of experimental research

Testing of fresh concrete showed that designed self-compacting concrets are with high-compactness, with the entrapped air to 3,8%, normal weigth concrete with bulk density from 2193 to 2371 kg/m^3, consistency class SF2, with slump-flow from 690 to 740 mm, which is suitable for the usual, i.e. the most common application; eg. for the execution of walls and pillars.

By testing of hardened concrete on cube samples with edge length of 15 cm, the values of the bulk density within the range of 2213 to 2392 kg/m^3 and compressive strength within the range of 44,4 to 60,1 MPa are obtained.

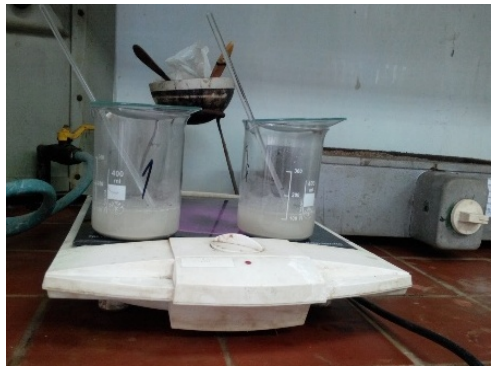
Chlorides content in concrete, shown in Table 5, was determined through the chloride ions content in component materials. It is expressed as the percentage chloride ion by mass of cement plus total mass of addition of type II, for concrete B-5, B-6, B-7 and B-8, for which, as such type of addition, fly ash is applied.

Table 5. Results of chloride content test

Concrete mixture	Chloride ions content in concrete	The chloride ions content in relation to the mass of cement	The chloride ions content relative to the mass of cement and fly ash
	m_{Cl}	m_{Cl} / m_c	$m_{Cl} / (m_c + m_{ma\text{-}II})$
	[g/m^3]	[%]	[%]

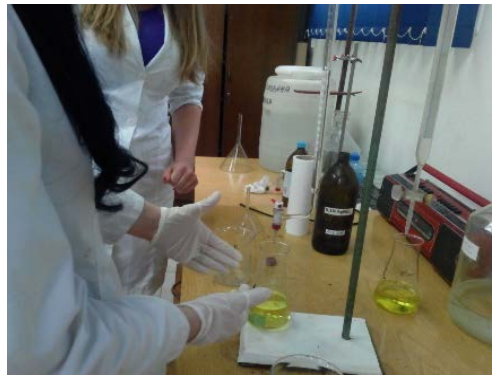
Concrete mixture	Chloride ions content in concrete	The chloride ions content in relation to the mass of cement	The chloride ions content relative to the mass of cement and fly ash
	m_{Cl}	m_{Cl} / m_c	$m_{Cl} / (m_c + m_{ma\text{-}II})$
	[g/m^3]	[%]	[%]
B-1	105,11	0,021	–
B-2	166,42	0,034	–
B-3	98,76	0,024	–
B-4	161,62	0,040	–
B-5	99,64	0,025	0,021
B-6	157,85	0,040	0,033
B-7	98,28	0,025	0,023
B-8	158,80	0,040	0,036

On Pictures 3-6. the chemical test is shown, performed in order to determine the content of chloride in limestone filler. At the first picture, boiling of samples is shown, which are previously mixed with destilated water. Picture 4 shows filtering through the medium density filter paper. On Pictures 5 and 6 is shown, respectively, titrating with standard silver-nitrate solution ($AgNO_3$) and the visage of the filtrates, collected in conical bottles according to Erlenmajer. The visage of the titrated filtrate, with a noticeable transition from yellow to darker shades and the visage of a non titrated filtrate, with standard (starting) yellow color is shown on Picture 6.



Picture 3. Testing of Cl^- content in a limestone filler – samples boiling in destilated water

Picture 4. Testing of Cl^- content in a limestone filler – samples filtering



Picture 5. Testing of Cl^-content in a limestone filler – samples titration

Picture 6. Testing of Cl^- content in a limestone filler – titrated and non titrated filtrates

3.2.1. Analysis of experimental research

The analysis and discussion of the experimental research was carried out through the examination of the simultaneous influence of the applied type of aggregates and the

application of additions to the chloride ion content in the designed self-compacting concrete using a multi-parameter analysis. For the multi-parameter analysis, the so-called method of factorial experiment is used. The above method tested the hypothesis about the existence of a link between the content of chloride in concrete and varied influencing factors. In addition, it has been determined which of the selected parameters has the greatest impact on the analyzed property, and how much the relative sizes of the impact of these parameters are. Also, by testing the level of significance of the relative magnitudes of influence, through Student's test for factor polynomial coefficients, analytical forms of the connection "chloride content in concrete - influential parameters" were formulated. Conclusions were made according to the conducted analysis with a probability of safety of 0,95.

Table 6. gives the input data needed for calculating the coefficients of the polynomial of the factorial experiment, which describes the effect of the applied type of aggregate and the application and type of addition on the value of the chloride ion content in the designed concrete.

Table 6. Chloride ion content in concrete in the function of variables

N	Concrete mixture	Z_1	Z_2	Z_3	Chloride ion content in concrete
		Type of agreggate	Limestone filler	Fly ash	
			$m_{ma,I}$	$m_{ma,II}$	m_{Cl}
			[kg/m^3]	[kg/m^3]	[g/m^3]
1	B-1	river	0	0	105,11
2	B-2	recycled	0	0	166,42
3	B-3	river	85,6	0	98,76
4	B-4	recycled	85,7	0	161,62
5	B-5	river	0	84,2	99,64
6	B-6	recycled	0	84,5	157,85
7	B-7	river	42,2	42,2	98,28
8	B-8	recycled	42,2	42,2	158,80

Based on the above and the application of the expression for determining the value of the polynomial coefficients, which defines the functional dependence of the analyzed property on the variable parameters, by the factorial experiment method, the values of the polynomial coefficients are obtained, as given in Table 7.

Table 7. Coefficients of polynomial for functional dependence $m_{Cl} = m_{Cl}(Z_1,Z_2,Z_3)$

Coefficients of polynomials	b_0	b_1	b_2	b_3	b_{12}	b_{13}	b_{23}	b_{123}
Value coeff. polynomial	130,81	30,36	-1,45	-2,17	0,48	-0,68	1,34	0,09

The functional dependence of the chloride ion content in concrete and the simultaneous effect of varied influential parameters is given by the expression:

$$m_{Cl} = 130{,}81 + 30{,}36x_1 - 1{,}45x_2 - 2{,}17x_3 + \\ +0{,}48x_1x_2 - 0{,}68x_1x_3 + 1{,}34x_2x_3 + 0{,}09x_1x_2x_3 \quad [g/m^3] \qquad (1)$$

The calculated values of the coefficients of the factor polynomial have the following physical meaning:

- b_0 defines the average value of the chloride ion content of all tested concrete,
- b_1 defines the influence of the application of the type of aggregate on the chloride ion content in concrete (the sign "-" refers to the influence of the application of the river aggregate, and the sign "+" on the impact of the application of the recycled concrete aggregate),
- b_2 defines the influence of limestone filler on the chloride ion content in concrete (the sign "-" refers to the concrete mixed without limestone filler and the "+" sign on the concrete mixed with limestone filler),
- b_3 defines the influence of the application of fly ash on the chloride ion content in concrete (the sign "-" refers to concrete mixed without fly ash, and the sign "+" on concrete mixed with fly ash),
- b_{12} defines the additional influence of the interaction of the applied type of aggregates and limestone fillers on the chloride ion content in concrete (the sign "-" refers to concrete mixed with river aggregate and limestone filler, as well as concrete with recycled concrete aggregate, without limestone filler, and the sign "+" on concrete mixed with a river aggregate, without limestone filler, as well as concrete with recycled concrete aggregate and limestone filler),
- b_{13} defines the additional influence of the interaction of the applied type of aggregate and fly ash on the chloride ion content in concrete (the sign "-" refers to the concrete mixed with the river aggregate and fly ash, as well as concrete with a recycled concrete aggregate, without fly ash, and the sign "+" on concrete mixed with river aggregate, without fly ash, as well as concrete with recycled concrete aggregate and fly ash),
- b_{23} defines the additional influence of limestone filler and fly ash interaction on the chloride ion content in concrete (the sign "-" refers to concrete mixed only with one addition (limestone filler or fly ash), while the other is omitted, and the sign "+" on concrete mixed with both additions, as well as concrete made without additions) and
- b_{123} defines the additional influence of the interaction of the applied type of aggregates, limestone fillers and fly ash on the chloride ion content in concrete (the sign "-" refers to concrete mixed with a river aggregate and both additions or are both omitted, as well as concrete mixed with a recycled concrete aggregate and only with one addition, and the sign "+" on concrete prepared with a river aggregate and with only one addition, as well as concrete with a recycled concrete aggregate and both additions or both are omitted).

The absolute value of the polynomial coefficients describes the influence of the varied factor on the value of the chloride ion content - a higher absolute value indicates a significant influence of the variable factor on the value of the chloride ion content in the concrete.

Values, that can be calculated by using the given expression (1), are identical with the obtained experimental values of the chloride ion content in concrete.

By analyzing the polynomial coefficients in Table 7, it is concluded:

- The most important influence on the value of chloride ion content is the choice of the type of aggregate. By using a river aggregate, they receive less, ie, using a recycled concrete aggregate, a higher value of the chloride content in the concrete. Considering the obtained value of the coefficient of polynomial $\boldsymbol{b_1}$ in the amount of 30,36, it is concluded that, in the case of the application of a recycled concrete aggregate, an average increase in the chloride ion content in concrete in the amount of about 60,7 g/m^3 is achieved, about 46,4%, compared to the case of the river aggregate.
- The effects of the application of additions are significantly lower in relation to the effect of selecting the type of aggregate. The coefficients of the polymers $\boldsymbol{b_2}$ and $\boldsymbol{b_3}$ are negative, which indicates that the application of any of the relevant additives affects the average reduction in the value of the chloride ion content in the concrete, compared to the cases where they are eliminated. Namely, it has been shown that the use of limestone filler reduces the amount of chloride ions in concrete in the amount of about 2.9 g/m^3, or about 2.2%, on average, while it decreases with the use of fly ash in the amount of about 4, 3 g/m^3, or about 3.3%.

Additional effects from the combined effect of variables (expressed in coefficients b_{12}, b_{13}, b_{23} and b_{123}), reflect the change in the value of the chloride ion content in concrete for a sum of at most ± 2.6 g/m^3, ie for a maximum of 4%, which, in relation to the total value of chloride content, shows that these combined effects are practically negligible. However, it is noted that the coefficient b_{23}, which describes the interaction effect of additions, is significantly higher than other coefficients of interaction (the value of this coefficient is greater than the sum of other coefficients), which has proved to be frequent in analyzes of other properties mentioned above.

In order to simplify the forms of functional dependence of the chloride ion content in concrete and variables, and in accordance with the analysis of the values of the coefficients of the polynomial, the coefficients of interaction b_{12}, b_{13} and b_{123} are rejected, so that the given function has the form:

$$m_{Cl} = 130{,}81 + 30{,}36 \cdot x_1 - 1{,}45 \cdot x_2 - 2{,}17 \cdot x_3 + 1{,}34 \cdot x_2 \cdot x_3 \qquad [g/m^3] \qquad (2)$$

By rejecting the mentioned coefficients of the polynomial $m_{Cl} = m_{Cl}(Z_1,Z_2,Z_3)$, the differences between the experimentally determined values of the chloride content in the concrete and the values calculated by the factorial analysis are increased. The stated differences, expressed in percentage terms, are given in Table 8, are obtained by means of the expression:

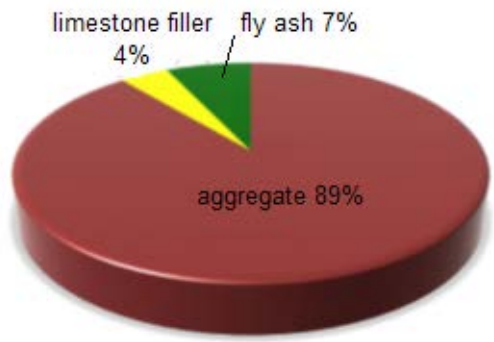
$$\Delta = \frac{\Delta m_{Cl}}{m_{Cl}} \cdot 100 = \frac{m_{Cl} - m_{Cl\text{-}R}}{m_{Cl}} \cdot 100 \qquad [\%] \qquad (3)$$

By analyzing the above differences, they are found to have absolute values within acceptable limits, which implies that the shape function (2) can be used with great reliability to display and analyze the chloride ion content in concrete, depending on the type of aggregate used and the application of limestone filler and/or fly ash.

Table 8. Differences between real and design (applying $m_{Cl} = b_o+b_1x_1+b_2x_2+b_3x_3+b_{23}x_2x_3$) values of the chloride ion content in concrete

N	Concrete mixture	Z_1	Z_2	Z_3	Chloride ions content		Differ. betw. tests and designs values of chloride content	
		Type of agreggate	Limestone filler	Fly ash	tests (real)	designed (theory)		
			$m_{ma,I}$	$m_{ma,II}$	m_{Cl}	m_{Cl-R}	Δm_{Cl}	Δ
			[kg/m^3]	[kg/m^3]	[g/m^3]	[g/m^3]	[g/m^3]	[%]
1	B-1	river	0	0	105,11	105,403	-0,292	-0,3
2	B-2	recycled	0	0	166,42	166,128	0,292	0,2
3	B-3	river	85,6	0	98,76	99,828	-1,068	-1,1
4	B-4	recycled	85,7	0	161,62	160,553	1,068	0,7
5	B-5	river	0	84,2	99,64	98,383	1,257	1,3
6	B-6	recycled	0	84,5	157,85	159,108	-1,258	-0,8
7	B-7	river	42,2	42,2	98,28	98,178	0,102	0,1
8	B-8	recycled	42,2	42,2	158,8	158,903	-0,103	-0,1

Picture 7. shows the percentage of participation of varied parameters in their joint influence on the chloride ion content in concrete. As can be seen, the dominant influence of the variables on the value of the chloride content is dominated by the type of applied aggregate, with 89% of the joint effect, then the fly ash with 7% of the total influence, and at least of all variables, the effect of the application limestone filler, specifically in the amount of 4%.



Picture 7. Partial fraction of the influence of variables on the

4. CONCLUSION

The higher content of the component material, which contain a higher concentration of chloride ions, causes the increase of these ions in concrete. In addition, it is shown that a significant influence on the amount of chloride contained in concrete has the ratio of the applied amounts of powder component and aggregates, as well as the type of applied aggregate. Namely, in the case of designed concretes, the difference in the content of chloride in the river and recycled concrete aggregate was significant (higher amount of chloride ions in the recycled concrete aggregate), and significant differences in the chloride ions content in the concrete were obtained. Specificaly, when comparing the use of a river aggregate (for which no chloride content is found) and a recycled concrete aggregate (with 0.007% of chloride ions), it is obtained that in the case of the application of a recycled concrete aggregate, an average increase in the chloride ion content in concrete is from about 60.7 g/m^3, i.e. about 46.4%, compared to the case of use of the river aggregate. In addition to the above, a much smaller impact, but still significant, has the use of additions. By their application, the amount of cement, or the amount of the component with the highest chloride content, decreases, thus reducing the total content of chloride in the concrete. Specifically, for the addition in the amount of 21%, compared to the mass of the cement, it has been found that by using limestone filler chloride ion content is averagely reduced the in the concrete for about 2.9 g/m^3, i.e. about 2.2%, while by using fly ash, the average decreases by about 4.3 g/m^3, i.e, about 3.3%.

A multi parameter analysis carried out has established a functional dependence of the content of chloride in concrete and the application of various types of additions and aggregates.

It was also concluded that by using concrete components materials from the domestic resources, for self-compacting concrete technology, it is possible to design concrete class Cl 0.10 according to EN 206-1:2013, which is applicable for all types of reinforcement plans, i.e. to meet even the strictest criteria, which are required when applying prestressing steel.

ACKNOWLEDGMENT

Part of the research presented in this paper was realized within the project TR36017, which was carried out at the Department of Civil Engineering and Geodesy of the Faculty of Technical Sciences of the University of Novi Sad and the regional unit - Institute for Material and Construction Testing Banja Luka, buisniss unit of the Institute for Urbanism, Civil Engineering and Ecology of Republic of Srpska.

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09| Оригинални научни рад
Research paper
doi 10.7251/STP1813155H ISSN 2566-4484

ENERGETSKA EFIKASNOST U STAMBENIM ZGRADAMA, RAZLIKA IZMEĐU PREDVIĐENE I STVARNE POTROŠNJE ENERGIJE

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Apstrakt:

Od devedestih, uzastopne EU direktive i odgovarajuća nacionalna i regionalna regulativa zahtjevaju da nova gradnja i obnova postojećih bude što energetski efikasnija. Nekoliko mjera koje bi trebalo korak po korak da smanjuju primarnu energiju korištenu za grijanje i hlađenje su postale obavezne kao uslov. Međutim, u stvarnosti, predviđene uštede ovim mjerama nisu vidljive u praksi. Dva efekta su odgovorna za ovo. Prvi je navika stanara, koji su više energetski štedljivi nego što proračun pretpostavlja. Zapravo, dok u energetski neefikasnim objektima, navike u prosjeku dovode do 50% niže potrošnje energije za grijanje nego što se predviđa, ovaj procenat pada na nulu ili je čak i negativan u ekstremno energetski efikasnim domaćinstvima. Drugi problem je sa niskovoltažnim distribucionim mrežama koje nisu dizajnirane da transportuju maksimume u električnoj energiji koji se javljaju tokom ljetnih sunčanih dana, što ujedno znači i manje generisane obnovljive energije. To ilustruju i primjeri koji bi u teoriji trebali biti energetski neto-nula objekti zbog primijenjenih mjera i prisustva dovoljno fotonaponskih ćelija na svakom krovu. Može se zaključiti da je upitna politika zahtijevanja ekstremne energetske efikasnosti koja je daleko iznad trenutne ukupne optimalne vrijednosti za stambene objekte. Ali, uprkos ovim činjenicama, vlade i administracije nalažu još ekstremnije zahtjeve u pogledu energetske efikasnosti.

Ključne riječi: energetska efikasnost, navike stanara, fotonaponske ćelije

ENERGY EFFICIENCY IN RESIDENTIAL BUILDINGS, LESS STRAIGHT FORWARD THEN PRESUMED

Abstract

Since the 1990s, the successive EU directives and related national or regional legislations require new construction and retrofits to be as much as possible energy-efficient. Several measures that should stepwise minimize the primary energy use for heating and cooling have become mandated as requirement. However, in reality, related predicted savings are not seen in practice. Two effects are responsible for that. The first one refers to dweller habits, which are more energy-conserving than the calculation tools presume. In fact, while in non-energy-efficient ones, habits on average result in up to a 50% lower end energy use for heating than predicted. That percentage drops to zero or it even turns negative in extremely energy-efficient residences. The second effect refers to problems with low-voltage distribution grids not designed to transport the peaks in electricity when

sunny in summer. Through that, a part of converters has to be uncoupled now and then, which means less renewable electricity. This is illustrated by examples that in theory should be net-zero buildings due to the measures applied and the presence of enough photovoltaic cells (PV) on each roof. We can conclude that mandating extreme energy efficiency far beyond the present total optimum value for residential buildings looks questionable as a policy. However, despite that, governments and administrations still seem to require even more extreme measurements regarding energy efficiency.

Keywords: energy efficiency, dweller habits, photovoltaic cells

1. AN EP-LEGISLATION AS EXEMPLARY CASE

Till the early 1970s, energy was not an issue. Coal, oil and gas were so cheap nobody cared about the quantities burned. But in 1973 the Jom Kippoer war and the oil ban by OPEC lead to a sudden rise in prices. As a reaction energy efficiency became a hot topic with the first research programmes launched and for the building sector a better thermal insulation as a main subject of interest. The Iran crisis in 1979 still lifted the energy prices and turned less energy consumed definitely into an economic must. How far to go with energy efficient construction from an economic point of view and how to insulate correctly without degrading moisture tolerance and durability became the focus of research in building physics. When the energy prices relaxed in the 1980s, global warming, with CO_2 as main culprit, took over as driver for more energy efficiency.
Energy performance legislation replaced motivating, with for buildings legal tools to predict primary energy use for heating, cooling and domestic hot water with inclusion of building coupled renewable production.

2. AN EP-LEGISLATION AS EXEMPLARY CASE

In Flanders, Belgium, the insulation decree came into force in 1992, followed by an energy performance decree by January 1, 2006, containing four requirements for new residential construction with control and fines if not realized [1]:

- U-values for the building parts equal or lower than given upper limit values
- An overall insulation level (K) for the whole building lower or equal to a given limit value, K being defined as (see figure 1):

$$C \leq 1 \quad K=100U_m \qquad 1 \leq C \leq 4 \quad K=100\frac{U_m}{\frac{C}{3}+\frac{2}{3}} \qquad C>4 \quad K=50U_m \tag{1}$$

With U_m the mean thermal transmittance, included thermal bridging, of the envelope having a surface A_T (m^2) enclosing the protected volume V (m^3) and C compactness of the building, defined as:

$$C=V/A_T \tag{2}$$

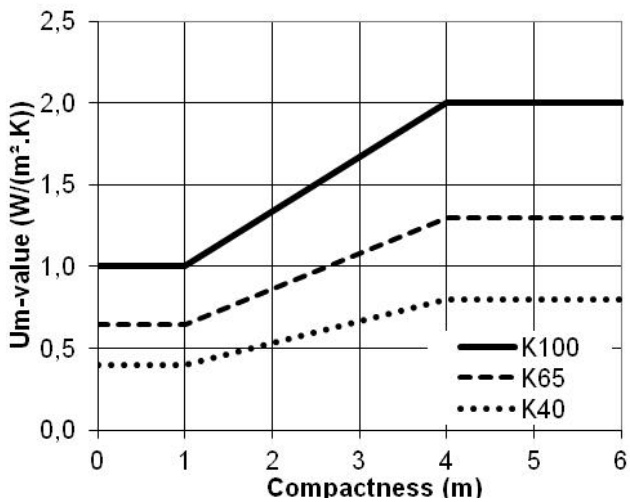

Figure 1. Level of thermal insulation

- A level of primary energy consumption (E) for the whole building lower or equal to a given limit value, E being defined as:

$$E=100\frac{E_{char,ann,prim,en,cnos}}{115A_T+70V+167.5V\left[0.2=0.5\exp\left(-\frac{V}{500}\right)\right]} \quad (3)$$

With $E_{\text{char,ann,prim,en,cons}}$ the calculated annual primary energy consumed for heating, cooling, electric auxiliary power and domestic hot water, using a legally mandated energy calculation tool, mainly based on the EN-ISO 13780 standard.

- A control on overheating

In the building energy simulation tool (BES) used, a few parameters are preset. Imposed is a month-based reference year with temperature and solar radiation as variables. 18°C is the indoor temperature to use all over the heated volume. The infiltration flow is $0.04n_{50}V$ $[m^3/hour]$ with n_{50} the infiltration rate at 50 Pa overpressure indoors in 1/h, equal to 12/C if not measured, otherwise as measured. Only the windows give solar gains, while the internal gains equal (0.67+220/V)t_{mo}V with t_{mo} the length per month in Ms. Does the overheating indicator pass 8000 Kh, then active cooling becomes likely, though unavoidable when touching a value 17500 Kh. To stay below, extra passive measures that temper overheating are needed. Active cooling is penalized as it lifts the E-level quite importantly, while a solar boiler and PV lower it.

Since 2006 the requirements became tighter stepwise, see table 1, 2 and 3. Since January 1, 2018 an S-level combining insulation, solar gains and air-tightness of the envelope in one number, replacing the K-level. One could discuss this as calculating solar gains is loaded with uncertainties, while they do not only lower energy use but also increase overheating risk. Common dweller habits as hanging curtains, or a broadleaf tree in front of a window also have a hardly predictable impact. Insulation instead is a dweller habits independent measure with performance guarantee, at least if correctly executed.

Table 1. U_{max}-values and R_{min}-values, per year mentioned from January 1 on

Building part year →	$U_{max}[W/(m^2K)]$ / $R_{min}[(m^2K)/W]$ 1992	2006	2010	2012	2014	2015	2016-..
Envelope							
Windows	3.5	2.5	2.5	2.2	1.8	1.8	1.5
The glazing		1.6	1.6	1.3	1.1	1.1	1.1
Roof	0.6	0.4	0.3	0.27	0.24	0.24	0.24
Opaque facade parts	0.6/1.0	0.6	0.4	0.32	0.24	0.24	0.24
Curtain walls	3.5	2.9	2.9	2.2	2.0	2.0	2.0
The glazing		1.6	1.6	1.3	1.1	1.1	1.1
Walls below grade	/ 1	/ 1	/ 1	/1.3	0.4/1.5	0.4/1.5	0.24
Floors: facing outdoors	0.6	0.6	0.6	0.35	0.3	0.3	0.24
Facing non-frost free spaces	0.6	0.4/1	0.4/1	0.35/1.3	0.3/1.75	0.3/1.75	0.24
Facing frost free spaces	0.9	0.4/1	0.4/1	0.35/1.3	0.3/1.75	0.3/1.75	0.24

On grade	1.2	0.4/1	0.4/1	0.35/1.3	0.3/1.75	0.3/1.75	0.24
Outer doors	3.5	2.9	2.9	2.2	2.0	2.0	2.0
Other							
Party walls	1.0	1.0	1.0	1.0	1.0	0.6	0.6
Partition walls between flats	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Walls contacting non frost-free spaces outside the protected volume	/ 1	/ 1	/ 1	/1.2	/1.4	/1.4	0.24

Table 2. Level of thermal insulation (K)

1992	1993	2006	2010	2012	2014	2015	2016	2018
65	55	45	45	40	40	40	40	S-level replaces K

Table 3. Level of primary energy consumption (E)

2006	2010	2012	2014	2016	2018	2020	2021
100	80	70	60	50	40	35	30

2.1. Other countries

In the Netherlands, energy efficiency is evaluated using the EPC-number, the ratio between the primary energy consumption as calculated ($Q_{\mathrm{tot,a,calc}}$ in MJ/a) and a reference value:

$$\mathrm{EPC}=\frac{1}{1.12}\left(\frac{Q_{\mathrm{tot,a,calc}}}{300A_{\mathrm{fl}}+65A_{\mathrm{T}}}\right) \tag{4}$$

with A_{fl} floor area and A_T the envelope surface, both in m². The primary energy use as calculated includes heating, domestic hot water, electric auxiliary power, lighting, cooling plus (de)humidification, subtracting the primary energy PV delivers, but added an agreed primary energy quantity for failing summer comfort if no active cooling is installed. In Germany, an EPR-value judges energy efficiency:

$$\mathrm{EPR}=e_{\mathrm{primar,heiz,a}}q_{\mathrm{heizen,a}}+e_{\mathrm{primar,w,a}}q_{\mathrm{w,a}} \tag{5}$$

with $q_{heizen,a}$ and $q_{w,a}$ end use respectively for heating and domestic hot water, both in kWh per year and m² floor area. $e_{\mathrm{primar,heiz,a}}$ and $e_{\mathrm{primar,w,a}}$ are the related primary conversion factors.

3. LESS STRAIGHTFORWARD?

Two effects share responsibility for a less straightforward relation between energy consumption as predicted by the mandated energy calculation tools and reality: dweller habits and distribution grid troubles with too much PV generated electricity

3.1. Dweller habits

As explained for Flanders, the legal tools use fixed dweller habits, permanently 18°C indoors, ventilation depending on protected volume and system installed, internal gains linked to the volume, no dweller impact on solar gains, etc. The question is: does this fit with reality? The answer is no. Rebound behavior is changing things [2]. Figure 2 confronts energy use for heating as calculated with data measured in 1050 dwellings [3] [4].

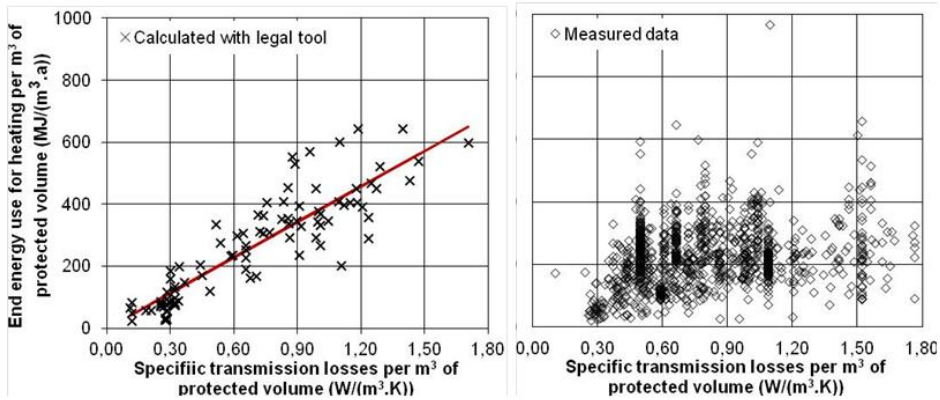

Figure 2. Calculated versus measured energy use for heating

The differences are striking. While calculated a more or less linear relation surfaces between use and transmission losses, both per m^3 of protected volume, the measured data reflect a more or less exponential relation with on average less use in less well insulated residences and a move to what's calculated in well insulated ones. The least square curves equal (see figure 3):

$$\text{Calculated: } \frac{Q_{heat,a,ref}}{V} = 382\left(\frac{U_m A_T}{V}\right) \qquad r^2=0.94$$
$$\text{Measured: } \frac{Q_{heat,a,meas,norm}}{V} = 253\left(\frac{U_m A_T}{V}\right)^{0.52} \qquad r^2=0.85 \tag{6}$$

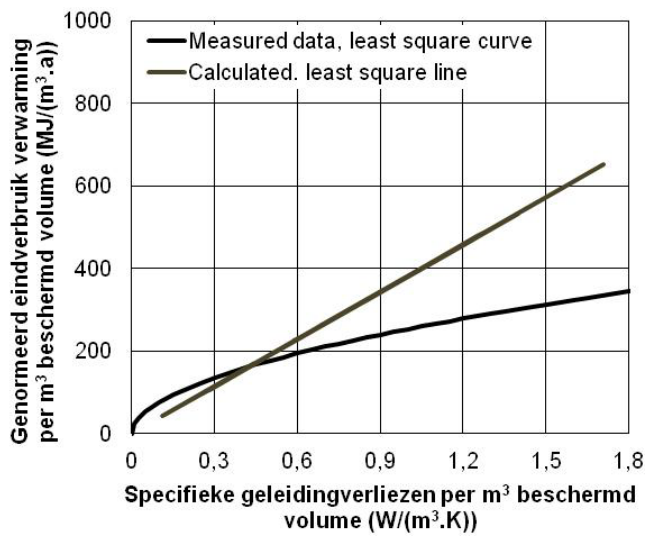

Figure 3. Calculated and measured data, least square line and curve

Both allow calculating what is called the rebound factor ($a_{rebound}$), which represents the impact the inhabitants statistically have on the annual end energy use for heating when considering large numbers of residences. As a formula that factor looks:

$$a_{rebound}=1-0.663\left(\frac{U_m A_T}{V}\right)^{-0.48} \quad (7)$$

Figure 4 gives the actual result and that published in a previous study, proving the rebound curve is very sensitive to how it's calculated.

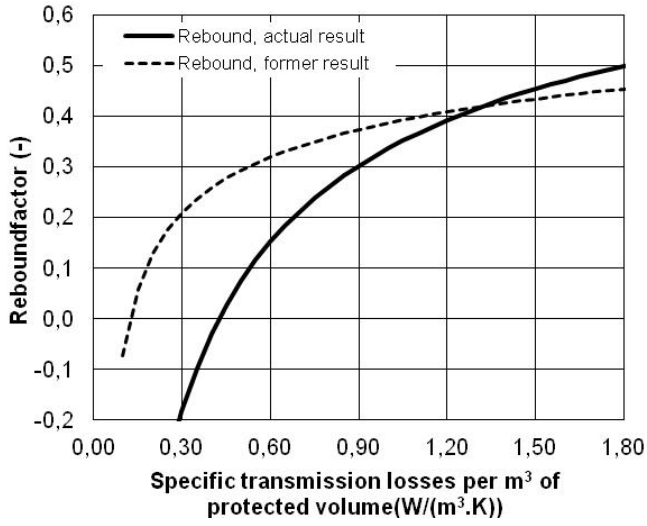

Figure 4. Rebound factor

For large numbers of residences, the overall end energy for heating ($E_{\mathrm{end,heat,tot}}$ in MJ/a) so totals most likely:

$$E_{end,heat,tot}=\sum_{1}^{n}\left(1-a_{rebound,n}\right)Q_{heat,a,ref,n} \quad (8)$$

with $Q_{heat,a,ref,n}$ the annual end energy for heating as calculated with the legal tool. Future changes to that tool will change the rebound curve as calculated. The effect as such of course remains. An important remark is that rebound factor as calculated does not apply at the level of one dwelling or apartment.

What are the reasons for such explicit rebound effect? A first and apparently most influential one is that inhabitants hardly heat bedrooms as table 5, giving weekly mean temperatures measured as function of the weekly mean outdoor temperature, underlines.

Table 4. Measured temperatures in dwellings

Where	Number of rooms	Least square line $\theta_i = a + b\theta_e$ a, °C	b	Correlation coefficient, r^2
Daytime rooms	283	19.5	0.11	0.06
Bedrooms	338	13.8	0.32	0.26
Bathrooms	37	16.5	0.34	0.43

While in daytime rooms the values look comfortable and hardly depend on the temperature outdoors, those measured in sleeping rooms are far below what is comfortable and largely change with the value outdoors, proving no heating is quite standard.
That non heated sleeping rooms turn warmer when a dwelling is better insulated see related energy benefit decrease, explaining why the rebound factor drops with lower transmission losses per m3 of protected volume, table 5 illustrates for a simple dwelling with the daytime rooms at the first and the bedrooms at the second floor.

Table 5. Simple dwelling, sleeping rooms not heated

Dwelling	U_m $W/(m^2K)$	n_{50} $1/h$	End use for heating, MJ/a All rooms heated	Bedrooms not	$a_{rebound}$ %
Footprint 10 x 10 m², 2 floors, V=600 m^3, A_T=540 m², windows south	1.48	12	204590	143060	30
	0.27	12	58870	5093	13
	0.27	3	38580	36310	6

A second reason is a wide spread use of on/off control with the heating on during the hours at home and off when absent and at night.
Besides rebound behavior, also tool limitations induce an overestimation of energy use for heating, among them neglecting the solar gains across opaque building parts. In fact, a steady state evaluation shows a sunlit wall in North-western Europe sees its monthly losses per m² drop with:

$$Q_{sungain,mo}=U\left(\frac{\alpha_s E_{sun,T}-10.4 d_{mo} e_L F_{s,sk} F_{Ts,sk} J}{25}\right) \quad \left[\frac{MJ}{mo}\right] \qquad (9)$$

where $E_{sun,T}$ is the total solar irradiation in MJ on the part's outside face for the month considered, α_s the short wave absorptivity and e_L long wave emissivity of that face, d_{mo} the number of days in the month considered, $F_{s,sk}$ the view and $F_{Ts,sk}$ the temperature factor for radiation with the sky and J the monthly cloudiness factor. For a south facing non insulated cavity wall, U=1.4 W/(m².K), that gain touches 13 MJ/m² in January of the reference year, 3.2°C cold, reducing the loss from 56 to 43 MJ/m² if on average it's 18°C indoors. After insulating the wall realizing a U-value 0.24 W/(m².K), that gain drops to 2.2 MJ/m².
In the Netherlands and Germany analogous trends surface, see figure 5, showing the rebound factors based on data from both countries [5]. The same holds for the UK [6].

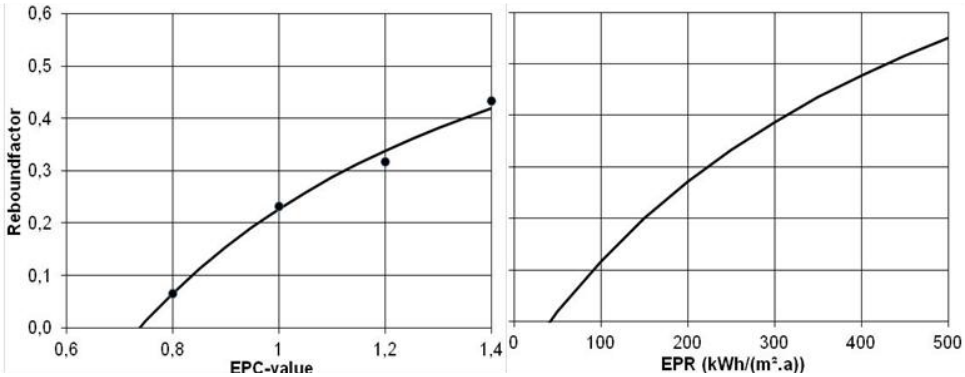

Figure 5. Left the rebound factor based on Dutch, right the rebound factor based on German data

4. PV TROUBLING THE LOW-VOLTAGE DISTRIBUTION GRIDS

4.1. In general

In Northwest Europe electricity production by PV peaks during the warmer half-year with a maximum at noon, but hardly matters during winter, see figure 6 [4].

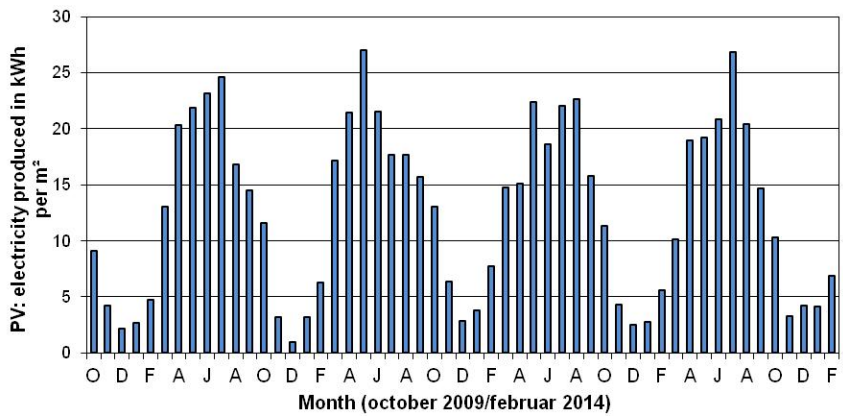

Figure 6. PV on a SW looking pitched roof with slope 40°, measured electricity produced per m²

In summer much power so is directly injected in the low-voltage grid because electricity use is mainly a morning and evening coupled reality then. When many close-by PV-installation inject simultaneously, transformers and linked low voltage grids may endure voltages and losses beyond the limits allowed.

A simulation showed what happens in an estate of 33 detached net zero energy dwellings, each dwelling designed to produce annually as much renewable electricity as primary energy is consumed for heating, ventilation, domestic hot water, lighting and appliances [7]. When the case, the dwellings are nZEB degree 1. A value below 1 characterizes dwellings that aren't net zero, a value above 1 dwellings that are net plus energy, Table 6 lists the main characteristics per dwelling type in the estate.

Table 6. Four dwelling types: main characteristics

Characteristics	Type 1	Type 2	Type 3	Type 4
				
Heated floor area (m²)	127	98	149	123
Window to heated floor ratio (-)	0.12	0.19	0.16	0.13
Compactness (m)	1.23	1.10	0.81	1.18
Mean U-value ($W/(m^2K)$)	0.15	0.17	0.16	0.16
Heating power (W)	2600	2740	3220	3190

The insulation thicknesses in floors, facades and roofs equal the economic optimum for residences [8]. Air-tightness touches 0,6 1/h at 50 Pa overpressure indoors. An air to water heat pump with storage tank cares for heating and domestic hot water, while a purpose designed balanced ventilation system with 84% efficient air to air heat recovery guarantees a healthy indoors. Enough mass, outside shading and window operation prevents overheating. The 34 degree sloped PV panels all look south and are coupled to a radial low voltage distribution grid.

Without PV all dwellings would only consume electricity, causing the grid voltage to drop the closer to the line's end, reason why the transformer to the mid-voltage grid guarantees 230+2 % =234,6 V. PV injection lowers that power flow, even reverses it at higher injection rates with too high voltages as possible consequence. If passing 244 V, an increasing number of PV converters have to be switched off to avoid such overload, turning related PV injection to zero.

Starting from a stochastic distribution of habits and appliance use, each dwelling got an own energy profile. Related PV-generation is modelled on a minute-basis, this to acceptably approximate reality.

4.2. Energy use and PV generation

Left, figure 7 shows the electricity used annually for lighting and appliances, Next stands the one for heating and domestic hot water use per m² of heated floor area. Then comes the heat pump's seasonal performance factor (SPF), with at the right the PV peak power installed, ranging from 2,2 to 7,1 kWp, needed to compensate for the annual primary energy use. Related PV area goes from 12 to 42 m² for cells with peak power 177 W/m². Of course enough south looking roof surface is needed for that.

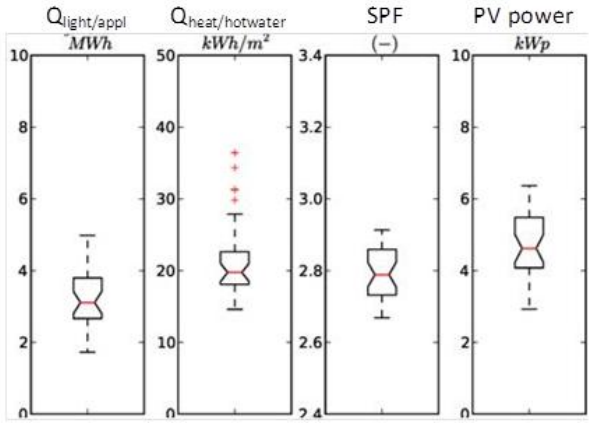

Figure 7. Left annual electricity use for lighting and appliances, next the same for heating and domestic hot water per m² of floor area, then the SPF of the heat pump, right installed PV peak power

4.3. The two not balanced

Are used to describe the balance, the supply (γ_S) and coverage degree (γ_D). The first indicates how much of the electricity generated is used in the dwelling itself, while the second learns which fraction of the electricity a dwelling consumes could be covered by the PV installation. In general, dwellings with few PV, say an nZEB degree 0.04, have a high supply degree, 0.92 ± 0.5, as nearly all electricity produced then is consumed in the dwelling, limiting the extra load on the grid to nearly zero. An nZEB degree 1 instead sees that supply degree drop to some 0,26 ± 0,03, indicating that on average 74 % of the electricity generated must be injected in the grid. Figure 8 shows how things look year round in an nZEB degree 1 dwelling.

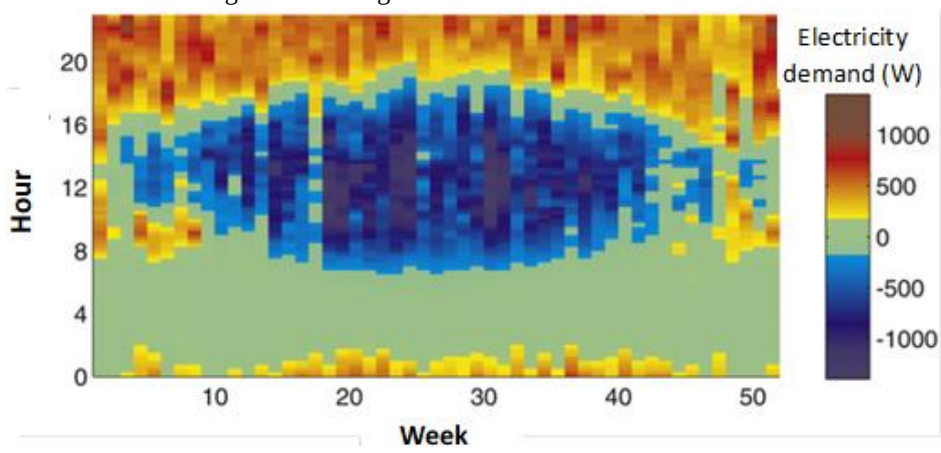

Figure 8. nZEB 1 dwelling, electricity coming from (red) or injected (blue) in the grid

Blue stands for the PV injecting power in the grid and red for the dwelling using electricity from the grid. Reality disappoints, mainly due to the heating demand in winter and the many inhabitants that are working, so are at home only in the evening, at night and next

morning, with most electricity used when in winter the rare sunny days sees the sun gone and when in summer the noon solar peak still has to come and is passed.

4.4. Impact of the low voltage grid

Local grids allow a dwelling where electricity consumption is shifted in time compared to others to benefit from PV electricity generated by the other. Anyhow, grid capacity induces two restrictions: voltages may not pass 244 V and avoid 1 à 2 % extra cable losses. Besides, injection of the PV-surplus in the mid voltage grid should not overload the transformer to low voltage.

As an example, figure 9 shows the supply (γ_S) and coverage degree (γ_D) at dwelling and estate level for different grid configurations for each of the 33 dwellings having an nZEB degree going from 0 to 2.

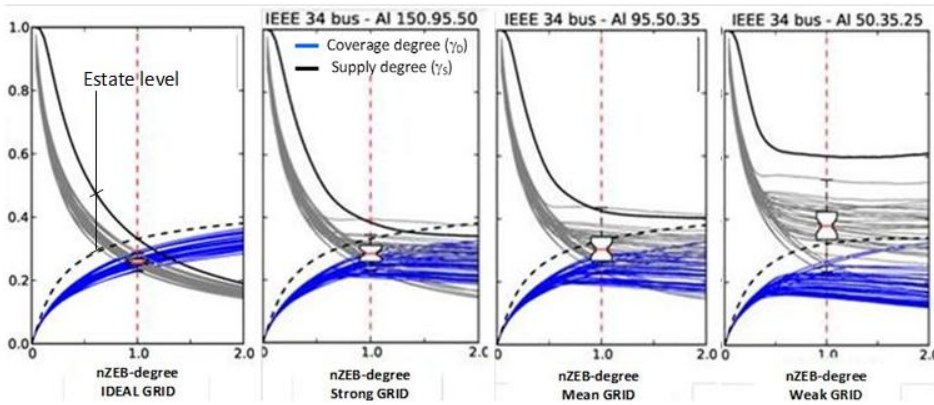

Figure 9. Supply (γ_S, gray) and coverage degrees (γ_D, blue) at estate and dwelling level for different grids depending in the dwelling nZEB degree. The symbol shows the mean γ_D and spread for all dwellings being nZEB1

Independent of grid quality, the supply degree at estate and dwelling level rises thanks to the electricity exchange between dwellings. For a very low nZEB degree, 0.04, that degree's value touches up to 0.99, while for nZEB 1, 0,33 is the result. Despite the upgrade compared to no exchange, still 67 % of all PV electricity is stored in the grid that, if weak, sees the voltage easily touch 244 V, requiring a shut-off of PV converters, so limiting the total renewable electricity generated. Of course, what's left gets more easily redistributed over all dwellings, what helps the supply degree.

What happens with the nZEB degree at estate level, figure 10 shows.

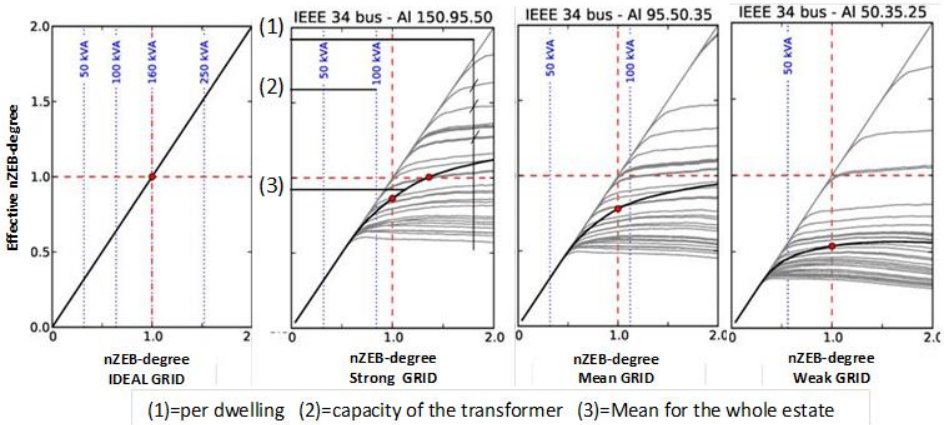

Figure 10. Net zero at estate level depending on the nZEB degree of the dwellings as designed. The vertical blue dotted line show the transformer capacity needed

With a strong low voltage distribution grid, the need to shut off PV converters lowers the nZEB degree for the estate with all dwellings designed nZEB 1, to 0.86 but for the dwelling farthest away from the transformer that value is only 0.59. A weak grid lowers both to respectively 0.53 and 0.33. Otherwise said, where in the estate a dwelling is located has its consequences. Those farther away from the transformer loose an ever increasing part of what the installed PV could generate, included the related economic return.

4.5. How to solve?

Minimizing converter shut off presumes several interventions. The distribution company may upgrade the local low voltage distribution grid and related transformers. Going for smart dishwashers, washing machines, drying machines, deep freezers and perhaps refrigerators may move part of the electricity use to the hours when solar energy is most likely available. This of course presumes changes in inhabitant habits [9]. The electricity PV generates can also help heating the storage vessels in the 33 dwellings or being stored in a battery for shifted use.

5. CONCLUSIONS

Moving to ever more severe insulation and EP-requirements as most countries do is less effective than predictions based on mandated BES tools advance. Advised therefore is to stop mandating additional measures once at the total present value optimum. Also all net zero energy talks require moderation, firstly because balancing non renewable energy use peaking in winter with building-linked PV electricity peaking in summer is not by definition the right way to go, secondly because the low voltage distribution grid quality largely impacts to what extend the production potentiality offered will be available in reality when promoting widespread installation, if not accompanied by measures such as upgrading grid quality, promoting smart appliances, instructing how to adapt habits and using hot water vessel or battery storage!

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10| Оригинални научни рад
Research paper
doi 10.7251/STP1813169K ISSN 2566-4484

POREĐENJE TRI METODE PRORAČUNA ENERGETSKIH CERTIFIKATA U SLOVENIJI

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Apstrakt:

Kako bi dobili ovlaštenje za izradu energetskih certifikata u Sloveniji, kandidati moraju pohađati propisanu obuku i položiti ispit. Pojednostavljena metoda proračuna toplotnih gubitaka koja se podučava na ovoj obuci zanemaruje toplotne mostove, što pouzdanost rezultata čini upitnim. U ovom radu uporedili smo tri metode proračuna toplotnih gubitaka kod „tipične" porodične kuće. Prva metoda predstavlja prethodno pomenuti pojednostavljeni proračun koji koristi korekcijski faktor; druga uzima u obzir toplotne mostove, koristeći numerički dobijene vrijednosti linijskih koeficijenata prolaza toplote, a treća koristeći zadane vrijednosti ovih parametara. Uzimajući u obzir da druga metoda daje najpreciznije rezultate, utvrdili smo da su rezultati prve metode preveliki, ali ipak manji nego rezultati dobijeni trećom metodom.

Ključne riječi: energetski certifikat, toplinski gubici, toplinski most

COMPARISON OF THREE CALCULATION METHODS OF ENERGY PERFORMANCE CERTIFICATES IN SLOVENIA

Abstract:

In order to get the authorization for issuing energy performance certificates in Slovenia, the expert candidate has to attend the prescribed course and pass the exam. The simplified method for heat losses calculation that is taught at this course neglects the thermal bridges, raising concerns whether the calculation results are reliable. In this paper we have compared three methods for calculation of thermal losses for a "typical" family house. The first is the above mentioned simplified calculation using a correctional factor; the second takes into account the thermal bridges, using linear thermal transmittances obtained by numerical calculation, and the third takes into account the thermal bridges, using default values for linear thermal transmittances. Noting that the second method returns the most exact values, we have found that the first method results are too large, yet still smaller than the third method results.

Keywords: energy performance certificates, thermal losses, thermal bridge

1. INTRODUCTION

Energy demand is one of the biggest challenges of the European Union (EU) today. Because of EU dependence on foreign energy sources as well as the energy usage negative impact on local environment and global warming, for decades the aim of EU politics has been to curb its consumption.

The most effective way to achieve this goal is to increase energy efficiency. According to data from 2012, heating and cooling represents 50% of all EU final energy consumption and more than 60% of that accounts for building heating and cooling [1][2]. It is therefore not a great surprise that the focal point of the efforts is the building heating and cooling. In fact, 76% of energy efficiency public funding within EU goes to buildings energy efficiency [3].

Part of these efforts goes to legislation, of which currently the most important are Directive 2010/31/EU on the energy performance of buildings [4] and Directive 2012/27/EU on energy efficiency [5]. Among others, the former has introduced the energy performance certificates as a certificate recognized by a Member State or by a legal person designated by it, which indicates the energy performance of a building or building unit. However, the directive is vague about the methodology of calculation and authorizes member states to determine it.

Slovenia is regulating the issuing of energy certificates by three separate laws, one making energy performance certificates obligatory (Ur. l. RS, 12/2014), one specifying calculation methodology (Ur. l. RS 92/2014), and one establishing system of licenses for the experts issuing energy performance certificates (Ur. l. RS 6/2010 and 23/2013). In general, it is prescribed that energy certificates are produced in accordance with existing regulations for the calculation of thermal losses, which closely follow the procedures prescribed by various ISO standards.

Part of the license procedure requires the expert candidates to attend the prescribed course and pass the exam. Surprisingly, the course excludes calculation of the thermal bridges contribution. In this article, we will analyze the impact of this simplification on the value of the calculated thermal losses for an example of a simple building.

2. CALCULATION METHODS

According to ISO 13789 [6], the four principal contributions to thermal losses are direct thermal losses, thermal losses through the ground, thermal losses through ventilation and thermal losses through unconditioned spaces. In this article we shall consider only the former two. Expression for direct thermal losses are described by direct heat transfer coefficient

$$H_{\mathrm{D}} = \sum_{\mathrm{i}} A_{\mathrm{i}}\, U_{\mathrm{i}} + \sum_{\mathrm{j}} l_{\mathrm{j}}\, \Psi_{\mathrm{j}} + \sum_{\mathrm{k}} \chi_{\mathrm{k}}\,, \qquad (1)$$

where U and A are thermal transmittance and area of the wall, respectively, Ψ and l are linear thermal transmittance and the length of the linear thermal bridge, respectively, and χ is point thermal transmittance of the point thermal bridge. Note that according to ISO 14683 [7], the third term in (1) due to the point thermal bridges, insofar as they result from the intersection of linear thermal bridges, can be generally neglected.

The second and the third term in (1) are corrections due to thermal bridges. For example, structural thermal bridges are locations on the thermal envelope where thermal transmittance is generally significantly higher than in its immediate neighbourhood. On

the other hand, geometric thermal bridges account for the difference in heat transfer calculation due to the usage of the external or internal building dimensions [8]. In the case of the external dimensions, calculation areas in the first term represent upper limit values and the corresponding heat transfer coefficient is larger than the exact value. On the other hand, in the case of the internal dimensions, calculation areas represent lower limit values and the corresponding heat transfer coefficient is smaller than the exact value. Since linear thermal transmittances for external dimensions are smaller than zero, $\Psi_{\mathrm{e}} < 0$, and linear thermal transmittances for internal dimensions are larger than zero, $\Psi_{\mathrm{i}} > 0$, taking into account geometric thermal bridges leads to the same exact result for thermal losses, regardless of the dimension system.

Slovenian legislation, in particular technical guidelines TSG-1-004:2010 [9], allow the simplified calculation. If all linear thermal transmittances for external dimensions are $\Psi_{\mathrm{e}} < 0.2\mathrm{W/(m \cdot K)}$ according to ISO 14683, thermal bridges can be disregarded and the thermal transmittance of the whole thermal envelope is increased by $\Delta U_{\Psi} = 0.06\mathrm{W/(m^2K)}$, leading to the simplified form for direct heat transfer coefficient

$$H_{\mathrm{D}} = \sum_{\mathrm{i}} A_{\mathrm{i}} \left(U_{\mathrm{i}} + \Delta U_{\Psi}\right). \quad (2)$$

In the prescribed course for the licenses, expert candidates are taught to use the above described simplified calculation regardless of the value of linear thermal transmittances, i.e. even when thermal bridges are not being well addressed. Yet, to get the upper limit thermal losses, they are to be calculated using external dimension system. To our knowledge all energy certificates in Slovenia are calculated according to these directions. But in most practical situations, the condition of the technical guidelines for the simplified calculation is not fulfilled, raising concerns whether the results are reliable.

On the other hand, one of the practical problems is how to obtain reliable values for linear thermal transmittances. ISO 14683 [7] provides several methods, of which the numerical calculations according to ISO 10211 [10] (typical accuracy ± 5 %) are the most precise and the default values provided by the standard itself (typical accuracy 0 % to 50 %) are the least precise. In this article we shall compare the results of the three calculations:

- the simplified calculation with external dimension system as taught at the prescribed course,
- the calculation taking into account thermal bridges with linear thermal transmittances obtained by numerical calculation with program AnTherm and
- the calculation taking into account thermal bridges with default values of linear thermal transmittances.

It should be noted that that default values obtained by ISO 14683 are calculated for parameters representing worst-case situations, rounded to the nearest 0.05 W/(m·K).

Heat transfer coefficient through ground H_{g} was also calculated, as prescribed by standard ISO 13370 [11].

Finally, in our case transmission heat transfer coefficient H_{T} is obtained as the sum of two coefficients

$$H_{\mathrm{T}} = H_{\mathrm{D}} + H_{\mathrm{g}}. \quad (3)$$

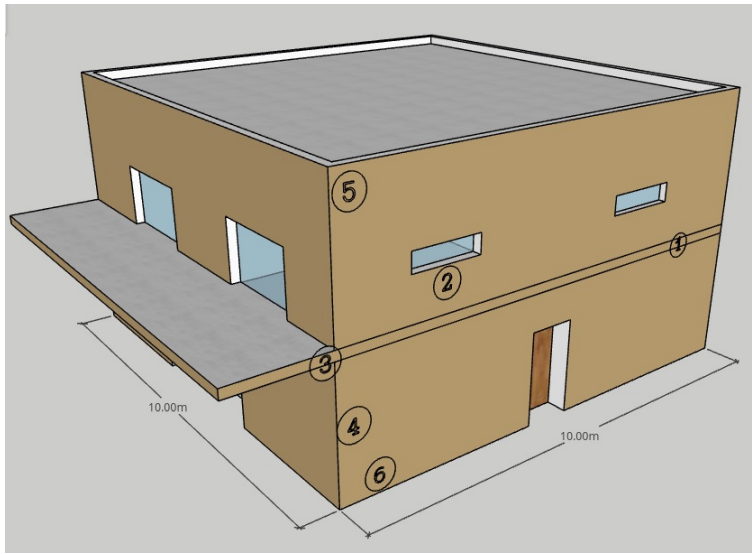

Figure 1. Design of a "typical" family house with two floors and a flat roof used for the calculation. We identified six types of thermal bridges, which are designated by numbers: 1- partition/wall, 2 - window/wall, 3 - balcony, 4 - wall/wall, 5 - roof/wall and 6 - ground floor/wall.

Table 1. The layers of the most important building elements of thermal envelope.

Floor	Wall	Roof
gravel	1,5 mm finishing layer	8 cm screed
10 cm reinf. concrete	adhesive mortar	20 cm XPS
12 cm XPS	20 cm EPS F	20 cm reinf. concrete
7 cm screed	adhesive and spackle mortar	
	38 cm Porotherm bricks	

3. RESULTS

As a simple example, we have designed a "typical" family house with floor plan of dimensions 10 m × 10 m, two floors of height 2.85 m corresponding to ceiling height of 2.5 m and a flat roof, as shown in Figure 1. In order to maximize the effect of thermal bridges, we intentionally designed the house with good thermal insulation, but with the thermal bridges not being well addressed. From our experience, in Slovenia the problems of thermal bridges are generally neglected, so this represents a common situation. All the calculations were done using the external dimensions of the building.

The most important layers of the building elements of thermal envelope are listed in Table 1.

Table 2. Areas and thermal transmittances of building elements of thermal envelope.

Element	$A(\mathrm{m}^2)$	U $(\mathrm{W}/(\mathrm{m}^2\mathrm{K}))$
Wall	200.3	0.126
Roof	95.3	0.162
ground floor	95.3	0.175
Windows	21.6	0.700

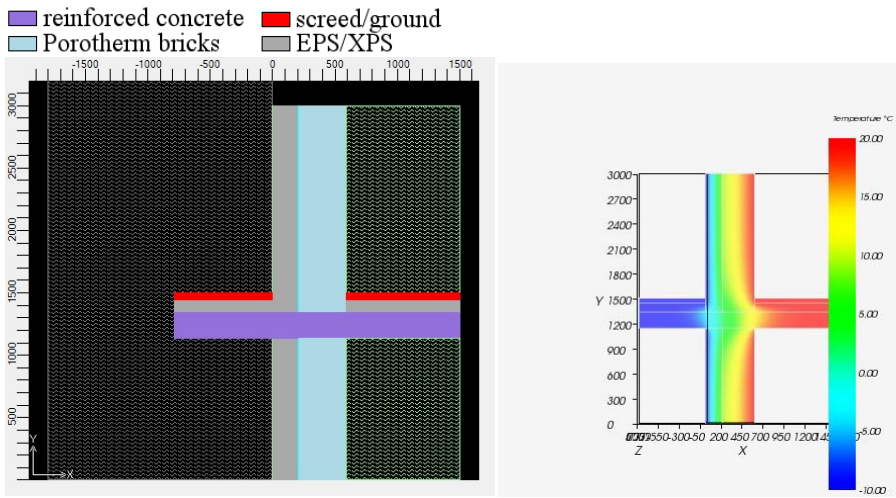

Figure 2. The calculation procedure for the thermal bridge number 3 - balcony. Left side picture shows the thermal bridge design, right side picture shows temperatures obtained by numerical calculation.

The areas and thermal transmittances of building elements of thermal envelope are presented in Table 2.

We have studied six types of thermal bridges, shown in Figure 1 and listed in Table 3. All calculations were made in accordance with ISO 10211 [10] using program AnTherm.

The most problematic thermal bridge, the balcony thermal bridge (number 3), is presented in Figure 2.

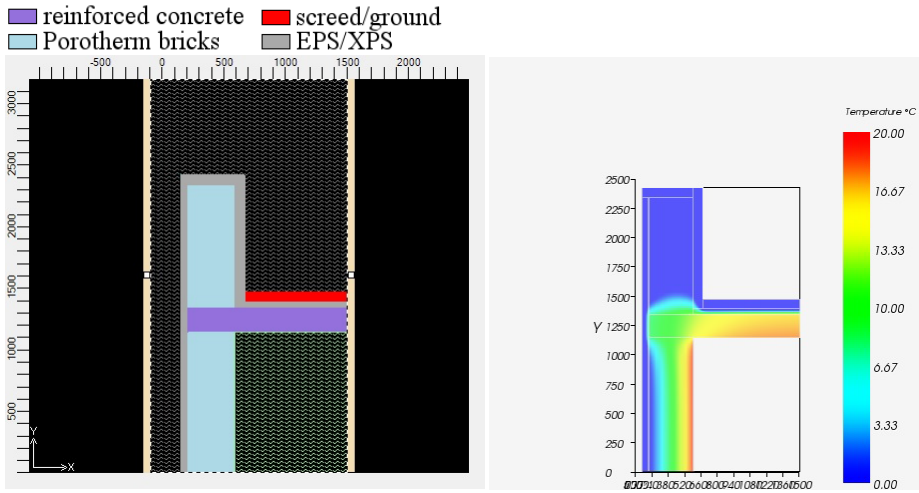

Figure 3. The calculation procedure for the thermal bridge number 5, roof/wall contact. Left side picture shows the thermal bridge design, right side picture shows temperatures obtained by numerical calculation.

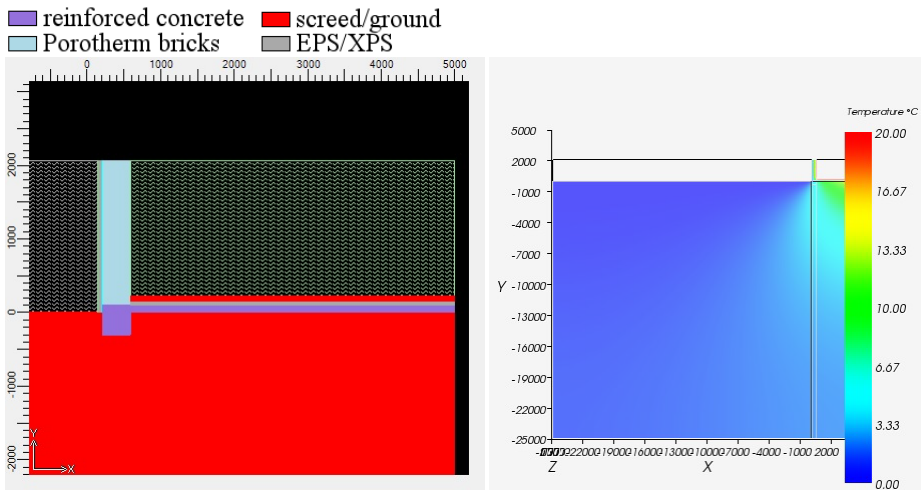

Figure 4. The calculation procedure for the thermal bridge number 6, ground floor/wall contact. Left side picture shows the thermal bridge design, right side picture shows temperatures obtained by numerical calculation.

Other important thermal bridges are the roof/wall contact thermal bridge (number 5), presented in Figure 3, and the ground floor/wall contact thermal bridge (number 6), presented in Figure 4. Note that ISO 10211 requires that temperatures for thermal bridges in contact with the ground are calculated in much wider region.

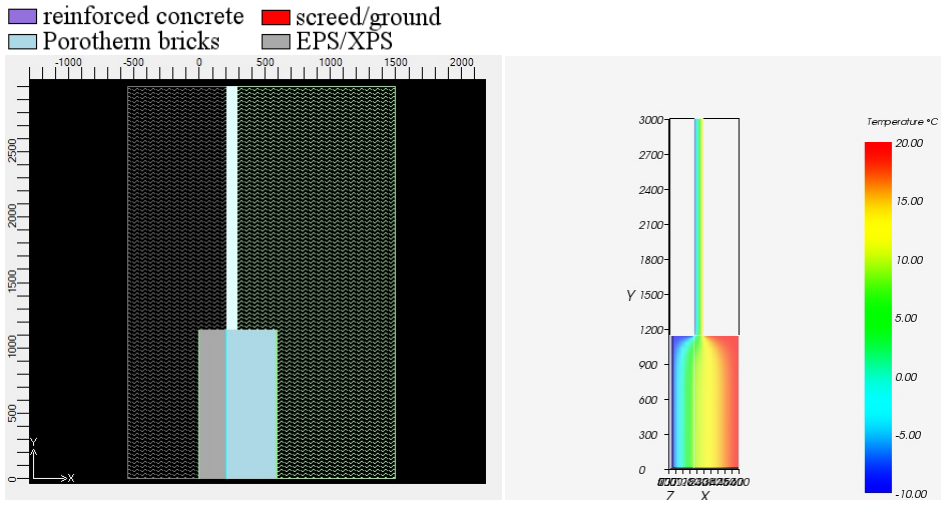

Figure 5. The calculation procedure for the thermal bridge number 2, window/wall contact. Left side picture shows the thermal bridge design, right side picture shows temperatures obtained by numerical calculation.

Table 3. Lengths and linear thermal transmittances of thermal bridges.

Figure 1 notation	Type/Description	l(m)	Ψ_e(W/(m · K)) numerical value	ISO 14683 notation	Ψ_e(W/(m · K)) default value
1	partition/wall	30.0	0.027	IF1	0.00
2	window/wall	74.6	0.055	W15	0.00
3	balcony	10.0	0.441	B1	0.95
4	wall/wall	22.4	-0.088	C1	-0.05
5	roof/wall	40.0	-0.014	R11	0.05
6	ground floor/wall	40.0	0.247	GF5	0.60

A special procedure was used to determine the approximate linear thermal transmittance of the wall-window contact, as shown in Figure 5. The window frame was simulated by a uniform material, which average thermal conductivity $\bar{\lambda}$ was determined from the equation

$$U_f = \frac{1}{R_{se} + \frac{d}{\bar{\lambda}} + R_{si}}, \qquad (4)$$

where U_f is thermal transmittance of the frame, d is frame thickness and R_{se} and R_{si} are external and internal surface resistances according to ISO 6946 [12], respectively. Note that the design of this as well as the previous thermal bridges is in accordance with the initial assumption that the thermal bridges are not being well addressed.

The results of numerical calculation and default values from ISO 14683 are presented in Table 3.

Table 4. The results for the transmission heat transfer coefficient and the thermal bridges' share.

Calculation type	H_T(W/K)	thermal bridges' share
No thermal bridges	75.2	0%
Simplified calculation	100.1	33%
Thermal bridges, numerical values	92.6	23%
Thermal bridges, default values	109.6	46%

The obtained value for the heat transfer coefficient through ground is 16.6 W/K. Finally, the results for the transmission heat transfer coefficient (3) are presented in Table 4.

4. DISCUSSION

First we comment differences between default values from ISO 14683 and values obtained by the numerical calculations. As expected, most default values are larger than numerical values, which is in accordance with the assumption that the former are calculated for parameters representing worst-case situations. Surprisingly, IF1 and W15 default values are 0.00 W/(m·K), despite the fact that according to our numerical calculations they should be at least 0.05 W/(m·K), after rounding to the nearest 0.05 W/(m·K).

The result of the calculation including thermal bridges, with linear thermal transmittances obtained by numerical calculation should be considered the most correct and referent: The transmission heat transfer coefficient is 0.222 W/K, while 25% of all thermal losses are due to the thermal bridges. Note that the similar calculation for the low-energy house case gave 8% share [13]. This is consistent with our results where design choice was meant to maximize effect of thermal bridges.

The simplified calculation returned even higher transmission heat transfer coefficient of 0.241 W/K, which is 9% higher than the referent value. This is obviously due to the fact that correction factor $\Delta U_\Psi = 0.06\ \mathrm{W/(m^2K)}$ is independent of the energy efficiency of the house, giving larger thermal bridges' share for better insulated buildings. We conclude that the simplified method, though returning values that are too high, gives good estimate for the worst-case scenario of our study case.

The result of the calculation including thermal bridges with default linear thermal transmittances, gives the highest transmission heat transfer coefficient of 0.264 W/K, which is 19% higher than the referent value. This is understandable, as linear thermal transmittances are calculated for parameters representing worst-case situations. However, default values for most critical situations like balcony and ground floor/wall thermal bridge (Table 3) are twice as high as the exact values and not reliable enough for the calculation.

5. CONCLUSION

In this paper we have compared three methods for calculation of thermal losses of a "typical" family house. The first is the simplified calculation using a correctional factor; The second takes into account the thermal bridges, using linear thermal transmittances obtained by numerical calculation; And the third takes into account the thermal bridges, using default values for linear thermal transmittances.

The second method gives the most exact, referent values. On the other hand, the first method gives values that are too high.

Since the numerical calculation of the linear thermal transmittances is a laborious process, the alternative to the first method would be the third method using default values of linear thermal transmittances. However, our calculations show that for our study case, the third method results are even further away from the referent ones.

We conclude that more precise default values of linear thermal transmittances would be beneficial in order to account for thermal bridges better. Further investigation is underway.

Acknowledgement

We would like to thank AnTherm for providing free academic use of the program for this study.

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11| Оригинални научни рад
Research paper
doi 10.7251/STP1813179P ISSN 2566-4484

ENERGETSKE PERFORMANSE OMOTAČA ZGRADE OBRAZOVANJA PREMA PASIVNOM I NISKOENERGETSKOM STANDARDU

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Rezime:

Visoki energetski zahtjevi i potreba za energetskim certifikovanjem zgrade značajno utiču na projektovanje i izvođenje objekta. Rad ima za cilj da prikaže energetske performanse omotača zgrade obrazovanja u pasivnom i niskoenergetskom standardu u klimatskim uslovima zone sjever za Republiku Srpsku (Bosna i Hercegovina). Studija slučaja projekta nove zgrade Arhitektonsko-građevinsko-geodetskog fakulteta, čija je izgradnja počela 2011. godine u Banjoj Luci, predstavlja osnovu za predstavljeno istraživanje. Vizionarski pogled na izgradnju pasivne zgrade za obrazovanje zahtijevao je značajne investicije koje, nažalost, nisu bile obezbijeđene. Troškovi planirane izgradnje novog koncepta su smanjeni, ne samo na osnovu smanjenja energetskih performansi omotača zgrade, nego i na osnovu tehničkih sistema grijanja, završnih slojeva poda, opreme i sl. U radu su prezentovane izmjene energetskih performansi omotača zgrade i njihovog uticaja na transmisione i ventilacione gubitke, a samim tim i na potrebnu energiju za grijanje objekta.

Ključne riječi: projektni parametri, energetske performanse omotača zgrade, pasivni standard, niskoenergetski standard, zgrada obrazovanja

ENERGY PERFORMANCE OF THE EDUCATIONAL BUILDING ENVELOPE ACCORDING TO A PASSIVE AND LOW-ENERGY STANDARD

Abstract:

High energy demands and obligation for building energy certification make an impact on architectural design and building construction. The paper aims to present energy performance of the educational building envelope in a passive and low-energy standard in the climatic conditions of the north zone of the Republic of Srpska (Bosnia and Herzegovina). The case study of design project for the building of Faculty of Architecture, Civil engineering and Geodesy, which construction started in 2011 in Banja Luka, serves as the basis for the presented research . The original plan for passive educational building development required large investments, which unfortunately were not provided. Planned

construction costs with new concept were reduced, not only with lower requirements of the envelope energy performance, but also technical systems such as heating type, lower costs on finishing layers of floors, furnishing etc. The paper presents changes in energy performance of the building envelope and its impact on transmission and ventilation heat losses, as well as the energy needs for heating.

Keywords:design parameters, energy performance of building envelope, passive energy standard, low-energy standard, educational building

1. INTRODUCTION

Contemporary approaches in architecture design are tightly connected to high energy efficiency demands requested by the governments, environmental organizations and EU initiatives. Those approaches greatly affect decisions making in terms of design and materialization of a building. As the research background, this study uses project for the new building of the Faculty of Architecture, Civil engineering and Geodesy at University of Banja Luka, which has been designed by adopting highest energy efficiency requirements and EU demands. The new approach implies construction of new building by using principles of energy efficiency (low energy, zero, zero plus or intelligent building) with specific standards and intelligent systems of optimization in contemporary construction.

The building has been designed as a two part structure consisted from - an old facility, the building from Austro-Hungarian period and the new facility designed for educational purposes. Even though a building design has been made as a contemporary, passive energy building, economical situation has also made influence to the process of the building construction. Therefore, the requirement of the high energy class and overall high building performance had to be changed to lower level.

Since the work analyses and proposes a solutions for modifications of energy grade, it is necessary to explain two grades which will be analyzed in the article. A passive house can be described as energy saving building where the heat comfort is provided without ordinary systems for heating or air conditioning. Heat needed in yearly period can be maximum as 15 $kWh/(m^2a)$. The structure needs to be built without heat bridges ($\Psi \leq 0.01W/(mK)$). Mutual usage of the primary energy cannot exceed 120 $kWh/(m^2a)$. Low energy house is a term which is related to the house with annual year heat demands between 40-60 $kWh/(m^2a)$ (what varies by the country), and at least $15kWh/(m^2a)$. In order to reach low energy parameters, a good insulated and air-tight building envelope as well as windows with thermal insulating glass are necessary to be provided. Also, the difference compared with a passive standard is that low energy standard implies traditional systems of heating. [1]

In the following text, a brief overview of the energy class change are shown for building envelope performance only.

2. BUILDING ANALYSIS

The first step towards modification of building energy performance is fundamental analysis of design documentation. A main task was to analyze and modify an original design plan, to reach more feasible building design with least possible design modifications. The special emphasis is made on building envelope since it has the greatest influence on the total energy loss of the building.

The first step towards building analysis - defining the material types and the exact thickness and properties of different types of materials and structural building elements which have to be built in is shown on Figure 1.

An important segment of this analysis is the type of the analyzed construction, since there is significant difference between recently constructed (new) part and old part of the building which already has a 51 cm thick wall (without an insulation).,

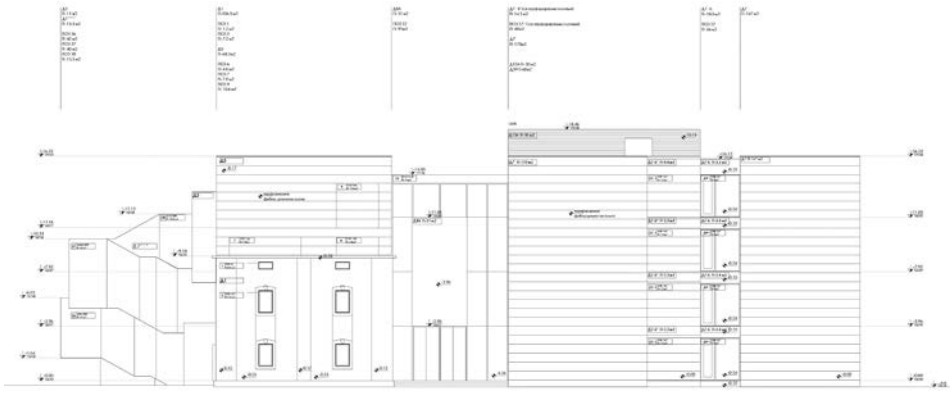

Figure 1. Analysis of South Elevation.

Figure 2. shows a comparison between two main construction elements consisted within an old part, where the major difference is in the structure type - a contact and ventilating facade.

Distribution of transparent and opaque elements on the envelope were analyzed and exact percentage of contribution of each has been found. According to the orientation and solar insolation, a further reduction of layers of insulation has been made. The replacement several transparent elements at the envelope has been planned to be done with lower thermal insulation elements, such as the envelope of the aula, which connects the old and new part of the building. According to the design plan the new building of Faculty of Architecture, Civil engineering and Geodesy has gross volume of V_e=34053 m^3 with conditioned floor area of A_u=7197 m^2 and the building shape factor of f_0=0.247. The share of transparent elements in total area of building envelope is 28.3 % [2].

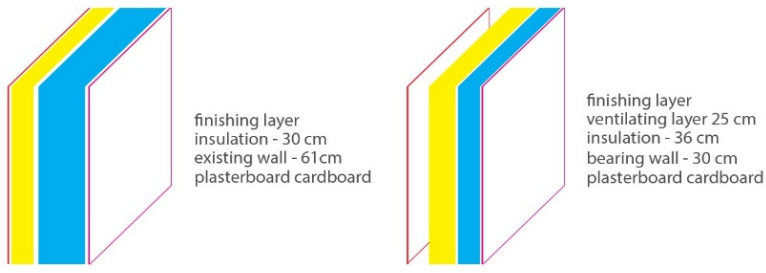

Figure 2. Difference in bearing part of the wall - camparison between existing wall (61cm of bearing part thickness) and new (proposed) type of the wall (36 cm of bearing part thickness).

2.1. REDUCTION OF SOLAR HEAT GAINS

The solar heat gains represent the increase in thermal energy of a building due absorption of incident solar radiation. [4] When analyzing the building envelope, next to the orientation as main natural parameter which directly makes influence on energy performance of a building is the shading, which has a purpose to prevent or reduce excessive amount of direct solar radiation inside a room. By analyzing a building, it is concluded that major part of the facades are oriented towards north and south, which is according to main energy efficiency principles, correct orientation since it provides the biggest solar heat gains during the winter and lower ones during the summer. The solar

heat gains through the windows are expected to have the greatest impact on energy performance of the building except in buildings with very poor insulation standards.

The average intensity of global solar radiation in July reaching an outer surface of westerly oriented window is 168 W/m^2 [6]. For example, a 5 x 5 m office with 6 m^2 of glazing would receive around 0.55 kW of solar heat gains, about 3.5 times greater than the heat gains from occupants and electrical appliances. [6] Considering that the building is intended for educational purposes, good lighting in classrooms must be provided too [7]. The educational section of building is oriented toward the east, but with significant amount of dense trees which absorb direct solar radiation. Offices and classrooms are west/east oriented with a triple glazing unit and thicker insulation on external walls.

In these positions the unit of glazing are not changed, in order to ensure the transmission of solar energy (g-coefficient of 0.5) which is more suitable for the summer period with the aim to prevent overheating of the space. Due to limits on energy demands, a design proposes a facade which can use a solar energy and light in the most optimized way, as it is shown in the figure 3, towards the angle of the sun's rays at 45 degrees north latitude [3]. An original design proposed a design with automatic movable shutters, but due to economic reasons, this solution has been replaced with basic, manually operated shutters.

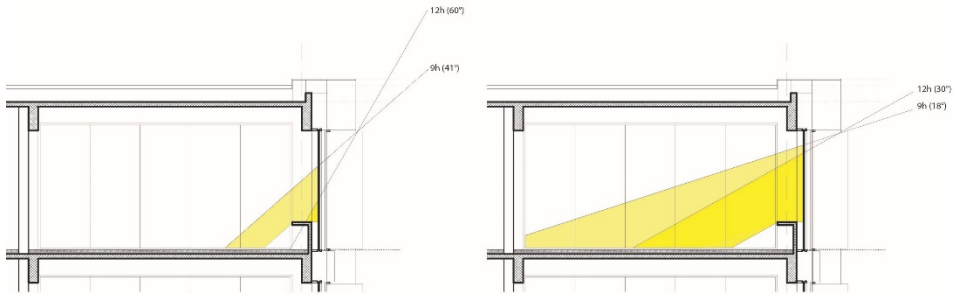

Figure 3. A solar gains during summer and winter with a shader on east elevation

According to Baker and Steemers [4] the use of tinted and reflected glass is not recommended as a shading strategy, since the ratio between useful daylight reduction and thermal reduction is not in good relation. When it comes to curtain walls, a clear, non-reflective glasses are proposed, with three layers of low-e glass, filled with krypton in spaces between. In this case, curtain walls are used not just in northern, eastern and southern facade, but also as a significant part of the roof. Therefore, the decision was to change a glazing type only on the space of "aula", because it was the space that makes the main entrance hall in the building, it connects the old and new part of the building, and it is planned to be heated at 18°C.

3. A DETAILED REVIEW OF ENERGY PERFORMANCE ANALYSIS AND MODIFICATION

In order to reduce transmission heat losses and categorize building in passive energy concept with annual energy need for heating below 15 kWh/m^2 designers aimed for the lowest possible U-values of the envelope elements. Originally planned building was designed with U-value of external walls ranging from 0.075 to 0.176 $W/(m^2K)$ and with thermal insulation thickness of 30 to 40 cm. Transparent elements were planned to be triple glazed windows (low-e filled with krypton) with thermally broken multi-chamber aluminum frames with U-values ranging from 0.960 to 1.220 $W/(m^2K)$. The opaque roof

elements were designed with thermal insulation thickness from 34 to 42 cm and U-value ranging from 0.078 to 0.116 $W/(m^2K)$. With such low U-values, heat losses by transmission are not significant even in the coldest months [8]. For the envelope designed in this way annual energy need for heating per conditioned floor area is $Q''_{h,nd}$=10.97 kWh/m^2 (table 1), which classifies the building into the energy class A according to the current Rulebook on energy survey and energy certificate publication [9]. The building is conceived as one of the first buildings of such of size in the country that requires that low amount of energy need for heating. This is a direct consequence of incorporation of the latest and futuristic energy efficient concepts in design of new buildings.

Table 1. Energy characteristics of originally and modified design of Faculty building

	Initial design plan	After modification	Relative increase [%]
$Q''_{h,nd}$ $[kWh/m^2]$	10.97	20.52	87.1
$Q'_{h,nd}$ $[kWh/m^3]$	1.928	3.602	87.1
H'_T $[W/(m^2K)]$	0.347	0.467	34.6
H [W/K]	7496.78	9626.6	28.4
Length of heating season [days]	123	160	50.9

According to this requirement for non-residential buildings with shape factor between 0.20 – 1.05 the annual energy need for heating per external volume should not be greater than 17.19 kWh/m^3 [5]. However, calculation shows that (Table 1) this quantity is equal to $Q'_{h,nd}$=1.928 kWh/m^3 which indicates that the annual energy demand for heating is around 9 times lower than the permitted value for this type of buildings. The heat transfer coefficient by transmission per overall area of building envelope is H'_T=0.347 $W/(m^2K)$ (Table 1). Rulebook on minimum requirements of energy characteristics of buildings prescribes limit value of 0.907 $W/(m^2K)$ for non-residential buildings with shape factor between 0.20 - 1.05 and the share of transparent elements lower than 30 %. By comparing the prescribed and calculated values of the heat transfer coefficient normalized to the area of the envelope it can be concluded that the transmission heat losses are around 2.5 times lower than the permitted ones. Beside transmission heat losses which depends on the thermal-insulating quality of the elements (or U-values), buildings lose heat by air-change as well [10]. Such losses are known as ventilation heat losses (including infiltration) and they depend on the tightness of envelope, characteristics of ventilation systems and the position of the building with respect to the environment and the microclimate [11]. As can be expected with passive energy building of the class A, the ventilation heat losses are significant (64.5 %) and dominant over the heat losses by transmission (35.5 %). The Overall heat transfer coefficient (by transmission and ventilation together) equals to H=7496.78 W/K (Table 1).

Modification of the initial design plan meant the reduction of a thermal insulation thickness of the external and basement walls, ground and basement floor, flat roof, replacement of a certain number of triple glazed low-e windows filled with krypton with double glazed low-e windows filled with air and the modification of ventilation system in building. Table 2. shows an example of exterior wall D1 with reduced thickness of thermal insulation. Each building envelope element has been modified in way that it still meets the prescribed conditions in terms of thermal properties, while the overall energy performance

of the buildings meets the B class level. Table 2 shows representative element of envelope whose U-value after modification of initial design equals to 0.192 $W/(m^2K)$. Interventions reduced the thickness of stone wool as a thermal insulation from 30 to 15 cm, which increased U-value from 0.109 to 0.193 $W/(m^2K)$. Satisfactory U-value is reached according to regulations [12] even after interventions.

Newly designed U-values of external walls and flat roof elements range from 0.091 to 0.262 $W/(m^2K)$ and 0.106 to 0.191 $W/(m^2K)$, respectively. By these interventions on the envelope transmission heat losses are significantly increased compared to the initial state. After modification of initial design plan annual energy need for heating per conditioned floor area increases almost twice with respect to the previous design value ($Q''_{h,nd}$=20.52 kWh/m^2) (Table 1) and therefore the energy class of building changes from class A to class B. The same relative increase characterizes the annual energy need for heating per conditioned floor area and per external volume ($Q'_{h,nd}$=3.602 kWh/m^3). By deteriorating the thermal characteristics newly designed can be classified into low energy buildings. The new heat transfer coefficient by transmission per overall area of building envelope is H'_T=0.467 $W/(m^2K)$ and the overall heat transfer coefficient by transmission and ventilation is H=9626.6 W/K (Table 1).

Table 2. Structure of a „D1" wall. An example of modified thermal performance of wall.

layer	material	thickness (before) [cm]	thickness (after) [cm]	density $[kg/m^3]$	thermal conductivity $[W/(mK)]$	thermal resistance (before) $[(m^2K)/W]$	thermal resistance (after) $[(m^2K)/W]$
	internal resistance					0.130	0.130
1	plaster cardboard	1	1	900	0.210	0.048	0.048
2	unventilated air layer	3	3	1	0.164	0.183	0.183
3	brick	65	65	1800	0.760	0.842	0.842
4	stone wool	30	15	30	0.038	7.895	3.947
	external resistance					0.040	0.040
	Total thermal resistance R $[(m^2K)/W]$					9.138	5.190
	Thermal transmittance U $[W/(m^2K)]$					0.109	0.193

As can be seen from Figure 4, the greatest share of transmission heat losses occurs, as expected, through the transparent elements (roof and vertical windows) both for initial and modified design plan (79.1 and 67.2 %, respectively). Next in line are external walls and opaque elements of roof with overall share of 14.3 and 19.2 % in total transmission heat losses of originally planned and modified Faculty building, respectively. Heat losses through ground walls and floors are not significant due to thermal mass of the ground. Third (gray) column in Figure 5 represents relative change of transmission heat losses compared to the original state. The largest modifications are made for the external walls

and opaque elements of roof, where the thickness of thermal insulation is reduced by 10 up to a maximum 25 cm. The relative increase in transmission heat losses are 86.7 and 65.2 % for external walls and opaque elements of roof, respectively. A much smaller relative change in transmission heat losses occurs through transparent elements (2.2 and 17.5 % for roof and vertical transparent elements, respectively), because the replacement of triple glazed windows was made only in the central part of the building "aula".

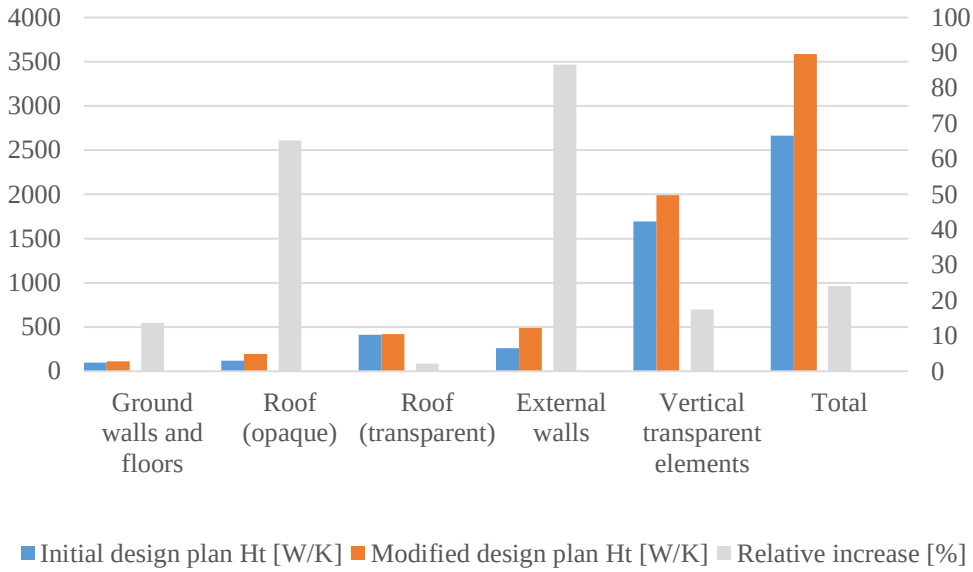

Figure 4. Transmission heat losses categorized by type of envelope

Length of the heating season for originally planned Faculty building is 123 days long (Table 1), which is 65 days shorter than the heating season length derived from the average housing insulation properties and climatic conditions of Banja Luka [13]. The heating season starts at early-November and ends in early-March. After modification of design plan the length of the heating season extends for additional 27 days (Table 1) and lasts from late October to late-March. According to the original design plan, larger amounts of heating energy are required only in December and January, while according to modified design plan this period covers two more months (February and November). After modification of design plan the energy need for heating in January and December becomes for about 1.9 greater.

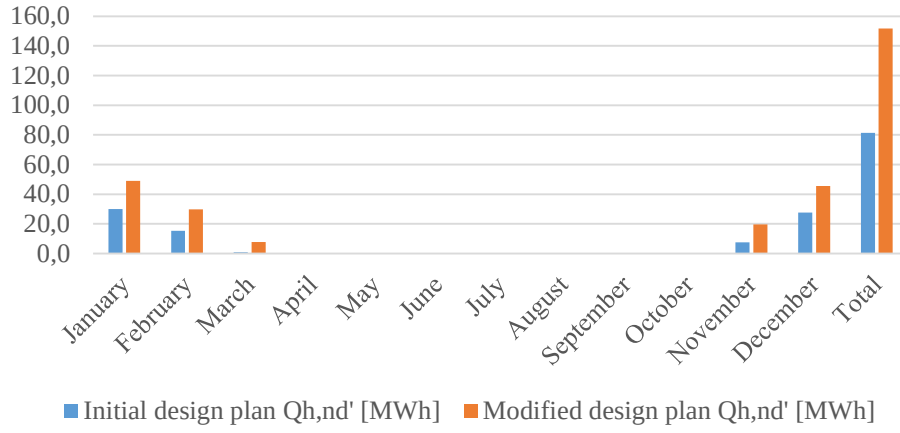

Figure 5. Monthly energy need for heating

4. CONCLUSION

The paper gives a brief review of architectural design decisions in accordance with energy efficiency demands. Since the original design plan for passive building required large investments, which unfortunately were not provided, it was necessary to change design of the building and its envelope according to new economic circumstances. As it is described in the paper economical demands, although crucial for building of an object, can be respected without major changes in design. Furthermore, the cost reductions can be achieved not only on the basis of lower energy performance, but also by reducing technical systems such as heating and ventilating type, lowering costs of finishing layers of floors, furnishing and other elements which passive standard implied.

Modifications of initial design plan lead to larger transmission and ventilation heat losses causing the annual energy need for heating per conditioned floor area increased almost twice with respect to the previous design value and thus resulting in the change of the building energy class from A to B.

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12| Оригинални научни рад
Research paper
doi 10.7251/STP1813189P ISSN 2566-4484

ANALIZA LINIJSKOG KOEFICIJENTA PROLAZA TOPLOTE JEDNOSTAVNOG BALKONSKOG TOPLOTNOG MOSTA

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Apstrakt:

U ovom radu je analiziran linijski koeficijent prolaza toplote jednostavnog toplotnog mosta koji se javlja na spoju uniformne balkonske ploče i zida. Model zavisi od pet parametara: debljina, dužina i toplotna provodljivost balkonske ploče; debljina i toplotna provodljivost zida. Rezultati istraživanja ukazuju da dužina balkonske ploče ne utiče na linijski koeficijent prolaza toplote, dok je zavisnost od druga dva parametra ploče linearnog tipa. S druge strane, zavisnost od parametara zida je komplikovanijeg oblika, a odgovarajući izrazi koji opisuju ovu zavisnost su uspješno izvedeni. Ovo istraživanje predstavlja prvi korak u pronalaženju semi-empirijske jednačine, koja bi mogla uspješno opisati linijski koeficijent prolaza toplote toplotnog mosta koji se javlja na spoju betonske ploče i homogenog višeslojnog zida.

Ključne riječi: prenos toplote, toplotni most, balkon, numerička simulacija

ANALYSIS OF LINEAR THERMAL TRANSMITTANCE OF A SIMPLE BALCONY THERMAL BRIDGE

Abstract:

The linear thermal transmittance of a simple balcony thermal bridge with a uniform balcony slab and wall was analysed. In a five-parameter model (thickness, length and thermal conductivity of a balcony slab; thickness and thermal conductivity of an adjacent wall), it was found that the length of the balcony slab does not influence the thermal transmittance, while its dependence on the other two slab parameters is linear. The influence of wall parameters on the linear transmittance proved to be more complicated, but appropriate expressions were successfully found. The study presents the first step in the search of a semi-empirical formula that can successfully describe the linear transmittance of a balcony thermal bridge with a homogeneous multi- layer wall.

Keywords: heat transfer, thermal bridge, balcony, numerical simulation

1. INTRODUCTION

Due to ecological and also economy reasons, energy efficiency of buildings is gaining on importance. Laws regarding energy efficiency are getting stricter and we are past the stage, when heat losses can be simply treated by just adding a thicker insulation layer and/or better fenestration. Heat losses and gains in buildings have to be understood on a deeper level, especially including the heat losses through thermal bridges and ventilation. Some case studies show, that the heat losses through thermal bridges can reach 50% of all building heat losses or, in some special cases, even larger ratio is possible [1]. Specifically, balcony thermal bridges and thermal bridges around fenestration are the most critical.

Nevertheless, the proper treatment of the heat losses through thermal bridges, at least in Slovenia, is usually inaccurate. For example, [2] allows treating heat losses through thermal bridges just by adding general value of 0.06 W/m^2K to the heat flow rate per square meter if the linear transmittance of thermal bridges does not exceed 0,2 W/mK. Nevertheless, this general value is used even in cases where thermal bridges with linear transmittance larger than 0,2 W/mK are present. There are probably several reasons for this practice. One of these reasons is, that the calculation of the linear transmittance of thermal bridges is more complicated than simple calculation of the heat loss trough uniform wall. These calculations usually require usage of expensive software, or consume time and require good knowledge of numerical calculation tools.

Apart from numerical calculations, SIST EN ISO 14683 [3] in certain cases allows simpler treatment of thermal bridges. One of the techniques is to use cataloged values. Nevertheless, values of linear transmittance in catalog in [3] are usually rater large in comparison with real values [1] and therefore, their usage is disfavored. Another method would be to use semi-empirical expressions, similar to those used in treatment of heat losses through ground, defined in [4].

Such expressions for some thermal bridges are for example proposed by [5, 6]. Nevertheless, in these studies, the expression for linear thermal transmittance of thermal bridges was assumed to be of the form

$$\psi = l_{tb} U_{tb} + \frac{f(r_w)}{\Delta\theta} \tag{1}$$

where:

ψ is the linear thermal transmittance of the thermal bridge $[W/mK]$,

l_{tb} is the thickness of the thermal bridge (e. g. balcony slab thickness) $[m]$,

U_{tb} is the thermal transmittance of the thermal bridge (e. g. balcony slab) $[W/m^2K]$,

$f(r_w)$ is the linear function of thermal resistances of adjacent walls $[W/m]$,

$\Delta\theta$ is the temperature difference between interior and exterior $[^oC]$.

For the $f(r_w)$ linear regression model is proposed. Although the above expression is logical, real situation is probably richer in structure. This is, for example, indicated by cataloged values in [3], where it can be noted, that the value of linear transmittance can

strongly depend on the position of insulation layer. Likewise, the values of $f(r_w)$ in [5, 6] show stochastic features, although no stochastic nature is expected.

Therefore, in this paper, a semi-empirical expression for a linear thermal transmittance of a simple balcony thermal bridge will be proposed without any assumption on the form. Analysis will be done on a simple model case of a balcony consisting of a uniform single layer balcony slab and uniform single layer wall that can be later used as a base for more complicated analysis of a thermal bridge with a multiple layer wall.

The paper is structured as following. Theoretical introduction is given is section 2. In section 2.1, basic expressions are defined and method of calculation of a linear thermal transmittance of a thermal bridge is explained. In section 2.2, software used in calculations is introduced. Results are given in sections 3 and 4 In section 3, single parameter variations are presented. In section 4, semi-empirical expression for a linear thermal transmittance of a balcony thermal bridge is given. Conclusions are stated in section 5.

2. FRAMEWORK

Analysis is done on a simple model case of a balcony, consisting of a uniform single layer balcony slab and uniform single layer wall (see Fig. 1), later to be extended on a multiple layer balcony slab and wall. This simple example therefore depends on five parameters: thermal conductivity of the wall (λ_w), thermal conductivity of a balcony slab (λ_s), thickness of a wall (d_w), thickness of a balcony slab (d_s) and length of a balcony slab (l). Parameters l_1, l_2 and l_3 were set to 2.5 m.

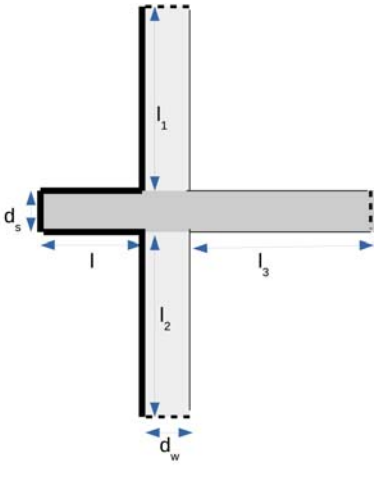


Figure 1. Two dimensional model of a simple balcony thermal bridge

2.1 BASIC DEFINITIONS

The overall heat loss of a building can be described by a heat transfer coefficient H, defined as a heat flow rate trough building's thermal envelope, divided by temperature difference between inside and outside of a building

$$H = \frac{\Phi}{\Delta\theta} \tag{2}$$

where:

H is a heat transfer coefficient $[W/K]$,

Φ is a heat flow rate $[W]$,

$\Delta\theta$ is the temperate difference between inside and outside of the building $[^oC]$.

The heat transfer coefficient depends on dimensions of the building. Larger is the surface of thermal envelope of the building, higher, in general, is the heat transfer coefficient. On the other hand, heat loss trough a specific wall is specified by thermal transmittance: a heat flow rate through a unit area of wall, divided by temperature difference on both sides of a wall

$$U = \frac{\Phi}{A\Delta\theta} \tag{3}$$

where:

U is a thermal transmittance $[W/m^2K]$,

Φ is a heat flow rate $[W]$,

A is an area of the wall $[m^2]$,

$\Delta\theta$ is a difference in air temperatures on both sides of the wall $[^oC]$.

It is expected than, that the heat transfer coefficient can be simply calculated by summing up thermal transmittances through all thermal envelope components multiplied by their area. Nevertheless, this is not a case, as heat loss trough thermal bridges, like wall junctions, balconies, around windows and similar geometrical and structural object, is more complicated. Namely, heat flow rate in these cases in not perpendicular to the wall surface as in the case of homogeneous building components. Therefore, more precisely, the relation between thermal transmittances and heat transfer coefficient, can be written as

$$H = \sum_i U_i A_i + \sum_j \psi_j l_j + \sum_k \chi_k \tag{4}$$

where:

H is a heat transfer coefficient $[W/K]$,

U_i is a thermal transmittance of the i-th wall $[W/m^2K]$,

A_i is an area of the i-th wall $[m^2]$,

ψ_j is a linear thermal transmittance of the j-th linear thermal bridge $[W/mK]$,

l_j is a length of the j-th linear thermal bridge $[m]$,

χ_k is a point thermal transmittance of k-th point thermal bridge $[W/K]$.

So, according to their geometry, thermal bridges can be divided into linear and point thermal bridges. Linear thermal bridges can be presented by line (e. g. junction of two walls, thermal bridge around windows…), while point thermal bridges can be presented by a point (e. g. junction of three walls, junction of a pillar with a roof…). According to [3], in most cases, point thermal bridges can be neglected.

Heat flow rate trough linear thermal bridge is calculated by solving a Laplace equation

$$\nabla^2\theta = 0 \tag{5}$$

where:

θ is a temperature in a given point $[^oC]$,

on a two dimensional geometrical model of a thermal bridge with its surroundings. An example of such geometrical model for a balcony thermal bridge is presented in Fig. 1. Details of how to construct two dimensional model of a thermal bridge and what boundary conditions have to be used, is defined in [7].

The following boundary conditions are used:

- Density of heat flow rate perpendicular to the cut-off surfaces (dotted line in Fig 1.) has to be zero (adiabatic boundary condition)

$$q = \lambda\frac{\partial\theta}{\partial r} = 0 \tag{6}$$

where:

q is density of the heat flow rate perpendicular to cut-off surfaces $[W/m^2]$,

λ is thermal conductivity $[W/mK]$,

$\frac{\partial\theta}{\partial r}$ is partial derivative of a temperature field in a direction perpendicular to cut-off surface $[K/m]$.

- Density of heat flow rate perpendicular to surfaces facing exterior (thick full line in Fig. 1), has to be

$$q = \frac{\theta_e - \theta_{es}}{R_{se}} = 0 \tag{7}$$

where:

q is density of the heat flow rate perpendicular to the surfaces facing exterior $\left[W / m^2\right]$,

θ_e is external temperature $\left[{}^oC\right]$,

θ_{es} is temperature on a boundary (surfaces facing exterior) $\left[{}^oC\right]$,

R_{se} is external surface resistance $\left[m^2 K / W\right]$.

- Density of heat flow rate perpendicular to surfaces facing interior (thin full line in Fig. 1), has to be

$$q = \frac{\theta_i - \theta_{is}}{R_{si}} = 0 \tag{8}$$

where:

q is density of the heat flow rate perpendicular to the surfaces facing interior $\left[W / m^2\right]$,

θ_i is internal temperature $\left[{}^oC\right]$,

θ_{is} is temperature on a boundary (surfaces facing interior) $\left[{}^oC\right]$,

R_{si} is internal surface resistance $\left[m^2 K / W\right]$.

Thermal coupling coefficient (L_{2D}) is than defined as an integral of a density of a heat flow rate over outside or over inside surfaces, divided by the external and internal temperature difference:

$$L_{2D} = \frac{\int q dr}{\Delta\theta} \tag{9}$$

where,

L_{2D} is thermal coupling coefficient $\left[W / mK\right]$,

q is density of a heat flow rate $\left[W / m^2\right]$,

$\Delta\theta$ is the difference between external and internal temperatures $\left[{}^{o}C\right]$.

From thermal coupling coefficient, the linear thermal transmittance is them simply calculated as

$$\psi = L_{2D} - LU_{w} \tag{10}$$

where:

ψ is linear thermal transmittance $\left[W / mK\right]$,

L_{2D} is thermal coupling coefficient $\left[W / mK\right]$,

$L = l_1 + l_2 + d_s$ is the length of the modeled element $\left[m\right]$,

U_w is the thermal transmittance of the wall $\left[W / m^2 K\right]$.

Here, the external dimension of the wall ($L = l_1 + l_2 + d_s$) is used. Alternatively, one can also use internal wall dimensions ($l_1 + l_2$) as long as internal dimensions are used consistently when calculating heat transfer coefficient (see Eq. (2)). In this study, external dimensions are used, as its usage is prescribed in [2].

2. 2. FREE FEM PDE SOLVER

A thermal coupling coefficient of a balcony was calculated using Free Fem [8]. Free Fem is an open source partial differential equation solver based on a final element method. It is capable of solving 2D and 3D partial differential equation and gives a user a good control over a calculation details. User writes a short script in which he or she defines geometry, type of final elements, method of how the final elements are spanned (e. g. adapt mash), differential equation to be solved, initial and boundary conditions, details of calculations (e. g. precision, numerical method for dealing with matrices), etc.. As all information are defined trough script, Free Fem is more tedious to use than other graphically based PDE solvers, but in return gives better control over input parameters and greater freedom in data analysis. In this study, uniform triangle mash was used with around 25 000 P2 parabolic elements [8] and the precision of calculation was set to a relative error of 10E-9.

3. SINGLE PARAMETER VARIATIONS

Before overall fit of all parameters is done, linear thermal transmittance of the balcony will be calculated by varying one of the parameters, while all other parameters are kept fixed. By this method, one can gain some insight into importance and influence of a specific parameter on a linear thermal transmittance of a balcony. To be able to get a better understanding of the shape of the function describing the dependence of linear thermal

transmittance of a balcony on a specific parameter, parameters were also varied outside their realistic values. The results are shown in Figs. 2-4.

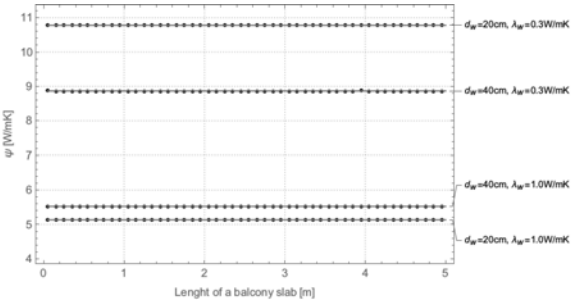
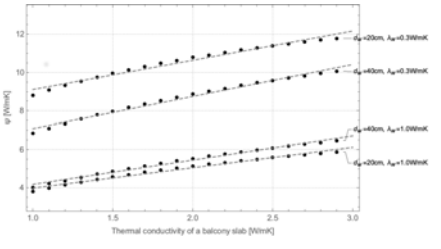


Figure 2. Influence of the length of a balcony slab on a linear thermal transmittance of the balcony



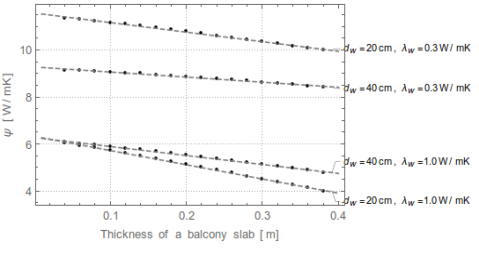


Figure 3. Influence of the thickness and thermal conductivity of a balcony slab on linear thermal transmittance of the balcony

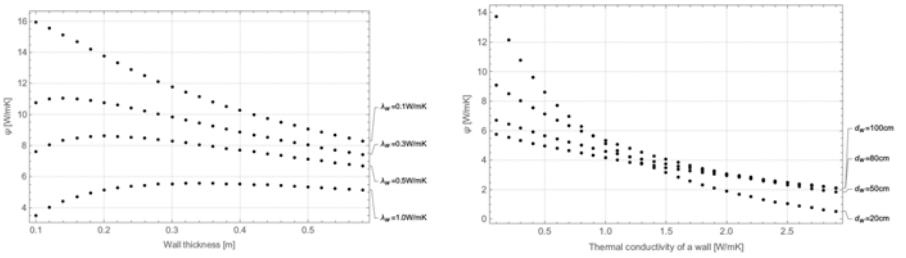


Figure 4. Influence of the thickness and thermal conductivity of a wall on linear thermal transmittance of the balcony

From Fig. 2, one can easily conclude, that the length of the balcony slab has no influence on thermal transmittance of the balcony. This is welcome fact, as it deduces the number of model parameters from five to four. It is also in accordance with the assumption made by [5, 6] and stated in Eq. (1). Furthermore, it can be deduced from Fig. 3 that the linear thermal transmittance of the balcony can be presented as a linear function of both thickness and the thermal conductivity of the balcony slab, which further simplifies the analysis. Surprisingly, it can be also perceived, that the linear thermal transmittance of the balcony falls with the increasing thickness of the balcony slab, which is unexpected and in contradiction to the assumption made by [5, 6]. Finally, from Fig. 4, it can be observed that the dependence of thermal transmittance of a balcony of thickness and conductivity of a wall is rich in structure, and more complicated regression function instead of linear should be used. From the above observations, the following solution is proposed: first, two different balcony slab thickness (d_{s1} , d_{s2}) and balcony slab thermal conductivities (λ_{s1} , λ_{s2}) will be chosen. Next, in section 4, at each combination of these fixed values, the function of thickens and the thermal conductivity of the wall that best describes the linear thermal transmittance of the balcony, will be found. From these data, one should than be able to deduce linear thermal transmittance of the balcony at any set of parameters by simple interpolation.

From Fig. 3 (left) it can be observed, that the dependence of linear thermal transmittance of the balcony on balcony slab thickness is strongly linear, so any two balcony slab thicknesses can be chosen. To be near the realistic span of parameters, d_{s1}=10cm and d_{s2} =20cm would be used, but any other similar choice would be equally good. On the other hand, the linearity of liner thermal transmittance of a balcony on balcony slab thermal conductivity is not so strong (Fig. 3, right), so representative parameters should be chosen more carefully. As values of linear thermal transmitance of in points λ_{s1} =1.5W/mK and λ_{s2} =2.5W/mK coincide with the linear function found by regression, these two values will be taken as reference values.

4. REGRESSION MODEL OF LINEAR THERMAL TRANSMITTANCE OF THE BALCONY

First, the dependence of linear thermal transmittance of the balcony on thermal conductivity of the wall will be studied. Namely, from Fig. 4, it can be seen that this dependency is easier to deduce. The fit was done using exponential function, arc-tan function and rational function. All three expressions fit data with a very good precision, although arc-tan function and rational function fit data somewhat better then exponential function. Due to simplicity, rational functions are used. In Fig 5 therefore, the dots present calculated values of linear thermal transmittance at fixed parameter values, while full line presents best rational function found by the regression of the form:

$$\psi = A(d_w) + \frac{B(d_w)}{C(d_w) + \lambda_w} \tag{11}$$

where:

ψ is a linear thermal transmittance of a balcony $[W/mK]$,

λ_w is a thermal conductivity of a wall $[W/mK]$,

$A(d_w), B(d_w), C(d_w)$ are functions of wall thickness.

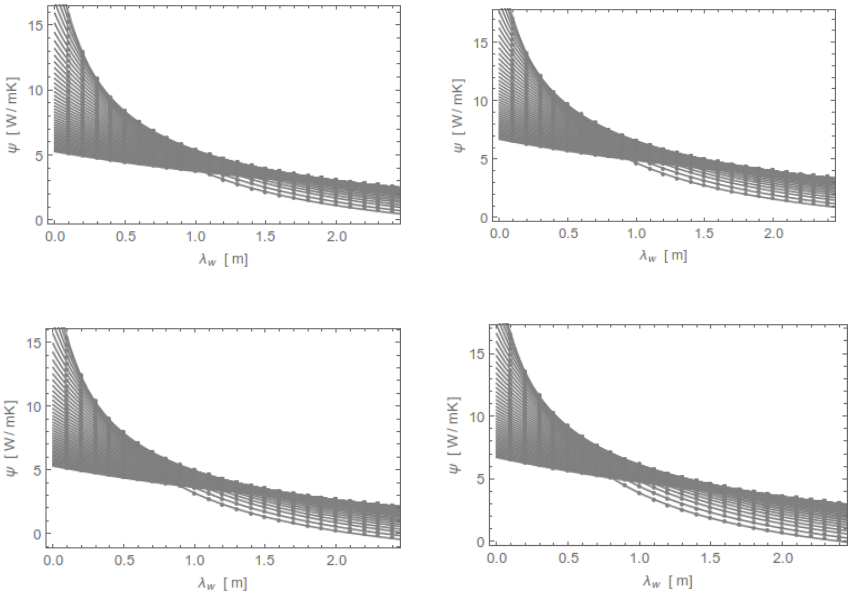


Figure 5. Dependence of the linear thermal transmittance of the balcony on the thermal conductivity of the wall (first row d_s1=10 cm, second row, d_s2=20 cm, first column λ_s1 =1.5 W/mK, second column λ_s2 =2.5 W/mK)

Multiple lines present variations of the wall thickness, while four diagrams present solutions at four sets of balcony slab thickness and thermal conductivity.

Regression functions $A(d_w)$, $B(d_w)$ and $C(d_w)$ are presented in Fig. 6-8. Dots present values of parameters belonging to different lines in Fig. 5, while full lines presents functions found by regression model. Similar as before, four diagrams present solutions at four sets of balcony slab thickness and thermal conductivity.

It is can be concluded, that the function $C(d_w)$ can be simply approximated with the linear function. The shapes of the functions $A(d_w)$ and $B(d_w)$ were harder to deduce, but it was fund out that the following expressions approximate the data with relatively good precision:

$$A(d_w) = \frac{1}{A_1 d_w + A_2} + A_3 + A_4 d_w + A_5 d_w^2, \tag{12}$$

$$B(d_w) = B_1 \ln(B_2 d_w + 1) + B_3 d_w, \tag{13}$$

$$C(d_w) = C_1 d_w, \tag{14}$$

where:

d_w is the balcony wall thickness $[m]$.

Coefficients A_i, B_i and C_i are given in Table 1.

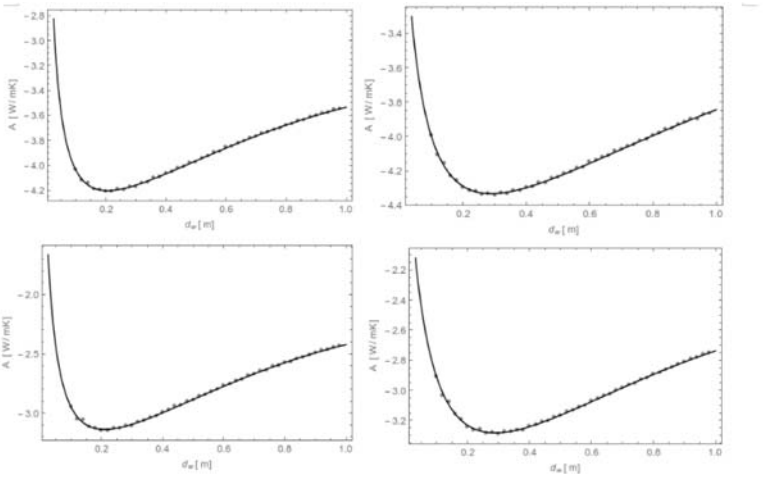


Figure 6. Function A(d_w) for different combinations of balcony slab thickenss and thermal conductivity (first row d_s1=10 cm, second row, d_s2=20 cm, first column λ_s1 =1.5 W/mK, second column λ_s2 =2.5 W/mK)

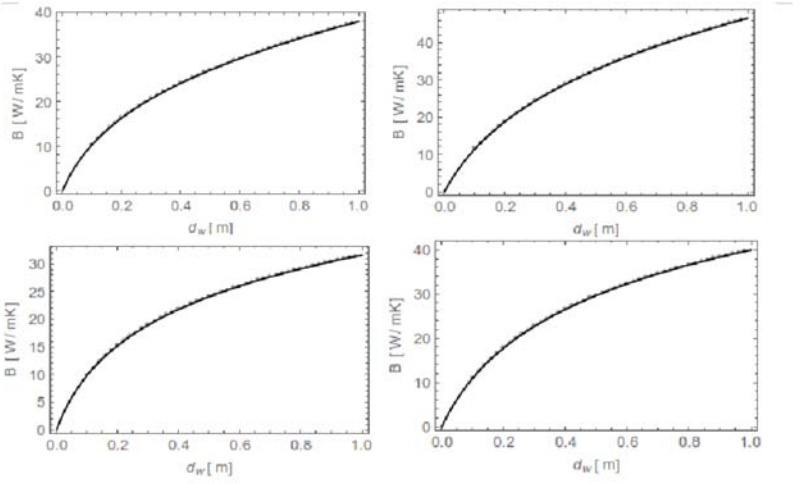


Figure 7. Function B(d_w) for different combinations of balcony slab thickenss and thermal conductivity (first row d_s1=10 cm, second row, d_s2=20 cm, first column λ_s1 =1.5 W/mK, second column λ_s2 =2.5 W/mK)

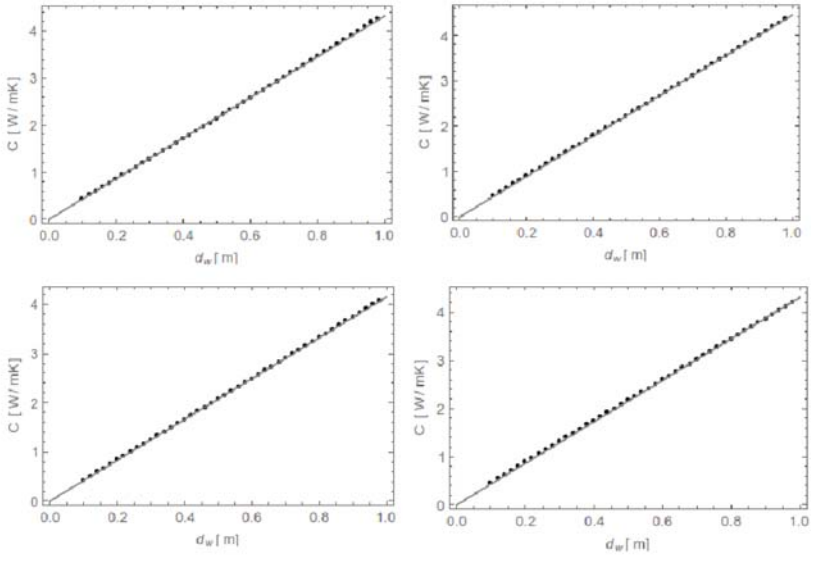


Figure 8. Function C(d_w) for different combinations of balcony slab thickenss and thermal conductivity (first row d_s1=10 cm, second row, d_s2=20 cm, first column λ_s1 =1.5 W/mK, second column λ_s2 =2.5 W/mK)

The linear thermal transmittance of the balcony with parameters $d_w, d_s, \lambda_{w,} \lambda_s$ can now be calculated in a following way:

- First one calculates the linear thermal transmittance at given wall thickness and thermal conductivity at all four combinations of representative balcony slab thicknesses (d_{s1}=10cm and d_{s2}=20cm) and thermal conductivities (λ_{s1} =1.5W/mK and λ_{s2}=2.5W/mK): $\psi_{11}(d_w, \lambda_w, d_{s1,} \lambda_{s1})$, $\psi_{12}(d_w, \lambda_w, d_{s2,} \lambda_{s1})$, $\psi_{21}(d_w, \lambda_w, d_{s1,} \lambda_{s2})$ and $\psi_{22}(d_w, \lambda_w, d_{s2,} \lambda_{s2})$, using Eq. (11)-(14) and coefficients from Table 1.
- From above values and using interpolation, the linear thermal transmittance at wanted balcony slab thickness and thermal conductivity is calculated

$$\psi_1(d_s, \lambda_{s1}) = \frac{\psi_{12}(d_{s2,} \lambda_{s1}) - \psi_{11}(d_{s1,} \lambda_{s1})}{d_{s2} - d_{s1}}(d_s - d_{s1}) + \psi_{11}(d_{s1,} \lambda_{s1}) \quad (15)$$

$$\psi_2(d_{s,} \lambda_{s2}) = \frac{\psi_{22}(d_{s2,} \lambda_{s2}) - \psi_{21}(d_{s1,} \lambda_{s2})}{d_{s2} - d_{s1}}(d_s - d_{s1}) + \psi_{21}(d_{s1,} \lambda_{s2}) \quad (16)$$

$$\psi(d_{s,} \lambda_s) = \frac{\psi_2(d_{s,} \lambda_{s2}) - \psi_1(d_{s,} \lambda_{s1})}{\lambda_{s2} - \lambda_{s1}}(\lambda_s - \lambda_{s1}) + \psi_1(d_{s,} \lambda_{s1}) \quad (17)$$

Table 1. The coefficients for the regression functions $A(d_w)$, $B(d_w)$ and $C(d_w)$

	$\psi_{11}(d_{s1,} \lambda_{s1})$ $[W/mK]$	$\psi_{12}(d_{s2,} \lambda_{s1})$ $[W/mK]$	$\psi_{21}(d_{s1,} \lambda_{s2})$ $[W/mK]$	$\psi_{22}(d_{s2,} \lambda_{s2})$ $[W/mK]$
A_1 $[K/W]$	11.6	9.55	5.9	3.88
A_2 $[mK/W]$	0.17	0.19	0.3	0.29
A_3 $[W/mK]$	-4.99	-4.05	-5.29	-4.61
A_4 $[W/m^2K]$	2.06	2.31	1.72	2.36
A_5 $[W/m^3K]$	-0.69	-0.79	-0.43	-0.73
B_1 $[(W/mK)^2]$	12	12.1	18.6	18.93
B_2 $[1/m]$	12.3	12.62	7.88	8.03
B_3 $[W^2/m^3K^2]$	6.83	-0.03	5.85	-1.69
C_1 $[W/m^2K]$	4.31	4.14	4.45	4.31

5. CONCLUSION

A linear thermal transmittance of a simple balcony model with uniform single layer slab and uniform single layer wall was studied. It was found that the length of balcony slab does not have influence on the linear thermal transmittance, while it linearly depends on two other slab parameters: thickness and thermal conductivity. The influence of the wall parameters on a linear transmittance proved to be more complicated, but appropriate expressions were successfully found. Finally, a method that gives the linear thermal transmittance of a simple balcony thermal bridge for any combination of all five parameters to a good precision, is presented. The study presents the first step in a search for a semi-empirical formula that can describe the linear thermal transmittance of a balcony with multiple layer homogeneous walls. If successful, the same method can be used for deducing semi-empirical expressions for other types of critical thermal bridges (like, for example, thermal bridge around windows).

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13| Оригинални научни рад
Research paper
doi 10.7251/STP1813203T ISSN 2566-4484

ANALIZA EFIKASNOSTI RADA SISTEMA HLADNJAČE FRATELLO TRADE AD BANJA LUKA

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Abstract: Cilj ovog rada je pokazati važnost izbora rashladnog sredstva u rashladnim postrojenjima, te dobiti uvid na koji način taj izbor utiče na sistem u pogledu efikasnosti i ekonomičnosti sistema. Analiza uticaja rashladnog sredstva na efikasnost i ekonomičnost sistema urađena je na primjeru hladnjače za skladištenje smrznute ribe Fratello Trade AD, BanjaLuka. Pomoću parametara ovog sistema ispitano je da li bi postrojenje bilo efikasnije iekonomičnije da se odabralo drugo rashladno sredstvo. Postojeće rashladno sredstvo koje koristi ovo postrojenje je R-404A. Segmenti u pogledu efikasnosti i ekonomičnosti koji se ispituju su koeficijent performansi postrojenja i godišnja potrošnja električne energije, odnosno troškovi za istu. Koeficijent performansi postrojenja daje uvid u to koliko se za jedan kW unesene električne energije u sistem dobije kW hlađenja. Što je veći ovaj koeficijent, time je sistem efikasniji. Na nivou proračuna godišnje potrošnje električne energije dobija se uvid sa kojim rashladnim sredstvom sistem daje najmanje novčane troškove. U radu je dat sam postupak analize baziran na izboru rashladnog sredstva.

Ključne riječi: rashladno sredstvo, rashladno postojenje, efikasnost, ekonomičnost.

EFFICIENCY ANALYSIS OF THE REFRIGERATION SYSTEM IN FRATELLO TRADE AD BANJA LUKA

Abstract: The aim of this paper is to show the importance of choosing a refrigerant in cooling plants, and to provide an insight into how this choice influences the system in terms of its efficiency and cost-effectiveness. The analysis of the influence of a refrigerant on the system's efficiency and cost-effectiveness was done on an example of a refrigerator storing frozen fish in Fratello Trade AD, Banja Luka. Using the parameters of this system, this study examines whether the plant would be more efficient and economical if another refrigerant was chosen. The existing refrigerant used by this plant is R-404A. Segments that are examined in terms of efficiency and economy include the performance coefficient of the plant and the annual consumption of electricity, that is, their respective costs. The performance coefficient of the plant gives an insight about the correspondence between kW of input electricity and kW of cooling power generated in the system. The higher this coefficient, the more efficient the system is. The calculation of annual energy consumption helps to determine which refrigerantis most cost-effective. The paper shows the analysis based on the choice of the refrigerant.

Key words: refrigerant, cooling system, efficient, economical.

1. INTRODUCTION

Refrigeration facilities are intended for the preparation, processing and storage of light-duty foodstuffs using low temperatures. The foods are cooled or refrigerated in refrigerators and stored in fresh or frozen state under conditions of well-defined temperature and relative humidity regimes. The need for freezing and storing foodstuffs today is very high. With the increase of food standards, i.e. the need for a better quality and cleanliness of food, as well as the need for energy savings, design and construction of refrigerators should be conceived according to the latest standards, laws, professional rules and technologies offered on the market. Also, in order for food to be as good as possible, attention must be paid to all food handling procedures. One of the more important ways to conserve food is cooling. The basic modes of refrigerationare cooling and freezing. In the case of cooling, the air temperature in the refrigerator isabove 0 [°C], while the freezing temperature is lower. The division of thermal treatment methods based on the temperature of crystallization (freezing) of water is specific from the aspect of the treated product, since it should be kept in mind that the water contained in the plant material does not freeze at0 [°C] because it is a colloidal solution thatfreezes at temperatures lower than 0 [°C]. Refrigeration is mainly applied in the case where fresh fruit, vegetables and other food products are to be preserved as long as possible. In addition, semi-finished and ready-made food products are preserved in this way. By cooling, all types of fruit is preserved, a large number of varieties of fresh vegetables, as well as flowers, medicinal herbs, mushrooms, forest fruits, etc. In addition to agricultural products, refrigerators are important for the storage of semi-finished products and ready-made food products, such as fruit and vegetable porridges, aromas, cakes, etc. The air temperature rangesfrom 1 [°C] to 12 [°C]. Various agricultural products are stored at different air temperatures in refrigerators. For example, some types of fruit can only be held for a few days, and some for around ten months. Freezing is used for a wide variety of agricultural and food products. Air temperature in the freezer compartment can start at degrees below zero and reach - 70 [°C]. It depends on the type of food and from the planned storage time. Fruit must be prepared before freezing in accordance with the ultimate purpose of frozen fruits, or whether it is intended for export or distribution to the domestic market. When freezing vegetables, thermal treatments are applied in order to inactivate enzymes. Therefore, before the freezing process itself, it is necessary to take the necessary measures that a particular freeze product requires. When storing foodstuffs in the cooling chambers, the most commonly used warehouse racks are made of hot-dip galvanized steel structures, in which the so-called euro pallets of standard dimensions are used. Depending on the type of product, packaging can be different. The most common are plastic or wooden crates, boxes or cartons.

1.1. BASIC ELEMENTS OF REFRIGERATORS, BASIC SCHEME AND OPERATING PRINCIPLE

The task of acooling device is to cool certain bodies or objects below the ambient temperature and to keepthem at that temperature. Refrigeration devices are based on the natural propertyof gas. It implies that the gas is heated when it is compressed (it passes from the gas to the liquid state) and cools when it expands (it passes from the liquid to the gaseous aggregate state). These changes in aggregate states are achieved by a series of different elements in the cooling system, the most important of which are a compressor, a condenser, an evaporator and an expansion valve. There are a number of supporting

elements, such as filters, receivers, various flow control valves, temperature and pressure regulators, and so on.

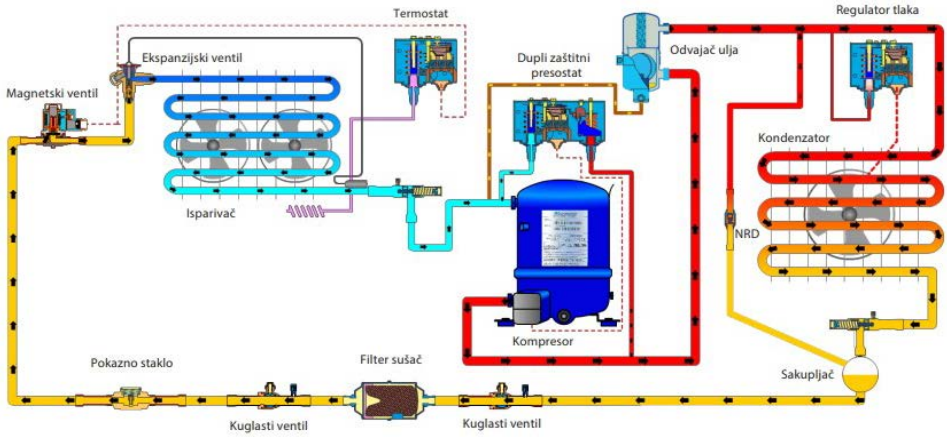


Figure 1. The basic scheme of a refrigerator [5]

1.2. REFRIGERATION

Refrigerants are materialsthat are found in cooling devices. They pass the heat cycle and serve as heat exchangers. The thermodynamic efficiency of aplant depends on the choice of arefrigerant. The most commonly used refrigerant systems are freons. Freons are actually a collective name for several types of gases used in cooling systems. Halogenated carbonate refrigerants include a group of artificial, synthetic refrigerants. The trade name for them is freons or F – gases.

Table 1 Groups of halogenated carbonate refrigerants [8]

Code	Chemical name	Characteristics	Composition
CFC	Chlorofluorocarbon	Fully halogenated saturated hydrocarbon derivatives	Mostly methane and ethane, e.g.
HCFC	Chlorofluorocarbon	Partially halogenated saturated hydrocarbon derivatives	Contains hydrogen and chlorine, e.g.
HFC	Hydrofluorocarbon	Partially halogenated saturated hydrocarbon derivatives	Contains hydrogen, does not contain chlorine, e.g. R-407c

Refrigeration plants that work with CFC and HCFC refrigerants have a good cooling coefficient because these agents have more favorable properties. They are primarily non-flammable, non-toxic, and compatible with the materials from which the plants are built. However, due to their properties to damage the ozone layer, CFCs were discontinued from use in 2010. According to the Montreal Protocol, these refrigerants will be used in Bosnia and Herzegovina by 2015, but as long as there are technically functional installations that use them, they will be replaced over time according to the rules of the Montreal Protocol and the Vienna Convention.

1.3. ENERGY EFFICIENCY OF REFRIGERATION PLANTS

The term energy efficiency is most often encountered with two possible meanings, one of which refers to devices, the other to measures and behaviors. An energy efficient device is one that has a high degree of beneficial effect, i.e. small losses when transforming one type of energy into another. Refrigeration machines and appliances in industry consume a significant share of energy in industry, according to some estimates, up to 20 %. Cooling energy costs in some industries, such as food industry, reach up to 70 % of the total energy costs. This is why when considering potential energy efficiency measures, attention must be paid to cooling devices.

In cooling devices, the cooling fluid evaporatesat a low temperature evaporator, by cooling the environment in which the evaporator is located, e.g. cooling chamber. The compressor increases the temperature and pressure of the refrigerant, which is then cooled and condensed in the condenser, heating the environment in which the condenser is located. In some cases this heat can also be used for heating. In the liquid state, the coolant is compressed by the pressure and temperature by the pressure relief valve, and the fluid re-enters the evaporator in the liquid state.

Cooling devices use electricity so their components i.e. a compressor and auxiliary equipment can operate. In order to reduce the consumption of cooling energy as much as possible, it is obviously necessary to minimize the difference between evaporation and condensation temperature. The main consumer of electricity in refrigeration units is the compressor that consumes about 65 % of total energy consumption in thesystem. Savings in cooling devices can be basically achieved by efficient device design, as well as their proper use and maintenance.

1.4. MEASURES FOR A MORE EFFICIENT COOLING PLANT

Measures for a more efficient cooling system can be obtained bydesigning devices efficiently, bringing the equipment into the existing state, automating the system, improving insulation, refilling the cooling system, modernizing or replacing the compressor. These measures and what is meant by them are described in more detail in the paragraphs below.

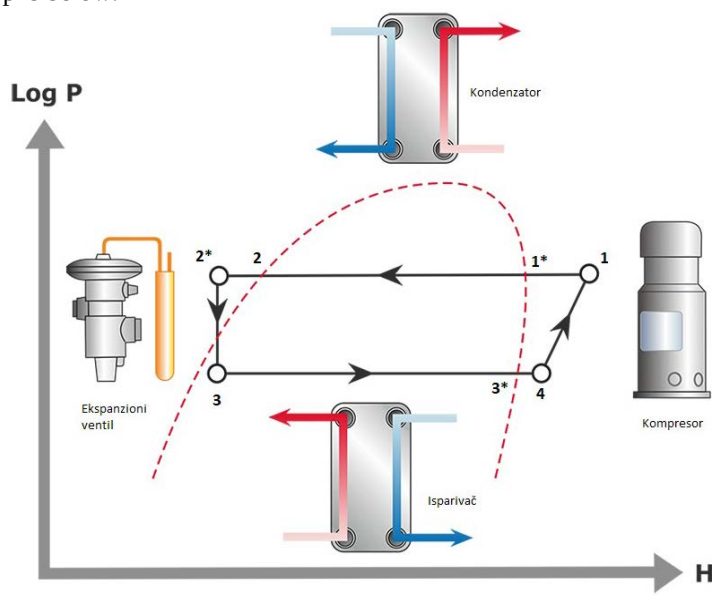


Figure 2. Cooling cycle inp-hdiagram of the workingfluid [14]

The cooling process [Figure 2] consists of evaporation of the working fluid in the evaporator 3-3 *, overheating 3 * -4 controlled by the thermoexpansion valve. Overheating is necessary in order to avoid hydraulic shock inside the compressor, i.e.so that the compressor would not withdraw the liquid phase.

After that, the compressor sucks the overheated steam and compresses it to a higher energy level 4-1. After the compressor, the overheated steam enters the condenser where it cools 1-1 *, condenses 1 * -2 and cools 2-2 *. Refrigeration is carried out so that the throttle valve only receives a liquid phase, as it can not function properly if it receives vapor. The pressure or expansion valve dampens the working fluid 2 * -3 from the condensation pressure to the evaporation pressure. The process is then repeated.

2. ANALYSIS OF REFRIGERATIONIN "FRATELLO TRADE" AD, BANJA LUKA

The "Fratello Trade" AD facility is located in Ramici, Banja Luka.

The structure is made of reinforced concrete, measuring 31.64 × 44 meters, and 7 meters high. The design was carried out in accordance with the requirements for storing frozen fish. The calculation of the plant in 2004 was done by the Soko Mostar company, whose data were used for this paper. The facility consists of three warehouse chambers, packing rooms and manipulative space, as well as office space. The total capacity of the storage chamber is 5700 cubic meters.

The temperature regime in all three chambers is -25 [°C]. Only cooling chambers will be considered as a wholein this paper. The compressor suppresses the overheated steam of the working medium. On the compressor supply line there is a shut-off and non-return valve with the function of closing the flow of the working fluid in one direction, and allowing the flow in the other direction. After passing through the valves, the working fluid goes into the oil separator. Next, the separated oil in the separator with special water goes into the oil collector, and then passes through the oil filter, and ultimately passes through the oil regulator where the lubrication of the compressor will be carried out.

The working fluid, after the oil separator, goes to the condenser, but first passes through the filter as an additional measure for removing possible residual oil particles. As the working fluid enters into the air condenser, its cooling is carried out, and it passes into the liquid phase.

Exiting the condenser, it passes through another filter, then the shut-off valve goes into the receiver. The receiver has a safety valve that serves to monitor the pressure in the receiver; in case of too high pressure, the safety valve would open. On the line, two pressure switches, high and low pressure, are installed before the gas drier, which serves as protection against excessively low suction pressure and excessively high pressure.

The liquid fluid then passes through the filter gas drier, which serves to absorb moisture from the working medium and to filter it. The indicator glass shows the amount of liquid phase. This is followed by a shut-off valve. After the shut-off valve, the liquid agent goes to the evaporator. First, there is an electromagnetic valve which serves to control the flow of the liquid phase of the agent, after which it enters the evaporator through an expansion valve which also regulates the flow of the agent but in the function of the operating temperature at the exit from the evaporator. The working fluid now receives heat in the evaporator from the food in the chamber, that is, cooling occurs in the chamber. After that, leaving the evaporator, all the working fluid was not evaporated, and a mixture of

superheated and saturated phases was obtained. This mixture goes into a suction accumulator, where the liquid part of the phase remains, and the overheated portion is sucked in through the suction filter which is further sucked by the compressors, its suction part carrying the shut-off valves. On their suction and pressure parts compressors have pressure regulators that control the pressure on the suction and pressure of the compressor. The cooling cycle is then repeated the same way. The operating principle of chambers 1 and 2 is the same.

2.1. ANALISIS PROCEDURE

The analysis of the efficiency and economy of the plant is based on the type of installed compressor, selected refrigerants, logp-h diagrams of refrigerants, and data taken from the project documentation obtained at the "Fratello Trade" AD Banja Luka cooling plant.

The compressor installed in the system is 6G - 34Y 40 HP, manufactured by Bitzer. It is a semi-hermetic piston compressor. It has six cylinders and is characterized by robust valve construction, high wear resistance of moving parts, and high efficiency of embedded engines that are cooled by suction gas. In addition, a patented oil return system ensures safe operation.

The refrigerants used in the analysis were primarily selected based on the installed compressor, that is, whether the compressor can operate with this refrigerant. The first refrigerant is R-404A with which the existing system works and the characteristics obtained with this refrigerant will serve as the basis and orientation in relation to which the comparison is made. The following refrigerants are selected: R-407C and R-449A.

2.2. PARAMETERS REQUIRED FOR ANALYSIS

Table 2. Parameters required for analysis

Cooling requirements in chambers	94.8[kW]
Compressor cooling capacity	123.2[kW]
Condensation temperature	40 [°C]
Evaporation temperature	-35 [°C]
Temperature of cooling the working medium in the condenser	15 [K]
Temperature of the overheating of the working medium in the evaporator	7 [K]
Refrigerants	R-404A, R-407C, R-449A

The necessary data are entered in the Bitzer and CoolPack software. All data, except refrigerant, remain constant. So considering all input data only the refrigerant changes. In this way, the compresor characteristics are obtainedfor each refrigerant.

The most important characteristics used for further analysis include

- Cooling capacity of compressors and
- Compressor power.

It is used a Bitzer software program; where a working medium was entered in the *Refridirent* field, the evaporation temperature was entered in the *Evaporatind SST* field, the condensation temperature entered in the *Condensind* SDT field, operating temperature of the condenser in *Liq.sub (in condenser)* and the overheating temperature of the working medium in the evaporator entered in the *Suct.gas superheat* field. After entering the parameters, the necessary results were read. From the *Coolond capacity* field, the cooling

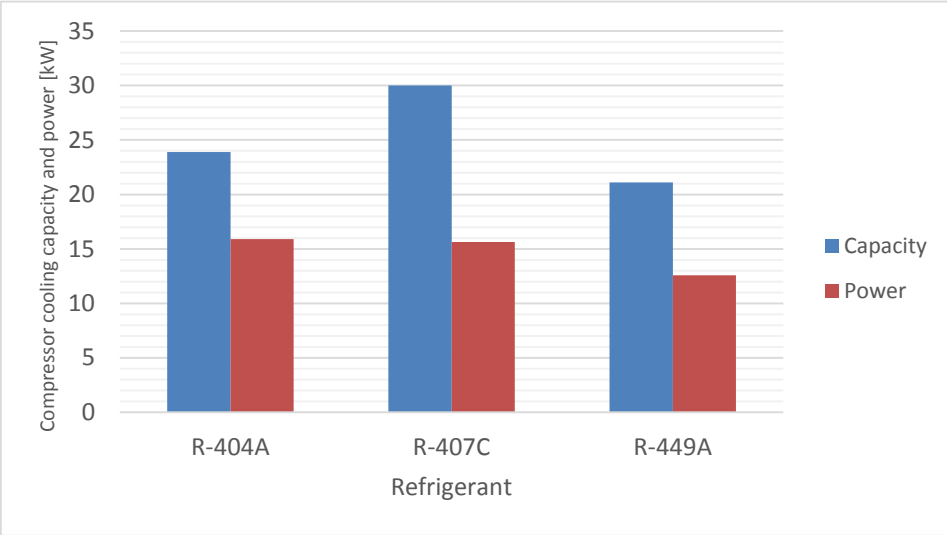
capacity of the compressor was read, and the power of the compressor from the *Power input* field.

2.3. ANALYSIS OF COOLING CAPACITY AND COMPRESSOR POWER

The obtained results are given in Table 3 and shown graphically in Chart 1. Based on the results, cooling capacity was first analyzed and then compressor power.

Table 3. Cooling capacity and compressor power [16]

Refrigerant	R-404A	R-407C	R-449A
Capacity [kW]	23.9	30.0	21.1
Power [kW]	15.91	15.65	12.57



Graph 1. Compressor capacity and power for the existing and replacement refrigerant

2.4. ANALYSIS OF COMPRESSOR COOLING CAPACITY

Based on the cooling capacity of the compressor, the number of compressors needed to meet the total system requirements of 123.2 [kW] is determined.

1. Using R-404A, five compressors are required, which is identical with the number of compressors in the existing system.
2. Using R-407C, four compressors are required, as the compressor for this refrigerant has a slightly higher cooling capacity.
3. Using R -449A, six compressors are required due to the lower cooling capacity of one compressor.

2.5. COMPRESSOR POWER ANALYSIS

As for the compressor power is concerned, R-404A has the greatest power, R-407C compressor has a slightly lower power, while the lowest power is provided by a compressor using R-449A. If only power is to be analyzed for one compressor, it could be seen that the compressors for R-404A and R-407C refrigerantsare at the very top of their electricity consumption, while the compressor using R-449A has the lowest power consumption. However, taking into account the number of compressors needed to meet

the needs of the system, the question is whether therewill remain such a schedule in terms of electricity consumption or it is likely to change. The answer to this will be obtained from a part of the analysis that includes annual electricity consumption.

2.6. SYSTEM EFFICIENCY – COP PERFORMANCE

The system performance coefficient will be tested using the compressor power and chambercooling requirements.

2.7. ANALYSIS OF SYSTEM EFFICIENCY USING COMPRESSOR POWER AND COOLING REQUIREMENTS

Input data needed to obtain the value of system performance coefficient are taken from the first part of the analysis. The required data include the compressor power and the number of compressor. The analysis is done to sum up the power of all compressors, for each refrigerant.

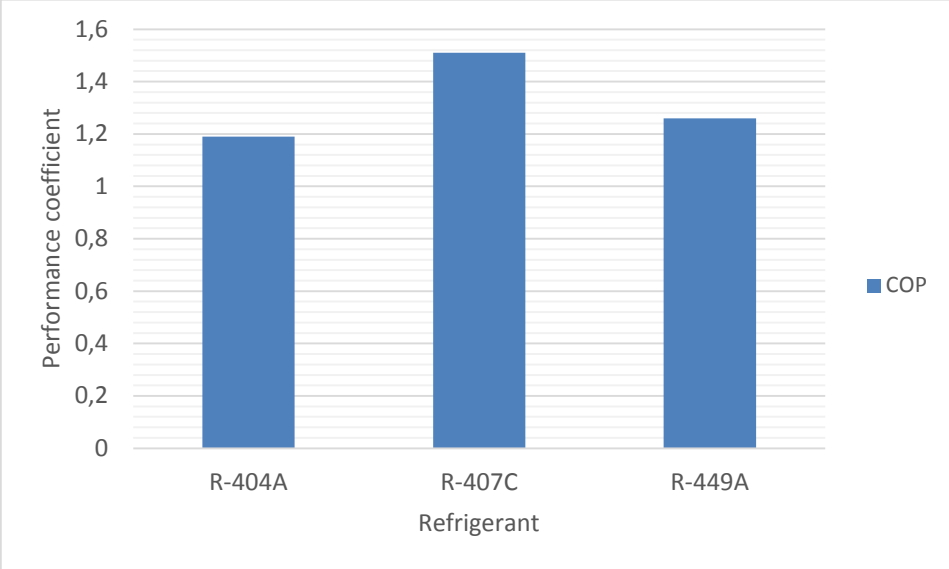
Table 4. Data needed to analyze the system performance coefficient

Refrigerant	R-404A	R-407C	R-449A
Compressor power[kW]	15.91	15.65	12.57
Number of compressors	5	4	6
Total power in the system[kW]	79.55	62.6	75.42

Using the data in Table 4 and cooling requirements in chambers of 94.8 [kW], the values of performance coefficient are obtained. The results are shown in Table 5.

Table 5. System Performance Coefficient – COP

Refrigerant	Qh/P	COP
R-404A	94.8/79.55	1.19
R-407C	94.8/62.6	1.51
R-449A	94.8/75.41	1.26



Graph 2. System Performance Coefficient – COP

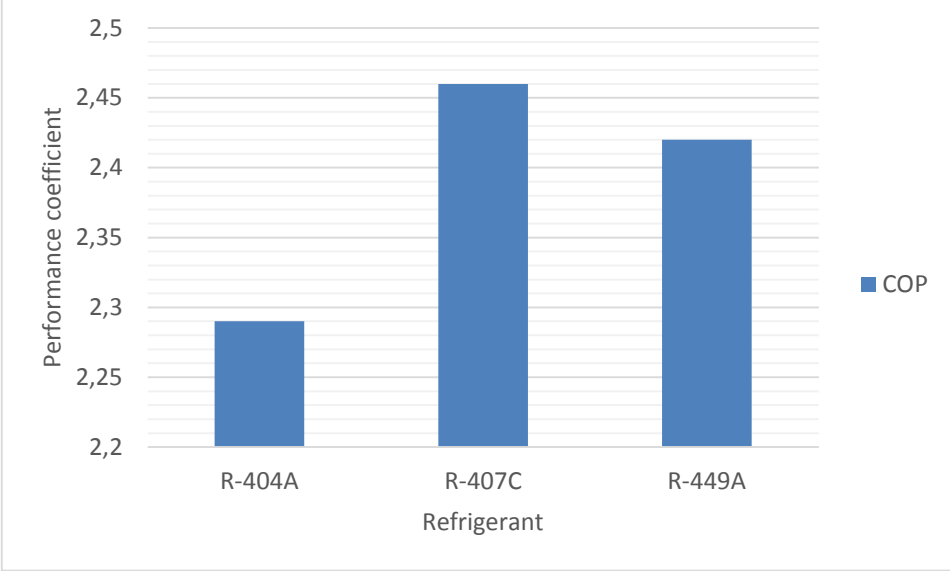
In Figure 2 it can be seen that, depending on the refrigerant used, the value of the system performance coefficient changes. With the R-404 refrigerant, the system has the smallest coefficient. This means that for the introduced kilowatt of electricity in the system, it receives the least cooling of kilowatts, more precisely 1.19 [kW]. A slightly higher coefficient of performance is obtained by the R-449A refrigerant, which means that 1.26 kW of cooling is obtained for one kilowatt of electricity. The R-407C refrigerant has the best results, and has the highest performance coefficient of 1.51, which means that 1.51 kW of cooling is obtained for 1 kW of electricity.

3. ANALYSIS USING A P-H DIAGRAM OF REFRIGERANTS

The enthalpy values are read from the p-h refrigerant diagram, literature. The values of enthalpy are shown in Table 6, as well as the values of the system performance coefficient for the selected refrigerants.

Table 6. Enthalpy values and system performance coefficient – COP

-	R-404A	R-407C	R-449A
1.	352.63	397.41	386
2.	402.97	465.59	450
4.	237.4	229.4	230
$COP = \frac{h_1 - h_3}{h_2 - h_1}$	2.29	2.46	2.42



Graph 3. Performance coefficient – COP

The results of system performance coefficient obtained by p-h diagram show the same results in terms of refrigerant efficiency as in the previous analysis. The lowest coefficient is obtained by R-404A, then R-449A, whereas R-407C has the highest performance coefficient. There are differences between the numerically determined COP values and

COP values from the p-h diagram. They are alone because it is about reading the values from the diagram, and on the other hand, the more precise reading and definition of the values of enthalpies from thermodynamic tables.

4. ANNUAL CONSUMPTION AND THE SYSTEM'S ELECTRICITY COSTS

The input data required for this analysis are the sum of the compressor power of each refrigerant, the number of hours the compressor performs during one day and the agreed price of electricity. The number of hours spent by the compressor is taken from the project documentation of the plant, and the agreed price of electricity is taken as the average price in the industry per kilowatt-hour. Input data are given in Table 7.

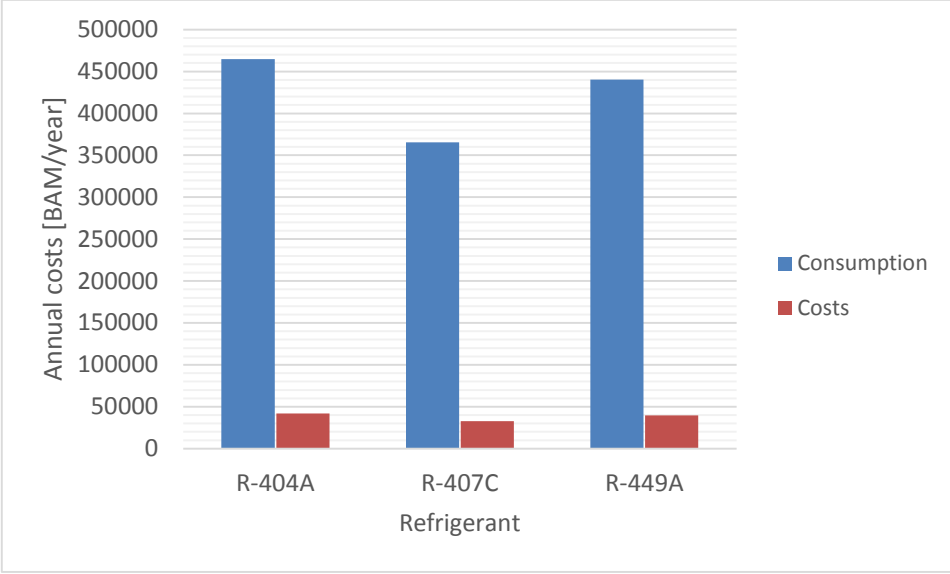
Table 7. Data necessary for analysis of annual consumption and electricity costs

Name	R-404A	R-407C	R-449A
Compressor power[kW]	79.55	62.6	75.42
The number of hours the compressor performs during one day [h/day]	16	16	16
Contracted price of electricity [BAM/kWh]	0.09	0.09	0.09

After defining input data, the daily and annual consumption of electricity, as well as the annual costs, are calculated. Daily electricity consumption is defined as the product of the compressor power and the number of hours that the compressor is in operation for one day. Annual consumption of electricity is obtained as a product of daily electricity consumption and the number of days in the year when the compressor is in operation. Finally, annual costs are obtained as a product of annual electricity consumption and contracted electricity prices. The results obtained are shown in Table 8.

Table 8. Annual consumption and electricity costs

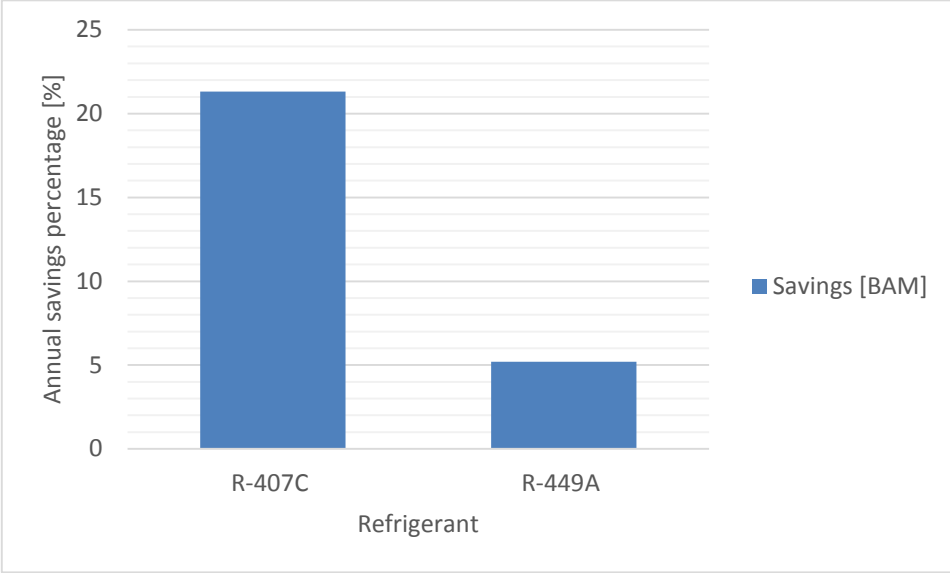
-	R-404A	R-407C	R-449A
Daily consumption el.en. [kWh/day]	79.55*16=1272.8	62.6*16=1001.6	75.42*16=1206.72
Annual consumption el. en. [kWh/year]	1272.8*365=464572	1001.6*365=365584	1206.72*365=440452.8
Annual costs [KM/year]	464572*0.09=41811.5	365584*0.09=32902.6	440452.8*0.09=39640.8



Graph 4. Annual electricity consumption and costs

Based onthe results obtained, it can be seen that the system has the highest consumption of electricity, and therefore its costs, when using R-404A, followed by R-449A showing the mean value of consumption, while R-407C has the lowest value of consumption and costs.

In order to gain easier insight into the electricity consumption and costs, Graph 5 shows annual percentage savings with the R-407C and R-449A refrigerants in comparisonto the refrigerant in the R-404A system.



Graph 5. Percentage savings of electricity per year compared to refrigerant R-404A

In Graph 5, we can see that the R-449A refrigerant has a 5.19 % savings in consumption compared to the R-404Arefrigerant. While, the refrigerant R-407C shows significant savings of 21.31 %.
All listed parameters are given in Table 9, for each of the analyzed refrigerants.

Table 9. Parameters required for final analysis

	R-404A	R-407C	R-449A
Total cooling capacity of the compressor [kW]	11,5	120	126.6
Number of compressors compressors	5	4	6
COP	1.19	1.51	1.26
COP (p-hdijagram)	2.29	2.46	2,42
Annual costs of el. en. [BAM]	41 812	32 903	39 641
ODP	0	0	0
GWP	3943	1624	1273
Critical temperature [°C]	73	87	83.7
Security class	A1	A1	A1
Slip temp. [°C]	1.1	7.4	8.5

5. CONCLUSION

If the results obtained in the analysis of given parameters are summarized, it can be seen that there are advantages and disadvantagesfor each refrigerant. The following points the parameters are presented on the basis of which a conclusion is made as to which refrigerant shows the best results.

- Cooling compressor capacities. It is important here that the resulting cooling capacity covers the needs of the calculated compressorcapacity.
- Number of compressors. It refers to the economic aspect or price. A larger number of compressors also means more expensive investment. Also, a larger number of compressors also requires higher maintenance costs. However, the maintenance costs that increase with the increased number of commuters are not considered in more detail in this paper
- Performance coefficient of the plant. How many kilowatts of cooling we get for one kilowatt of energy input into the system.
- Annual electricity costs. The aim is to get as cost-effective system as possible with as little cost as possible.
- Characteristics of analyzed refrigerants. ODP and GWP factors, safety class, critical temperature and slip temperature.

When taking into account the efficiency and cost-effectiveness of the system relative to the refrigerant being selected, the comparison of results shows that R-407C has the best properties.
This refrigerant requires the lowest number of compressors which directly implies the lowest expenses in regards with the compressor and auxiliary equipment, such as valves, pressure regulator and oil flow regulator. R-407C has the highest perforamnce coefficient, meaning that it provides the highest kilowatts of cooling for one kilowatt of input electrical

energy. Also, the same results in terms of the efficiency, that is, performance coefficient, were obtained by using p-h diagrams for the refrigerants.

Annual electricity costs for R-407C are the lowest, which in comparison to R-404A shows a considerable savings in the amount of 21 % annually. If refrigerant properties are considered, R-407C is the best choice. Its GWP factor is one third lower than the GWP factor of R-404A, which implies that the greenhouse effect is lower. Critical temperature is also higher which is another advantage as it is easier to achieve higher condensation temperature. The above given conclusion imply that the refrigerant choice surely has an impact on the overall system, starting from its efficiency to the economic factor. Therefore, before the selection of a particular refrigerant it is crucial to consider a number of options and select the one showing the best results.

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14| Оригинални научни рад
Research paper
doi 10.7251/STP1813216J ISSN 2566-4484

3D CADASTRE – A MOTIVATION AND RECENT DEVELOPMENTS OF TECHNICAL ASPECTS

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Abstract:

The paper gives motivation for considering a 3D cadastre based on the registration of 3D spatial units, i.e. the (bounded) amount of space to which a person is entitled by means of real right. This approach gives a better insight into the registration of rights and restrictions. In 2012 the international standard ISO 19152 Land Administration Domain Model (LADM) was approved. The LADM is a conceptual model, its purpose is not to replace the existing systems, but rather to provide a formal language for describing them, so that their similarities and differences can be better understood and it also offers the concepts for the modelling of 3D spatial units. Based on the LADM, country profiles can then be defined and extended. The paper further explores the technical aspects of a 3D cadastre, especially summarizing the main findings and challenges in 3D information modelling and 3D spatial databases for a 3D cadastre.

Keywords: ISO 19152 LADM, 3D spatial units, technical aspects of 3D Cadastre.

3D KATASTAR – MOTIVACIJA I TRENUTNA DOSTIGNUĆA TEHNIČKIH ASPEKATA

Apstrakt:

Ovaj rad daje motivaciju za razmatranje 3D katastra zasnovanog na registraciji trodimenzionalnih prostornih jedinica, tj. (ograničenog) prostora na koji pojedinac ima stvarno pravo. Ovaj pristup daje bolji uvid u registraciju prava i ograničenja. 2012. godine je odobren međunarodni standard modela upravljanja zemljištem ISO 19152 (LADM). Model upravljanja zemljištem (LADM) je konceptualni model, njegova svrha nije da zamijeni postojeće modele, već da obezbijedi formalni jezik za njihovo opisivanje, tako da se njihove sličnosti i razlike mogu bolje razumijeti. Takođe, on pruža i koncepte za modelovanje trodimenzionalnih prostornih jedinica. Na osnovu modela LADM, nacionalni modeli mogu biti definisani i proširen. U radu se dalje istražuju tehnički aspekti 3D katastra, posebno sumirajući glavna otkrića i izazove u 3D modelovanju informacija i 3D prostornim bazama podataka za 3D katastar.

Ključne riječi: ISO 19152 LADM, 3D prostorne jedinice, tehnički aspekti 3D katastra

1. INTRODUCTION

The cadastre is a source of information serving for protection of rights to real estates, for tax and fees purposes, for environmental, agriculture and forest land protection, for protection of natural resources, cultural monuments, for urban planning, for evaluation of real estates, for scientific, economical and statistical purposes so as for creation of further information systems. The challenge is how to register the 3D situations (e.g. overlapping constructions) in the cadastre which is usually based on 2D parcel paradigm. Due to the increasing number of people living especially in big cities and pressure on the use of the land in such areas the amount of these 3D situations is still growing. Therefore the change of paradigm from the traditional cadastre based on 2D parcel towards the 3D cadastre based on the registration of 3D property unit should be considered. The definition of 3D cadastre is given in [1]: A 3D cadastre is a cadastre that registers and gives insight into rights and restrictions not only on parcels, but also on 3D property units. A 3D property unit is that (bounded) amount of space to which a person is entitled by means of real rights.

The main factors for considering the 3D cadastre are: a considerable increase in (private) property values, the number of tunnels, cables and pipelines, underground parking places, multilevel buildings and also an upcoming 3D approach in other domains (e.g. 3D Geographical Information Systems) which makes a 3D approach of cadastral registration technologically realizable [2]. When talking about the building of the 3D cadastre, the legal, organizational and technical aspects need to be addressed. This paper focuses on the technical aspects, especially on summary of the recent developments of the 3D information modelling and 3D spatial databases for 3D cadastres.

The rest of the paper is structured as follows: the section 2 gives the examples of situations which is hard to register using 2D parcels. It is obvious that using 3D spatial units (3D property units) would give better insight into these 3D cadastral situations. The section 3 introduces the international standard ISO 19152 Land Administration Domain Model [3] which supports the registration of 3D RRR (right, restrictions and responsibilities) using 3D spatial units and section 4 then presents the LADM based country profiles. The recent development of technical aspects of 3D Cadastres are described in the section 5. The section 6 concludes the paper.

2. MOTIVATION FOR 3D CADASTRE

In the last decades the number of 3D situations (which also need to be registered in the cadastre) is increasing. [2] defines these 3D situations as situations in which different property units (with possibly different types of land use) are located on top of each other or constructed in even more complex structures. The examples of such 3D situations are given in this chapter and also their registration in 2D cadastre based on 2D parcels is demonstrated. Figure 1 displays the situation when one construction (an apartment building) is partially located above the other construction (a restaurant) and the way in which this 3D situation is depicted on the valid 2D digital cadastral map.

Figure 1. (up left) At first sight one could say that there are two tall buildings and one smaller standing between them. (up right) In fact, there is a building (highlighted in blue), which is partially located above the other building (highlighted in green). (down) The 3D situation depicted on the 2D cadastral map in combination with orthophoto.

The figure 2 introduces a general principle how the untypical constructions are displayed in 2D cadastral map. It can be easily recognized that the footprint does not provide user with information about the whole extent of legal space to which the owner's rights are attached.

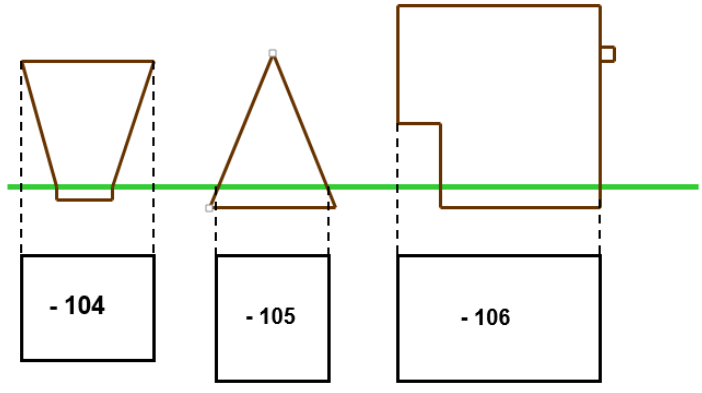

Figure 2. Visualization of the untypical building in the 2D cadastral map [4].

Another example of the typical 3D situation gives fig. 3. There are buildings over public roads.

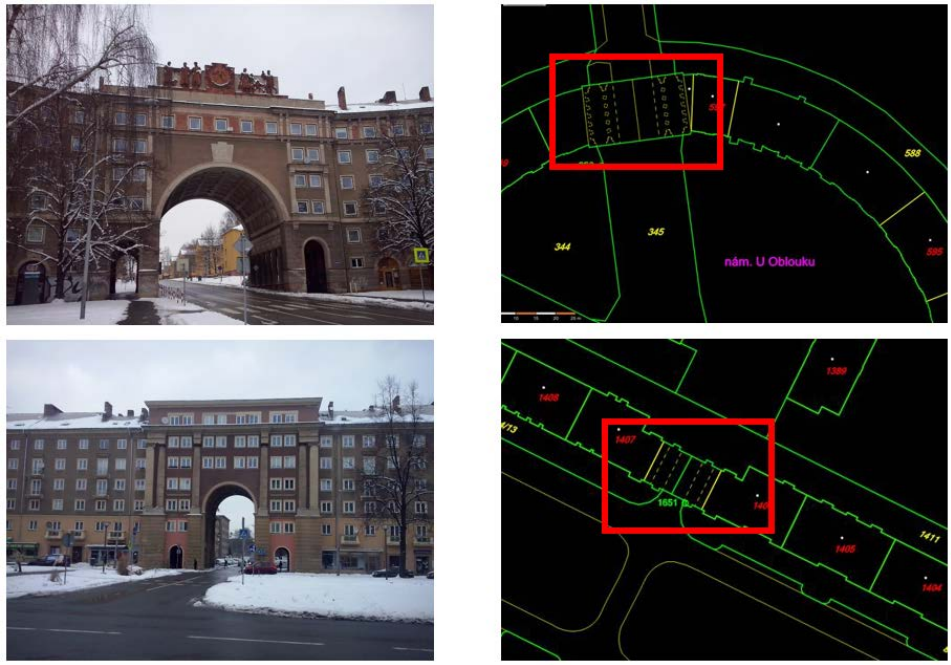

Figure 3. Buildings (left column) and their portrayal in existing 2D digital cadastral map (right column). On the cadastral map one can see only the outlines of the building (on the surface level).

In the cadastre, also the underground constructions should be registered. Figures 4 and 5 demonstrate the principle how the underground constructions are displayed in existing 2D cadastre in the Czech Republic. Recently several studies have examined how the underground constructions could be registered in 3D cadastre [5, 6].

Figure 4. (left) Visualization of the underground construction of the archeological park in Pavlov [4]; (right) Entrance to the archeological park in Pavlov (photo: Institute of Archeology of the CAS, Brno).

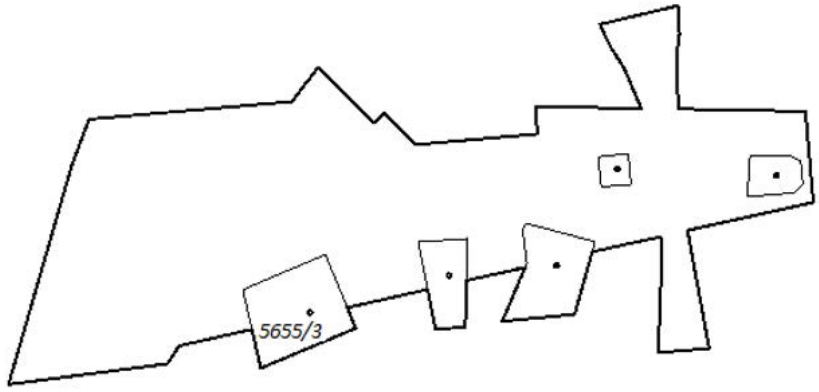

Figure 5. 2D visualization of the boundaries of underground construction (Archeological park Pavlov, Czech Republic) on the cadastral map. Every component of the construction located above ground is displayed on a "separate" building parcel. However, in fact, only one building parcel is registered in the cadastre (here with parcel number 5665/3). (down) The photography of the underground object with components located above the ground. Highlighted in red is the part of the underground object corresponding to the building parcel 5655/3 (source of photography: http://alesjungmann.cz/project/archeopark-pavlov).

3. MOTIVATION FOR 3D CADASTRE

This International Standard [3] defines the Land Administration Domain Model (LADM). The LADM is a conceptual model. The purpose of the LADM is not to replace existing

systems, but rather to provide a formal language for describing them, so that their similarities and differences can be better understood. LADM is a descriptive standard, not a prescriptive standard. The LADM provides a reference model which will serve two goals:

- to provide an extensible basis for the development and refinement of efficient and effective land administration systems, based on a Model Driven Architecture (MDA), and
- to enable involved parties, both within one country and between different countries, to communicate, based on the shared vocabulary (that is, an ontology), implied by the model.

The LADM:

- defines a reference Land Administration Domain Model covering basic information-related components of land administration (including those over water and land, and elements above and below the surface of the earth);
- provides an abstract, conceptual model with four packages related to
    - parties (people and organizations);
    - basic administrative units, rights, responsibilities, and restrictions (ownership rights);
    - spatial units (parcels, and the legal space of buildings and utility networks);
    - spatial sources (surveying), and spatial representations (geometry and topology);
- provides terminology for land administration, based on various national and international systems, that is as simple as possible in order to be useful in practice. The terminology allows a shared description of different formal or informal practices and procedures in various jurisdictions;
- provides a basis for national and regional profiles; and
- enables the combining of land administration information from different sources in a coherent manner.

The LADM offers two concepts for modelling the 3D spatial units. In terms of LADM, 3D spatial unit is a single volume (or multiple volumes) of space. These concepts are the boundary face string concept (figure 6) and boundary face concept (figure 7).

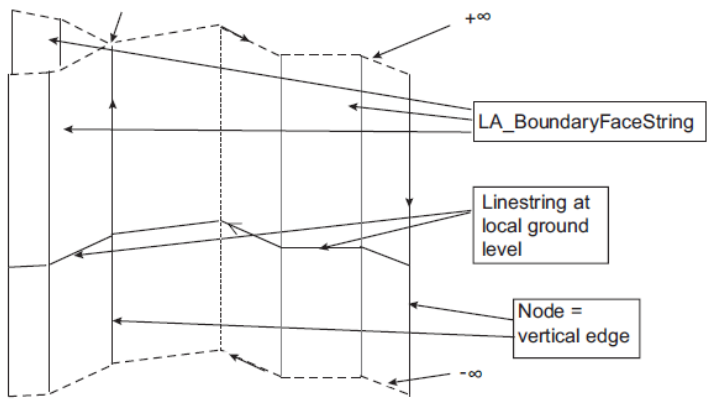

Figure 6. Boundary Face String Concept [3].

Boundary face string is a boundary forming part of the outside of a spatial unit. Boundary face strings are used to represent the boundaries of spatial units by means of line strings. In a 3D land administration system it represents a series of vertical boundary faces where an unbounded volume is assumed, surrounded by boundary faces which intersect the Earth's surface.

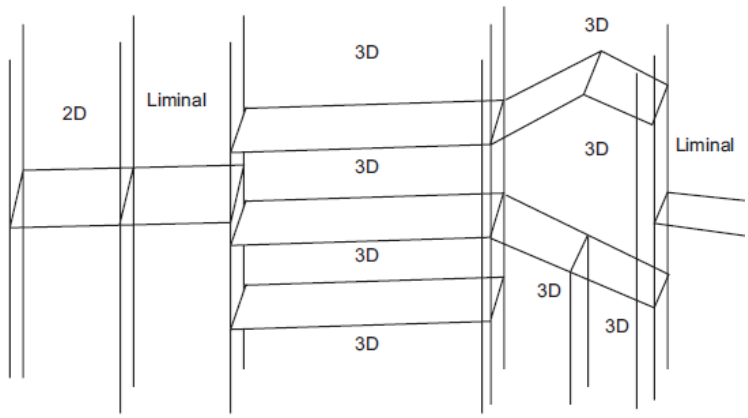

Figure 7. Side view showing the mixed use of boundary face strings and boundary faces to define both bounded and unbounded 3D volumes [3].

Boundary face is a face that is used in the 3-dimensional representation of a boundary of a 3D spatial unit. Boundary faces are used when the implied vertical and unbounded faces of a boundary face string are not sufficient to describe 3D spatial units. Boundary faces close volumes in height, or in depth, or in all directions to form a bounded volume. The volumes represent legal spaces.

4. LADM-based country profiles

The ISO 19152 Land Administration Domain Model (LADM) is regarded as a conceptual model that enforces certain relationships between the entities. To test the compliance between the LADM and the national data cadastre model, it is necessary that an application scheme (i.e., a country profile) is developed.

On principle, there are three main ways in which the LADM based country profile can be developed: (1) use LADM classes, attributes, codelists and relationships between classes "as is", (2) show an inherited structure between the LADM and the existing cadastral model, or (3) show a mapping of elements between LADM and the existing cadastral model. The last two approaches were used for the creation of the LADM based country profiles for example in Croatia [7], Czech Republic [8], see figure 8, Poland [9], and Serbia [10]. In all these mentioned countries the cadastre is currently based on registration of 2D parcels.

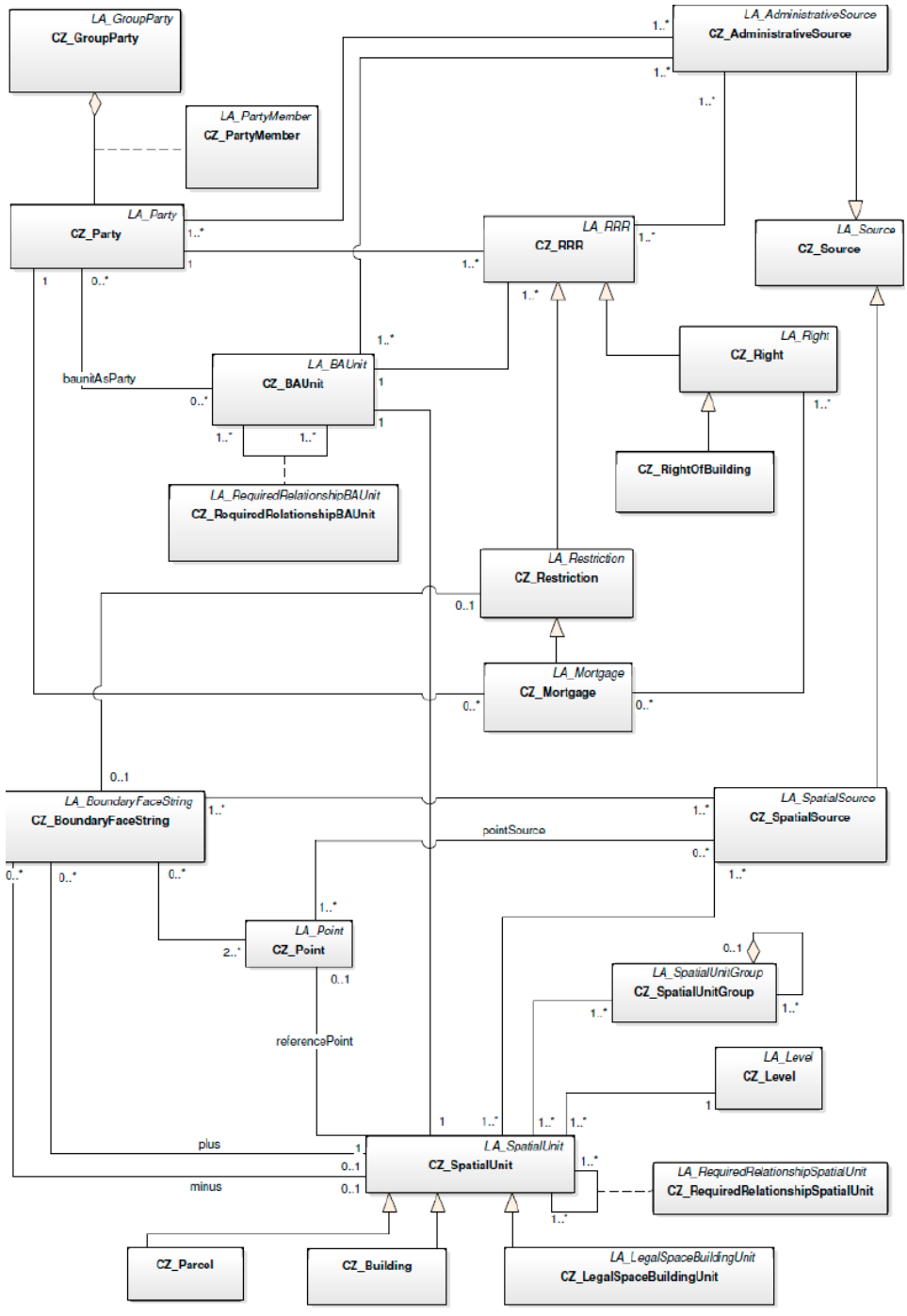

Figure 8. The Czech LADM-based country profile [8].

LADM allows for registration of 3D parcels and recently several prototypes of 3D LADM based country profiles have also even been developed, for example: Russian Federation

[11], Poland [12], Malaysia [13, 14], Israel [15], Greece [16], Trinidad and Tobago [17] or Turkey [18].

5. RECENT DEVELOPMENTS OF TECHNICAL ASPECTS OF 3D CADASTRES

5.1. 3D CADASTRAL INFORMATION MODELLING

The various aspects of 3D Cadastral Information Modelling need to be addressed, e.g. the possibilities of linking 3D legal right, restriction, responsibilities (RRR) spaces, modelled with LADM, with physical reality of 3D objects (described via CityGML, IFC, InfraGML, etc.). This is closely related to the legal framework and initial registration of 3D spatial units (3D parcels).

An initial categorization of 3D parcels was given in [19] and forms the starting point for the further investigations into suitable corresponding database representations, exchange format, and data capture encodings. The following categories were introduced, now listed in the order of growing complexity:

1. 2D spatial unit (actually prism of 3D space): defined by a 2 dimensional shape.
2. Building format spatial unit: defined by the extents of an existing or planned structure (e.g. apartment).
3. Semi-open spatial unit: defined by 2D shape with upper or lower surface.
4. Polygonal slice spatial unit: defined by 2D shape with upper and lower surface.
5. Single-valued stepped spatial unit: defined by only horizontal and vertical boundaries (among others the facestring from 2D space) and single valued .
6. Multi-valued stepped spatial unit: as above but now multi valued.
7. General 3D spatial unit: defined also by boundaries other than horizontal and vertical, as depicted in figure 9.

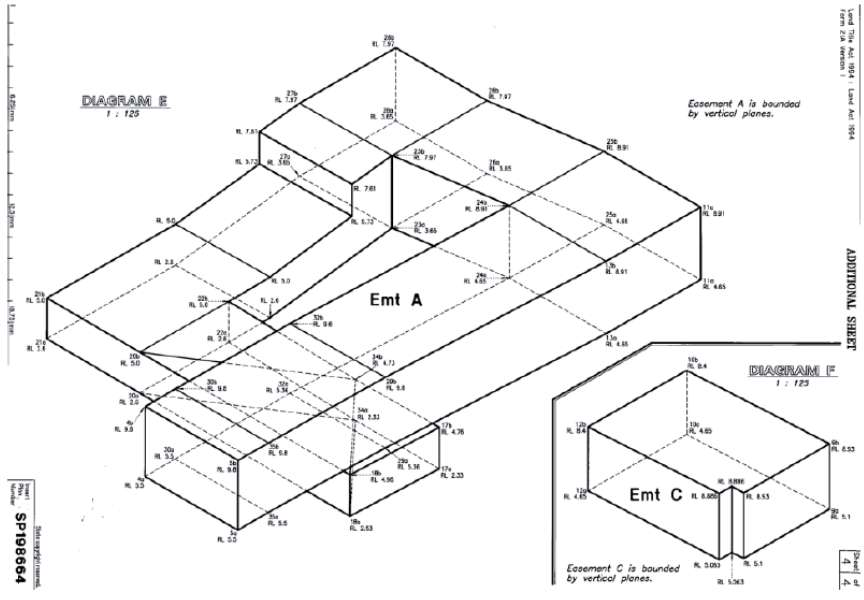

Figure 9. A general 3D spatial unit [19].

Cadastral data models, (e.g. Land Administration Domain Model (LADM)), including the 3D support, have been developed for legal information modelling and management purposes without providing correspondence to the object's physical counterparts. Building Information Models (e.g. BIM/IFC) and virtual 3D topographic/ city models (e.g. LandXML, InfraGML, CityGML, IndoorGML) are used to describe the physical reality. The main focus of such models is on the physical and functional characteristics of urban structures [20]. However, by definition, those two aspects need to be interrelated; i.e. a tunnel, a building, a mine, etc. always have both a legal status and boundaries as well as a physical description; while it is evident that their integration would maximize their utility and flexibility to support different applications. A model driven architecture (MDA) approach, including the formalization of constraints is the preferred. In the Model Driven Architecture (MDA) design approach as proposed by the Object Management Group (OMG) the information model, often expressed in the form of a UML class diagram is the core of the development. This so called platform independent model (PIM) is then transformed into Platform-Specific Model (PSM). This could be a relational database schema for a spatial DBMS, or XML schema for a data exchange format or the structure of maps, forms and tables as used in the graphic user interface (GUI) of a spatial application. Constraints have been proved effective in providing solutions needed to avoid errors and enable maintenance of data quality; thus the need to specify and implement them is vital [21].

How to create and maintain valid 3D parcels is still a challenge in practice [22]. At least three aspects should be clearly developed in order to manage the 3D parcels correctly [22]: (1) precise geometric models that describe the shapes and geographic locations of various 3D parcels based on flat faces; (2) volumetric or solid models that indicate boundary faces with orientation to present the corresponding 3D parcel objects; and (3) the topological relationships that encode the information about adjacencies between 3D parcels, using shared common faces/edges to preserve the consistency of the objects' geometries and support spatial query and management.

5.2. 3D SPATIAL DATABASES FOR 3D CADASTRES

Constructing 3D data models and their topological relationship are two important parts of 3D cadastre [23]. 3D Spatial Systems should then enable [24]:

- data model to handle a variety of 3D objects,
- data quality control,
- geo-referencing,
- comprehensive location based search and analysis,
- handling level of detail for seamless operation,
- high performance dissemination of 3D data,
- support high performance real-time 3D rendering,
- support for 3D standards.

Although a lot of work has been completed on defining a 2D or 3D vector geometry in standards by the OGC and the ISO, it is still insufficient to define 3D cadastral objects. 3D objects have a more rigorous definition for cadastral purposes. For a volumetric 3D cadastral object, for example, the polyhedron needs to satisfy characteristics such as closeness, interior connection, face construction and proper orientation. The LADM addresses many of the issues in 3D representation and storage of 3D data in a DBMS. It allows in-row storage of 3D data in a mixed 2D-3D database allowing for fast retrievals

and analysis; it allows for 3D data to be stored in different levels of detail, overlapping 2D footprint of 3D objects, and supports liminal parcels, as well as allows attribution of different boundary lines and faces. However, an identified issue is the duplication of definition of boundaries for separate spatial units. Three-dimensional objects can be represented using voxels (volumetric pixels) as it brings advantages in object representation, object count and volume, 3D operations and simple analysis, better representation of the various levels of detail of a 3D city model, and representing 3D as a solid instead of point, line and polygon. The challenges to this are the storage and efficient handling by current spatial databases, although there are GIS systems that are working towards creating a column store structure to accommodate voxels. 3D objects can also be represented as a point cloud. LiDAR point clouds could assist to either be a reference framework of as-constructed features, or a 3D data acquisition tool for 3D physical objects, or a verification tool for pre-existing BIMs or other models. Point cloud data can be for data such as administrative, vector, raster, temporal etc. and a generic DBMS should be able to combine these data for a point cloud data type with characteristics such as xyz values, attributes per point, spatially coherent data organisation, efficient storage and compression, data pyramid support for multi-scale or vario-scale support, temporal support, query accuracy over a range of dimensions, analytical functions and parallel processing. Spatial indexing is used by databases to improve search speeds, of the three types of indexes namely B-Tree, R-Tree and GiST, the latter two are found to be useful for GIS data. Figure 10 displays the 3D R-tree index structure.

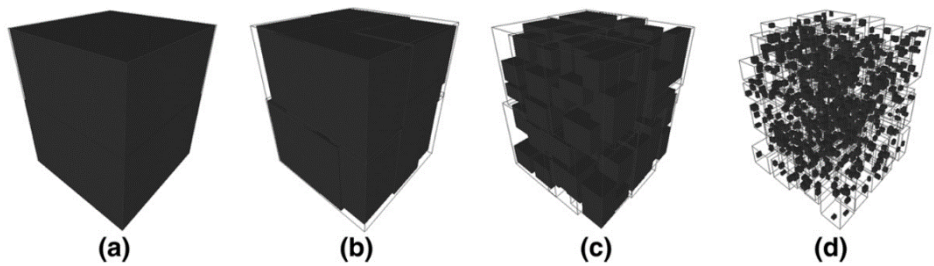

Figure 10. 3D R-Tree generation procedure. (a) Root layer. (b) 2nd middle layer. (c) 3rd middle layer. (d) Leaf layer [25].

As with 2D geometry, 3D volumetric primitives would need to satisfy the adjacency and incidence (gaps and overlaps) relationship so that they are mutually exclusive and spatially exhaustive in the domain. While standards and definitions for solids such as the PolyhedralSurface in the SQL Geometry Types of OGC as well as other definitions for solids exist, they are not utilized very well currently and do not comply very well with standards. Validation of such solids and exchange of datasets between formats and platforms are highly problematic and do not usually follow any standards and error reports are usually cascading rather than in a single report making it very cumbersome to deal with errors individually. Operations on and amongst 3D objects have been described by OGC, such as 3D architecture (Envelope(), IsSimple(), Is3D() etc.) and Spatial relationships (Equals(), Intersects(), Touches() etc.), however existing DBMS often implement them differently. 3D topological structures are an important consideration in a 3D cadastral DBMS. Topological relationships between neighbouring parcels can be between two objects or between many of the objects neighborhood parcels. While 3D topological structures have been defined, they have not fully compliant to standards such

as the LADM. The LADM not only provides a conceptual description of a land administration system, but also provides a 3D topology spatial profile. LADM also stipulates that geometrical information along with an associated topological primitive help to describe 3D spatial units. LADM volumes can be bounded or unbounded at the top or bottom which is a reflection of real-world situations where there may be limited or unlimited rights or restrictions on the ground or skyward direction of a volumetric property. Various methods and characteristics of constructing 3D spatial units using LADM 3D topological model have been discussed in Janečka et al. (2018) in the context of a LADM specific topological model since a single model is not suitable for all types of applications. The approach based on the Tetrahedral Network (TEN) model is a suitable 3D topological model for volumetric parcels and is proposed as an alternative to boundary representation. Two fundamental considerations are that real-world phenomena have a volumetric shape, and can be considered a volumetric partition assist in modelling of 3D space. All elements of a TEN are convex and are well-defined allowing easy validation, analytical capabilities and integration with topography and other 3D data. TEN can be stored as explicit tetrahedrons or as vertices and the star or edges. Another method is to construct and perform topological validations of 3D cadastral objects on the fly based on boundary 3D face information. This can create both manifold and non-manifold solids and can model real-world cadastral features and legal spaces. The validation requirements for volumes are reduced and rely on the algorithm to create the volume using 3D faces and stored references. Finally, another approach is to use 2D topological features with stored height values, which is then used to construct and validate 3D topological features. This approach can save storage space but is not totally viable for a 3D cadastre. Developments were observed in the SDBMS domain where more spatial data types, functions and indexing mechanisms were supported. Two available SDBMS, Oracle Spatial and PostGIS were analyzed in detail, while other SDBMS such as Microsoft SQL Server, MySQL have been seen to follow Simple Feature Access international standard. Most of these software including ESRI support 2D topology very well, however 3D topology is not supported natively yet. Comparison of various SDBMS for storing, and representing large point clouds was done with various software excelling in some aspects. ESRI's TIN structure, Oracle Spatial providing suitable data structure and mechanisms, MonetDB's in-memory perspective rather than a buffer perspective and ability to move data between storage hierarchies, Oracle Exadata's flat table model for data loading and querying and handling large number of points are some of the features of the current SBDMs. A discussion on recent development of spatial databases follows with discussion on nD-array DBMS, comparison between file-based solutions vs. nD-array DBMS, and the development of modern Graphics Processing Units (GPUs) and their use in massive parallel architectures for processing large-scale geospatial data. In conclusion, the paper proposes a 3D topology model based on TEN synchronized with LADM specifications and the development of conceptual and physical model seems to be suitable for 3D cadastre and 3D registration. This topological model would utilize surveying boundaries to generate 3D cadastral objects with consistent topology and rapid query and management. Definitions for the validation of 3D solids should also consider the automatic repair of invalid solids. Point cloud and TIN related data structures available in SDBMSs should enable storage of non-spatial attributes such that database updates would store all relevant information directly inside the spatial database [26].

6. CONCLUSIONS

In the last 20 years the researchers and professionals have paid the big attention to the 3D cadastre. Nowadays one can find the countries with legislation supporting the registration of 3D spatial units (Sweden, Queensland, Victoria, also the Netherlands, big cities in China like Shanghai). The registration of 3D spatial units can be seen as the first step towards the 3D cadastre. However, also the organizational and technical aspect have to be addressed. Even some countries do support the registration of 3D spatial units, this is done mostly using 3D drawings (e.g. survey sketch capturing the 3D geometry of the object or 3D pdf file showing the legal extent of 3D spatial units [27]). To enable the effective functioning of the 3D cadastre, the 3D data have to become an integral part of the cadastral spatial database. To meet this condition, the necessary steps are standardization in the field of 3D cadastre (ISO 19152 LADM), 3D information modelling (e.g. 3D LADM based country profiles) and further development of 3D spatial databases.

Another important technical aspect of the 3D cadastre is relation with other initiatives like BIM (Building Information Modelling). The capturing of 3D data is often seen as the most expensive phase of establishing the 3D cadastre. Re-usage of data like BIM could help to bridge this stage. The usage of BIM for the 3D cadastre purposes has already been addressed [28-30].

Even the developed LADM based profiles often have not yet been implemented in the production environments [31], the situation might be different in the future. For example, in the Czech Republic, the Strategy for the BIM implementation was approved by the Czech government. From 2026 the Czech Office for Surveying, Mapping and Cadastre is obliged to ensure the reusing of the BIM data for 3D cadastre purposes. It can be expected that this Strategy will enforce the change in the existing cadastral data model towards the registration of 3D spatial units. The cadastral data model could be then modified and extended to support the registration of 3D spatial units in the standardized way, according to the LADM possibilities and realized using well-functioning 3D spatial databases.

ACKNOWLEDGEMENTS

The author of the publication was supported by the project LO1506 of the Czech Ministry of Education, Youth and Sports.

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15| Оригинални научни рад
Research paper
doi 10.7251/STP1813231Z ISSN 2566-4484

ANALIZA REZULTATA DOBIVENIH METODOM AUTONOMNOG STARTA BAZNOG UREĐAJA I TILT OPCIJOM

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Sažetak:

Visoko precizni pozicijski servis (VPPS) hrvatske mreže referentnih GNSS stanica pod imenom CROPOS danas je vrlo brz, pouzdan i precizan sustav korišten za određivanje koordinata točaka u Republici Hrvatskoj. Prednosti GNSS mreža za potrebe RTK pozicioniranje dobro su poznate, međutim, u nekim je situacijama klasičan sustav RTK baza-rover prikladno rješenje, čak i kada korisnik nema mogućnost postaviti bazni uređaj na točku čije su koordinate poznate u državnom koordinatnom sustavu (HTRS96). Korištenjem metode autonomnog starta baznog uređaja, isti je moguće postaviti na najpogodnije mjesto za primanja signala GNSS satelita. Osim što bazni uređaj šalje diferencijalne korekcije roveru, simultano obavlja i prikupljanje statičkih opažanja za kasniju obradu i korekciju koordinata baznog uređaja i rovera. U ovome su radu testirane mogućnosti navedene metode. Uz to, testirana je i funkcionalnost opcije za mjerenje pri nagibu štapa (TILT opcije) koju je tvrtka Topcon integrirala u prijamnik Hiper HR.

Ključne riječi: CROPOS VPPS servis, autonomoni start baznog uređaja, TILT opcija

ANALYSIS OF POSITIONING RESULTS OBTAINED BY A SINGLE BASE RTK WITH AUTONOMOUS BASE START AND TILT OPTION

Abstract:

HPPS service of the CROPOS system is today a fast, reliable, precise and commonly used tool for coordinates determination in Croatia. The advantages of a networked RTK method are well known, but in some situations, a single-base RTK method could be a reliable method for coordinates determination, even without a base station having known coordinates. Single-base RTK method with Autonomous base start can be set up on any (unknown) station with a clear sky and GNSS satellites visibility enabled. Differential corrections are usually broadcast to the rover GNSS receiver via a communication link, enabling the coordinates determination with cm-level precision in real time. Simultaneously, the base GNSS receiver collects static observations for base station determination in post-processing and subsequent rover coordinates shift. In this paper, the above mentioned method was tested on the ground, together with TILT option integrated into newest Topcon GNSS receiver.

Keywords: CROPOS HPPS service, Autonomous base start method, TILT option

1. INTRODUCTION

Nowadays, due to technological improvements, surveyors can get their job done much faster and accurate than ever before. Such improvements include precise satellite positioning techniques which were developed after GPS (Global Positioning System) satellites were launched. Today, it is common to use both American GPS and Russian GLONASS for satellite positioning purposes, while European Galileo and Chinese BeiDou are still under development and are expected to reach Full Operational Capability (FOC) by 2020.

GNSS RTK (Real Time Kinematic) is the most widely used and the fastest method for coordinate determination on the surface of the Earth. Like other satellite relative positioning method, RTK method requires at least two GNSS (Global Navigation Satellite System) receivers: base and rover. At the early stages of RTK method, a base receiver was set up at station with known coordinates observing the same GPS (Global Positioning Satellites), calculating the differential corrections of phase observations which were via the radio link transferred to the rover GPS receiver enabling it to solve the phase ambiguities and subsequently the coordinates in real-time. This positioning method was referred to as conventional RTK providing cm-level accuracy up to 20 km distance from the base receiver [1]. In the meantime, the concept of Networked RTK (NRTK) was developed, modelling the distance dependent errors of the GNSS observations (ionospheric and tropospheric refraction, orbital errors) and thus extending the distance between permanent GNSS stations up to 70-100 km [2]. Such networks have become essential surveying tool and are used in most geodetic tasks. Although GNSS networks have many advantages over conventional RTK method, there are some situations in which they cannot be properly utilized. One of these situations is certainly when a mobile Internet signal is not available. Despite a generally good spatial coverage of mobile Internet availability, there are still poorly populated areas (mainly mountainous area) with no signal. Without it, NRTK positioning is not possible since the rover cannot receive correction messages from the server. In such situations, a conventional single-base RTK is more appropriate solution. Having that in mind, a technique which allows the operator to set up a base receiver at arbitrary location (not over a known point) and perform RTK measurements was developed. Such method is based on performing both static and RTK observations at the same time and is called 'Autonomous base start method with coordinate shift'. It is a method that requires post-processing, but it also enables the user to simplify their field work and finish it much faster compared to conventional RTK method. The most important part is that end results are satisfying in terms of both accuracy and precision.

Another great step in modern RTK positioning was made by virtue of integration capabilities of GNSS and IMU (Inertial Measurement Unit) measurements. By utilizing inertial based measurements, it is possible to perform RTK observations without maintaining vertical position of a GNSS range pole. Today, there are several GNSS receivers available on the market which incorporate so-called tilt option. Such option has shown big potential and is getting more attention every day.

The aim of this paper was to test both Autonomous base start method and TILT option on the ground. Complete field and post-processing procedures, followed by accuracy and precision analysis and conclusion are systematically carried out.

2. CROATIAN POSITIONING SYSTEM – CROPOS

CROPOS is the state network of permanent GNSS reference stations of the Republic of Croatia. The network consists of 33 stations at the average distance of 70 km distributed over the national territory for the purpose of collecting satellite observation data and determination of correction parameters [3]. The inclusion of additional permanent GNSS stations data from the neighboring countries into CROPOS enabled a better coverage and reliability of the system as well as the better modelling of corrections in the border areas of the Republic of Croatia [3], [4]. The system provides three services which differ in accuracy, availability, and way of data transfer, data format and positioning methods. High Precise Positioning Service - HPPS (VPPS in Croatian) is the most frequently used tool by surveyors for every kind of land and cadastral survey in Croatia. The VPPS offers a networked solution of phase measurements in real-time, and the coordinates are determined with declared accuracy 2 cm (2D) and 4 cm (3D). Geodetic Precise Positioning Service (GPPS) provides the GNSS observation data collected at CORSes or at arbitrarily selected Virtual Reference Stations (VRS) with a sub-centimeter level of accuracy. Observation data are available for post-processing in versions of RINEX format (2.10, 2.11, 3.02). CROPOS as system of networked permanent GNSS stations is based on VRS (Virtual Reference Station) concept. Currently, the GNSS receivers Trimble NetR5 involved in CROPOS support the observation of only GPS and GLONASS satellites thus, the differential corrections and CORS observation data are available only for those satellite systems [3].

3. AUTONOMOUS BASE START METHOD

One of significant disadvantages of single base RTK is the necessity of having at least one point with known coordinates in national coordinate system. It is necessary because the base receiver needs to be started from a known point to ensure rover's absolute positioning accuracy. It is not unusual that there is no such a point in the field or it is not situated in a suitable location for satellite positioning. If a user has to utilize single base RTK method in such location, it is often necessary to traverse or to use any other traditional surveying method for coordinates determination. Nevertheless, such methods are considered to be impractical and time consuming. Another option is to perform fast static observations. While relative static method is highly accurate and simple, it takes some time to be carried out. Moreover, it disables quick start of the base receiver and prolongs field work.

Mentioned problems indicate that a proper solution should utilize both static and RTK observations simultaneously. Such solution involves setting up the base receiver on any (unknown) station with a clear sky and GNSS satellites visibility provided. Base receiver is then started with Autonomous position, providing the base station coordinates with low precision, usually around 2 m [5]. In spite of that, relative positions between base and rover are determined with high precision. Simultaneously with the GNSS satellites observation and differential correction broadcasting, the base GNSS receiver collects static observations for subsequent station coordinates determination in post-processing. Once the base station coordinates have been determined, rover RTK receiver coordinates can be corrected accordingly. Such coordinate "shift" is possible since the vector between the first (inaccurate) base point and the one determined with static observations is known. After coordinate shift, all of the rover's coordinates are considered to match the desired RTK accuracy [5].

For the purposes of field investigations presented in this paper, Topcon's Magnet Office Tools software was used to perform all of the necessary computations, including coordinate shift.

4. TILT TECHNOLOGY

GNSS RTK method made a great impact on surveying techniques and has developed rapidly over the last 20 years. The increase of number of satellites, development of permanent GNSS networks, better algorithms enabling detection and elimination of multipath, high-quality GNSS antennas, faster initialization and general simplification of RTK workflows has led to a global democratization of such technology.

Significant step towards such democratization of GNSS technology occurred in 2013, when Trimble presented GNSS receiver R10 utilizing "Trimble SurePoint" option. It allowed the user to perform tilted measurement and still get reliable results since such technology compensated for mis-leveled field measurements out of plumb by as much as 15° [6]. Although the so-called tilt option was very innovative and enabled users to perform field measurements faster, first receivers incorporating this option have shown some disadvantages. Some of those receivers couldn't perform tilted stake-out, user had to ensure that receiver is aligned with field computer [6] and had to define when tilted measurement was about to be carried out in field software. Additionally, the performance of tilt compensation was often slow providing data with variable quality.

A big step forward was made in 2016, when Topcon company announced its new GNSS receiver Hiper HR (Figure 1). This receiver incorporates patented TILT (Topcon Integrated Levelling Technology) technology able to compensate measurements out of plumb by as much as 15° (Figure 2). As a company that has a long and successful history with GNSS+INS (Inertial Navigation System) integrations (mostly for precise agriculture and machine control purposes), Topcon integrated 3-axis digital compass and its own 6-axis Hybrid IMU to create advanced 9-axis MEMS (Microelectromechanical system) [7]. Unlike its predecessors, TILT technology enables tilted stake-out, user doesn't have to align the receiver and field computer to perform accurate tilted measurement, tilt compensation is turned on all the time (it is not necessary to tell the software if one would measure with tilted pole or not) and it is operating really fast.

Figure 1. Topcon Hiper HR (https://www.topconpositioning.com)

Figure 2. TILT technology (https://www.topconpositioning.com)

Like any receiver with TILT option, it is necessary to perform digital compass calibration prior to any field measurements. In case of Hiper HR, the calibration consists of three steps [8]:

1) calibrate level,
2) calibrate compass,
3) calibrate compass in the horizontal plane.

Compass calibration is recommended in the following situations [8]:

- survey location changes frequently,
- receiver's firmware has been updated,
- receiver takes a shock such as being dropped,
- temperature has changed by 10 degrees or more,
- receiver is transported by a car or airplane,
- receiver is near a strong magnetic object or material, such as a permanent magnet, electromagnet, electric transformer, AC power supply, etc.

5. GEODETIC NETWORK ESTABLISHMENT

In order to perform the field investigations, an appropriate geodetic network had to be established. The chosen location was dr. Franjo Tuđman's park in Zagreb, Croatia. The network consisting of 10 stations is shown on Figure 3. The coordinates of stations S1 and S2 were determined by static method, while coordinates of the remaining stations were determined by terrestrial observations (total station), since those stations had partially obstructed horizons. Such stations were chosen to simulate a real-life situations since today’s surveyors expect their receivers to get fixed solution in almost any location.

Both static and terrestrial measurement were conducted on December 5th 2017.

Figure 3. Geodetic network configuration (https://www.google.hr/maps)

For the purposes of static observation, Topcon Hiper HR and Topcon Hiper SR GNSS receivers were used. Receivers were set up over stations S1 (Hiper HR) and S2 (Hiper SR), which were marked with wooden stakes (a nail served as a center). Elevation mask was set on 10° and observation interval was 10 seconds. Observed constellations were GPS and GLONASS. Antenna heights were measured before and after the station occupation. According to the 'Regulations on the fundamental geodetic works performance ' [9], minimum static observation time window should be 20 min + 2 min per km of the longest baseline. Thus, a minimal observation time for this purpose should have been 22 min. In spite of that, the observation time window was deliberately extended. In the end, static occupation of both stations lasted for 47 min.

After static observations were done, receivers were removed from tripods and were replaced with total station (S1) and prism (S2). For this purpose, Sokkia SET500 total station was used. Station S2 served as the azimuth reference mark. Points P1, P2, …, P8 were surveyed by measuring distances and angles in both theodolite faces. During the measurement, the total station was set up on station S1 all the time, the tripod with prism was moved from one point to another.

6. RTK MEASUREMENT

6.1. Field GNSS observation planning

Before conducting any field GNSS observation, it is always recommended to carry out the mission planning. For the purposes of precision analysis, the aim was to define two-time windows, one with better and the other with worse satellites visibility. Observation conditions are influenced by a number of visible satellites, DOP (Dilution of Precision)

values etc. Since RTK observations were planned for December 6th 2017, mission planning was carried out for that day by using online tool Navmatix [10].
The satellite visibility and DOP values plot pointed out that the best time interval for satellite observations was the one between 7:00 and 13:00 (UTC), due to high number of satellites (17 in average) and low DOPs (GDOP being 1.5). On the other hand, the worst time period was the one between 13:00 and 19:00 (UTC), with 14 satellites and maximal GDOP value of 2.2. Therefore, the first session of RTK measurements were carried out between 8:00 and 12:00 (UTC), while the second session was carried out between 14:00 and 18:00 (UTC).

6.2. RTK field survey - Autonomous base start method and CROPOS HPPS

After the geodetic network was established and mission planning was done, it was possible to conduct the RTK survey in order to test Autonomous base start method and TILT option on the ground. After the coordinates of all stations were determined by a single base RTK utilizing Autonomous base start method, CROPOS HPPS was used as well. Five observations were done on each station: one with vertical range pole and 4 with tilted range pole. The ranging pole was tilted in 4 directions: north, east, south and west in order to determine whether the tilt orientation affects the positioning accuracy. Those 4 observations were done by using TILT option. According to the Technical specifications for coordinates determination [11], minimal observation duration for points that define landmarks and other borders must be 5 epochs. Since the goal of this paper was to simulate real-life RTK measurements, all of the observations were carried out according to those specifications. Observations were performed with Topcon Hiper HR and Hiper SR GNSS receivers and field computer Topcon FC-5000 running Magnet Field software.
The survey procedure is explained as follows. The first step was to calibrate a digital compass integrated in Hiper HR receiver. It was done by following 3 steps described in chapter 4. At the beginning, Bluetooth connection between receiver and field computer was established. For the purposes of calibration and all of the field measurements, Topcon Magnet Field software was used. First step of calibration includes setting a tripod with a universal tribrach and tribrach adapter. Tribrach must be levelled. Receiver is set on an adapter and level calibration step is triggered inside the software. After waiting for 30 seconds, the software displays a message that the first calibration step is completed. The second step consists of rotating the receiver in vertical plane along the Y axis. After one turn, receiver should be rotated about 30° to the left in a vertical plane along the X axis and then rotated again for 360° in a vertical plane along the Y axis. Those two steps must be repeated until receiver completes a full circle around the X axis. Finally, the third step is done by setting the receiver back on a tripod and by rotating it clockwise in the horizontal plane. After competing 15 turns, the software displays the massage that calibration is done.
Occupation and observation of all stations was firstly done by the single-base RTK method. The base GNSS receiver Topcon Hiper SR was setup on a tripod over the arbitrary station named B, which was chosen for its good position and clear horizon. In order to ensure that the base receiver was placed over the same station in second session, station B was marked with a nail. The slant antenna height was measured twice from the nail up to the Antenna Reference Point (ARP) and static observations were triggered by pressing the ON/OFF button 3 times within 2 seconds. It should be noted that all observation settings were set prior to measurement by using Topcon Receiver Utility (TRU) software which was installed on FC-5000 field computer. Elevation mask was once again set to 10° while

the logging interval was set to 10 seconds. After static observations was started, base receiver was connected to FC-5000 inside Magnet Field software via Bluetooth in order to perform the base start step. For the base reference position, coordinates of station B were used. Since those coordinates were unknown, they were determined with Hiper SR receiver by Autonomous positioning method. Communication link between base and rover receivers was established by using Topcon's patented long-range Bluetooth called LongLink. It enables the communication range of 300 m and is ideal solution for small-scale projects. Rover GNSS receiver Hiper HR was setup on the range pole with bipod support. The bipod was used to get the rover in vertical position and as a support for tilted measurements. After the pole was set in vertical position, "Reset RTK" option inside the field software was triggered. It is the option that resets the RTK engine after which the receiver restarts the initialization process [12]. It was done so the initialization time could be measured by stopwatch installed on a cell phone. Initialization time was measured only once on each station. After all stations have been occupied, static observations were stopped and base receiver was removed from station B. Hiper HR receiver was then connected to CROPOS HPPS and the measuring procedure was repeated. There were no visible problems or difficulties during the first session.

The second session was carried out between 14:00 and 18:00 (UTC) according to the plan. It was performed identically as the first session, starting up with single-base RTK with Autonomous base start method and ending up with networked RTK. However, one problem was encountered during the second session. Tilted measurements could not have been done on station P4 since the software displayed the warning about strong magnetic field. Most likely such a warning was caused by the proximity of the transformer station. Since such stations are much more active during the evening hours (residential area), the mentioned problem hasn't occurred during the first session. According to that, tilted measurements weren't conducted on station P4 in the second session.

7. DATA POST-PROCCESING

7.1. Geodetic network coordinates computation

After all field activities were done, the next step was to perform data post-processing. Firstly, coordinates of geodetic network stations were computed. It was done by post-processing of raw static data (stations S1 and S2) and by computing coordinates of stations P1 – P8 upon measured angles and distances. All the data were processed in Topcon Magnet Office Tools software. Before conducting any processing, 2 VRS and 1 CORS raw data files in RINEX format were downloaded from CROPOS GPPS service. They were imported into software together with Topcon's raw observation files in *.tps format created by Hiper HR and Hiper SR receivers. After processing baselines, fully constrained adjustment was carried out with fixed 2 VRS and 1 CORS stations (control points). Due to short baselines (around 600 m), adjustment provided good position accuracies resulting in 1 mm standard deviation in both horizontal and vertical direction for both stations. Finally, raw observation file from total station was imported and coordinates of remaining stations were computed. The plane coordinates (E, N) were determined in the official coordinate system HTRS96/TM, the heights were determined in HVRS71 system.

7.2. Rover coordinates shift in single-base RTK with Autonomous base start

Since GNSS base RTK receiver was started in Autonomous mode, it was necessary to shift the reference base coordinates to their "truth" coordinates. Such coordinates were

determined by static observations during the RTK survey. Since two sessions were performed, there are two sets of coordinates for the same station B. In theory, those two coordinate sets should be identical. However, two static sessions have led to coordinate difference in horizontal (0.5 cm) and vertical direction (1 cm). In case both coordinate sets had been used for the purposes of coordinate shift, it would have led to inconsistent accuracy and precision analysis. Thus, it was decided to use only coordinates of station B provided by static observations in the first session.

After post-processing of static data collected by Hiper SR receiver during the RTK survey in the first session (in the same way as coordinates of stations S1 and S2 were obtained), job file containing all field measurements conducted by a single-base RTK method was imported into Magnet Office Tools. Under a tab named "GPS Occupations", which contains all stations occupied during the survey, there is a column called "Method" (Figure 4). It describes the way station coordinates are used or determined (Static, Kinematic, Base, Topo). During the survey, "Base1" was the arbitrary name of base reference point, consequently the "Method" for that station was automatically set to "Base" inside the software. In order to perform coordinate shift, it is necessary to change the base reference point from "Base1" to "B", which is, in this case, the station with accurate coordinates determined in post-processing. Finally, coordinates shift is done by pressing the "Adjustment" key. After that, all stations are placed to their "truth" coordinates. The same procedure was followed for the station coordinates determined by single-base RTK method in the second session.

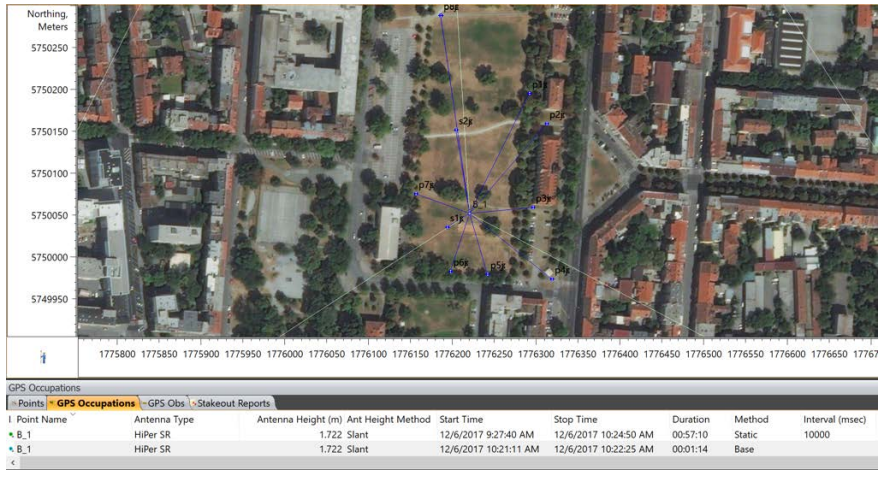

Figure 4. GNSS vectors after coordinate shift carried out in Magnet Office Tools

8. ANALYSIS OF THE OBTAINED RESULTS

After post-processing step, all station coordinates were exported to *.CSV file and imported into Microsoft Excel for further analysis. The analysis of obtained results was divided into three separate segments: coordinate accuracy analysis, coordinate precision analysis and TILT option accuracy analysis. Although the initialization time were also measured in the field, those data are not presented since there is no significant difference between used methods. Both CROPOS HPPS service and single-base RTK method provide the same initialization time of 5-6 seconds on each station and in both sessions.

8.1. Coordinates accuracy analysis

In order to provide valid accuracy analysis, it is necessary to have reference coordinates of occupied stations. Reference coordinates values were determined by GNSS post-processing method (S1, S2) and by total station measurements (P1-P8). Coordinates accuracy was estimated by subtracting the reference coordinates from RTK determined coordinates. Since the complete analysis is too detailed, average, minimum and maximum coordinate deviation values are taken into consideration and are listed below (Table 1 – 4)

Table 1. Coordinates accuracy provided by single-base RTK method during first session

	dN (m)	dE (m)	dH (m)
AVG	0,00	0,00	0,02
MAX	0,03	0,01	0,04
MIN	-0,02	-0,05	0,00
AVG	0,00	0,00	0,02
MAX	0,02	0,01	0,04
MIN	-0,02	-0,02	0,00

Table 2. Coordinates accuracy provided by CROPOS HPPS during first session

	dE (m)	dN (m)	dH (m)
AVG	0,00	-0,01	-0,04
MAX	0,01	0,01	-0,02
MIN	-0,03	-0,03	-0,08
AVG	0,00	-0,01	-0,03
MAX	0,01	0,01	0,00
MIN	-0,02	-0,03	-0,06

Table 3. Coordinates accuracy provided by single-base RTK method during second session

	dE (m)	dN (m)	dH (m)
AVG	-0,01	0,00	0,02
MAX	0,01	0,06	0,10
MIN	-0,05	-0,03	-0,02
AVG	-0,01	0,01	0,02
MAX	0,01	0,06	0,04
MIN	-0,04	-0,01	0,00

Table 4. Coordinates accuracy provided by CROPOS HPPS during second session

	dE (m)	dN (m)	dH (m)
AVG	-0,01	0,01	-0,04
MAX	0,04	0,05	-0,02
MIN	-0,04	-0,01	-0,06
AVG	0,00	0,01	-0,04
MAX	0,02	0,03	0,00
MIN	-0,02	-0,01	-0,06

White table part represents the values where all coordinate deviations were taken into account (from all 5 observations on each station), while blue table part represents the values where only observations with vertical pole positions were considered and TILT option wasn't used. The purpose of such distinction was to estimate whether TILT option affects the overall accuracy. Presented tables show that there is no significant difference in terms of accuracy between two tested methods. Furthermore, coordinate differences obtained in two sessions can be considered insignificant. Single base RTK method performs slightly better in terms of accuracy, with average deviation values of 1 cm horizontally and 2 cm vertically. Only one deviation value could be distinguished as significant. It is the maximum height difference (0.10 m) value in Table 3. The reason for such deviation could be slightly higher VDOP value (3.09) visible in job file for the measurement made on station P1. It is also important to point out that TILT option does not affect coordinate accuracy since the deviations values are almost the same in both blue and white table parts.

8.2. Coordinate precision analysis

Precision analysis can be done when at least two observation sessions were made on the same station. Coordinate precision is estimated by subtracting the second session coordinate values from the first session coordinate values. Similar to accuracy analysis, only average, minimum and maximum coordinate difference values are presented below (Table 5 – 6).

Table 5. Coordinate precision – single base RTK methos

	dE (m)	dN (m)	dH (m)
AVG	0,002	-0,002	0,002
MAX	0,051	0,028	0,044
MIN	-0,025	-0,057	-0,074
AVG	0,007	-0,007	0,004
MAX	0,045	0,008	0,040
MIN	-0,016	-0,057	-0,013

Table 6. Coordinate precision – CROPOS HPPS

	dE (m)	dN (m)	dH (m)
AVG	0,007	-0,024	0,000
MAX	0,043	0,015	0,039
MIN	-0,032	-0,061	-0,034
AVG	0,000	-0,017	0,005
MAX	0,023	0,015	0,039
MIN	-0,022	-0,061	-0,017

The white and blue table part contents are analogous to those in accuracy analysis. It can be argued that coordinate repeatability is quite satisfying, despite observation conditions

during the second session. Lower satellite number and less favorable conditions (in terms of clear horizon and obstacles) on some stations haven't affected the results. Minimum height difference value (-0.074 m) in Table 5 should be pointed out since it is the result of measurement error on station P1 described in accuracy analysis. Another significant value is the minimum Northing difference (-0.061 m) in Table 6. It is about the observation on station P3. It is not possible to determine the cause of this error since the observation conditions were optimal when this station was occupied. It is also meaningful to notice that the observation was done with vertical pole position, which means that TILT option is not responsible for such coordinate difference.

Despite the above mentioned, data provided by both methods are equally satisfactory for the practical purposes. Just like with accuracy analysis, TILT option does not affect station coordinate precision in a negative way.

8.3. TILT option accuracy analysis

Accuracy analysis of TILT option was done by estimating what would have been the position error of point in case the TILT option hadn't been used in order to compensate tilted measurement, and by comparing that value to the true position error. True error was calculated by subtracting the coordinate obtained by tilted measurement from coordinate obtained by vertical pole position observation. In order to calculate the "expected error" value, antenna height needs to be known. During the entire survey, antenna height was set to 2,000 m. Complete analysis is shown in Table 7 and Table 8. It is important to mention that all tilt values were completely coincidental and they vary from 2 to 9 degrees. There were no rules regarding the tilting of the range pole. It is obvious that TILT option was able to compensate tilted range pole measurements very successfully. Maximum error values during first and second sessions were 5 cm and 7 cm, respectively. Average position error is 1 cm for the first session and 2 cm for the second session. According to that, it can be argued that there is no significant difference between TILT option performance independently of positioning method (single-base RTK, CROPOS HPPS) or measurement session.

Table 7. TILT option accuracy analysis – 1st session

	Single base - session 1			CROPOS HPPS - session 1		
#	TILT [°]	Expected error	True error	TILT [°]	Expected error	True error
P1_i	6	0,21	0,01	3	0,10	0,01
P1_j	9	0,31	0,02	7	0,24	0,02
P1_s	5	0,17	0,02	3	0,10	0,01
P1_z	7	0,24	0,01	5	0,17	0,01
P2_i	5	0,17	0,02	5	0,17	0,03
P2_j	7	0,24	0,04	6	0,21	0,02
P2_s	5	0,17	0,01	4	0,14	0,03
P2_z	6	0,21	0,02	4	0,14	0,02
P3_i	6	0,21	0,02	4	0,14	0,02
P3_j	5	0,17	0,03	5	0,17	0,04
P3_s	4	0,14	0,01	2	0,07	0,02
P3_z	3	0,10	0,04	4	0,14	0,05

P4_i	4	0,14	0,02	4	0,14	0,01
P4_j	6	0,21	0,04	5	0,17	0,01
P4_s	2	0,07	0,02	1	0,03	0,01
P4_z	4	0,14	0,02	5	0,17	0,01
P5_i	4	0,14	0,01	3	0,10	0,01
P5_j	6	0,21	0,00	7	0,24	0,01
P5_s	2	0,07	0,01	2	0,07	0,01
P5_z	4	0,14	0,01	5	0,17	0,02
P6_i	5	0,17	0,01	4	0,14	0,00
P6_j	6	0,21	0,02	7	0,24	0,00
P6_s	5	0,17	0,01	3	0,10	0,01
P6_z	5	0,17	0,01	4	0,14	0,01
P7_i	3	0,10	0,01	3	0,10	0,01
P7_j	6	0,21	0,01	7	0,24	0,02
P7_s	3	0,10	0,01	4	0,14	0,01
P7_z	4	0,14	0,01	4	0,14	0,01
P8_i	4	0,14	0,02	3	0,10	0,01
P8_j	6	0,21	0,01	7	0,24	0,02
P8_s	2	0,07	0,01	3	0,10	0,01
P8_z	5	0,17	0,01	4	0,14	0,01
S1_i	8	0,28	0,02	4	0,14	0,01
S1_j	6	0,21	0,01	7	0,24	0,01
S1_s	6	0,21	0,02	3	0,10	0,02
S1_z	5	0,17	0,01	5	0,17	0,01
S2_i	8	0,28	0,01	2	0,07	0,02
S2_j	8	0,28	0,01	9	0,31	0,01
S2_s	3	0,10	0,00	3	0,10	0,02
S2_z	5	0,17	0,01	6	0,21	0,01

Table 8. TILT option accuracy analysis – 2. session

	Single base - session 2			CROPOS HPPS - session 2		
#	TILT [°]	Expected error	True error	TILT [°]	Expected error	True error
P1_i	7	0,24	0,00	5	0,17	0,01
P1_j	8	0,28	0,01	7	0,24	0,02
P1_s	5	0,17	0,02	6	0,21	0,03
P1_z	6	0,21	0,01	4	0,14	0,03
P2_i	5	0,17	0,01	5	0,17	0,02
P2_j	8	0,28	0,03	5	0,17	0,05

P2_s	7	0,24	0,02	6	0,21	0,02
P2_z	4	0,14	0,00	5	0,17	0,05
P3_i	6	0,21	0,03	4	0,14	0,04
P3_j	7	0,24	0,01	7	0,24	0,04
P3_s	4	0,14	0,01	3	0,10	0,03
P3_z	5	0,17	0,01	5	0,17	0,03
P4_i	-	-	-	-	-	-
P4_j	-	-	-	-	-	-
P4_s	-	-	-	-	-	-
P4_z	-	-	-	-	-	-
P5_i	5	0,17	0,01	6	0,21	0,02
P5_j	7	0,24	0,01	7	0,24	0,04
P5_s	3	0,10	0,00	4	0,14	0,02
P5_z	5	0,17	0,01	4	0,14	0,01
P6_i	5	0,17	0,02	6	0,21	0,01
P6_j	7	0,24	0,04	7	0,24	0,02
P6_s	3	0,10	0,01	4	0,14	0,02
P6_z	5	0,17	0,04	4	0,14	0,01
P7_i	4	0,14	0,00	4	0,14	0,01
P7_j	6	0,21	0,01	7	0,24	0,00
P7_s	4	0,14	0,01	5	0,17	0,01
P7_z	5	0,17	0,01	5	0,17	0,02
P8_i	5	0,17	0,07	5	0,17	0,02
P8_j	7	0,24	0,06	5	0,17	0,03
P8_s	5	0,17	0,07	5	0,17	0,02
P8_z	5	0,17	0,06	4	0,14	0,04
S1_i	4	0,14	0,01	5	0,17	0,02
S1_j	6	0,21	0,01	6	0,21	0,03
S1_s	4	0,14	0,01	5	0,17	0,01
S1_z	4	0,14	0,00	6	0,21	0,03
S2_i	4	0,14	0,01	4	0,14	0,02
S2_j	8	0,28	0,02	7	0,24	0,02
S2_s	3	0,10	0,00	2	0,07	0,01
S2_z	7	0,24	0,01	4	0,14	0,01

9. CONCLUSION

The aim of this paper was to examine two different RTK method and TILT option. Tested methods were 'Autonomous base start' method with coordinate shift and CROPOS HPPS (Networked RTK). For the purposes of field investigations and subsequent accuracy

analysis, a geodetic network was established and coordinates determined. Moreover, in order to conduct precision analysis, all station coordinates were determined during two independent sessions. Those analyses enabled deriving valid arguments about used methods.

Today, Autonomous base start method is not regularly used by surveyors due to the existence of GNSS networks. Nevertheless, certain situations require a single-base RTK method to be utilized. Autonomous base start method simplifies the field work and allows the surveyor to get their job done faster due to the fact that it eliminates the need for known base station reference coordinates. Furthermore, such approach enables the surveyor to set up the base receiver on any suitable location. Although this method requires post-processing, it can be done quite simple and fast. Results obtained by Autonomous base start method meet the desired accuracy level of 1 cm in horizontal and 2 cm in vertical direction. Level of coordinate precision is also very high, resulting in average values of 1 cm or less. Those results indicate that this method could be utilized for not only the cadastral needs, but also for the purposes of more precise geodetic tasks.

CROPOS HPPS is most widely used RTK positioning method in Croatia. CROPOS network covers the whole state territory, but its significant limitation is a mobile Internet signal coverage. Obtained coordinate accuracy assessment indicate that CROPOS HPPS meets its specification, resulting in 1-2 cm accuracy in horizontal and 3-4 cm in vertical direction. Average coordinate precision value is 2 cm, which is also very satisfying. However, it should be noted that such results are probably highly influenced by proximity of one of CROPOS reference stations. The distance between nearest CORS and location of the surveyed area was only 600 m. In order to get a true evaluation about CROPOS HPPS service accuracy and precision, the survey should be carried out in a location which is equally remote from all three used reference stations. In spite of that, obtained results definitely wouldn’t be considerably worse than those presented in the paper.

Finally, the goal was to test the TILT option which was integrated into Topcon's newest GNSS receiver Hiper HR. This technology was tested thoroughly and has shown very high level of accuracy, resulting in average values of position errors of 1-2 cm. Such results suggest that this option is accurate enough to be used in practice. During the field work it was observed that TILT option makes RTK survey much faster and easier since operator doesn’t have to concentrate on maintaining the range pole in vertical position. Tilt compensation proved to work really fast. The only significant disadvantage of used TILT option was the necessity to perform digital compass calibration. Although such procedure takes only about 2 minutes, it definitely forms an obstacle for some surveyors. Future progress and development of GNSS+INS integration will certainly lead to standardization of such technology. It can be argued that most of future GNSS receivers will rely on such integration.

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16| Оригинални научни рад
Research paper
doi 10.7251/STP1813247J ISSN 2566-4484

KARTIRANJE KORIŠĆENJA ZAMLJIŠTA/ZEMLJIŠNOG POKRIVAČA UPOTREBOM SENTINEL-2 I ALGORITAMA ZA MAŠINSKO UČENJE

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Abstract: Korišćenje zemljišta/zemljišni pokrivač (LULC) ima značajan uticaj na degradaciju zemljišta, eroziju i dostupnost vode, stoga kartiranje prostorne raspodjele LULC je od suštinskog značaja za upravljanje zemljištem. Precizno kartiranje LULC klasa pomoću upotrebom daljinske detekcije zahtijeva robusne metode klasifikacije. Posljednjih se godina koriste razni algoritmi klasifikacije i satelitske slike. Za ovu studiju korišćeni su Sentinel-2 satelitski snimci umjerene prostorne rezolucije. Kako bi se ocijenio potencijal ulaznih snimaka i izradila karta korišćenja zemljišta u složenom urbanom području Banja Luke, Republika Srpska s najvećom mogućom preciznošću, primijenjeni su algoritmi za mašinsko učenje: Supported Vector Machine (SVM) i Random Forst (RF). Ukupna tačnost klasifikacije od 90,82% s kappa vrijednošću 0,87 i 88,29 s kappa vrijednšću od 0,84 postignuta je pprimjenm SVM i RF. Rezultati, prezentovani u ovom radu, su pokazali da algoritmi za mašinsko učenje i Sentinel-2 satelitski snimic mogu efiksno koristiti za izradu karata korišćenja zemljišta. Rezultati, prezentovani u ovom radu, su pokazali da algoritmi za mašinsko učenje i Sentinel-2 satelitski snimic mogu se efiksno koristiti za izradu karata o korišćenju zemljišta.

Keywords: korišćenje zemljišta/zemljišni pokrivač, Sentinel 2, SVM, RF

LAND USE / LAND COVER MAPPING FROM SENTINEL 2 DATA USING MACHINE LEARNING ALGORITHMS.)

Abstract: Land cover/land use (LULC) have an important impact on land degradation, erosion and water availability therefore mapping of patterns and spatial distribution of LULC is essential for land management. Accurate mapping of complex land cover and land use classes using remotely sensed data requires robust classification methods. Various classification algorithms and satellite images have been used in recent years. For this study, moderate resolution Sentinel-2 image was used. In order to evaluate the potential of the input image and derive land cover map in complex urban area of Banja Luka, Republic of Srpska with highest possible precision, two machine learning algorithms where applied: Supported Vector Machines (SVM) and Random Forst (RF). An overall classification accuracy of 90,82% with kappa value of 0,87 and 88,29 with kappa value of 0,84 was achieved using SVM and RF. The study showed that of machine learning algorithms on Sentinel-2 imagery can results in accurate land cover maps.

Keywords: land cover/ land use, Sentinel 2, SVM, RF

1. INDRODUCTION

Land cover refers to the physical characteristics of earth's surface, captured I distribution of vegetation, water, settlements while land use refers to the way in which land has been used by humans and their habitat [1]. Understanding landscape patterns, changes and interaction between human activities and natural phenomena are essential for proper land management, decision improvement and understanding different changes such as degradation level of forest and wetlands, rate of urbanization, intensity of agricultural activities, landslide, erosion e.g. Land use/ land cover classification is time-consuming and expensive process. Remotely sensed data from various earth observation satellites can provide accurate and timely geospatial information of urban and per-urban areas at diverse spectral, spatial and temporal scales [2]. In recent decades, remotely sensed dataset are become an attractive alternative to ground based survey and mapping methods for documentation, characterization and quantification of the LULC. The accuracy of the produced maps is affected by spatial and spectral resolution of remotely sensed imagery, cloud cover, quality of training data and image classification techniques. RS data classification is based on a unique relationship between a land cover class and its reflected radiation at certain wavelength (reflectance) contained in a spectral band of an image, e.g., a one-pixel–one-class relationship [3]. The classification of LULC in urban areas is challenging dual heterogeneous landscapes and multiple object within pixel. Mixed pixel is a common confounding factor in classification using moderate resolution datasets due to the large pixel size. To resolve these issues investigators have utilize different supervised classification techniques such as maximum likehood, artificial neutral network, decision tree, supported vector machine, random forest etc. Table 1. Shows application of different classification techniques for LULC class delineation.

Table 1. Classification techniques for LULC class delination

Authors	Platform	Classification technique	Accuracy	
			Kappa	Overall
[4]	Rapideye	SVM RF	0.92 0.92	91.80% 93.07%
[5]	AwiFS	Decision tree		91.81%
[6]	WorldView 2	RF ORF-SVM 1A11	0.82 0.83	83.70% 85.20%
[7]	Landsat	RF	0.73	82,00%
[8]	Sentinel 1	SVM RF K-NN	0.75 0.73 0.73	80.80% 79.60% 79.48%
[9]	Landsat 8	SVM MLC	0.89 0.88	91.3% 90.4%
[10]	Landsat	ANN SVM		97.15% 96.25%
[11]	Landsat	STARFM		74.50%
[20]	Landsat TM	RF ML	0.92 0.83	

Whereas the application of classification algorithm as random forest and supported vector machine has been explored in LULC classification using multispectral imagery, there is a paucity of knowledge on the performance od those algorithm on medium resolution Sentinel-2 imagery. This study compared the performance of RF and SVM classifiers on the Sentinel 2 image in a heterogeneous urban landscape of Banja Luka, Republic of Srpska. The main objectives of the study are to assess (i) accuracy of RF and SVM algorithm for LULC classification and (ii) potential of medium resolution open source Sentinel-2 image for LULC mapping.

2. MATERIALS AND METHODS

2.1. STUDY AREA

The City of Banja Luka is the study area chosen for this paper. It is located in the South-Western part of the Republic of Srpska, i.e. in the Western part of Bosnia and Herzegovina. The City of Banja Luka is the biggest political and territorial unit occupying 1239 km2 with the population of 250000. Situated in a basin 164 m above sea level, where the Dinaric Alps from the south descend into the Pannonian Basin in the north, Banja Luka has temperate continental climate with the prevailing influences from the Pannonian plain [27]. The biggest part of study area is covered by forest and agricultural land.

1 oblique random forest using support vector machines and the one against one combination approach;

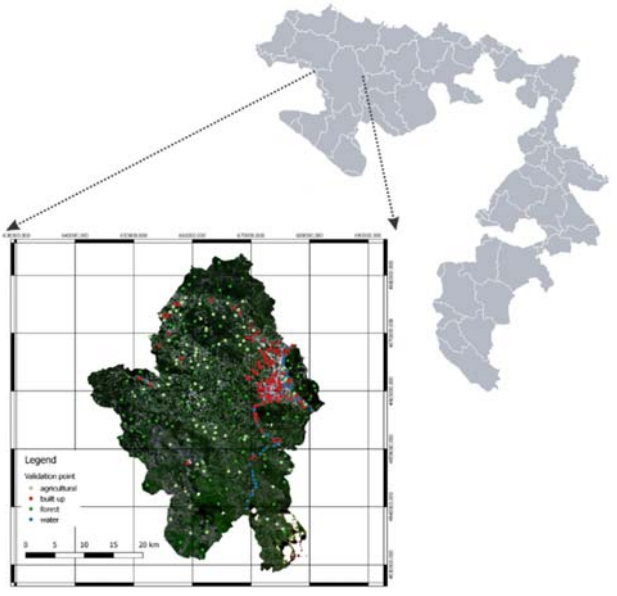


Figure 1. Study area

2.2. Sentinel-2

SENTINEL-2 is a European wide-swath, high-resolution, multi-spectral imaging mission. The full mission specification of the twin satellites flying in the same orbit but phased at 180°, is designed to give a high revisit frequency of 5 days at the Equator. Sentinel-2 multispectral images are used in this study. Sentinel-2 images consists of 13 spectral bands: four bands at 10 m (B2, B3, B4 visible and B8 Near infrared specter)), six bands at 20 m (B5, B6, B7, B8a Near Infrared and B11, B12 Shortwave Infrared) and three bands at 60 m spatial resolution [28]. The atmospherically and terrain corrected Bottom-of-atmosphere BoA (surface) reflectance Sentinel 2 Level 2A image from 18.05.2017. used in classification are provided from [29]. The input data comprise reflectance values of the tree 10 m bands (Band 2, 3 and 4) resampled at 20 m and the reflectance value of the 20 m bands (Band 8a, 11 and 12).

2.3. Software environment R

SVM and RF classification are performed in R. R is a language and environment for statistical computing, graphics and data manipulation and is available as free software under the terms of the Free Software Foundation's GNU General Public License in source code form. R can be extended via packages. Package contains code, data, documentation, tests. Linking code to a package makes it easy to share with other users who can easily capture, install and learn how to use it.

In this paper following packages are used: sp (provide plotting spatial data as maps, spatial selection, summary, print), raster (provide reading, writing, manipulating, analyzing and modeling of gridded spatial data), rasterVis (provide methods for enhanced visualization and interaction with raster data), caret (set of function for creating predictive models), snow (Support for simple parallel computing in R), rgdal (provides bindings to GDAL and

access to projection/transformation operations from the PROJ.4), randomForest and e1071 (Functions for latent class analysis, short time Fourier transform, fuzzy clustering, support vector machines, shortest path computation, bagged clustering, naive Bayes classifier…).

2.4. Classification

A pixel-based image analysis was carried out in order to identify four classes (water, forest, built up and agricultural), using a Support Vector Machine and Random Forest learning algorithm. The ground truth samples (training data) were located according to Google Earth. The same training dataset was used for both classification approaches. The 214 training polygons was created.

2.4.1. SUPPORTED VECTOR MACHINE

Supported Vector Machine is a supervised machine learning algorithm, proposed by Vapnik [12], which can be used for both classification and regression. SVM is suitable to distinguish the patterns and objects and it can be used for pixel-based and object-based classification. Satellite image classification with SVM require a training data. Training data are represented by $\{x_i, y_i\}, i = 1, \ldots r, y_i = \{1,-1\}$ where r is a number of training samples and Training vector consists of two classes $y_i = 1$ for class α_1 and $y_i = -1$ for class α_2. If classes are linearly separable it is possible to define at least one hyperplane defined by vector w with bias b which can separate the classes properly (training error is 0) (1):

$$w \cdot x + b = 0 \tag{1}$$

To find such hyperplane w and b are estimated in the way that $y_i(w \cdot x_i + b) \geq 1$ for $y_i = 1$ (class α_1) and $y_i(w \cdot x_i + b) \geq -1$ for $y_i = -1$ (class α_2). These two can be combined to provide (2):

$$y_i(w \cdot x_i + b) - 1 \geq 0 \tag{2}$$

There are many hyperplanes which could be fitted to separate two classes but there is only one n dimensional optimal hyperplane. Optimal hyperplane between two classes is founded by maximizing the gap between the classes closest point (see Figure 2). The training points who are closest to the optimal hyperplane and lying on the two boundaries, given with $w \cdot x_i + b = \pm 1$, are called support vectors and the middle of the margin is optimal separating hyperplane.

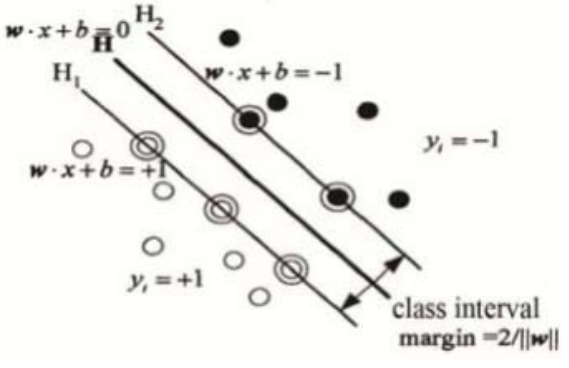


Figure 2. Optimal hyperplane [13]

Mathematically, this means that we want maximize the distance between supported vectors. This distance is equal to $\frac{2}{\|w\|}$. This is expressed as:

$$\min \frac{1}{2}\|w\| \tag{3}$$

Subject to following constraints:

$y_i(w \cdot x_i + b) \geq 1$

Where |(|w|)| is the norm of the hyperplane. Using the Lagrangian multiplier, the cost function can be defined as (4):

$$\frac{1}{2}\|w\|^2 - \sum_{i=1}^{r} a_i(y_i((w \cdot x_i) + b) - 1) \tag{4}$$

Where a_i is the Lagrangian multiplier.

For the non-linearly separable classes, and the constrain of equation 2 cannot be satisfied. To deal with such cases using only linear separate boundaries set of new variables that the distance the case is from the optimal hyperplane and so the amount of coloration of the consistence may be introduces [14].

The Equation (1) becomes (5):

$$\min \frac{1}{2}\|w\|^2 + C\sum_{i=1}^{r} \xi_i \tag{5}$$

Under the constraints of $y_i(w \cdot x_i + b) \geq 1 - \xi_i$ i=1,…, r. Where C controls the magnitude of the penalty associated with training samples that lie on the wrong side of the decision boundary. To generalize the above method to non-linear discriminant functions, the Support Vector Machine maps the input vector x by non-linear mapping $\phi(x)$ into a high-dimensional feature space and then constructs the optimal separating hyperplane in that space [15]. According to the Marcer's theorem the inner product of the vectors in the mapping space can be expressed as a function of the inner products of the corresponding vector in the original space [16]. The inner product operation (6):

$$\phi(x_i)\phi(x_j) = K(x_i, x_j) \tag{6}$$

Where is $K(x_i, x_j)$called kernel function. Radial basis function defined with [14], [16], [17] (7):

$$K(x_i, x_j) = e^{-\gamma|x_i - x_j|^2}, \gamma > 0 \tag{7}$$

is one of the most powerful kernels. If we choose $K(x_i, x_j)$ the non-linear SVM is reduced to its linear version. The classical linearly constrained optimization problem can be translated (using a Lagrangian formulation) into following dual problem (8):

$$\text{Maximize: } \sum_{i=1}^{r} a_i - \frac{1}{2}\sum_{i=1}^{r}\sum_{i=1}^{r} a_i a_j y_i y_j K(x_i, x_j) \tag{8}$$

Subject to $\sum_{i=1}^{r} y_i a_i = 0$ $0 \le a_i \le C$, i=1,…, r. a_i is a Lagrange multiplier corresponding with each constraint in original problem.

Using appropriate kernel function in optimal classification surface can achieve linear classification after nonlinear transformation, while computational complexity does not increase. The final result is the discriminant function f(x) conveniently expressed as a function of the data in original (lower) dimensional feature space (9):

$$f(x) = \sum_{i \in S} a_i y_i K(x_i, x_j) + b \tag{9}$$

For this research, SVM was run in R software. The parameters which had to be defined in order to apply the algorithm were: input data (all bands from the Sentinel-2 image), SVM-type (C-classification), SVM-kernel (Radial Basis Function), cost (C = 100) and gamma (γ=0.5). The determination of parameters was solved by cross validation and grid search on the training data set.

2.4.2. RANDOM FOREST

The random forests algorithm is a machine learning technique proposed by Breiman [18], Consists of a collection of tree-structured classifiers $\{h(x, \Theta_k), k = 1,...\}$ where the $\{\Theta_k\}$ are independent identically distributed random vectors and each tree casts a unit vote for most frequent class to the input vector (x). A RF uses a random subset of input features or predictive variables in the division of every node, instead of using the best variables, which reduces the generalization error. Additionally, to increase the diversity of the trees, a RF uses bagging or bootstrap aggregating to make the trees grow from different training data subsets [20]. In bagging a each randomly selected subset (without replacement) of certain proportion of the training dataset is used to grow each tree [19]. The samples which are not used in the training subset are included as part of another subset called out-of-bag (oob). OOB elements can be classified by the tree to evaluate performance. RF use the Gini Index as a measure for the best split selection, which measures the impurity of a given element with respect to the rest of the classes [18]. For a given training dataset T, the Gini Index can be expressed as:

$$\sum \sum_{j \neq i} \left(f(C_i, T)/|T|\right)\left(f(C_j, T)/|T|\right) \tag{10}$$

Where $f(C_i, T)/|T|$ is the probability that a selected case belongs to class C_i. Thus, by using a given combination of features, a decision tree is made to grow up to its maximum depth (with no pruning). Hence, RF, as it grows without pruning, presents an added advantage. This RF also provides an assessment of the relative importance of the different features or variables during the classification process [21]. To assess the importance of each feature (e.g. satellite image band), the RF switches one of the input random variables while keeping the rest constant, and it measures the decrease in accuracy which has taken place by means of the oob error estimation and of Gini Index decrease [18].

The RF algorithm was implemented using carter and raster package within R. Two parameters are required to construct an RF framework: the number of decision tree (k) in the ensemble and the number of input predictors (m) randomly selected at each node.

2.5. Accuracy assessment

Confusion (error) matrix is frequently used for standard pixel-based accuracy assessment. Confusion matrix is simple cross tabulation of the predicted class label against the reference data for a sample of cases at the specific locations, it provides a foundation on which both classification accuracy and characterize errors can be define [22].

Predicted Class \ Actual Class	A	B	C	D	Σ
A	n_{AA}	n_{AB}	n_{AC}	n_{AD}	n_{A+}
B	n_{BA}	n_{BB}	n_{BC}	n_{BD}	n_{B+}
C	n_{CA}	n_{CB}	n_{CC}	n_{CD}	n_{C+}
D	n_{DA}	n_{DB}	n_{DC}	n_{DD}	n_{D+}
Σ	n_{+A}	n_{+B}	n_{+C}	n_{+D}	n

Figure 3. Confusion matrix. Diagonal of the matrix contain the number of pixel correctly classified for each class, whereas the off-diagonal elements represent pixel where is disagreement in the predicted and actual class [23].

Many measures of classification accuracy can be derived from a confusion matrix: kappa coefficient, overall, commission and omission error.

Overall accuracy describes the proportion of the total number of correct classified for all class and total number of pixel in confusion matrix (sum of diagonal members of matrix divided by total sum of pixels) Eq (11). Commission error (CE) and Omission error (OE) describe the errors related to individual classes. CE represents pixels that belong to another class but are labeled as belonging to the target class (i.e. the percentage of pixels classified as water but which do actually not belong to that class). OE represents the pixels that belong a class but fail to be classified into that class (i.e. percentage of pixels which are water but which were not classified as such)

$$Overallaccuracy = \frac{\sum_{i=1}^{k} n_{ii}}{n} \cdot 100 \qquad (11)$$

Overall accuracy have often been criticized because in the some cases may have been allocated to the correct class purely by chance [23]. For highlights the difference between correctly classified pixels and the chance agreement presented by sum of the rows and columns Cohen [24] introduced Kappa statistics Eq(12). Kappa statistics is used as a measure of classification accuracy reduced for accidentally correct class agreement.

$$Kappacoefficient = \frac{n\sum_{i=1}^{k} n_{ii} - \sum_{i=1}^{k} n_{i+}n_{+i}}{n^2 - \sum_{i=1}^{k} n_{i+}n_{+i}} \quad (12)$$

Registered value reflects the overall classification accuracy and consistency between the image and the reference grid with a random distribution of pixels in the classes. Interpretation of Kappa coefficient proposed by Landis and Koch [25] is showed in Table 3.

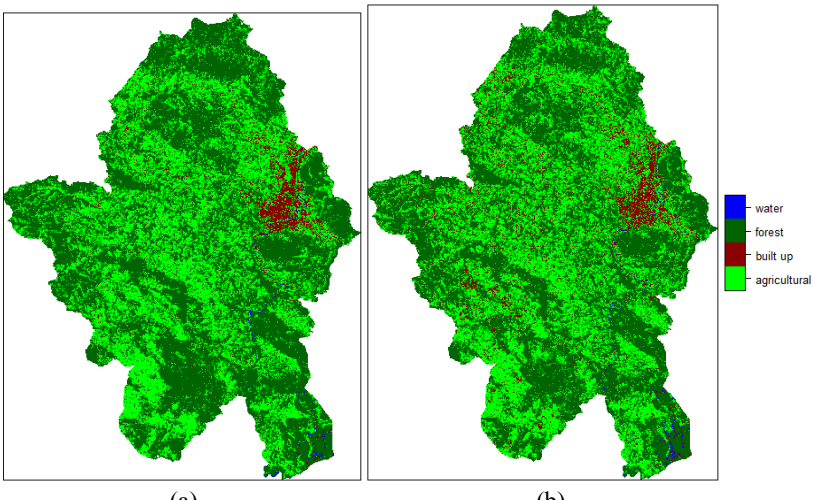
Table 2. Kappa coeficient interpretation [25]

Kappa coefficient value	Interpretation
$0.81 \leq \hat{K} \leq 1$	Perfect agreement
$0.61 \leq \hat{K} \leq 0.8$	substantial agreement
$0.41 \leq \hat{K} \leq 0.6$	moderate agreement
$0.21 \leq \hat{K} \leq 0.4$	Fair agreement
$0.0 \leq \hat{K} \leq 0.2$	Poor agreement

It is a well-known phenomenon in binary classification that a training set consisting of different numbers of representatives from either class may result in a classifier that is biased towards the more frequent class. The balanced accuracy can be defined as the average accuracy obtained on either class which avoids inflated performance estimates on imbalanced datasets [26].

3. RESULTS AND DISCUSION

The results of classification are presented in Figure 3 .



(a) (b)

Figure 4. Results of Sentinel 2 classification based on (a) SVM (b) RF

The results of the image classification was validated by pixel-by-pixel accuracy assessment based on validation points. The validation points were selected over different locations representing different land cover/land use classes. A 316 validation points where created from which 89, 104, 75 and 48 respectively for agricultural, built up, forest and water class. Same points are used for the RF and SVM classifier. Table 4 provide overall and per class classification accuracies achieved by random forest and SVM classifier.

Table 3. Accuracy assessment of Sentinel 2 classification based on SVM and RF

Algorithm	Class	Kappa	Overall accuracy	Omission	Commission	Balanced Accuracy
SVM	Agricultural	0.87 (0.78-0.88)	90.82 (83.89-91.44)	14.61 (6.78-22.44)	21.84 (14.33-29.35)	0.90
	Built up			10.58 (4.21-16.95)	6.06 (0.83-11.29)	0.93
	Forest			5.33 (-0.48-11.14)	13.41 (5.49-21.33)	0.95
	Water			2.08 (-3.43-7.59)	2.08 (-3.43-7.59)	0.99
RF	Agricultural	0.84 (0.81-0.90)	88.29 (84.22-91.62)	17.98 (9.52-26.43)	21.35 (12.90-29.80)	0.87
	Built up			13.46 (6.46-20.46)	12.62 (5.76-19.48)	0.90
	Forest			2.67 (-1.82-7.16)	3.95 (-1.32-9.22)	0.97
	Water			0	2.08 (-3.42-7.59)	0.99

Both classifier produce high overall accuracy and perfect agreement with reality. Although, SVM classifier had a higher accuracy than the RF there were no significant difference ($p<0.05$) in the agreement with reality between the classification obtained using RF and SVM classifier. In general water class achieved lowest value (higher accuracy) of commission and omission error for both classifier while lowest accuracy was produced for agricultural class. RF classifier produce higher commission error for built up class (12.62%) then the SVM (6.06%) while SVM produce higher omission and commission error for forest class (5.33;13.41) then RF algorithm (2.67; 3.95). The high omission error of the agricultural class was caused by the confusion with built up since some crop surface have similar spectral signature as built up. Results of accuracy assessment were validated through computation of area of delineated LULC classes. Results are shown in Table 4.

Table 4. Estimated area of LULC classes [km2]

Class	RF	SVM	RF-SVM
Agricultural	507.78	516.76	-8.98
Built up	72.16	65.91	6.25
Forest	654.27	652.25	2.02
Water	4.58	3.88	0.70

4. CONCLUSION

This research evaluated the potential of space borne multispectral sensor Sentinel-2, with advanced classification techniques RF and SVM to delineate land cover/land use classes in a heterogeneous urban landscape. Results in this study showed that RF and SVM classifier can be successfully used for land use/land cover mapping from Sentinel 2 imagery achieving a kappa coefficient of 0.84 and 0.87 respectively. Comparing the two classifiers, results demonstrate a slightly better overall performance of SVM. Classification results illustrated that water class could be successfully identified using both RF and SVM while highest omission and commission error is detected for agricultural class.

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17| Оригинални научни рад
Research paper
doi 10.7251/STP1813260K ISSN 2566-4484

РАЗВОЈ ПРОГРАМА ЗА ИЗРАВНАЊЕ ГЕОДЕТСКИХ МРЕЖА У OPEN-SOURCE РЈЕШЕЊУ

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Резиме:

У раду је представљена могућност примјене програмског пакета R за аутоматизацију поступка изравнања геодетске основне 2Д мреже примјеном методе најмањих квадрата (класичан датум и минималан траг кофакторске матрице). Обрађена је и примјена програмских библиотека, којима се проширују могућности за израду погодног графичког корисничког интерфејса у R. Програмски пакет R омогућава брзу статистичку обраду велике количине података и због тога има све већу примјену у многобројним научним областима. Аутоматизација изравнања геодетских мрежа обухваћена је у многим комерцијалним програмским рјешењима за обраду података геодетских мјерења, због чега примјена open-source рјешења може имати посебан значај за научну и стручну јавност.

Кључне ријечи: програмски пакет R, изравнање геодетских мрежа.

DEVELOPMENT OF SOFTWARE FOR GEODETIC NETWORK ADJUSTMENT IN OPEN-SOURCE ENVIRONMENT

Abstract:

The paper presents the possibility of using the software R for the automatization of the procedure for geodetic 2D network adjustment with the least squares method (classical geodetic datum and min. trace of the cofactor matrix). Software libraries have also been processed, which expand the possibilities for creating a suitable graphical user interface in R. The R packages enables fast statistical processing of large amounts of data and therefore has a growing application in many scientific fields. Automatization of the geodetic network adjustment is encompassed in many commercial software solutions for data processing of the geodetic measurements, which makes application of open-source solutions have special significance for the scientific and professional public.

Keywords: software R, geodetic network adjustment.

1. INTRODUCTION

R is advanced open-source programing language for statistical analysis and data manipulation. R is integrated suite of software facilities for data manipulation, calculation and graphical display. Among other things it has [1]:

- an effective data handling and storage facility,
- a suite of operators for calculations on arrays, in particular, matrices,
- a large, coherent, integrated collection of intermediate tools for data analysis,
- graphical facilities for data analysis and display either directly at the computer or as a hard copy, and
- a well-developed, simple and effective programing language which includes conditionals, loops, user defined recursive functions and input and output facilities.

The main lack of programming language R is the lack of adequate graphical support. All commands need to be typed in the console, as opposed to some other programming languages, but this approach, on the other hand, allows the processing and monitoring of the processing of a large amount of data in short period of time. Another huge advantage of R compared to other programming language is a possibility to allocate the names to the rows and columns, as well as the possibility to perform various operations with these names [2].

The mathematical model used for geodetic network adjustment, which best describes the state of such system is the Gauss-Markov model (GMM). The system should be linear or linearized. GMM consists of the functional and stochastic part and defines the relations between stochastic observations and unknown parameters of the geodetic network.

In the linear and linearized measurement models adjustment is performed using the Least Squares Method (LSM). The mathematical model implies a mathematical description of assumptions about measurements and their functional relations with unknown parameters [3].

The problem of geodetic network adjustment has been addressed in domestic and International literature in the areas of processing and analysis of geodetic measurements. References for the development of, general purpose, software in the programing language R, is available on the official website r-project [4]. Kilibarda and Pejović in their paper, entitled "Application of open source/free software (R + Google Earth) in designing 2D geodetic control network" [5], presents the possibility of using R when designing the geodetic networks and the possibility of its connection with Google Earth. The same problem is addressed by Sekulić and others, in the paper entitled, "Development of Interactive 1D/2D Geodetic Control Network Design and Adjustment Software in Open Source/Free Environment (R + Google Earth + Google Maps)" [6]. These papers are the first research in this field, in our area.

Geodetic network adjustment, with a large number of measurements, was a challenge for geodetic experts, until the commercial software intended for this purpose has emerged. Software development process with graphical support in the open-source environment (programing language R) is presented in this paper. Based on the input measurement data (directions and lengths) and the approximate points coordinates, the program determines the most probable values of unknown parameters based on LSM, and after that creates the adjustment report and graphical representation of the error ellipses.

2. LIBRARIES AND FUNCTIONS

Programming language disposes of a numerous of basic functions, that are adequately explained in the publicly accessible literature. On the other hand, it turned out that these functions are not enough to cover the needs of all users, so the additional libraries are developed for certain areas, that serve as a complement to the basic functions and extend the possibilities of the programming language R. These libraries can be downloaded from especially developed R internet services.

Some of the additional libraries used for the development of the software, in the R, are:

- gWidgetsRGtk2, a library that enables the creation of Graphical User Interface (GUI) content,
- plotrix,
- pracma, pseudo-inversion of the matrix, and
- knitr, a package for the dynamic creation of the reports in R.

2.1. Library „gWidgetsRGtk2“

The library enables the creation of the GUI, which simplifies the use of the program and its application in everyday work. It represents the implementation of the gWidgets library for the RGtk2 environment, which provides a link between gWidgets and Gimp Tool Kit (GTK) libraries [7].

2.2. Library „plotrix“

The plotrix package is intended to provide a method for getting many sorts of specialized plots quickly yet allow easy customization of those plots without learning a great deal of specialized syntax. The library is developed and maintained by Jim Lemon [8].

2.3. Library „pracma“

This package provides R implementations of more advanced functions in numerical analysis, with a special view on optimization and time series routines. Uses Matlab function names where appropriate to simplify porting. The library is developed and maintained by Hans Werner Borchers. One of the functions in this library is "pinv" which enables the finding the pseudo-inverse matrix (G inversion or Moore-Penrose inversion). This function is used for a geodetic network adjustment with a datum defined as a minimum trace on all points [9].

2.4. Library „knitr“

The knitr package was designed to be a transparent engine for dynamic report generation with R. It has solved some long-standing problems with package Sweave. The design of knitr allows any input languages (e.g. R, Python and awk) and any output markup languages (e.g. LaTeX, HTML, Markdown and so on). This library is available in some other programming languages besides R, such as C++ and Python. The main advantage of this library is that the user has the control over the output, from the beginning to the end [10] [11].

3. DEVELOPMENT OF THE SOFTWARE FOR AN ADJUSTMENT

There are two basic types of geodetic network adjustment,

- adjustment based on observation equations, and
- adjustment based on condition equations.

In a parametric adjustment, observations are expressed in terms of unknown parameters that were never observed directly. This generally leads to larger systems of equations, but the adjustment is straightforward in its development and solution and, as a result, is well suited to computers. In complicated networks, it is often difficult and time-consuming to write equations to express all conditions that must be met for a conditional adjustment, so it is harder to program it. The lack of adjustment based on observation equations is that datum parameters must be defined. This is solved by finding the inverse of a matrix [12] [13].

LSM can be expressed in mathematical notation as,

$$\mathbf{v}^{T}\mathbf{P}\mathbf{v} = \min. \tag{1}$$

A functional model in adjustment computations establishes the relation between measurements and unknown parameters, should be linear or linearized and in matrix form can be represented as,

$$\begin{aligned} \mathbf{v} &= \mathbf{A}\mathbf{x} + \mathbf{f} \\ \mathbf{L} &= \mathbf{A}\mathbf{X} \\ \mathbf{L} &= \mathbf{l} + \mathbf{v} \end{aligned} \quad . \tag{2}$$

Bearing in mind the scope of the adjustment procedure, it can be briefly shown as the algorithm in Figure 1.

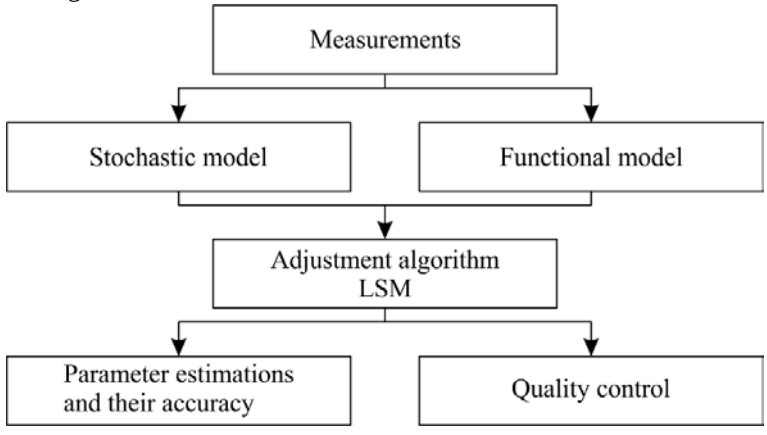

Figure 1. Components of LSM

3.1. Overview of the functionality of the software for the adjustment

Figure 2 shows a diagram with steps that need to be performed before running the adjustment, in order to make it possible.

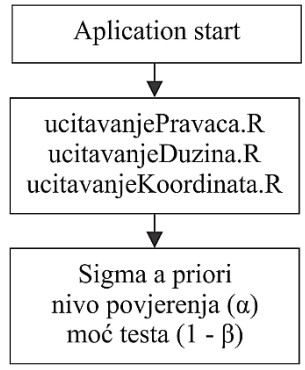

Figure 2. Software start

Figure 3 shows the main menu of the application. GUI is developed using the library gWidgetsRGtk2.a

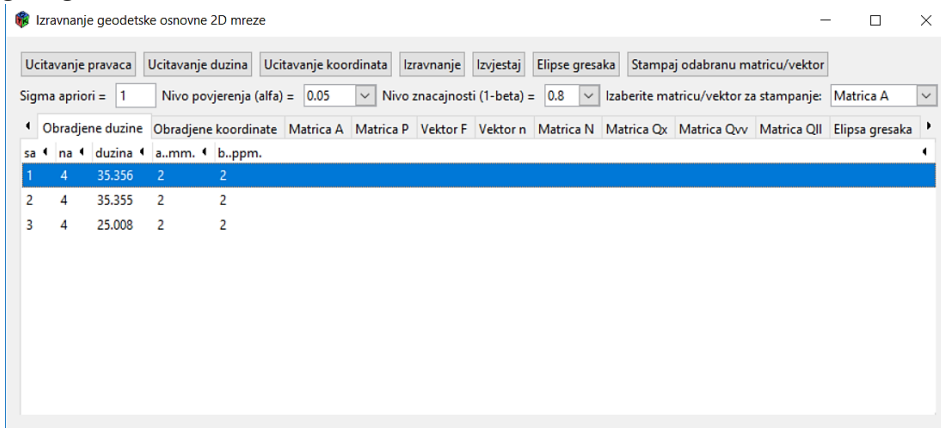

Figure 3. The main menu of application GUI (Software in R)

The first step, after starting the program, is to load measurement results and the points coordinates.

	A	B	C	D	E	F
1	1	4	0	0	53	3
2	1	6	44	4	11	3
3	1	5	90	18	4	3
4	2	3	0	0	12	3
5	2	6	44	50	29	3
6	2	4	90	45	23	3
7	3	2	0	0	10	3
8	3	5	267	49	24	3
9	3	6	313	34	47	3
10	4	2	0	0	10	3
11	4	6	46	44	32	3
12	4	1	89	32	58	3
13	5	3	0	0	25	3
14	5	1	182	46	9	3
15	5	6	269	39	36	3
16	6	2	0	0	29	3
17	6	3	88	44	45	3
18	6	5	132	38	34	3
19	6	1	179	30	58	3
20	6	4	272	39	34	3

Figure 4. Direction measurements input file

Figure 4 shows the file that is used to load direction measurement values, in column A there is a label of station point, in column B the label of the sight point, in column C, D and E the values of the measured directions (degrees, minutes and seconds, respectively), and the value of standard deviation of the measured direction is in column F.

	A	B	C	D	E
1	2	5	224.523	2	2
2	3	4	282.051	2	2

Figure 5. Distance measurements input file

Figure 5 shows the file that is used to load distance measurement values, in column A there is a label of station point, in column B the sight point, in column C the value of the distance measurements and the value of standard deviation $(a[\text{mm}]+b[\text{ppm}])$ of distance measurements in columns D and E.

	A	B	C	D	E
1	1	100.0000	100.0000	1	1
2	2	300.0000	300.0000	1	1
3	3	298.5985	101.2651	0	0
4	4	102.4875	303.9821	0	0
5	5	201.4561	98.2547	0	0
6	6	197.7365	198.5932	0	0

Figure 6. Points coordinate input file

Figure 6 shows the file that is used to load the points coordinates, in column A there is label of the point, Y and X coordinate of a point are in the columns B and C. Columns D and E serve for datum definition, ones in these columns means that the specific coordinate of that point defines the datum. Depending on the number of datum parameters, the program selects and defines the datum.

In addition to above-mentioned data, it is necessary, in the software, to specify the values of the a priori dispersion factor, the risk level (α), and the statistical power $(1-\beta)$.

After completion of data entry, the adjustment procedure can be started. In Figure 7, a diagram of the adjustment procedure is shown, which is in accordance with the adjustment procedure shown in the previous section.

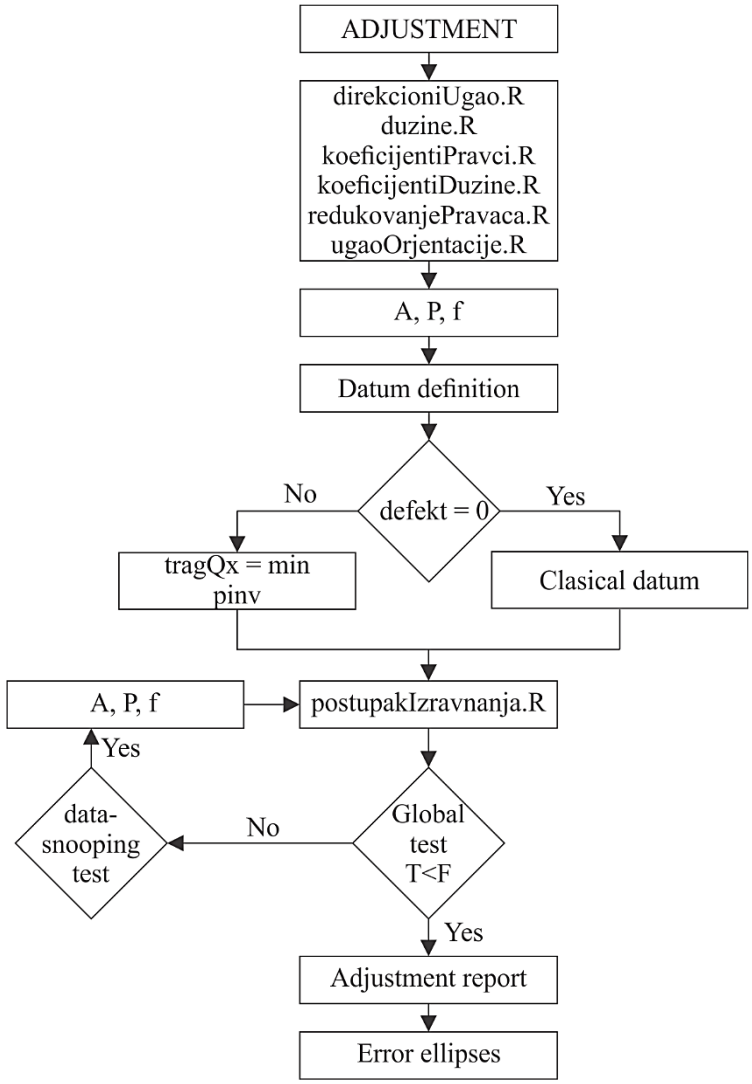

Figure 7. Diagram of the adjustment procedure in the software

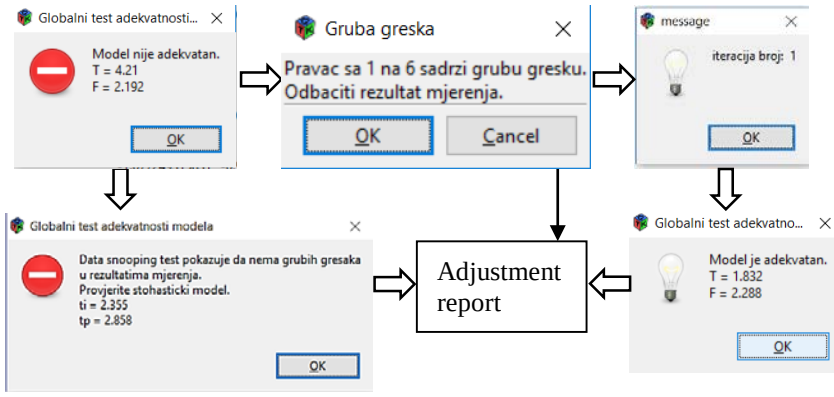

Figure 8. Global test in the software

As shown in the diagram (Figure 7), the data-snooping is repeated while the global test of the model shows contradictions or until the data-snooping show that there are no outliers in measurement results (Figure 8).

Part of the code used for the computation of error-ellipses is shown in Figure 9, which is according to the diagram (Figure 7) the last step in the geodetic network adjustment in the software.

```
elipseGresaka <-
  data.frame(row.names = c("lambda 1", "lambda 2", "a", "b", "teta", "odnos"))
matricaKx <- sigma0 * matricaQx
k <- 0
for (i in seq(1:nrow(a))) {
  (a[i, 1] == 0)
  k <- k + 1
  naziv <- row.names(a)[i]
  elipseGresaka[1, k] <- 0
  colnames(elipseGresaka)[k] <- naziv
  segmentKx <-
    matricaKx[c(paste("Y", row.names(a)[i], sep = ""),
                paste("X", row.names(a)[i], sep = ")),
              c(paste("Y", row.names(a)[i], sep = ""),
                paste("X", row.names(a)[i], sep = ""))]
  val <- eigen(segmentKx)$values
  lambda1 <- val[1]
  lambda2 <- val[2]
  aElipsa <- sqrt(lambda1)
  bElipsa <- sqrt(lambda2)
  tetaElipsa <-
    atan2(lambda1 -  segmentKx[1, 1], segmentKx[1, 2]) * 180 / pi -
                  floor((atan2(lambda1 -  segmentKx[1, 1], segmentKx[1, 2]) *
                                                    180 / pi) / 360) * 360
  elipseGresaka["lambda 1", naziv] <- lambda1
  elipseGresaka["lambda 2", naziv] <- lambda2
  elipseGresaka["a", naziv] <- aElipsa
  elipseGresaka["b", naziv] <- bElipsa
  elipseGresaka["teta", naziv] <- tetaElipsa
  elipseGresaka["odnos", naziv] <- aElipsa / bElipsa
}
```

Figure 9. Part of code, used for error-ellipses computation

3.2. Practical examples

Adjustment of the measurement results in the geodetic 2D network was performed in the MS Office (Excel) software package, and the following results are obtained (Figure 10).

Mjerenje	Od	Do	$\hat{v}$	$Q_{\hat{v}\hat{v}}$	$\hat{l}$			$Q_{\hat{l}\hat{l}}$	rii	Gi	u-v
pravac	1	4	2,0223	2,6221	0	00	02,022	6,3779	0,2913	15,5711	0,0000
pravac	1	5	-2,0223	2,6221	90	17	08,978	6,3779	0,2913	15,5711	0,0000
pravac	1	6	gruba greska								
pravac	2	3	-0,0243	3,0564	-1	59	59,976	5,9436	0,3396	14,4225	0,0000
pravac	2	6	1,3386	3,6629	44	50	18,339	5,3371	0,4070	13,1745	0,0000
pravac	2	4	-1,3143	3,4519	90	45	09,686	5,5481	0,3835	13,5712	0,0000
pravac	3	2	0,0262	3,0352	0	00	00,026	5,9648	0,3372	14,4729	0,0000
pravac	3	5	0,8387	2,7953	267	49	14,839	6,2047	0,3106	15,0812	0,0000
pravac	3	6	-0,8649	3,4701	313	34	36,135	5,5299	0,3856	13,5356	0,0000
pravac	4	2	3,5374	3,3860	0	00	03,537	5,6140	0,3762	13,7027	0,0000
pravac	4	6	-2,4080	4,2318	46	44	19,592	4,7682	0,4702	12,2570	0,0000
pravac	4	1	-1,1293	3,1490	89	32	46,871	5,8510	0,3499	14,2088	0,0000
pravac	5	3	-0,1295	2,1877	-1	59	59,871	6,8123	0,2431	17,0472	0,0000
pravac	5	1	1,0569	2,1371	182	45	45,057	6,8629	0,2375	17,2477	0,0000
pravac	5	6	-0,9274	2,8215	269	39	10,073	6,1785	0,3135	15,0110	0,0000
pravac	6	2	-1,5705	2,5168	-1	59	58,430	6,4832	0,2796	15,8935	0,0000
pravac	6	3	0,1755	2,4103	88	44	16,175	6,5897	0,2678	16,2410	0,0000
pravac	6	5	0,0810	3,2525	132	38	05,081	5,7475	0,3614	13,9811	0,0000
pravac	6	1	0,4828	1,7203	179	30	29,483	7,2797	0,1911	19,2241	0,0000
pravac	6	4	0,8312	2,3248	272	39	05,831	6,6752	0,2583	16,5368	0,0000
duzina	1	2	1,8345	2,2980	224,5248			1,9037	0,5469	7,7652	0,0000
duzina	3	4	-0,5169	1,5470	282,0505			2,7713	0,3582	9,7268	0,0000

Opsti test adekvatnosti modela				
$\hat{\sigma}_0$ =	0,853802		f1 =	7
σ_0 =	1		f2 =	1E+10
	T =	1,371784		
	F =	4,142332		
	prihvata se nulta hipoteza			

Ocjene nepoznatih parametara							
	y [mm]	x [mm]	Y [m]	X[m]	σ_Y [mm]	σ_X [mm]	σ_{POL} [mm]
3	4,4977	1,3673	298,6030	101,2665	2,3755	1,8441	3,0073
4	7,6834	1,4119	102,4952	303,9835	2,4673	2,1406	3,2664
5	5,5804	-1,0777	201,4617	98,2536	1,9483	1,1656	2,2704
6	4,2759	4,9034	197,7408	198,5981	1,4902	1,5455	2,1469

Elipse gresaka					
	a [mm]	b [mm]	teta		
3	2,4070	1,8028	75	54	58,11
4	2,5535	2,0369	64	42	7,68
5	1,9493	1,1640	87	45	19,27
6	1,7182	1,2873	41	16	46,72

Figure 10. Adjustment report (Excel)

The results obtained by geodetic network adjustment performed in the software developed in R, are shown in the report in Figure 11.

```
Izravnanje geodetske 2D mreze
Autori: Zoran Kokeza, Miroslav Vujasinovic
==========================================================================================
Izbor datuma: datum definisan koordinatama tacaka
Datum definisu: Y1, X1, Y2, X2
Broj merenih velicina je n = 22
Broj tacaka geodetske mreze je: 6
Broj stanica sa kojih su mereni pravci je: 6
Broj merenih pravaca je: 20
Broj merenih duzina je: 2
Broj nepoznatih parametara je u = 10
Sigma apriori = 1.0000
Sigma aposteriori = 0.8538
==========================================================================================
Nakon izravnanja
==========================================================================================
broj iteracija = 2
broj grubih gresaka = 1
Broj merenih velicina je n = 21
Broj stanica sa kojih su mereni pravci je: 6
Broj merenih pravaca je: 19
Broj merenih duzina je: 2
==========================================================================================
Ocjene dobijene iz izravnanja i kriterijumi kvaliteta i tacnosti
==========================================================================================
Mjerenje     Od     Do          v      Qvii          loc          Qlii      rii       Gi       u-v
  Pravac      1      4      2.022     2.622      0 00 02.022     6.378     0.29    21.52     0.00
  Pravac      1      6                          gruba greska
  Pravac      1      5     -2.022     2.622     90 17 08.978     6.378     0.29    21.52     0.00
  Pravac      2      3     -0.024     3.056    359 59 59.976     5.944     0.34    19.93     0.00
  Pravac      2      6      1.339     3.663     44 50 18.339     5.337     0.41    18.21     0.00
  Pravac      2      4     -1.314     3.452     90 45 09.686     5.548     0.38    18.76     0.00
  Pravac      3      2      0.026     3.035      0 00 00.026     5.965     0.34    20.00     0.00
  Pravac      3      5      0.839     2.795    267 49 14.839     6.205     0.31    20.85     0.00
  Pravac      3      6     -0.865     3.470    313 34 36.135     5.530     0.39    18.71     0.00
  Pravac      4      2      3.537     3.386      0 00 03.537     5.614     0.38    18.94     0.00
  Pravac      4      6     -2.408     4.232     46 44 19.592     4.768     0.47    16.94     0.00
  Pravac      4      1     -1.129     3.149     89 32 46.871     5.851     0.35    19.64     0.00
  Pravac      5      3     -0.129     2.188    359 59 59.871     6.812     0.24    23.56     0.00
  Pravac      5      1      1.057     2.137    182 45 45.057     6.863     0.24    23.84     0.00
  Pravac      5      6     -0.927     2.821    269 39 10.073     6.179     0.31    20.75     0.00
  Pravac      6      2     -1.570     2.517    359 59 58.430     6.483     0.28    21.97     0.00
  Pravac      6      3      0.175     2.410     88 44 16.175     6.590     0.27    22.45     0.00
  Pravac      6      5      0.081     3.252    132 38 05.081     5.748     0.36    19.32     0.00
  Pravac      6      1      0.483     1.720    179 30 29.483     7.280     0.19    26.57     0.00
  Pravac      6      4      0.831     2.325    272 39 05.831     6.675     0.26    22.86     0.00
  Duzina      2      5      1.835     2.298        224.52483     1.904     0.55    10.73     0.00
  Duzina      3      4     -0.517     1.547        282.05048     2.771     0.36    13.44     0.00
==========================================================================================
Usvojeni nivo znacajnosti je: 0.05
Globalni test adekvatnosti modela
Vrednost testa nulte hipoteze je: 1.3718
Dozvoljena vrednost je: 4.1423
Suma rii = : 7.0000
==========================================================================================
OCJENE NEPOZNATIH PARAMETARA SA OCJENOM TACNOSTI
==========================================================================================
oznaka tacke      y[mm]      x[mm]      Y[m]       X[m]      my[mm]     mx[mm]     mp[mm]
          1     0.0000     0.0000   100.0000   100.0000     0.0000     0.0000     0.0000
          2     0.0000     0.0000   300.0000   300.0000     0.0000     0.0000     0.0000
          3     4.4977     1.3673   298.6030   101.2665     2.3755     1.8441     3.0073
          4     7.6834     1.4119   102.4952   303.9835     2.4673     2.1406     3.2665
          5     5.5804    -1.0777   201.4617    98.2536     1.9483     1.1656     2.2704
          6     4.2759     4.9034   197.7408   198.5981     1.4902     1.5455     2.1469
==========================================================================================
Elementi elipse gresaka
oznaka tacke      A[mm]      B[mm]       teta
          3     2.4070     1.8028    75 54 58.1
          4     2.5535     2.0369    64 42 07.7
          5     1.9493     1.1640    87 45 19.3
          6     1.7182     1.2873    41 16 46.7
```

Figure 11. Adjustment report (software in R)

Adjustment results check between Excel and software, shows that the same results are obtained in both ways. The advantage of the software over the Excel is reflected in the speed of adjustment, during which the possibility of human error is reduced to a minimum. Figure 12 shows the drawing of the points, with error ellipses, whose parameters are shown in the adjustment reports (Figure 10 and Figure 11).

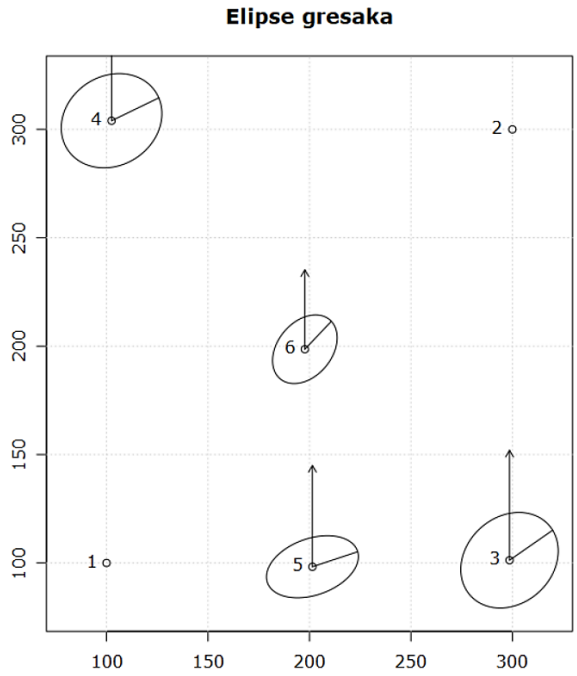

Figure 12. Error ellipses (software in R)

4. DISCUSSION AND CONCLUSION

R in practical application for processing and analysis of geodetic measurements proved to be quality program because it is based on a simple syntax for manipulating with a large amount of data. In the matrix computations, it shows the improvement in relation to other software solutions, where this programming language allows the allocation of the names to the rows and columns, as well as management of these names.

The disadvantage of this solution is lack of the support for GUI application programming. This lack has been recognized by experts, and the library called gWidgets has been developed, that has expanded the possibilities of programming language R. There are some other solutions, which are also open source, but they are primarily used for displaying the content within the Internet environment.

The standard way of managing software solutions in programming language R is to monitor the flow of the program execution in the console, which makes data entry more difficult. Unlike this approach, the gWidgets library enables the development of software with graphical support for simple management of complex software solutions (data entry, processing and presentations).

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18| Оригинални научни рад
Research paper
doi 10.7251/STP1813272V ISSN 2566-4484

GEODETIC DETERMINATION OF VERTICAL DISPLACEMENT OF BUILDINGS DURING CONSTRUCTION

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Abstract:

The methodology of planning and performing geodetic activities in determining vertical displacement of engineering objects or specific structural elements and units is presented in this paper. Data from observation of a building for students' accomodation in Banja Luka, collected during its construction, are presented. The geodetic control of geometry and deformation analysis of the performed building construction are primary tasks of the engineering geodesy in the construction of objects. Vertical displacement and deviations of objects are caused by numerous factors. The geodetic tehnical documentation, developed during implementation of these tasks, represents a valuable basis for the development of observation projects during exploitation of objects and for forming an engineering building information system.

Keywords: vertical displacement, engineering geodesy, Pelzer method.

ГЕОДЕТСКО ОДРЕЂИВАЊЕ ВЕРТИКАЛНИХ ПОМЈЕРАЊА ОБЈЕКАТА У ТОКУ ИЗГРАДЊЕ

Резиме:

У раду је приказана методологија планирања и извођења геодетских радова за одређивање вертикалних помјерања инжењерских објеката или појединих конструктивних елемената и цјелина. Представљени су подаци осматрања објекта за смјештај студената у Бањој Луци, прикупљени у току изградње. Геодетска контрола геометрије и деформациона анализа изведене конструкције објекта основни су задаци инжењерске геодезије при изградњи објеката. Вертикална помјерања и одступања објеката узрокована су многобројним факторима. Геодетска техничка документација, настала реализацијом ових задатака, представља драгоцјену основу за израду пројекта осматрања у току експлоатације објекта и формирање информационог система инжењерског објекта.

Кључне ријечи: вертикална помјерања, инжењрска геодезија, метода Пелцера.

1. INTRODUCTION

By the influence of various internal, external, as well as other causal factors, to soil and objects (buildings), vertical and horizontal displacements of objects occur. We define displacement as a change of the position of a point in space, which is divided into a horizontal and a vertical component. The consequence of deformation is the stress of the structure, unpredicted by calculations, which causes cracks and/or damages, and in extreme cases even collapse of objects or some structural parts.

Vertical displacements can be lifting or subsidence of objects [1]. According to the intensity of displacement in the course of time, subsidence can be equal or unequal. Equal subsidence may occur if the pressure from an object is equally distributed to all points of the object, which is positively reflected to the stability and firmness of the object. Unequal subsidence occurs when the pressure of different intensity affects some parts of an object and it has a far greater impact, very often a negative one, to the stability and firmness of the object.

Causes for subsidence of objects are divided into two basic groups: general (characteristics of soil, temperature and groundwater level, wind effect, etc.), and special (defects in soil testing, designing and constructing buildings, etc.). The most common forms of deformations, which are a consequence of unequal subsidence of soil, are: inclination, bending, distortion, twisting, and cracks. The direction, size and character of deformations are the basic indicators which enable the interpretation of measurement results, due to: assessment of the construction state, assessment of the state of the object related to the process of construction, remediation, reconstruction of the object, or verification of theoretical assumptions.

Deformation measurement methods can be divided into geodetic and geotechnical (physical) [2]. Geotechnical methods and instruments can only be used to measure relative deformations. Geodetic methods and instruments are used to determine displacements and deformations of objects in the absolute system, on the ground of a referent network in a deformation free zone. The method of precise geometric leveling is most often used for determining vertical displacement of objects during construction [3], [4], [5]. For some objects, due to conditions of performing measurement and positions of points, the trigonometric leveling is also used.

This paper gives the theoretical bases of designing geodetic works for determining vertical displacements of buildings during construction, which consists of: a) designing the geodetic control 1D network, and b) statistical determining of displacement of points on objects through the deformation analysis methods. The represented methodology has been applied in observing the Pavilion 4 of the students' accommodation building in Banja Luka. Final values of vertical displacements of points on the building have been obtained by the Pelzer method.

2. DESIGNING GEODETIC WORKS FOR DETERMINING VERTICAL DISPLACEMENT

A quality performance of geodetic works is possible only if there are quality projects of geodetic works. The geodetic determination of vertical displacement of characteristic points of engineering objects includes: establishment of the geodetic control 1D network

(GC1DN) and determining the stability of points by application of a specific statistical method.

Bearing in mind the specificities of applying geodetic methods and techniques in engineering and technical areas, the success of geodetic works depends on the quality of establishing geodetic networks. For geodetic networks in the deformation analysis the term geodetic control networks is used. They are designed by the optimization method principles. There are four basic orders of optimization [6]:

- Zero order − choice of the datum,
- First order − choice of an observation plan,
- Second order − defining the precision of measurements, and
- Third order − adding new network points (changing of geometry).

For designing geodetic control networks, all orders are used simultaneously. The designing is conducted with research and analytical methods [6]. The research procedure is used for defining the criteria which a geodetic network needs to meet in terms of: geodetic datum and observation plan, measurement precision and calculating accuracy [7]. If some of the defined criteria are not met, then the geometry of the network, observation plan or measurement precision changes. The analytical method means the implementation of a unique series of mathematical steps for directly meeting the defined criteria.

Defining of the quality criteria requires cooperation with civil engineers, with respect to the principles of geodesy. The task of civil engineers is to define, for a particular object, the size of displacement that is necessary to be determined "with certainty" between two measurement epochs, to define characteristic points and the period of repeating measurements. The quality of geodetic networks is defined by measures of precision and reliability, and the price of the project implementation depends on the criteria set [6]. The reliability of geodetic networks is a measure of possibility to detect gross errors of geodetic measurements (internal), and the impact of undetected gross errors to assessments of unknown parameters (external) [7] [8].

2.1. DESIGINING GEODETIC CONTROL 1D NETWORK

The procedure of designing geodetic control networks can be defined as an algorithm, shown in Figure 1, with steps corresponding to the content of a technical report of the geodetic works design.

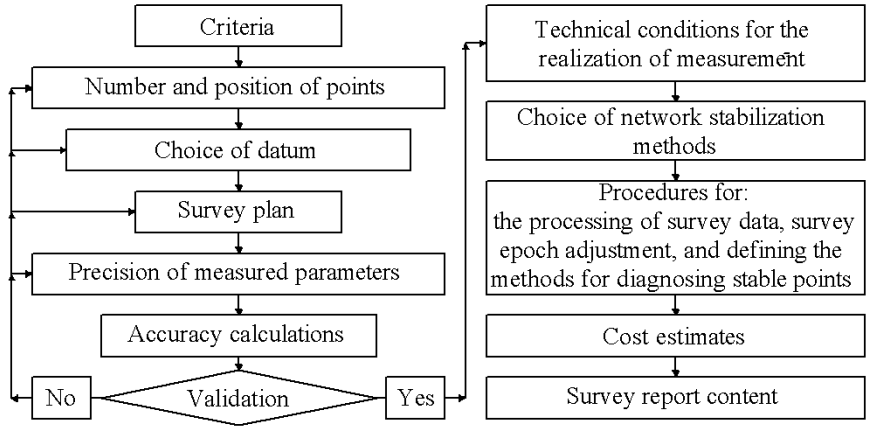


Figure 1. Algorithm of designing geodetic control networks [6]

The GC1DN for determining vertical displacement of objects consists of a group of points (benchmarks) that are not influenced by the engineering object mass and possible deformations, and a set of points at characteristic places of an engineering object.

Some criteria for designing the GC1DN are defined for each observed object, while some are known and common in the geodetic theory and practice. The most important criteria are:

- Size of displacement which can be detected by measurements in the GC1DN (dp) between two measurement epochs,
- Standard deviation of the height of GC1DN points,
- Local measure of internal reliability of individual measurements, and
- Marginal gross error which can be discovered for each measurement through the gross error presence test.

The standard deviation of the height of network points is defined based on the displacement size value as

$$\sigma_{\mathrm{POL/GKM}} \leq \frac{\mathrm{dp}}{5}. \tag{1}$$

The value of the internal reliability local measure that is to be achieved for each measurement in the GC1DN is $r_{ii} \geq 0.2$. The last criteria also refers to the reliability of geodetic networks and it means that the value of the marginal gross error which can be detected by the gross error test, should be in the interval from $5\sigma_{l_i}$ to $7\sigma_{l_i}$, where σ_{l_i} is a standard deviation of individual measurements.

The geodetic basic 1D network (GO1DN) should have minimally 3 points stabilized outside the impact of a construction site, object mass or possible deformations. When choosing the position of basic network points, it is very important to have data on composition and bearing capacity of soil and stability of the object into which they are installed, so that the installed points could be stable in the course of time. Correct data and conclusions of the "stable soil" can be given by geologists and geomechanitians. In choosing points for discretization of objects in geometrical sense, attention should be paid that the chosen points are placed on constructions where the biggest deformations or displacements are expected [2].

The GC1DN datum for determining vertical displacements is defined in two ways:

- As the minimal trace of the cofactor matrix at all points, and
- As the minimal trace of the cofactor matrix at a part of points (stable points).

Defining the datum through the minimal trace of the cofactor matrix at all points is used in Zero order of observing objects, and the minimal trace of the cofactor matrix at some of points is used in all the others epochs of observing objects (minimum trace only at stable points).

The optimal number of height differences to be measured in the geodetic control 1D network is determined in accordance to the expression 2, based on the value of the global measure of the internal r_{ii} reliability. We strive to have its value from 0.2 to 0.3.

$$n = \frac{u - d}{1 - \overline{r}} \tag{2}$$

The necessary accuracy of measured values in the GC1DN is defined on the basis of the previously determined standard deviation of the height of points, by calculation, which ensures that the adopted precision of measured height differences has a minimum impact on determining the network point height. The calculation of accuracy of measured size in the GC1DN depends on the type of planned measured sizes in the network. For activities in the engineering geodesy area, a precise geometrical and trigonometric leveling are usually used.

The required standard deviation of the height difference measurement, by a precise geometric leveling, can be expressed in the function of the point height standard deviation as

$$\sigma_{\Delta H} = \sigma_{H_R} \sqrt{2} = \sigma_{POL/GKM} \sqrt{2} \,. \tag{3}$$

After calculating the accuracy, it is necessary to perform a project design verification, by comparing the values of the defined network quality criteria and values acquired by calculation. If the obtained values of all the criteria are less than or equal to defined values, it is considered that the project design is correct and it is transferred to defining technical requirements for the implementation of measurements. If the obtained value of a criterion is greater than the defined value, it is considered that the project design is not correct and the procedure goes back to some of designing phases. Which designing phase will be corrected or changed depends on which criterion has not been met.

The defining of technical requirements for the project realization includes:

- Defining the manner of network point stabilization,
- Detailed elaboration of a measurement method (choice of instruments and tools, procedure and requirements for measurements),

Defining criteria for measurement monitoring and control.

2.2. DETERMINING THE GEODETIC CONTROL 1D NETWORK STABILITY

For the conventional deformation analysis in space, two classes of models are used. A model based on the geometric test of congruence of characteristic points in different time epochs is called the congruence method. There are several methods of determining deformations under this method, which were named after authors' names (surnames). For practical calculations shown in the paper, the Pelzer method was used, in literature also known as the Hanover process. The process of determining the stability of the GC1DN points with this method can be represented in the form of an algorithm (Figure 1). Due to the enormity of the method, only basic settings have been explained.

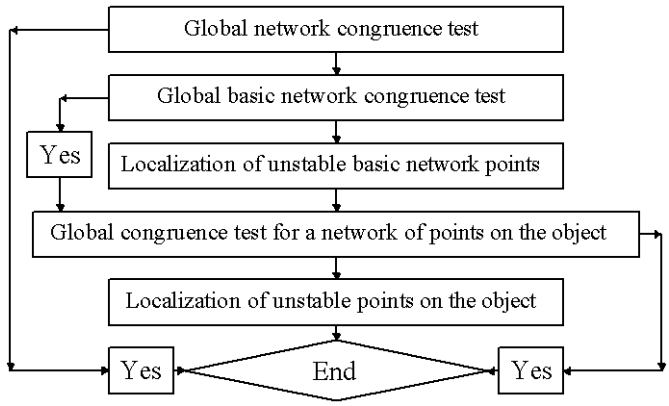


Figure 2. Algorithm of determining the stability of points by the Pelzer method

The basic characteristic of this method is testing global congruence by using the calculated "intermediate failure" (splitting) of a network measured twice and testing whether statistically significant displacement of points is present, which emerged between two surveys of the network - two measurement epochs.

Network congruence means the stability of points in that network, i.e. points are congruent if they have kept their position between two epochs. The network congruence is checked by testing the null (H_0) and alternative hypothesis (H_a)

$$H_0: M(\mathbf{x}_0) = M(\mathbf{x}_1) \quad \text{or} \quad M(\hat{\mathbf{d}}) = 0 \tag{4}$$

$$H_a: M(\mathbf{x}_0) \neq M(\mathbf{x}_1) \quad \text{or} \quad M(\hat{\mathbf{d}}) \neq 0 \tag{5}$$

where

$\mathbf{x}_0$, is the vector of assessed height of zero (starting or previous) epoch points,

$\mathbf{x}_1$, is the vector of assessed height of the current epoch points, and

$\hat{\mathbf{d}} = \hat{\mathbf{x}}_1 - \hat{\mathbf{x}}_0$, is the vector of differences of assessed height of points between epochs.

Accepting the zero hypothesis means that point heights are congruent, while rejection of the zero hypothesis means that point heights are not congruent in both epochs. For the purpose of checking these hypotheses the "intermediate failure" or splitting is calculated as follows

$$\theta^2 = \frac{\hat{\mathbf{d}}^T \mathbf{Q}_{\hat{\mathbf{d}}}^{+} \hat{\mathbf{d}}}{h} \tag{6}$$

where

$h = \text{rang}\mathbf{Q}_{\hat{\mathbf{d}}}$, is the rank of the cofactors matrix of height difference,

$\mathbf{Q}_{\hat{\mathbf{d}}} = \mathbf{Q}_{\hat{\mathbf{x}}_0} + \mathbf{Q}_{\hat{\mathbf{x}}_1}$, is the cofactors matrix of height differences, and

$\mathbf{Q}_{\hat{\mathbf{d}}}^{+}$, is the pseudo-inversion of cofactors matrix of height differences.

The null hypothesis statistics test is calculated as

$$\overline{T} = \frac{\theta^2}{\hat{\sigma}_0^2}, \tag{7}$$

where $\hat{\sigma}_0$ is a priori of the dispersive factor, which, in case of the null hypothesis follows the central F-distribution

$$T \sim F_{h,f}, \tag{8}$$

In the case of the alternative hypothesis, the statistics test follows the non-central F-distribution

$$T \sim F_{h,f,\lambda}, \tag{9}$$

where:
f=f0+f1, is a unified number of freedom degrees from the zero and first epoch, and
λ, is the non-central distribution parameter.
If the zero hypothesis H_0 is not rejected, there is no significant displacement and then the assessments $\hat{\sigma}_0$ and θ may differ within random errors. The remaining non-closing must be explained by the measurement accuracy [3]. If H_0 is rejected, the existence of statistically significantly displaced points is very certain. The represented general test is used for a further analysis: testing the stability of basic geodetic network points, finding unstable geodetic basic network points and for determining the displacement of points on objects.

3. CASE STUDY - OBSERVATION OF THE STUDENT'S HALL IN BANJA LUKA DURING ITS CONSTRUCTION

Pavilion 4 of the students' accommodation building has been constructed in the University City in Banja Luka (Figure 3). It consists of two parts, a building with floors as follows C+GF+5, and a building with floors as follows C+GF, separated by dilatation (Figure 4). The buildings are built from reinforced concrete. The subject of geodetic observation of vertical displacement was the part of the building with C+GF+5 floors. The observation of the building was carried out from 25 July 2014 until 2 June 2015 in five independent geodetic measurement epochs, that is, during concreting of every other concrete slab and during the installment of finishing work elements.
Having in mind the importance, function and construction of the building and characteristics of the soil on which the building was built, an internal observation project was developed, which basically included: defining of geodetic network geometry, defining of coordinate system and geodetic network datum, defining of the type and number of measured sizes in the geometric network, defining the accuracy of measured sizes and calculation of accuracy of networks. The basic aim of the observation was to determine thevertical displacement of points on the building, the size of which was less than or equal to 1 mm [9].

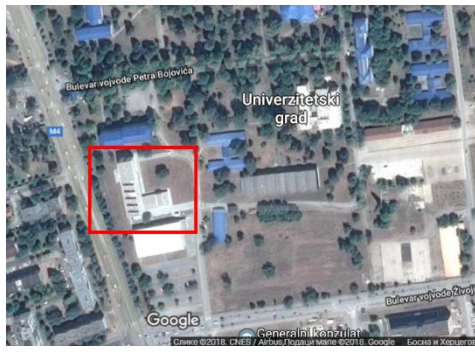


Figure 3. Position of Pavilion 4 in the University City

Figure 4. Pavilion 4 - appearance of the constructed building

The geodetic control 1D network (Figure 5), intended for the observation of the vertical displacement of Pavilion 4 of the students' accommodation building, consisted of a total of 12 geodetic points. Three of those points were of the basic 1D network, and nine points were on the building. The basic 1D network points were marked by R1, R2, and R4, and the points on the building were marked by RD1-RD9. The points on the building marked by RD7, RD8 and RD9 were stabilized in the building's cellar (in the main corridor), while the remaining points on the building were stabilized on the exterior of the building into the concrete of the first concrete slab (approximately in the height of the physical soil surface). The allocation of GC1DN points had been made in such a way that the measurements in the geodetic control network were performed as soon as possible and that all possible deformations on the building were established correctly.

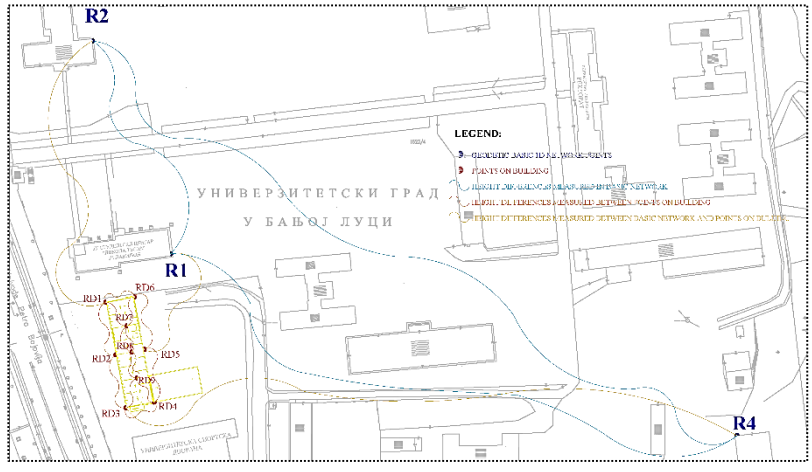


Figure 5. Sketch of the geodetic control 1D network [9]

Points on the building were stabilized with the previous consultation with the main project designer of the building and the designer of the building's construction. The materialisation of points was carried out with appropriate marks, shown in Figure 6 and Figure 7.

Figure 6. Points of geodetic basic 1D networks [9]

Figure 7. Points on the building [9]

During the final works on the building (plastering, installment of locksmiths, and façade), 6 points on the building (RD1, RD2, RD4, RD5, RD8, and RD9) were destroyed or damaged, which affected the network geometry and the observation plan in the final (fifth) epoch. The protection of the installed points on the building was a contractor's duty.

The measurement of height differences in the geodetic control 1D network was carried out under the method of precise geometric leveling. In the first four epochs, 19 height differences were measured in each epoch, while in the fifth epoch 9 height differences were measured due to the change of the network geometry. The planned measurements of height differences were carried out with the instrument Leica DNA 03, combined with a couple of fiberglass slats with the barcode division.

The point height assessment and the geodetic control 1D network accuracy assessment were obtained by the direct leveling of the measured height differences under the least squares method, by applying the Gauss-Markov model.

The GC1DN coordinate system was local, and the approximate values of point heights were obtained by adopting the value of the point height $H_{R1} = 100,000$ m and based on the value of the measured height differences. The network datum has been defined by the approximate values of the height of all network points (minimum trace on all points) and the minimal trace at the basic network points in using the Pelzer method for establishing the stability of points on the building.

A standard deviation of height difference of 0.1 mm per station has been adopted in leveling. The assessment of standard deviation of height difference per station has been obtained on the basis of the value of height non-closing of the leveling polygon.

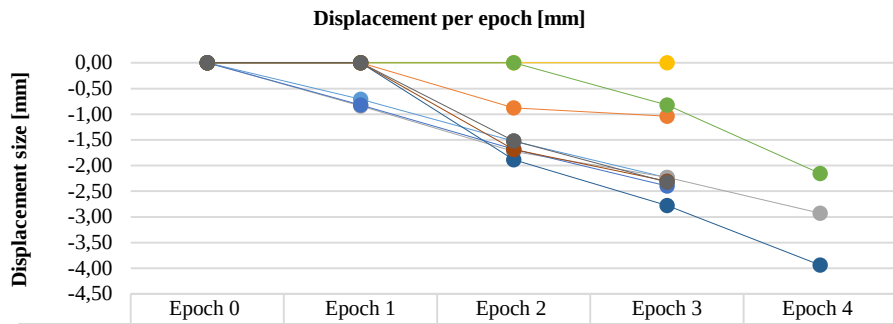
The network accuracy assessment has been shown through the assessment of precision measures (standard deviation of point heights), and the reliability measures (local measure of the internal reliability and the marginal gross error which can "certainly" be obtained by the data snooping test. By leveling the geodetic control 1D network per epoch, the following results have been obtained:

- Minimum value of the local measure of the internal reliability is 0.2 and maximum is 0.6, and
- Average value of the standard deviation of the height of points is 0.1 mm.

Determining the stability of the geodetic control 1D network points was performed through applying the Pelzer method. Determining the heights of the network points was conducted for all measurement epochs, separately, by direct leveling under the least squares method, with the application of the Gauss-Markov model. The datum requirement in leveling measurement epochs was defined by a minimum trace on all points, and in

application of the Pelzer method, by a minimum trace on the basic network stabile points. Based on the results obtained, it has been concluded that the GB1DN points were stable during all measurement epochs.

Conclusions on vertical displacements of the points on the building can be made based on the numerical and graphical data shown in Figure 8.



	Epoch 0	Epoch 1	Epoch 2	Epoch 3	Epoch 4
RD1	0,00	-0,71	-1,52	-2,23	
RD2	0,00	0,00	-0,88	-1,04	
RD3	0,00	-0,84	-1,72	-2,23	-2,93
RD4	0,00	0,00	0,00	0,00	
RD5	0,00	-0,82	-1,68	-2,40	
RD6	0,00	0,00	0,00	-0,82	-2,15
RD7	0,00	0,00	-1,89	-2,78	-3,94
RD8	0,00	0,00	-1,69	-2,30	
RD9	0,00	0,00	-1,52	-2,32	

Figure 8. Representation of point displacements per epoch - all points [9]

4. CONCLUSION

The successful designing of a geodetic network is possible with defining the quality criteria in cooperation with civil engineers, respecting the principles of the geodetic profession. The task of civil engineers is to define, for a particular object, the size of displacement which is necessary to be determined "with certainty" between two measurement epochs, to define characteristic points, and to define the period of measurement repetition. The quality of geodetic networks is defined by the measures of precision and reliability, and the price of the project implementation depends on the criteria set.

For the purpose of timely registering of object construction deformations for all objects, the geodetic control of geometry and testing of deformations by applying geodetic measurement methods are initiated. The project of geodetic determining of vertical displacement of objects and constructive elements should be developed in the course of developing a construction project and the project of geodetic marking. Today's trend in the area of deformation measurements, regardless of whether they are conducted during the construction or exploitation of buildings, is based on research of displacements in time and space. This approach most certainly follows the development of new measurement

methods and technologies. As a consequence, the obligation of interdisciplinary cooperation during the analysis and determining of causes and physical characteristics of observed objects emerges.

The practical application shows that the required size of displacement can be identified "with certainty," respecting the described methodology of designing and performing the geodetic determining of vertical displacement of objects during their construction.

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19| Оригинални научни рад
Research paper
doi 10.7251/STP1813283R ISSN 2566-4484

3D MODELI OBJEKATA U PROCESU REKONSTRUKCIJE

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Apstrakt:

Poslednjih nekoliko godina terestričko i avionsko lasersko skeniranje je postala moćna tehnika za brzo i efikasno trodimenzionalno prikupljanje podataka za različite vrste objekata. Vazdušni laserski sistem (LiDAR) prikuplja tačne geometrijske podatke jako velikih područja za vrlo kratko vrijeme dok terestrički laserski skener prikuplja guste i geometrijski tačne podatke. Kombinacija ova dva segmenta laserskog skeniranja obezbjeđuje različite oblasti primene. Jedna od primena je i u procesu rekonstrukcije objekata. Objekti snimljeni tehnologijom laserskog skeniranja i pretočeni u konačni model predstavljaju osnovu za izgradnju objekta onakvog kakav je bio u svom prvobitnom obliku. U ovom radu će biti prikazane dvije studije slučaja zasnovane na upotrebi terestričkog i avionskog laserskog skeniranja i obrade podataka dobijenih istim.

Keywords: zgrade, lasersko skeniranje, rekonstrukcija,3D model

3D MODELS OF OBJECTS IN PROCESS OF RECONSTRUCTION

Abstract:

Within the last years terrestrial and airborne laser scanning has become a powerful technique for fast and efficient three-dimensional data acquisition of different kinds of objects. Airborne laser system (LiDAR) collects accurate georeferenced data of extremely large areas very quickly while the terrestrial laser scanner produces dense and geometrically accurate data. The combination of these two segments of laser scanning provides different areas of application. One of the applications is in the process of reconstruction of objects. Objects recorded with laser scanning technology and transferred into the final model represent the basis for building an object as it was original. In this paper, there will be shown two case studies based on usage of airborne and terrestrial laser scanning and processing of the data collected by them.

Keywords:buildings, laser scanning, reconstruction, 3D model

1. INTRODUCTION

Laser scanning is one of the leading data sources that can be used in different areas. By its wide application, laser scanning has found its place in the modern world of technologies. 3D model of the object presents the foundation of modern engineering. It can be used in construction, geodesy, architecture, mechanics... Nowadays, with new service development, there is increased need for automated, efficient extraction systems which produce data used in navigation systems, location based services, augmented reality and spatial infrastructure planning.

The results of this of methods of recording objects can be stored in databases, in different formats and different forms of the 3D models. Obtained data are also part of the advanced geographic information systems and various analyzes can be performed.

Formation of 3D models of objects is important in the process of documenting buildings, and is carried out for the purpose of reconstruction, restoration, analysis or visualization of the building. The model must therefore respond to requirements such as geometric accuracy, realistic display, precision, etc.

In this paper two case studies will be shown. The dataset of first case study was collected by using terrestrial laser. Area of interest is Monument to Victims of Raid located on the banks of the Danube. The goal was to display the monument to the tiniest details. Main software for processing is Geomagic Studio. It provides the industry's most powerful point cloud editing, mesh editing, and advanced surfacing functions [1].

The second case dataset was derived from integration of data that was collected by terrestrial scanner and the LiDAR system. Case study represents suburbs of Petrovaradin that abounds in the buildings of a longer life. Used processing software is also GeoMagicWrap combined with Leica Cyclone (LC). LC is a family of software modules that provides the widest set of work process options for 3D laser scanning projects in engineering, surveying, construction [2]. The data were processed in different software in order to display a different detail level of the 3d model.

2. RELATED WORK

Laser scanning is most commonly used for geometrical 3D object recording of complex objects and making 3D models. With their ability to scan a very large number of 3D points in seconds without signalization laser scanning offers high application potential, especially in construction, architecture and cultural heritage. There are many publications dealing with this topic. In this work, papers related to this will be highlighted. The Kersten case study was The Bismarck Monument in Hamburg. In his work a combination of triangle meshing and CAD was performed [3]. Jocea also used terrestrial technology and data as processes in GeoMagic software [4].

Specifically, on the subject modeling facades of objects, based on the cloud of points received from terrestrial laser scanning on one side, or cloud points created by a merged cloud of airplane and terrestrial laser scanning on the other, unfortunately there is still no match between them. The reason for the small number of papers is that the biggest problem is the fitting obtained models and their georeferencing due to different accuracy of sets aerospace and terrestrial laser scan data.

Some of the papers that dealt with the topic of cloud-based facade modeling are P. Babahajiani, L. Fan and S. Becker, N. Hall. Babahajiani and L. Fan used a complete scene parsing system which is devised and experimentally validated using 3D urban scenes point cloud that have been gathered by LiDAR acquisition devices. The steps such as segmentation, feature extraction, visualization is generic and adaptable to solve object class recognition problems in different streets with varying landscape [5].

S. Becker and N. Hall used terrestrial LIDAR data, as well as facade imagery, to increase the quality and amount of detail for the respective 3D building models [6]. A publication with the topic of merging cloud points created by LIDAR and terrestrial laser scanning for modeling of objects and facades is A. Gruen, where Unmanned Aerial Vehicles (UAV) and Mobile Laser Scanners (MMS) were used as techniques for surveying and mapping. The building models have been created using the semi-automatic modeling software CyberCity Modeler [7].Also one of good examples of modeling building facade isPajic, who used Leica Cyclone as the main processing software [8].A. Iavarone and D. Vagners also used two technologies for acquisition, airborne LIDAR and tripod-mounted laser scanner [9]. Amovic used only LIDAR technology and created 3D model of the faculty building [10]. Popovic generated 3D model of Petrrovaradin Fortress and stored it in CityGML format. [11]

3. TECHNOLOGY OF AIRBORNE AND TERRESTRIAL LASER SCANNING

Technology of terrestrial laser scanning is widely used for reaching of detailed 3D models of any kind of urban objects. On the other side, airborne laser scanning is specialized for collecting a lot of data inthe shortestperiod of time, but is not so detailed. This is why these two techniques are so complementary.

Terrestrial laser scanner (TLS) cannot be called either a robotized total station or a digital camera but is widely accepted as a surveying method. TLS belongs to the family of so-called active sensors. The pulse carries are a laser and it cannot record a specific point but can provide a continuous scan of the object around the scanner. This method is also known as a ground-based laser scanner or a terrestrial LIDAR system. Laser scanning can be named as three-dimensional vector measuring system with radial component bases on electrooptical distance measurement [12].

To classify terrestrial laser scanners is a very difficult job. There are few options depending on which criteria we want to use. For example, measurement principle (pulse or phase method, triangulation) or technical specifications that are achieved [13]. No one scanner is universal for every single use, so the selection of the scanner depends on the type of object/area that has to be scanned and final accuracy of point cloud/model.

The hardware part is based on the tripod and the scanner mounted on it, which allows distance measurement, horizontal angle, vertical (zenith) angle.

Hardware is also enriched with polygonal mirrors, as well as encoders that register the orientation of the mirrors. 3D coordinates are the output result, instead of the measured length, horizontal and vertical angles. Airborne laser system is also called the LiDAR system and consists of air and terrestrial segment. In the aim of computing coordinates of laser scanning points aerial scanning system dispose of positioning and orientation system based on GNSS and inertial measurements for local position and previously mentioned orientation of laser scanning system at the moment of pulse emission.When it

comes to precision and accuracy of this technology, most often corresponds to the conditions given by the user [14].

The main principle of airborne laser scanning is based on the use of phase differences and pulse echoes for measuring the distance from the air platform (plane, helicopter) to the point on the surface of the earth. The product of this surveying is a point cloud, just like terrestrial laser scanner.

4. CASE STUDY

As already stated at the beginning of the work, two case studies will be processed in this paper. Both locations are located in Novi Sad and they are the most recognizable elements of this city.

4.1. Petrovaradin Fortress (Donji Grad)

Donji Grad (lat.Suburbium) as a part of Petrovaradin fortress represents the baroque structure ofthe city. It is mostly preserved from damaging withthe exceptionthat some building has lost their previous appearance.The buildingsare mostly high with bulky roofs, small courtyards and narrow streets (Figure 1).

Figure 1. Petrovaradin fortress (Donji Grad)

The facades are decorative, with symbols of guard or statues of saints beneath the roof. Surveying of this part of Petrovaradin fortress was done with terrestrial laser scanner (Leica ScanStation P20) in three days and aerial laser scanner (Riegl LMS – q680i). At the end of scanning with terrestrial scanner, there were at total 30 stations and 40 positions of markers. The picture bellow shows sketch of marker positions as well as positions of laser scanner from which the acquisition was performed (Figure 2).

Figure 2. Positions of stations (TLS)

For final processing of model of fortress, both point clouds were combined into one, using Leica Cyclone software. There was used method of indirect registration by matching cloud to cloud. The reference cloud was cloud from terrestrial laser scanning due to higher accuracy of data. According to the data quality specification formulated by GSA (General Services Administration), which defines the required level of accuracy - LOA (Level of Accuracy) and level of detail - LOD (Level of Detail) laser points, in this project were used LOA 3 and LOD 3 (Table1). LOA requirements determine the tolerance of the positioning accuracy of the objects, which essentially rely on the accuracy of individual points in the point cloud. LOD requirements determine the minimum size of an object that can be pulled out of the cloud, which relies on density that can be captured [15].

Table 1. GSA accuracy level and level of details

GSA Level	LOA (Accuracy) mm (inch)	LOD (Detail) mm x mm (inch x inch)
1	± 51 (± 2)	152 x 152 (6 x 6)
2	± 13 (± 1/2)	25 x 25 (1 x 1)
3	± 6 (± 1/4)	13 x 13 (1/2 x 1/2)
4	± 3 (± 1/8)	13 x 13 (1/2 x 1/2)

The result of scanning is huge number of points, each with its X, Y and Z coordinates, as well as an additional attribute - value of the reflection of laser. Modern advanced scanners have also information in the form of RGB values. When points are colored with values of reflection or colors, the structure becomes more recognizable (Figure 3).

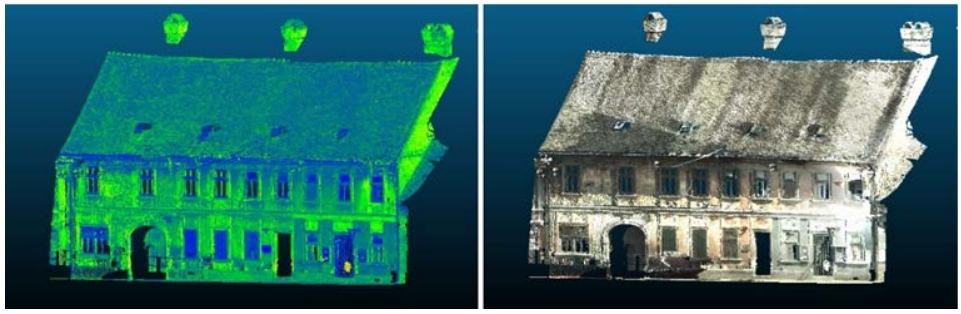

Figure 3. Segment of Petrovardin fortress presented with values of reflection (left) and RGB values (right)

There are few operations that we have to do on the merged point cloud such as: resampling, noise reduction, meshing, filling of holes on the model and reduction of number of triangles of the generated model. Final modeling made in Geomagic Studio is shown in the picture below (Figure 4).

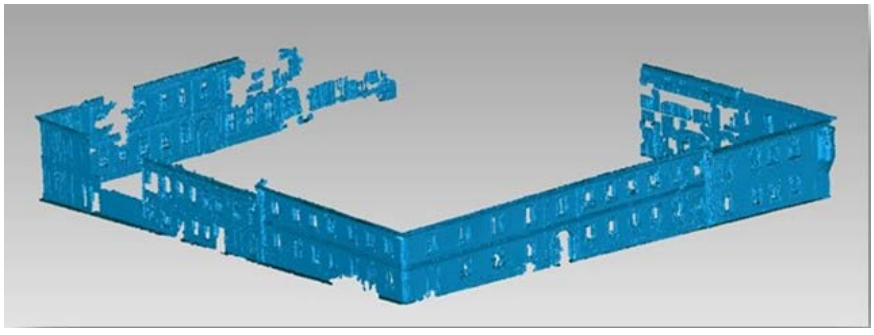

Figure 4. Final model of part of Petrovaradin fortress

Merged point clouds were published using internet-based application Potree [16]. The main advantage of Potree is that offers possibility to measure distances directly on the point cloud (Figure 5). Also, it has option to make different cross sections that is with previous option useful for possible reconstruction of object.

Figure 5. Measuring of distances on point cloud in Potree

4.2. MONUMENT TO THE VICTIMS OF THE RAIDS

The second case study was an important object of cultural heritage in Novi Sad, monument to the victims of raids. For scanning of this monument were used three markers. The resolution was set to 3.1mm/10m and scanning on each station lasted 7minutes. This is the indicator how long it takes to scan such an object. On the other side processing of the raw point cloud lasted a little bit longer. During processing of laser points, the main problem was points that were collected under the influence of the reflection of water in Danube river and the structure of material of monument.

Processing steps were the same as in the previous case with emphasis on the usage of algorithm that fills holes on the parts where points were not collected. Main holes were on the heads of humans what are represented on the monument. To solve this problem, we have used an algorithm for filling holes on the model based on points that surround specific hole. In the picture below there is an example of filled holes using algorithm provided by Geomagic software. Red dots represent corrected parts of the model and yellow dots are example of raw hole (without correction).

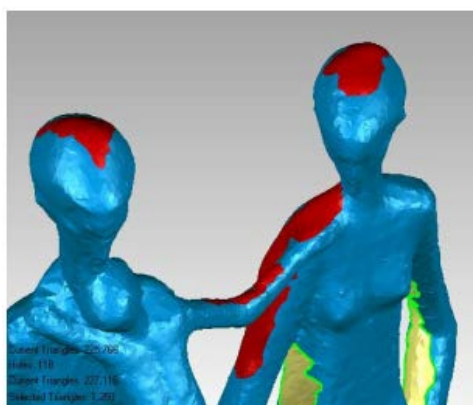

Figure 6. Holes on the model (red and yellow)

The holes were an obstacle in processing of the raw data, so by their elimination the final model was successfully generated. Figure 7 contains a Monument to the Victims of the Raids. On the left side, there is a photo of the real look of the monument. The right side of Figure 7 represents a model that was created in GeoMagic software.

Figure 7. Monument to the Victims of the Raids

5. DISCUSSION

The aimofthis work is to design a simple and fast method to reconstruct objects using laserscanningdata only, which can be useful in many applications.Automated methods for reliable and accurate 3D reconstruction of created models of objects are essentialformany users and providers of 3D city data, civil engineers, urban planners, architects, environmental engineers. A 3D city model captures the geometric description of all objects of interest in an urban area in computer supported form.The obtained 3D models can be used further in the construction or reconstruction of objects. Models satisfy certain precision, accuracy and level of detail. The GeoMagic software proved to be a good solution for creating models represented in this paper. The obtained processed data can be further used in the processing, analysis, mapping. They can be stored in various formats, databases and represented through certain web services.

ACKNOWLEDGMENT

Results presented in this paper are part of the research conducted within the Grant No. 37017, Ministry of Education and Science of the Republic of Serbia.

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20| Оригинални научни рад
Research paper
doi 10.7251/STP1813292K ISSN 2566-4484

AN APPROACH TO CIRCULAR BUILDING RENOVATION USING PRODUCT SERVICE CONCEPTS

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Abstract:

Accelerating the rate and depth of energy renovations in buildings is one of the biggest challenges currently facing the construction industry. The increasing range and complexity of building technologies make product selection challenging. At the same time, we need to embrace new circular building strategies in which material waste is eliminated. In an ongoing process materials and components are reused or remanufactured and can constantly be replaced with new and more efficient ones. The paper describes the first pilot project for a facade leasing at the Delft Technical University that explores ways of implementing circular construction methods. It acts as collaboration catalyst to further develop the complex system of contracts, financing structures, and operational services required to turn the facade leasing project into a feasible proposition. First general conclusions are drawn concerning supply, demand side, financial and legal aspects.

Keywords: circular building, facade renovation, leasing, product service concepts

PRISTUP KRUŽNOM OBNAVLJANJU ZGRADA KORISTEĆI SERVIS PROIZVODNIH USLUGA

Apstrakt:

Povećanje stope i opsega obnavljanja energije u zgradama je jedan od najvećih izazova sa kojim se građevinska industrija suočava. Povećani obim i složenost građevinskih tehnologija otežavaju odabir proizvoda. U isto vrijeme, trebamo da uključimo nove kružne strategije građenja u kojima se eliminišu otpadni materijali. U toku procesa materijali i komponente se ponovno koriste ili su ponovno proizvedeni i uvijek se mogu zamijeniti novim i efikasnijim. Ovaj rad opisuje prvi pilot projekat za fasade na lizing (facade leasing) na Tehničkom univerzitetu u Delftu, koji istražuje načine primjene kružne metode izgradnje. Projekat je podsticaj za saradnju u cilju daljeg razvoja složenog sistema ugovora, finansijskih struktura i operativnih usluga potrebnih da bi se projekat za fasade na lizing pretvorio u izvodljiv poduhvat. Doneseni su prvi opšti zaključci u pogledu snabdijevanja, potražnje, finansijskih i pravnih aspekata.

Ključne riječi: kružno građenje, obnavljanje fasade, lizing, koncept proizvodnih usluga

1. INTRODUCTION: THE GROWING NEED FOR FASTER AND MORE FLEXIBLE BUIDING RENOVATIONS

Accelerating the rate and depth of energy renovations in buildings is one of the biggest challenges currently facing the construction industry. Across Europe, a large number of buildings constructed during the post-war boom of the 1950's to 1970's are quickly reaching the end of their original service life [1]. Their façades and building systems are far below current standards, their energy consumption is unsustainably high, their spaces are in many cases uncomfortable and dysfunctional, and, as if this wasn't enough, they are also very expensive to maintain.

1.1. THE EXISTING DUTCH UNIVERSITY BUILDING PORTFOLIO

In the case of Dutch universities alone, almost 60% of the building portfolio of 14 universities studied dates back to before the 1980'[2]. This represents hundreds of thousands of square meters of façades which need to be substantially improved in the coming decades if we are to meet emission reduction goals set by the European Union and the Paris Agreement. And yet, it is but a small sample of millions of square meters of commercial, residential, and public space across the continent which require similar and immediate action.

The paper describes a pilot project in the context of the building portfolio of the Delft Technical University and here buildings with approximately 180.000m2 GFA are in need of renovation. At the same time there is a request for new and flexible use space, since the institutional landscape is constantly changing and the universities need to accommodate modern education and research concepts. This asks for renovation concepts that allow for different uses such as offices, teaching studios, laboratories and even student housing. For the renovation of facades it means that, to a certain extend, different qualities in terms of daylight management and ventilation must be possible.

1.2. BOTTLENECKS IN THE CURRENT RENOVATION PROCESS

Today's process for retrofitting an existing building, or to improve the planned energy performance of a new construction, is difficult and involves a sensitive collaboration between a number of parties with, in many cases, conflicting financial incentives and commercial interests [3]. The increasing range and complexity of building technologies makes product selection challenging. Knowledge transfer barriers between the parties manufacturing these components, and those responsible for their maintenance and operation, can result in a suboptimal selection and operation of these systems. The companies responsible for developing and supplying these technologies are in most cases marginalized to a secondary role, and keep no direct interest in the long-term performance of their products, which regularly end up being disposed of by the client at the end of their service life, resulting in an unnecessary production of waste and the loss of valuable products and materials. For all these reasons, it becomes difficult to evaluate and monitor the ongoing benefits of a performance improvement project in terms of energy use, carbon footprint, resource consumption, or economic gains.

2. A CIRCULAR APPROACH TO NEW BUILDING ENGINEERING

The Ellen MacArthur Foundation (EMF), established in 2010, defines the Circular Economy the following [4]: "A circular economy is one that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles." Contrary to the linear model of make-take-dispose, in which goods are manufactured from raw materials, then sold on the market, used and finally disposed as waste, the circular model is regenerative, which means using waste as a resource for the manufacturing of new goods [5]. To be able to function well in the closed, circular system of the earth, the economy and the environment should also be balanced in inputs and outputs [6].

For the approach to renovation, the building is not seen as a cradle-to-grave project, in which materials come in at the start, are used for a limited amount of time, and are turned into waste or recycled into raw elements at the end, but as an ongoing process in which building components are constantly replaced with new and more efficient ones, while the old ones are broken down into spare parts which can be reused to produce the following technological generation.

2.1. IMPLEMENTING CIRCULARITY WITH NEW BUSINESS MODELS

The transition towards this new way for working, however, requires an extensive reorganization of incentives and responsibilities across all stakeholders in the construction value chain. Performance contracts, in other words the shift from an economic system based on the sale of products to one based on the provision of services, can play a determinant role in the economic and environmental feasibility of both future new constructions and renovations. By outsourcing the management and upgrade of technological systems to the suppliers responsible for developing them, we can achieve a faster market uptake of new and more efficient systems, while reducing the initial investment requirements of developers and building owners. Circular industrial loops are also facilitated, as suppliers who retain the ownership of their products have a significant incentive to extract maximum value from them as they reach the end of their service-life.

2.2. FACADE LEASING AS PRODUCT AND PROCESS INNOVATION

Façade leasing as a combined strategy relies on recent innovation on two fields: On one hand, technological innovation in the form of multifunctional façades results in building envelopes which have the potential of delivering an ongoing indoor comfort service. This can be done through the use of decentralized, façade-integrated building support systems which replace the traditional installations running through the ceilings and hallways of traditional constructions. The current range of such decentralized technologies has expanded to include a wide spectrum of energy generating technologies, air-handling systems, electric and communication infrastructure, and even advanced profit-generating elements such as media screens, or air-filtering solutions such as green façades. The placement of all these components on the exterior layer of the building does not only facilitate their maintenance and replacement, it also enhances the capacity of the façade to not simply protect the indoor spaces from the weather, but actively generate the energy required to control and monitor the indoor comfort conditions which it also provides.

On the other hand façade leasing relies on innovation in business and management practices, which includes new methods of financing, contracting, and operating these new and highly complex building systems, could facilitate the complicated transition required throughout the entire building process: First, it would support the initial design and engineering of components which can be more easily maintained and replaced. Second, it would promote high-quality production, based on durability and performance rather than lowest initial cost. Last and foremost, it would enhance the operation and reprocessing of components, incentivizing a long-term, ongoing collaboration between the suppliers of building technologies and the clients and users whose spaces are conditioned by the formers' systems.

3. THE TUDELFT PILOT PROJECT - A LIVING LAB

More than many other users and operators of commercial real estate, universities tend to have a long-term commitment and attachment to their locations and their campuses. The size of such campuses also provides an economy of scale which is difficult to replicate. More significant still, they have a social responsibility to lead the way towards better and more efficient practices, particularly those that involve a more efficient and responsible management of energetic and material resources. These and many other factors makes them the ideal testing ground for new methods of construction, organization, and collaboration.

In September 2016 a consortium of companies, ranging from component suppliers to façade fabricators, installed a pilot project temporarily replacing a section of the façade on the low-rise building of the Faculty of Electrical Engineering, Mathematics and Computer Sciences at TU Delft, commonly known as the EWI building (Fig. 1). The aim of this pilot project is to research ways of implementing circular construction methods. It demonstrates the state-of-the-art in façade-integrated technologies, and acts as anchor point and collaboration catalyst to further develop the complex system of contracts, financing structures, and operational services required to turn the Façade Leasing research project into a feasible and implementable proposition.

This solution does not seek to address the particular problems of the EWI building's future, but instead uses the building's representative quality as an icon of modernist architecture. Building such as the EWI, which are quickly reaching technical obsolescence, also display a degree of standardization and modularity that can make them the ideal target for deep energy retrofitting action, and hence for the implementation of new business model such as the one proposed by this project.

Four different façade panels were installed. The first one as the 'low-end' version with basic minimal u-value, and interior sun shades. The second panel (Fig. 2) has integrated PV cells and decentral ventilation system with heating, cooling and heat recovery, which is especially interesting for renovation purposes. Panel 3 and 4 have different configurations of in-glass or external sunshades, electrical or manual operable windows.

The panel configurations were analyzed according to their predicted energy performance by calculating savings through level of insulation, ventilation concept (with or without heat recovery), cooling and artificial lighting demand (depending on daylight managing system), or even potential energy gain through integrated PV panels. Building users evaluated the panels in terms of interior view and predicted visual and thermal comfort.

A total cost of ownership calculation (TCO) has been executed, including initial investment costs, energy costs, and maintenance effort.

It needs to be mentioned that the comparison is partly theoretical because all panels are installed at a single meeting room. Nevertheless, the comparison lead to interesting conclusions. For example that the owner preferred expensive external sun shades with a wind-resistance of up to 11 Beaufort, according to the requirements of the rough and windy Dutch coastal climate. Those proved to be most energy efficient and, due to their sturdiness, relatively cheap in terms of maintenance costs. Also interesting to mention is that the cheap panel No1, is one of the most expensive in terms of TCO. This demonstrates that a new product service oriented business model will lead to different solution, which potentially higher quality.

Figure 1. The Façade mock-up at the TUDelft, showcasing 4 different façade configurations

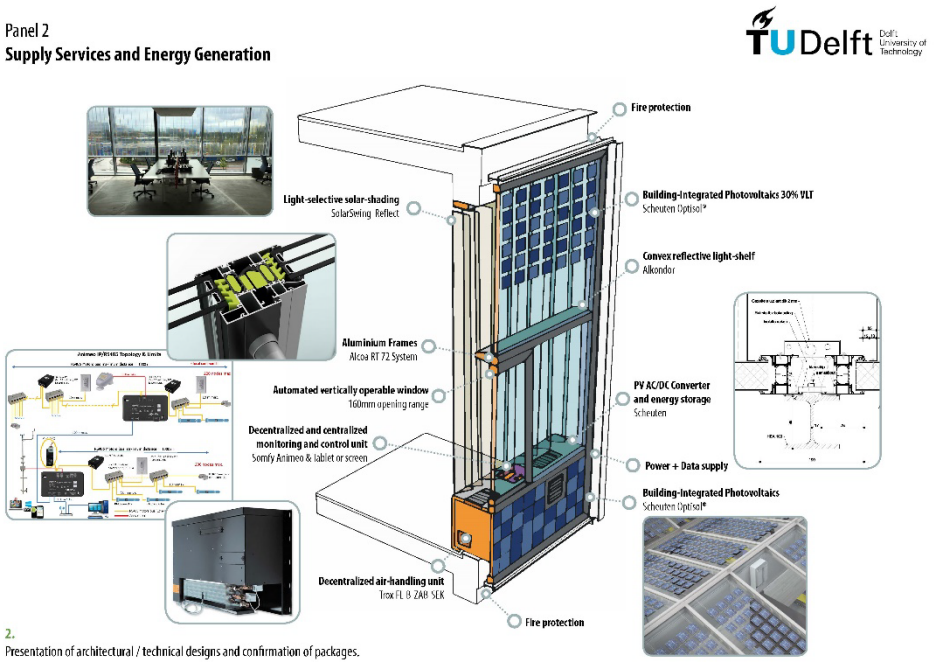

Figure 2. Technological breakdown of Panel 2 of the TU Delft pilot project, showing decentralized building support services. It is the most complex and expensive test unit. The other three panels are constructed with different product configurations of ventilation and shading systems.

4. CONCLUSION

The aim of the pilot project is to research ways of implementing circular construction methods, through product service concepts. It is a fist approach towards a highly complex and new territory and acts as anchor point and collaboration catalyst to further develop the complex system of contracts, financing structures and operational services required to turn the Façade Leasing research project into a feasible and implementable proposition.
In this paper first general conclusion can be drawn:

4.1. SUPPLY SIDE PERSPECTIVE

The project demonstrates the state-of-the-art in façade-integrated technologies. Especially the integration of building services and façade construction components is very challenging for the industry partners. It needs new project consortiums that bridge the traditional crafts. Generally, the façade industry is very mature and able to manage complex processes, oriented towards the whole life-cycle of facades. But it needs a considerable change in their management structures. The shift from a product delivery towards a service oriented industry can open new business fields and higher profit margins.

4.2. DEMAND SIDE PERSPECTIVE

The TU Delft has just formulated the goal to achieve higher circular standard throughout the whole organization. The concept of leasing facades generally offers a potential for a more flexible building stock management. The high initial investment can be translated into a monthly leasing fee, freeing investment capital. The main hurdles to overcome are reforming traditional decision making and managing structures. The whole procurement and facility management strategy needs to be reformed, potentially freeing personnel by outsourcing services.

4.3. LEGAL AND FINANCIAL ASPECTS

Building financing today is based on asset related values. Leasing concepts are challenging these financial models, since the ownership of building components, such as facades, would be held by external parties. That also raises legal questions. At the moment we are looking at lease in perpetuity concepts. Experts involved in this project agree that also legal and financial models will have to get innovated to accommodate new circular building models. Banks such as the ABNAMRO are working with us to develop new approaches.

4.4. A NEW APPROACH TO CIRCULAR BUILING

Generally, the concept allows a whole life-cycle view on the performance of the façade. Builders and system suppliers stay involved during the whole time and have the incentive to choose construction methods to optimize the performance and minimized maintenance costs. Possible changes and upgrades, desired by the client, can be accommodated and technical provisions can be made. A maximized residual value at the end of the life-time can have a considerable effect on the cost of the façade. In opposition to the current linear approach, this concept would certainly support circular building methods. However, the mock-up was build using traditional construction methods. These are very limited in its disassembly potential and thus allowing for a reuse of components to a higher level than simple recycling. With the need for circular building methods, we can expect a positive impact on the development of new building products as well at the development of a market for the 2nd life of building components.

5. THE FOLLOWING STEP

In early 2018 the project consortium has received further funding from the EIT Climate-KIC for the upscaling of this research pilot project to a large scale practical demonstrator case-study. Targeted is the renovation of the East Façade of the Civil Engineering building at the TU Delft. Final methodology, and objectives of this new project stage are currently being discussed, and will be made public as soon as they have been agreed upon by all parties involved.

While the 2016 EWI pilot project focused on the showcasing of available decentralized façade technologies, this demonstrator case-study brings together architects, builders, developers, and managers of buildings, as well as lawyers, financiers, scientists, and business developers, to produce the first practical example of a Façade-as-a-Service performance contract.

6. ACKNOWLEDGMENTs

The project was funded by the EIT Climate-KIC. Involved industry partners: ALUECO, VMRG, KAWNEER, ALKONDOR, TROX Technik, Somfy, Renson, Scheuten Glass, De Haan Westerhoff, Real Capital Systems, Kindow, Schuurmann, VML, Aldowa, MHZ, Panelen Holland

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21| Оригинални научни рад
Research paper
doi 10.7251/STP1813300A ISSN 2566-4484

INDUSTRIJSKO NASLEĐE U FUNKCIJI OČUVANJA IDENTITETA: PRIMER SMEDEREVA

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Abstract:
Kulturno nasleđe je prepoznato kao nezamenljiv i neobnovljiv strateški resursza održivi razvoj grada i jačanje njegovog identiteta u funkciji njegove konkurentnosti na regionalnom i globalnom nivou. Industrijsko nasleđe je deo kulturnog pejzaža koji proizilazi iz interakcije društvenih grupa i prostora kojim grupe pripadaju i u odnosu na koje grade kolektivni identitet i kulturna značenja, kroz slojevit i kompleksan odnos. Društvene vrednosti industrijskog nasleđa suvažan deo identiteta građana, jer predstavljaju deo memorije o životu ljudi, o industrijskom progresu i ponosu lokalnog stanovništva.Studija slučaja će biti sprovedena u Smederevu, na lokacijama industrijskog nasleđa duž obale Dunava. Identifikovanje vrednosti i značaja indistrijskog nasleđa će biti istraženo anketiranjem građana Smedereva. Anketa se sastoji iz utvrđivanja elemenata imidža mesta, na osnovu pet elemenata Kevina Linča, kao i identifikacije emotivne povezanosti građana sa mestom, razumevanje njegovih simbola i značenja prema Relfu.

Keywords: industrijsko nasleđe, kulturno nasleđe, identitet, grad, Smederevo

THE ROLE OF INDUSTRIAL HERITAGE IN PRESERVING THE IDENTITY OF A CITY: CASE STUDY SMEDEREVO

Abstract:
Cultural heritage is recognized as an irreplaceable and non-renewable strategic resource for the sustainable development of the city. It could serve as important trigger for strengthening identity and competitiveness of the city at the regional and global level. Industrial heritage is seen as a cultural landscape that stems from the interaction of social groups and the space they belong and in relation to which they build collective identity and cultural meanings, through a layered and complex relationship. Social values of industrial heritage are an important part of citizens' identity, because they represent a part of the memory of people's lives, about industrial progress and pride of the local citizens. The case study is conducted in Smederevo, at the area of industrial heritage along the Danube river bank. Identification of the value and significance of the Indistrial heritage will be investigated by a survey of citizens. The survey is based on the five Lynch`s elements of the image of the city, as well as the identification of the emotional connection of citizens with the city, the understanding of its symbols and meanings.

Keywords: industrial heritage, cultural heritage, identity, city, Smederevo

1. INTRODUCTION

Over the past few years, the protection of cultural heritage, as an irreplaceable and non-renewable strategic resource, has become a central theme of the most important international documents and contemporary urban development strategies. Recognizing the importance of protecting cultural heritage for the development of cities is the result of understanding culture as a new resource on which future development is based, or as new paradigms of sustainable development. Thus, protection of cultural heritage, as a mechanism for preserving urban identity and increasing the competitiveness of cities in the global market, represents a significant potential for sustainable development of cities.

The important part of cultural heritage in cities is industrial heritage which consists of the remains of industrial culture that are of historical, technological, social, architectural or scientific value [1: 1]. Besides the tangible values expressed through industrial technology and processes, engineering, architecture and town-planning, industrial heritage includes many intangible values embodied in the skills, memories and social life of workers and their communities [2: 1], such as technical know-how, the organization of work and workers, and the complex social and cultural legacy that shaped the life of communities and brought major organizational changes to entire societies and the world in general [2: 3]. Thus, being a part of the record of the lives of ordinary men and women, industrial heritage provides an important sense of identity [1: 1].

This paper deals with a problem of industrial heritage preservation within a contemporary development context. The adaptive reuse of industrial facilities and sites that have irrevocably lost their original purpose and their adaptation to new socio-economic context, without jeopardizing cultural and historical values, is a method of sustainable protection of industrial heritage. The problem of preservation of industrial heritage probably arises from the lack of understanding the values that are mostly seen as tangible. Neglecting the intangible values of industrial heritage, or the meanings contained in the memory of life and work, is one of the fundamental problems of sustainable protection of heritage. Lack of understanding of the multitude intangible values that abandoned sites of industrial heritage possess and messages they carry leads to their decline and complete disappearance, resulting in distortion of collective identity, based on the industrial past of community, and personal identity of citizens in terms of a sense of belonging to a community. So, the main question that arises from this assumption is what to preserve, what are important values of industrial sites that are valuable to preserve, and why? On the other hand, this problem arises from the lack of appropriate planning tools for identifying and analyzing industrial heritage meanings that are valuable to preserve. Defining the meanings of industrial heritage as one of initial tasks of urban conservation is usually done by urban planners and city authorities, without taking into consideration aspects of meaning deriving from people's interaction with space. Integrating intangible values into the process of urban conservation involves re-examining the relationship between the individual and the social and cultural environment, as well as understanding meanings attributed to some elements of heritage based on experience, memory and associations. This points to the need for improving the planning process of industrial heritage conservation in phase of initial tasks setting thought substantive citizen participation.

The aim of this paper is to define social values of industrial heritage based on the interaction of social groups and the places of cultural heritage they belong and in relation to which they build collective identity and cultural meanings, which contribute to

decision making in the initial phase of planning conservation. Moreover, the aim is to draw attention to the importance of preserving meanings assigned to industrial heritage and need for involvement of experts and other public in the planning process of urban conservation. In the first part of the paper, theoretical framework for investigating place meanings and defining social values of heritage is presented. The second part deals with the area of industrial heritage along the Danube river bank in Smederevo. Identification of the values and significance of the industrial heritage is investigated by a survey of citizens. The aim was to identify all social and physical meanings assigned to elements of industrial heritage, seen through five Lynch`s elements of the image of the city, as well as to understand affective attachment of citizens to industrial heritage and city.

2. THE IMPORTANCE OF PLACE ATTACHMENT IN INDUSTRIAL HERITAGE CONSERAVTION

In order to define social values of industrial heritage valuable to preserve and based on the interaction between the individual and the social and cultural environment, critical examination of the concept of place attachment from place attachment theory is of great importance. The theory of place attachment is based on the relationship between an individual and a group with a place, which is realized on the basis of social and symbolic meanings of the place whose roots are derived from phenomenological studies. In the literature there is terminological ambiguity of concept of place attachment, and the concept often refers to the similar terms such as: community attachment, sense of community, place dependence, sense of place and especially place identity. Still, the place attachment is most often defined on the basis of two subcategories of place identity and place dependence [3]. Place identity is described as the individual's incorporation of place into the larger concept of self [4], which means that place identity is substructure of self-identity. The definition of place dependence highlights the physical characteristics of a place as essential for attachment because it supports one's goals through amenities or resources [5]. Therefore, a place can be considered meaningful because it provides amenities for some activities or consists of emotional and symbolic values. Anyway, in many theoretical and empirical researches place attachment refers to the affective bonds people develop to specific place and that contribute to personal satisfaction, creativity, privacy, security, and serenity [6]. According to same authors, the main characteristic of this bond is the need to preserve closeness with place. Finally, place attachment is a symbolic relationship formed by people, attributing common cultural affective meanings to a certain place, which is the basis for an individual and collective understanding of the environment [7].

Based on the above, place attachment is useful concept in planning the adaptive reuse of industrial heritage which deals with struggle to balance urban development with conservation. The need for balance these two lies within the contradiction between the industrial heritage as a place of contemporary urban life and the industrial heritage as a place with the inherited social and cultural values important to the community. Once again this confirms that the value of industrial heritage does not lie purely in its physical structure, but also in the diverse socially constructed and intangible meanings attached to it. An urban intervention that does not respect the attachment of individuals and groups to places affects and changes the place meanings which eventually can be experienced positively or negatively by different members of community. In order to identify elements of industrial heritage and their meaning valuable to preserve it is important to understand all aspects of attachment to industrial heritage. So, a tripartite model of place

attachment defined by Scannell and Gifford [8] is taken as most relevant for this research. According to this model, the place attachment is a multidimensional concept defined by human dimension, psychological process, and place. The place attachment can be achieved at the individual and group level, which is often intertwined. Another dimension of place attachment concerns the way that individuals or groups relates to a place, and the nature of the psychological interaction that occurs in the environments. Three psychological processes, based on which attachment is developed, are affect, cognition and behavior. The basis of the relationship between individuals and the environment is the emotion [9 in 10]. This relationship also includes cognitive elements such as: memories, beliefs, meaning and knowledge that people associate whit places [8]. As cognition, place attachment involves the construction of place meanings as well as cognitions that facilitate the closeness to place. The third aspect of process of place attachment is the behavioral level in which attachment is expressed through actions (e.g. proximity- maintaining behavior)[8]. And finally, the most important dimension of place attachment is place itself. The place can be examined at different geographical values, and has typically been divided into social and physical attachment [11].

This tripartite organization of place attachment has much in common with a concept of place defined by Relph, and they complement each other. According to Relph, place is center of action and intention [12] and is included into "the intentional structures of all human consciousness and experience" [12: 42]. The essence of place lies in experiencing it from inside, which greatly differs from experiencing it from outside [12]. All these definitions clearly show the importance and the role of people in defining the places and place attachment. This concept of place in a comprehensive way includes intangible values which are related to the experience of space as well as tangible, which are related to the specifics of the physical features of place that affect the experience [13]. There are three main components of place: the static physical setting, the activities and functional values, and the meanings or symbolic values [12], which are "irreducible one to the other, yet are inseparably interwoven in our experiences of places" [12: 47]. These three components are always interrelated in specific way affecting each other and forming dialectics that make specific identity of place. According to Relph [12], the first two of these elements can be easily appreciated, but component of significance and meaning is difficult to grasp. The meaning of place is not property of physical setting, objects and activities- rather it is a property of human intention and experience and is central to all human existence [12]. Precisely this component is the one that explains the way place attachment is developed and maintained.

In case of abounded and underused industrial heritage, physical component can be understood as industrial buildings and structures and natural environment each of which offers its own characteristic possibilities for experience. Many sites are important because of the specific layout and architectural design of certain structures and structures that represent important urban landmarks. Structures such as silos, chimneys, conveyor belts and traffic structure represent distinctive elements in the overall image of the city and the great perceptual and visual quality of the landscape. According to some authors, the industrial structures have no aesthetic values and represent a result of technology of process of production and conditions of efficiency and safety. On the other hand, many industrial buildings have significant architectural values. Activities and functions of industrial sites can be distinguished as being former or present. In other words, they can be analyzed in the context of activities of industry that is closed and current uses of facilities if there are any. As a result of the former industrial activity and industrial life in

general, specific social relations are emerging from which the social significance of industrial heritage is further developed.

Finally, the meanings of abandoned industrial heritage stem from the experience of physical characteristics and previous activities, and thus create physical or social place attachment. Although the theory argues that physical characteristics are an integral part of the meaning of the place, the idea that the individual experience of place makes the basis of attachment more convincing [8].Meaning of place is constructed through emotional interaction between humans and places [14], as well as through cognitive process, and thus affects the development of people's attachment to place. The meanings are culturally determined, since culture articulates the exchange of information, the mode of communication, interaction of people and environment, and determines the way people experience space [15]. Members of the same cultural groups experience more or less the same urban structures and activities and are taught to appreciate certain quality of the place [12].Since they are formed as a result of intersubjective intentions and experience of the place, the meanings are not fixed categories and change in accordance with the change in the social, cultural, economic and political context. Places are continuously produced in interaction with the environment and, therefore, gain new meanings over time [16]. It is also important to consider that different social and cultural groups attribute different meanings to places of industrial heritage. Therefore, the relationship with industrial heritage changes over time and it is historically conditioned, which further leads to the conclusion that there is no unique identity of industrial heritage based on the historical development of industry and tradition.

The meaning of place stems from the direct experience of behavioral and empathic insiders who have an emotional and physical connection with the place, but also existential ones who have full association with the place [12]. Therefore, for defining meanings of industrial heritage it is important to consider the experience of the inhabitants of the cities in which the industrial heritage is located and where industrialization has left a deep trace on urban tissue, but also the workers whose existence depended on working in the industrial sector. Therefore, industrial heritage has individual and collective meanings which allow individuals and groups to feel attached to heritage. Both groups of meanings are important for the planning treatment of tangible and intangible traces of the industrial past in the process of urban conservation. In this way, the meanings of industrial heritage, as an intangible component, becomes an indicator of the importance of physical characteristics and activities for attachment to heritage. In other words, meanings are the field of representation of the relations of tangible and intangible values of industrial heritage.

3. INDUSTRIAL HERITAGE MEMORY IN FUNCTION OF URBAN CONSERVATION

Attachment to places that have suffered destruction and are destroyed and inaccessible is activated retrospectively through the process of losing and re-creating places based on memory [7]. The concept of memory is a prism through which the way of the past is understood and how social groups use ideas about the past with the goal of understanding personal identity in the present. Thus, the place attachment is based on the representation of the past which the environment contains [17 in 8]. In connection with this, attachment to industrial heritage sites is realized on the basis of the meaning of the legacy present in the memory. People use memory to create the meaning of the site and

connect with them, with memory representing a lively and active link between the past and the present [18].

Investigating the individual and collective memory in the context of preserving industrial heritage and urban conservation leads to thinking about the construction of memory, the impact of the social context on collective memory and its change, as well as the selection of elements of industrial past stored in collective memory. Attachment to industrial heritage can be analyzed through the degree, or intensity, and the quality or content of the collective memory, through which attachment is created.

The emotional aspect of attachment to industrial heritage refers to the intensity of memory, which varies based on personal emotions and experience of industrial heritage. In literature, positive experiences and emotions related to the industrial past are more often mentioned. Industrial heritage is understood as a symbol of progress and an important element of a stable social life and pride of the community. However, it is often neglected that there are opposing attitudes towards which industrial heritage is a symbol of social inequalities and class conflicts, and industrial activity is viewed through a prism of severe working conditions. In order to define the intensity of industrial heritage memory, it is important whether there are positive or negative emotional meanings attributed to heritage, or apathy identified, and the intensity value is less important. Also, in order to define the character of the attitude towards the industrial past it is important to determine whether these emotions are assigned to the period of active industrial production, stagnation or complete shutdown of industrial activity. Therefore, the intensity of the memory of industrial heritage is primarily the subject of qualitative research of place attachment, which deals with the question of what places mean, rather than the quantitative ones, which deal with the question of how much they mean. Anyway, the attachment to industrial heritage can be achieved on the basis of negative and positive emotions. The place attachment based on positive emotions gives a sense of belonging, while attachment based on negative experiences and emotions seems depressing and limiting [12]. Intensity of memory affects the positive or negative character of the overall image of industrial heritage, which is important for directing urban planning interventions in order to preserve and enhance the image, or to completely transform the negative image and create a new positive image of the site.

Cognitive and behavioral aspects of attachment to industrial heritage relate to the content of industrial heritage memory, which is analyzed on the basis of common physical and social meanings arising from the experience of physical and social component of industrial heritage. The physical component refers to aspects of the site and physical characteristics (e.g. industrial architecture, specific urban patterns, urban landmarks, etc.), while the social component refers to specific social relationships that have emerged as a product of industrial activities (labor heritage).The content of industrial heritage memory is a subject of qualitative research of place attachment, which deals with the question of what the places mean, and which elements of the places are assigned with meanings. Places are assigned with meanings through multi-sensory experience. The meanings are not just concepts, but also images, sensory-motor schemes, feelings, qualities and emotions that make the encounter with the world significant [19]. According to Stedman [20], the meaning of a place is a mediator between the physical characteristics of the place and the strength of the emotional connection with the place. Sixsmith [21] defines three experiential modes: personal (happiness, belonging, responsibility, etc.), physical (structure, services, architecture, work environment, etc.) and social (type of relationship, quality of relationship, friend and entertainment). Similarly, Gustafson [16] highlights that meanings attributed to places can be mapped

around and between the three poles of self, others and environment. The same author defines three dimensions of meanings: distinction, valuation, continuity and change.

Since the meaning of the place, and therefore the memory, change over time, in accordance with the economic, political and social context, in analyzing industrial heritage meanings it is important to take into account all stages of the place - from active industrial production and phases of industrial activity stagnation. In addition, sites of abandoned industrial heritage have different meanings for different social and cultural groups. Thus, the meanings of industrial heritage are different for generations that were part of an industrial past and generations that only remember the story of it. It is also important to mention that attachment to industrial heritage is achieved either through a positive experience, (for example, as a symbol of social solidarity and equality), or a negative experience of a heritage (as a source of environmental pollution).Finally, defining the content of industrial heritage memory facilitates the treatment of tangible and intangible traces of the industrial past, and defining further guidelines for establishing a balance between the preservation and transformation of industrial heritage values in the process of adaptive reuse. The quantitative and qualitative structure of the collective memory of industrial heritage presented in this way is part of the social and cultural values of industrial heritage that has an important role in the strategies for sustainable urban conservation.

In the following text the results of the case study conducted in Smederevo, at locations of industrial heritage along the Danube bank will be presented. Intensity and content of industrial heritage memory is investigated by a survey of citizens of Smederevo. The main aim was to identify physical elements of industrial heritage which represent important part of the image of the city, their meanings and the character of emotional connection of citizens with the heritage and the city.

4. SURVEY RESULTS

The accompanied survey to the previous theory was conducted in Smederevo. This city is selected due to its bright industrial past, with the backbone in “Sartid” company, the oldest (est. 1913) and the most important steelworks in Serbia [23]. The decent part of pre-war industrial heritage is protected by the Regional Institute for Protection of Cultural Monuments “Smederevo”.

The questionnaire was formed throughout six questions related to the type of memory people have about industrial heritage, feeling that those memories awaken in them, opinion of importance of those places nowadays, and most significant examples of industrial heritage in the city of Smederevo. The survey also included a few demographic variables as a gender, age, the period of life spent in Smederevo, and the possible employment in the industrial sector of Smederevo. The aim of those variables was to see the difference in observation of industrial heritage between those generations that were part of an industrial past and ones that only remember the story of it and abounded industrial objects.

Results of the survey were based on 100 completed questionnaires. Before presenting the structure of collected answers, it is important to give some information in brief regarding the structure of the survey respondents, formed on aforementioned demographic variables:

- Gender ratio in the survey is a little bit different than a general ratio for Smederevo - 64% of respondents were women and 36% of them were men, and a general ratio is 50.7% to 49.3% in a favour of women;
- Age structure was based on three main statistical groups (<18, 18-65, and >65 years). The ratio between the respondent groups was 4%/82%/14%, respectively. Comparing to general age structure in Smederevo (18%/65%/17%, respectively), the situation is also a bit different, with lower representation of the youngest group. It is also important to say that 33% of respondents are between 15 and 30 year-old which is the statistical group of young people;
- Third variable was about years of life in Smederevo. In those answers there were two categorisations, the first one was based on the exact years of life in Smederevo, and it was separated in three groups (<10, 10-20, and >20 years). The ratio between the respondent groups was 4%/6%/90%, respectively. Second categorization was based on relation between ages and years spent in this city. Respondents were thereby separated in three groups; those who live in Smederevo the whole life, those who come in the city before they were 18 years old, and those who come older than that limit. The ratio is 69%/ 15%/16%, respectively.
- The last variable was the question about employment in the industrial sector of Smederevo, and only 24% of respondents have been employed in it, which is really surprising result, considering the significant economic impact that industry has had in the city of Smederevo.

The first question refers to the type of memory that people have about local industrial heritage and associations that they link to it (figure 1). There were 17 possible answers, and respondents had possibility to mark more than one answer, so average number of them was four to five. Respondents often marked opposite answers in sense of positive and negative feelings at the same time. One group of answers was related to the greatness of industrial past, prosperity, equality and security it provided, second one was related to severe working conditions and the bad side of industrial past, and the third one was related to bankruptcy, collapse of the industry and existing abounded objects during post-socialist transition, but also possibility of its restoration. The results show that 42% of respondent are associated of greatness of that industry in the past, but at the same time 40% of them see abounded, neglected and unused space, and mostly the possibility of its restoration and revitalization (38%). A lot of people also link industrial complexes to the bankruptcy (22%), collapse of the industry and economy (34%). Objects of industrial heritage mostly remind people of the time when the industry was strong and everything that those times brought with itself, but at the same time, condition in which those objects are nowadays constantly remind people of all circumstances which caused that. The second question refers to the feelings that memory of industrial past awaken in people (figure 2). The previous question already gave some indications about that, but the results of this one ones more shown that emotions are mixed. Respondents also had the opportunity to mark more answers, so average number of them was around three. People usually feel pride and melancholy about the industrial past (48%) and, at the same time, disappointment and regret about its collapse and the present-day condition of it (58%), which logically leads to nostalgia (34%) as mostly mentioned emotion.

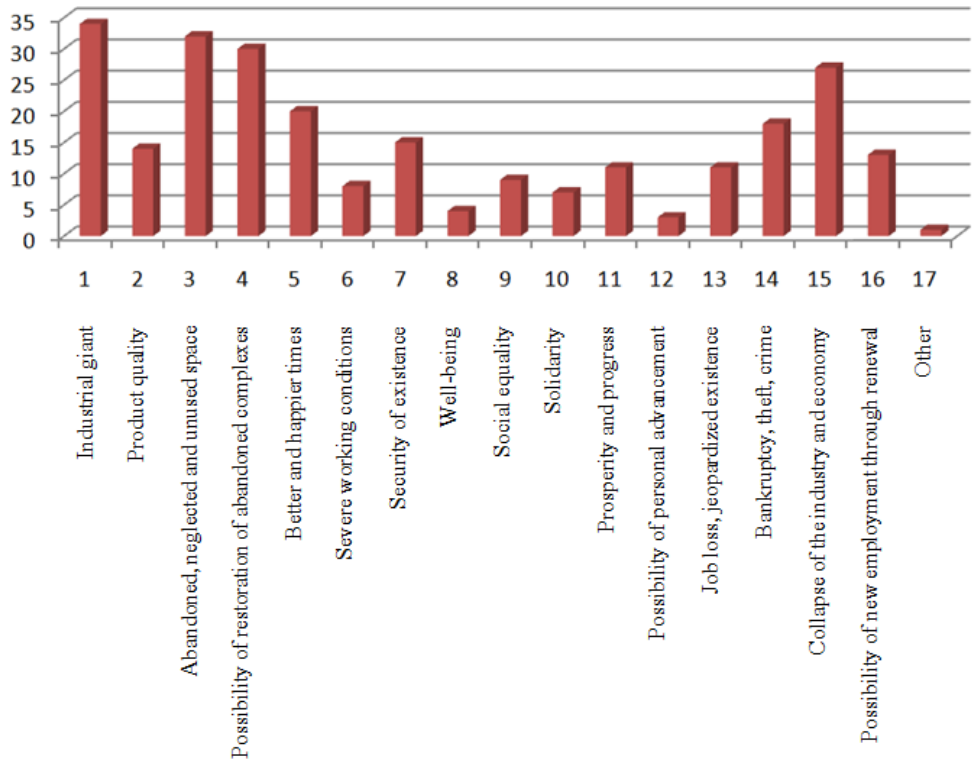

Figure 1. The column chart on the question "Which associations you link industrial heritage in Smederevo with, i.e. which meanings do you attribute to it?"

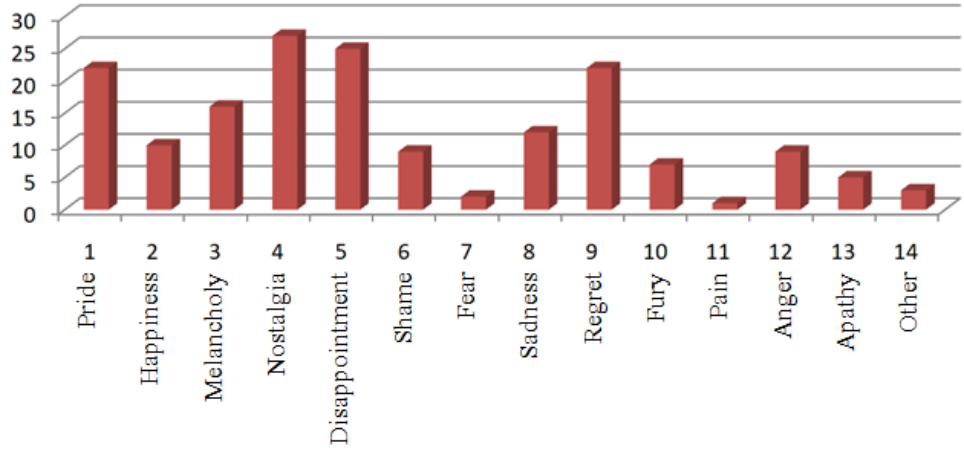

Figure 2. The column chart on the question "What kind of feelings does the memory of industrial past of Smederevo, awaken in you?"

The third, fourth and fifth question referred to the opinion about importance of industrial heritage (figure 3). Almost all respondents (91%) think that industrial heritage has cultural and historical values, also 94% of them marked that it represents significant element of the image of the city. A little bit smaller, but also big percent of respondents (84%) think that industrial heritage of Smederevo has the regional and national importance.

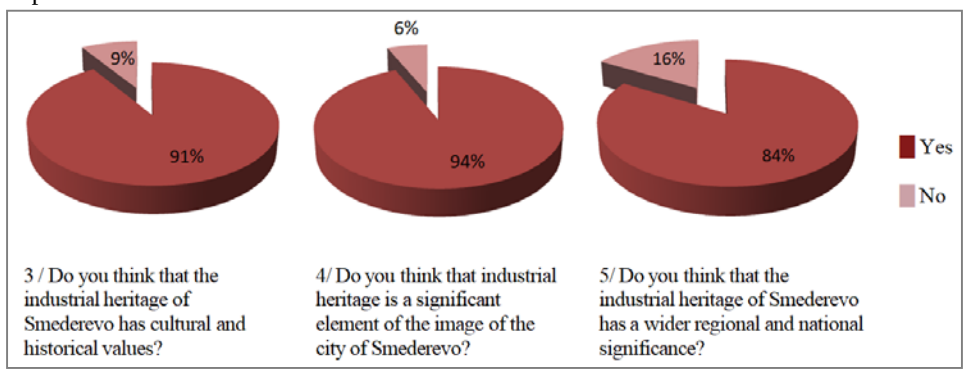

Figure 3. The pie charts on the third, fourth and fifth question

The sixth question was about the place of industrial heritage in Smederevo which a respondent considers as especially important, and the reason for that (figure 4 and 5). People mostly selected one to three structures/complexes, and most of them (74%) favoured the complex of Old Steelworks, especially those who marked only one of them. Respondents mostly mentioned the importance that this factory had before the new one was built (which still have a big economic impact), big size of complex itself, but also historical values, because the construction was started even before the WWI. Next mostly mentioned object is the Silo (18%), as a structure on the Danube riverbank and on the main pedestrian promenade, but also with great architectural values. The third one were Wine Callers (14%), as a structure at the entrance in the central zone of Smederevo from Belgrade, very significant for branding the city in the terms of viticulture, by also with great architectural values. Fourth and fifth most frequent answers were “Monopoly” building and (old) salt warehouse (14%), because of their position close to the Danube (“Monopoly”) and on its very riverbank (“Warehouse”).

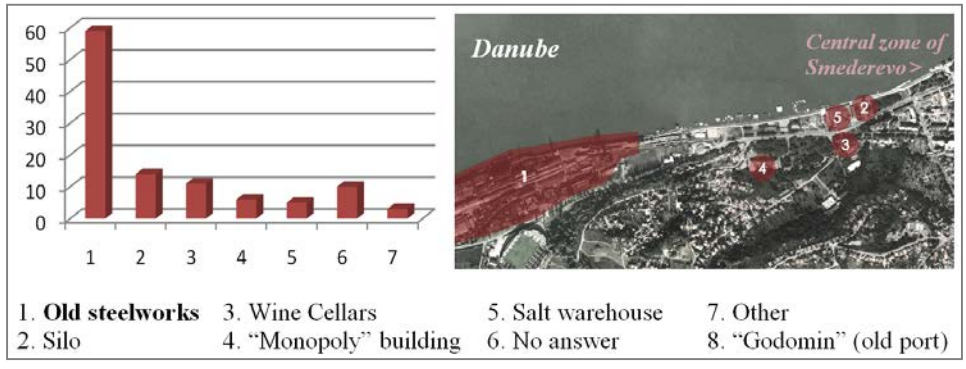

Figure 4. and 5. The pie charts on the question “What place of industrial heritage in Smederevo you considered as especially important and why

5. CONCLUSION

Industrial heritage is seen as a cultural landscape that stems from the interaction of social groups and the space they belong and in relation to which they build collective identity and cultural meanings, through a layered and complex relationship. Social values of industrial heritage are an important part of citizens' identity, because they represent a part of the memory of people's lives, about industrial progress and pride of the local citizens. With understanding industrial heritage as a complex concept that arises from the interaction between tangible and intangible values at the beginning of the 21st century, the concept of place attachment became more important in the context of urban conservation. Planning interventions that do not respect the existing urban structure and social character of a community can contribute to the loss of meaning of specific place. Losing significant urban places can jeopardize the attachment of members of the community to places and result in creating a sense of loss and alienation [22].

One of the challenges of urban conservation is defining the way in which social communities attach emotions and meanings to places, or intensity and content of place attachment. Identifying the dominant meanings and symbolic values, on the basis of which attachment to industrial heritage is achieved, is important for defining planning interventions aimed at preserving valuable tangible and intangible traces of the industrial past in the process of urban conservation. Place attachment has the power to induce the community to actively participate in development processes if those processes aim to strengthen local identity.

Starting from this theoretical framework, intensity and content of industrial heritage memory as social values are identified in this paper.

Throughout the survey, the multi-layer observation of industrial heritage can be recognized. This is especially true in the case of the largest and oldest (old steelworks) and centrally-located examples (old silo). First two questions, where respondents can mark several answers, show different, even opposite emotions and associations among them. In the city of Smederevo, a lot of abandoned industrial structures (brownfields) are part of the city central zone, so people have very strong relation to them. These structures of the city industrial past mostly remind them about the period when industry was strong and Smederevo was known for it. Therefore, the respondents feel pride; at contrary, really small number of respondents mentioned pollution, ecological issue or sever working conditions, as typical problems linked with heavy industry. Also it can be recognized that the current condition of industrial structures reminds people to harsh times during the 1990s and early 2000s, which consequently led to collapse of this industry, but also the city economy in general. Hence people link industrial heritage with their own destiny, because, in their opinion, these structures are spatial reflections of it. Then, their current condition causes also anger and regret among respondents, since many of them observe these facilities more as a cultural heritage than the reflection of the economical collapse and bankruptcy. This is related not only to the possibilities to revitalize their function nowadays, but also to the way of the presentation of heritage and collective identity through their reuse as brownfield sites.

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22| Оригинални научни рад
Research paper
doi 10.7251/STP1813313G ISSN 2566-4484

ГРАДИТЕЉСКО НАСЛЕЂЕ КАО ВАЖАН ЧИНИЛАЦ БРЕНДИРАЊА ГРАДА

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Апстракт

Градови данашњице у свом развоју сусрећу се са изазовом такмичења у глобалном свету и потребу за истицањем својим посебности. Нарочито су угрожени мањи градови који у процесу глобализације остају невидљиви поред великих метропола. Брендирање градова се последњих година истакло као могућност у стратегији развоја и привлачењу нових инвестиција.

Рад је истражује улогу идентитета и могућност употребе градитељског наслеђа у процесу брендирања града Бањалуке. То подразумева аутентичан изглед града, материјално, као и нематеријално наслеђе који представљају потенцијале у процесу брендирања. Такође је важна промоција наслеђа односно формирање слике града која представља више од форме и изграђене структуре. Према раније дефинисаној методологији у раду ће се испитати могућности улога ових фактора у процесу брендирања Бањалуке.

Кључне речи: брендирање, градитељско наслеђе, Бања Лука

BUILDING HERITAGE AS AN IMPORTANT FACTOR OF CITY BRANDING

Abstract

One challenge that present-day cities face as they develop is their having to compete on a global scale and to accentuate that which sets them apart from other cities. In that sense, smaller cities are especially under threat, as they live in the shadow of metropolises in the process of globalization. Recently, place branding has proven itself capable of providing opportunities in terms of development strategies and attracting new investment.

This paper examines the role of identity and the possibility of using building heritage in the process of branding, in this particular case, of the City of Banja Luka. This is in connection with the authentic appearance of the city and its tangible as well as intangible cultural heritage, which is all potential for branding. Heritage promotion is of equal importance, i.e., creating an image of the city according to which it transcends its form and built structure. In line with a previously specified methodology, the paper examines the potential roles of these factors in the process of branding of the City of Banja Luka.

Keywords:branding, building heritage, Banja Luka

1. INTRODUCTION

The globalization process, tourism development and frequent changes in economy contribute to growth of competition in the promotion of cities as potential places for future investments and development. In the post-industrial era of cities, a great attention is dedicated to branding campaign as a potential for economic development of a city and attracting investments. During this process, due to high competition, the attention is directed to distinguishing uniqueness of a place, particularly natural and building heritage. The city, which is authentic, attractive with developed identity, stands out and has a potential to attract tourists and investors. In the past, cities used to attract tourists by building theme parks in locations placed outside of the city or in suburban areas. Contemporary cities tend to attract investors within a historical city, "presence of countless smaller brands in town and city centers presents a challenge for entertainment [...] since they attract as many sightseers as shoppers". Evans,G. (2003.p.417.).

City branding provides a basis for developing a better image of the city, economic growth and attracting tourists, but on the other side, it "provides a basis for city residents to identify with their city" Kavaratzis, M. (2004). The topic regarding the potential of building heritage for attracting tourists has been analysed and higly studied. With the aim of more successful branding, the cities use their building heritage and defined visual identity whereas the experience of "active protection of cultural heritage" is crucial since it takes into consideration heritage and fitting in the context. Even though branding and urban regeneration themselves do not have negative characteristics, while implementing the process it is necessary to take into account negative aspects that can be incurred as a result of the activities, such as increase of a number of tourists, building, increase of a number of residents, increase of real estate prices, etc. These trends could lead to degeneration of cultural heritage and environment around us. In that context, it is necessary to take into consideration the fact that the city is not an ordinary product but a resource that has to be preserved and improved while development planning has to remain within realistic framework.

The paper examines the role of tangible cultural and historical heritage in creating city brand and it is a continuation of previously done researches (Cvijić, Guzijan 2013). The paper is going to analyze possibilities for using architectural heritage and spatial values of urban matrix in creating brand of the City of Banja Luka. The paper focuses on spatial dimension in branding, whereas other, intangible elements of creating city brand are going to be included only within spatial aspect.

2. CITY BRANDING

Branding is a social phenomenon based on the perceptions of target audiences - which might or might not be influenced by the physical and communicative aspects of a given city. (Sevin, H.E. 2014. p. 48). There is no a precise definition of place branding, however it can be said that place branding is a set of physical and socio-psychological attributes, which are distinctive in relation to competition which comprises a unique combination of functional attributes and symbolic values". (Kavaratzis, M., Ashworth, J.G. 2005. p.508). Perhaps more precise definition of place branding includes different actions that would produce a positive image of the city among different target groups through visual effects, local and international events through which the city would acquire a competitive advantage among other cities. "Branding is a mode of

communication and communication is a two-way process“ (Kavaratzis, M., Ashowrth, J.G., 2005. p.508) according to the authors since for branding symbolic, social and emotional value is not enough but it is an image of the brand, that is, its quality that is important for the consumers' perception. People perceive the city by creating an image and the best way to influence the people's perception is through the images of the cities. (Ashowrth, J.G., Kavaratzis,M.2009.p.521). There are examples of a number of post-industrial cities that recovered their vitality through branding and improving the city's image.

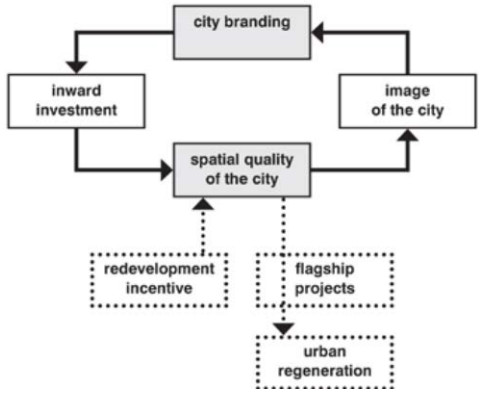

Figure 1. Mutual dependence of quality living space and place branding; the picture is from (Prilenska,V.,2012:14)

For the city branding, the professional literature uses a methodology based on three basic categories of potential for the brand creation: built environment, famous people and important events. As it was previously mentioned, the paper deals only with spatial aspects of branding, therefore it analyzes built environment, that is, spatial and building heritage that has the potential for place branding, which was analyzed as a case study using the example of the City of Banja Luka as well as the possibilities for utilizing its spatial capacities and building heritage in brand creation. Other categories are included to the extent necessary for spatial aspect. (Dinie,K. 2011).

According to Lynch, whose views are based on empirical research, most individuals perceive the city as a set of built objects.(Lynch,K.1960) In particular, five physical elements play a role in constituting people’s image of the city:

- Paths - paths are the channels along which the observer customarily, occasionally, or potentially moves. They may be streets, walk-ways, transit lines, canals, railroads.
- Edges - edges are the linear elements not used as paths by the observer. They are the boundaries between two phases, linear breaks in continuity: shores, railroad cuts, edges of development, walls. They are lateral references rather than coordinate axes.
- Districts - districts are the medium to large sections of the city, conceived of as having two dimensional extent, which the observer mentally enters „inside of“, and which are recognizable as having some common, identifying character.

- Nodes – nodes are points, the strategic spots in a city into which an observer can enter, and which are the intensive foci and from which a person is travelling.
- Landmarks - landmarks are another type of point-reference, but in this case an observer does not enter within them, they are external. They are usually rather simply defined physical objects: building, sign, store, or mountain.

City branding is a complex process which provides a framework for studies, strategies and activities. It must be based on truth and reality. Although there is no universal rule for city branding, some common steps of the branding process may be outlined.For example, Eran Ketter in his branding strategy recognises three stages of the branding process. They are analysis, planning and execution (Cvijić, Guzijan, 2013,26).
The analysis is a systematic record and classification of the potential of architectural heritage and its potential in the branding process. The planning is a development of strategies and studies that collect data from the previous step, and the execution is a set of concrete activities foreseen in the planning process.

3. CULTURAL AND HISTORICAL HERITAGE OF BANJALUKA AS A POTENTIAL FOR BRANDING OF THE CITY

The importance of cultural heritage has a universal value for an individual, community and society as a whole. Through building heritage, a concept of place branding emphasizes the city's uniqueness and authenticity as values that could be used for better presentation of a unique and recognizable image of the city. This represents attraction for tourists, and for the local residents it is a matter of pride. Many European cities use internal branding for local residents and their heritage and external branding focusing on values that are of interest to tourists. "Heritage includes different forms of cultural capital (….) whose definition could be identified as the built heritage with cultural and historical dimension justifying their preservation for future generations". (Benhamou,F., 2011.p.255). The analysis of cultural heritage in this paper is focused on building heritage, whereas other, mostly intangible heritage is included to the extent necessary for spatial aspect.
In the urban tissue of the City of Banja Luka there are many spatial elements as well as artifacts of building heritage.
Paths are very important linear elements in space. The City of Banja Luka has a number of linear elements that have certain spatial wholeness and characteristic of ambient wholeness. One of the most important linear elements are the following: Gospodska Street, banks of the river Vrbas, Kralja Petra Prvog Street, a path leading to Banj hill with beautiful views of the city and the river, Grčka Street and Srpska Street.

Figure 2. 3. Gospodska street - before and now

Edges are important elements contributing to the experience of the city since they represent significant communication points, whether they have extension and are developing into square or they remain as a connection of two communication directions. The most important examples are the Palas Hotel, which emphasizes a position of the cornerby dapping the ground floor, Hipotekarna Bank, which stresses a location where it is placed by its architecture, entrance and sculpture, Vakuf Palace, square at the National Theatre, Krajina Square, whose irregular shape provides a specific type of attraction and it represents a meeting point and location of important city events, and there is also a street corner where the National Assembly is placed and an old Government building as a specific spatial dominant. Furthermore, it is important to emphasize Car Dušan Boulevard, which represents a border between oriental and European part of the city. The Boulevard was formed after the stream Crkvena was shutdown. Even though this eliminated the division between oriental and European part, the presence of ambient wholeness Hanište with Ferhat Pasha Mosque has remained an important witness of oriental part of the city.

Districts represent wider spatial moves that carry certain authenticity, which gives them the potential for branding as a greater whole. This usually refers to historical core or preserved parts of the city. Important districts that could be used for branding are the city center with an Orthodox Church and monumental square, the fortress Kastel with remains of the historical core, Gornji Šeher as a historical settlement that is mostly a residence area nowadays with a great number of traditional houses built on hot springs and the village of Delibaša together with Abbey Marija Zvijezda and a brewery, mill and hydropower plant that served as a foundation of industry in the City of Banja Luka.

Nodes are important elements in the urban tissue. Regardless of physical preservation of monuments, which is sometimes incomplete, these elements could provide significant potential for the creation of brand based on an identity they carry within themselves. Among them are the Bosna Hotel with an authentic gate and garden, Safikada's grave, which is connected to a well-known legend from the City of Banja Luka, the monument to PetarKočić with the park of the same name where many city events take place, the monument on Banj Hill, National Theatre, Presidential Palace, the monument to an Austro-Hungarian soldier in Banjalučko polje.

Landmarks represent spatial dominants in the urban tissue. They, as well, serve as points of orientation. In relation to the surrounding, they dominate by their eitherdimensions, position or architecture. Important examples of landmarks are Christ the Savior Church with accompanying urban micro unity, Cathedral of Saint Bonaventure, which preserves

a memory of blessed Ivan Merz, Ferhat Pasha Mosque, Abbey of Saint Antun Podovanski, Clinical Hospital Centre, Administrative Centre and the fortress Kastel.

4. POSSIBILITY OF USING THE BUILDING HERITAGE FOR BANJALUKA BRANDING

Even though a settlement in the territory of the City of Banja Luka dates back to ancient times, the name Banja Luka was first mentioned in a chart of Hungarian king Vladislav II in 1494 (Pejašinović Z. 2009:19). The fortress Kastel is certainly the most important monument of architectural heritage whose establishment dates back to ancient period, although the contemporary design of the fortress is the result of reconstruction and upgrade from XVIII century. The fortress's design conditioned development of urban matrix around it and the gates routed main streets that connect the fortress with the surrounding.

During Ottoman Empire the City of Banja Luka significantly developed. The period is characterized by the development of two settlements: Gornji and Donji Šeher. Donji Šeher is actually a contemporary historical core of the City of Banja Luka. Remains of Ottoman architectural heritage are extremely important in urban and architectural development of the City of Banja Luka. Ferhat Pasha Mosque is certainly the most important monument of this era. It is placed within highly affected ambient wholeness where there used to be another very important architectural monument – Sahat Kula (Clock Tower), which was ruined in the war and has not been reconstructed yet. It is believed that the Tower remained from Saint Elizabeth Church and that Ferhat Pasha had the clock built on it. This period produced important residential ensemble that was developed under the influence of Ottoman but only some part of it have been preserved until present day.

A new period of development of the City of Banja Luka started with the arrival of Austro-Hungarian ruling in the territory of Bosnia and Herzegovina. The City was developing towards Central European cultural heritage, and first elements of urban planning were established. (Milojević, B. 49, 2005). Buildings that give special impression of the city such as railway station, directorate for military railway, national bank, the Bosna Hotel, gymnasium, Cathedral of Saint Bonaventure, etc. were established during this period. It is highly interesting that this period, apart from historical styles and Eclecticism in architecture, produced Secession and Bosanski Slog (Bosnian Style) as its regional form.

After the establishment of the Kingdom of Yugoslavia, the City of Banja Luka went through the second period of intensive development especially in the period from 1929 to 1941 when it became a capital of the Vrbas Banovina. This period witnessed dynamic building activities. By building Holy Trinity Church and bans' palaces, a historical micro unit was completely established, and by building House of the King Petar I, the city park and the Palas Hotel a recognizable City center was completely formed. The beginning of Modernism was visible in this period marked by a few impressive buildings such as Public Health Institute, Surgical Pavillion and Vakuf Palace, and many buildings that belong to residential architecture (Cvijić, 2014).

In the post-war period the City of Banja Luka was developing in line with socialist organisation. A great attention was dedicated to building residential areas. An important project was building of the Monument to Fallen Krajina People in 1961, which was created by a Croatian sculptor Antun Augustinčić.

In the catastrophic earthquake in 1969 a great part of building heritage of the City of Banja Luka was damaged or ruined. Architectural heritage was affected as well. Later reconstructions degraded and neglected certain monuments of culture. This period witnessed rapid urbanization of the city's outskirts. Building of the residential area Borik is very important.

After the civil war, the City of Banja Luka took the role of an administrative center of the Republic of Srpska, which was a reason to establish an administrative seat of the Republic. In addition to that, there was also intensive building of residential areas that provided accommodation for many people. In the first part of XXI century there was a need for an adequate urban reconstruction of the city that would take into consideration inherited urban and architectural tradition.

Preserved buildings and places contribute to protection of recognizable images of the city. A connection between branding and identity is certainly based on preserved remains of building heritage, as well as on its historical events and legends. There is an opinion that "meetings with the city are realized through perception and images" (Kavaratzis, M. 2004. p. 62) and due to this reason spatial dimension of branding is of a great importance. The city's image originates from a physical reality and is based on well-worn prejudices, desires and memories that take shape in the collective memory" (Kavaratzis,M.2004. p. 62). In the case of the City of Banja Luka, a mixture of different cultures and tradition that influenced the city is very important. There is also a significant number of tangible remains from the ancient times to the contemporary period. Heritage from the Ottoman period and architecture between two world wars might have the greatest importance since these are the periods when the City of Banja Luka was thriving the most.

Figure 4. 5. Hotel Bosna - before and now

As a precondition for further activities in the branding process of the City of Banja Luka there is a revalorization of architectural heritage in line with the contemporary principles and analysis of possibilities of its use in the branding process. The possibilities of using building heritage and spatial wholeness in planning of place branding of the City of Banja Luka, which is different than marketing, could be implemented through four communicative action of the city as it was illustrated by Kavaratzis. All proposed actions with the aim of branding are designed for spatial dimension of the city. All these activities contribute to building an attractive image of the City of Banja Luka, a better promotion and developed brand. Tangible cultural heritage is a desirable value that to the extent that it is preserved represents a foundation for further development.

- “Landscape strategies” refer to a place as a character – designing heritage through spatial and functional measures. They entail actions in planning of the use of urban design and public art in important historical wholeness and linear elements in the city. These actions include a restoration of Sahat Kula, finishing the reconstruction of the fortress Kastel that would include armory and the river Vrbas banks, rehabilitation of private residential buildings that were built in different periods and active protection of XX century heritage.
- “Infrastructure projects” refer to projects to improve the city’s infrastructure in terms of easier accessibility of tourists to all significant objects of building heritage, historical wholeness and public places. Within this group of activities, the attention should be paid to crosswalks, better designation of architectural monuments and pedestrian accessibility to the river Vrbas banks.
- “Organizational and administrative structure” refer to improvement of the city’s governing structure in terms of smooth implementation of projects regarding the promotion of building and cultural heritage, development of public private partnership, networking of institutions, non-governmental organizations and local communities. A particular focus has to be on creating a cooperation between the city administration and republic cultural institutions.
- “The city’s behavior” refers to the city leaders’ vision and relation of the city authorities towards building heritage by adoption of strategies for the promotion of heritage, financial incentives provided to stakeholders for organizing cultural events, incentives for reconstruction of private objects under the protection and other different ideas.

5. CONCLUSION

Branding is a slow and long-term process based on strategically defined goals and programmes for regeneration, planning and promotion. Branding entails an integrated aspect of economic, social, ecological and cultural measures designed at local, regional and state level.

The City of Banja Luka, regardless of destructions caused by the earthquake or war, has preserved building heritage to the extent that is necessary for development of brand. The problem is neglect, poor analysis and inadequate presentation of inherited structures whether it is about individual objects or urban micro units. A task of branding process is to notice the values of inherited structures and to present them by enriching them with adequate stories of legends from the past.

The City of Banja Luka is the administrative, cultural and economic center of the Republic of Srpska. Determination of decision makers and development of strategic documents are mandatory for successful place branding. Utilizing previously defined activities, which, above all, include revalorization of architectural heritage, is necessary to implement the protection, regeneration and presentation of architectural heritage of the City of Banja Luka.

Due to a long-term process of branding, cooperation of all relevant actors is important, and what is extremely significant is the city residents’ support, determination and their cooperation since the changes are meant primarily for the well-being of the residents and it is important to emphasize the fact that place branding is worthwhile only when the quality of life in the city is improved for its residents. Short-term marketing procedures

cannot produce results since place branding entails a transformation process and recognizing and eliminating negative effects that influenced the city's structure.

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23| Оригинални научни рад
Research paper
doi 10.7251/STP1813323M ISSN 2566-4484

INTEGRALNO URBANO PLANIRANJE U TEORIJI I PRAKSI

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Apstrakt:

Integralno urbano planiranje je savremeni planerski pristup blisko vezan sa kompleksnom prirodom grada i potrebom kreiranja održivih i otpornih naselja. Istraživanje je pokazalo da je primjena integralnog urbanog planiranja direktno povezana sa socio-ekonomskim uslovima, zakonodavnim okvirom, kao i profesionalnim i obrazovnim potencijalima društva, što je različito u svakoj zemlji. Pri tome je uočeno da je praksa integralnog planiranja prisutnija u gradovima EU nego u postsocijalističkim zemljama. Ovaj rad fokusira Republiku Srpsku, gdje postoje mnogi problemi u ovoj oblasti. Na osnovu provedenih analiza, vidljivo je da je neophodan konstantan rad na unapređenju metodologije integralnog planiranja, obrazovanja i obuke planera i zainteresovanih strana, jednako kao i jačanje institucionalnih i socio-ekonomskih preduslova za implementaciju integralnog planiranja, posebno u post-socijalističkim zemljama.

Ključne riječi: integralno urbano planiranje, održivi grad

INTEGRATED URBAN PLANNING IN THEORY AND PRACTICE

Abstract:

Integrated urban planning is a modern planning approach close connected with the complex nature of the cities and necessity of creating sustainable and resilient settlements. Research has shown that the implementation of integrated urban planning is directly connected to the socio-economic conditions, legal frameworks, technology, and professional and educational potentials of societies, which differ for each country. Research has shown, through concrete examples, that the practice of integrated planning is more prevalent in cities in EU countries than in post-socialist countries. This article focuses on the case study of the Republic of Srpska, where there are many problems in its implementation. Based on the analysis, it can be seen that it is necessary to constantly work on improving the methodology of integrated planning, education, and the training of planners and stakeholders, as well as strengthening the institutional and socio-economic preconditions for its implementation, particularly in post-socialist countries.

Keywords: integrated urban planning, sustainable city

1. INTRODUCTION

Integrated planning is one of the basic approaches to modern planning and is, due to the complex character of spatial phenomena, a logical and necessary one. The term 'integrated' is widespread today and describes all phenomena of sustainable development and management. Sustainable development nowadays is based on the balanced development of society, economy, and environment, while considering spatial and contemporary relations [1], [2]. It also integrates spatial-physical and social forms of development of urban space. Policy-making for sustainable urban development and the creation of institutional frameworks at all levels has acknowledged integrated planning as the mechanism for achieving a sustainable and resilient urban space and environment.

Integrated planning is, in theory, based on the evaluation and improvement of the rational planning of the 1950s [3], [4], and is a result of the complex nature of the urban context and the overall development of socio-economic relations, which have, in the last decades, become very dynamic [5], [6]. The degree of development nowadays in the fields of economy, social culture, and technology, and the historical flow of these processes, show the permanent complexity and interactive effect of influential factors on urban space and environment [7].

Besides horizontal inter-sectoral integration in planning, there is also vertical integration related to planning at various spatial and governance levels [8]. As some urban phenomena do not have clear spatial boundaries, it is necessary to analyze them through all spatial scales, from the local to the regional, national, and international levels, including the time dimension, which activates short- and long-term aspects of problems and their planning solutions [3]. Planning should be comprehensive in terms of including complex and dynamic development aspects. It should improve mechanisms for socially responsible, adaptable, and participative planning, with the aim of having sustainable and resilient planning of urban space and environment. Planning should also have a human aspect by improving the quality of citizens' life through the protection of nature, created values, and optimal conditions for present and future generations).

Integrated planning also includes defining the appropriate methodology of the planning process, the involvement of stakeholders and the public in the planning process, and urban management, which require additional knowledge and skills. The creation of appropriate regulations and policies in the field of socio-economic and ecological conditions, such as system organization at the international, national, and local levels, are preconditions for the realization of integrated planning in practice. The sustainable development of cities is considered at all levels of governance in creation of strategy documents for sustainable urban planning. The EU supports the creation of a network of European cities under the common theme of sustainable urban development. As reported in New Planning Culture in German Cities [9], many successful initiatives in this domain have already been realized. The renewal of urban space in German cities is the result of the new planning approach, proclaims the German Association of Cities (2013). Apart from the creative sustainable development of cities, it is clear that the more important goals have not yet been achieved, such as equality, security in many places, protection from climate change and so on [10], [11], [12], [13]. One of the reasons for this is the lack of integrated planning, especially in transitional countries [14], [15]. The importance of this theme immediately shows the need for theory and practice research to systematically improve planning methodology, regulations, institutional capacities, social economy, and education for the implementation of integrated planning.

This paper explains the concept of integrated planning and its theory and practice in the EU, with a special focus on planning practice in the Western Balkans (Case Study of the Republic of Srpska).

2. DEVELOPMENT OF AN INTEGRATED APPROACH TO PLANNING

Theories of integrated planning are based on the integrated nature of the planning process and urban phenomena. Urban planning can be described as a technical and socio-political process concerned with the welfare of people, control of the use of land, design of the urban environment, and the protection and enhancement of the natural environment. It is a multidisciplinary process that includes professionals from various fields in common planning activities. For a long time, they worked separately, and cities suffered from many chronic urban problems related to social justice, unemployment, traffic congestion, and environmental pollution. That these problems perpetually extend shows "the importance of across space-and-time planning approaches that account for short and long-term consequences and multiple levels of impacts of city and metropolitan-scale problems, including local, regional and national levels" [3, p.67].

Apart from improving the planning process, the comprehensive approach did not follow societal processes, and its aims went beyond human intellectual capabilities and technical and organizational capacity [16] in the 1960s. The relationship between social processes and planning, a crucial precondition for responsible and sustainable planning, has not been installed for a long time. Knowledge gained over recent decades of socio-economic development, environmental challenges (such as uncontrolled degradation of natural resources and climate change), and rapid technological progress in information accumulation and management should be passed on with the aim of supporting sustainable development with an integrated development approach.

Awareness of the necessity for global protection of the environment, social equality, poverty reduction, and the right to health and education has resulted in the idea of sustainable development that provides a path to desirable and appropriate outcomes. These ideas have been developing at international conferences for more than four decades (see, for example: the United Nations Conference on the Human Environment, Stockholm, 1972 [17]; Habitat I and II - Conference on Human Settlements, Vancouver, 1976 [18]; and Istanbul, 1996 [19]; the United Nations Conference on Environment and Development, Rio de Janeiro, 1992 [20]; the World Summit on Sustainable Development or ONG Earth Summit 2002, Johannesburg, 2002; Rio+10, 2002 and Rio+20, 2012 etc.). Activities related to urban planning and housing are coordinated by UN-Habitat, which produces studies and publications on all types of human settlements with the aim of protecting the environment and ensuring a better quality of life for the present and future generations [21], [22]. [23], [24], etc.

Climate change, economic recession, and refugee crises, which have affected the whole planet, emphasize the actuality of sustainable development and the necessity to permanently search for models for planning a sustainable and resilient environment. At the heart of this approach is integrated planning.

The global consideration of these issues through the institutions of the United Nations represents the highest level of integrated approach to development issues, which has both spatial and planning implications. The New Urban Agenda [24] promotes integrated

planning that aims to balance short-term needs with the long-term desired outcomes of a competitive economy, high quality of life and sustainable environment. The Agenda defines many other aspects of planning and management of urban and spatial development such as balanced territorial development policies and plans, high quality of buildings and public space, promoting integrated and participatory approaches in planning process, multiple use of space, etc. The Urban Agenda for the EU [25] is based on the principles of The New Urban Agenda and contributes to the implementation of The 2030 Agenda for Sustainable Development, notably goal 11 – "Make cities and human settlements inclusive, safe, resilient and sustainable" [26, p.14]. Apart from the need to coordinate with the UN documents, the results of the social, economic, and ecological connectivity of European space are integrated development policies, which EU bodies adopt for all their members. From this emerged the idea of the spatial integration of European cities [2], which plays a key role in pursuing the Europe 2020 objectives [27].

The above UN and EU documents are significant political, institutional, and organizational guidelines for the implementation of an integrated approach to planning and managing urban development.

3. THE METHODOLOGY OF INTEGRATED PLANNING PROCESS

The transition from traditional land-use planning to strategic planning was crucial for the development of the methodology of the integrated planning process. Strategic planning is about process, institutional design, and guidelines for integrated development. Land-use plans, with their 'physical' solutions to social problems, became strategic plans with short-term actions and the framing activities of stakeholders to help achieve shared concerns about spatial changes [1]. Albrecht [1] defined such a planning concept as a four-track approach with the tentative integration of different types of rationality: value rationality (the design of alternative futures); communicative rationality (involving a growing number of actors in the process); instrumental rationality (looking for the best way to solve problems and achieve the desired future); and strategic rationality (a clear and explicit strategy for dealing with power relationships).

Adopting a system approach involves the integration of the three key components – planning, development, and ecosystem sustainability – into a single urban planning and development process to create a sustainability-oriented urban planning and development culture [28, p.346]. The role of planners in this approach changes from one of merely providing expert opinion and technical leadership to mediating between and communicating with stakeholders [28]. Teriman [29] defined eight steps in the integrated planning approach: (1) redefine the problems in the domains of environment, society, economy, and institutions; (2) reconsider goals and objectives; (3) reassess alternatives; (4) re-evaluate selection; (5) development feasibility; (6) construction; (7) completion/delivery; and (8) occupation (Fig. 1.). This model offers sustainability assessment, which takes place after (4) and (8), as a very important mechanism for controlling the planning process. From that point, activities could be back to step (1) redefine the problem.

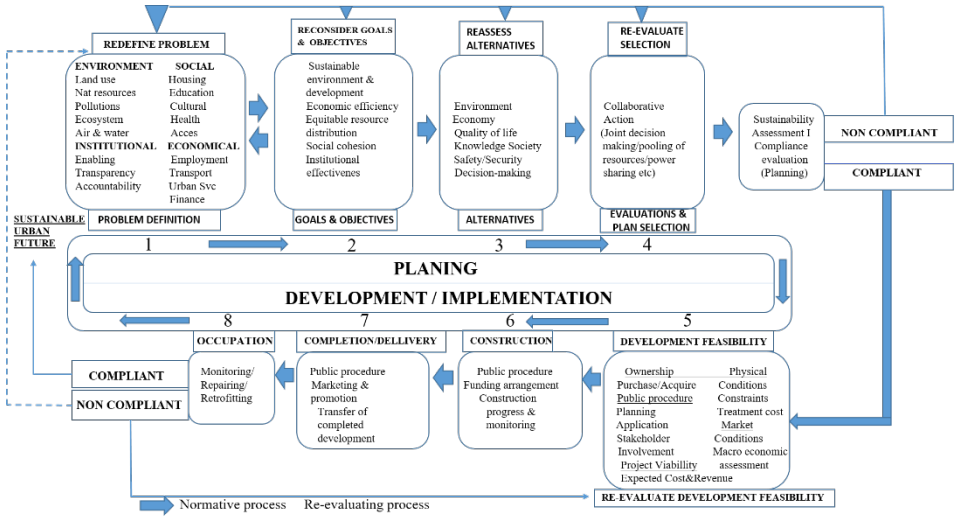

Figure 1. Proposed integrated urban planning and development process [28]

There are numerous sustainable urban development assessment methodologies that measure different sustainability dimensions of the built and natural environments such as land use, transport model, urban infrastructure, urban-ecosystem, etc., which support integrated urban planning and development processes.

A multidisciplinary analysis of all relevant environmental factors that influence planning – such as geomorphology, geology, seismology, natural resources, renewable energy resources, vegetation, climate, and climate change – as well as factors generated by human activities (such as construction, urban facilities, residential housing, education, cultural/health access, and the economy) is crucial for a comprehensive and integrated planning approach. Given the complexity of urban space in the domains of environment, society, economy, and institutional framework, such an analysis has the potential to redefine the problems, goals, and objectives of planning.

There is a necessary interaction among the basic planning steps that needs to be achieved in the process of integrated planning and management of the sustainable development and resilient urban space and environment. The whole planning process presents cycles in which the steps and activities influence each other.

It is also necessary to ensure the participation of all stakeholders in the development and implementation of the plan. Strengthening participation through the involvement of citizens in the planning and decision-making process is an important prerequisite to a comprehensive review of the problems and needs of the population, especially at the local level.

Integrated planning involves the flexibility achieved by using zoning and abandoning strict regulatory planning [30]. Zoning is the recommended model of regulation for the wider urban territories and areas with a lower construction index. It offers flexibility in defining building roles, parcels of land, and permitted, conditionally permitted, and prohibited land use. Thus, a dynamic social, economic, and environmental urban context [14], [6] can be more easily accepted in the planning process.

The zoning model is still being developed in former socialist countries and needs to be adapted to the specifics of their society, economy, history, law, land regulation, and urban development through history.

It should also be noted that strict regulatory planning has been, and still is, applied in relation to some aspects of planning in many countries (e.g. in conservation areas, areas with a high index of construction) and might continue to be used if considered necessary in some urban areas. The end of the 20th and the beginning of the 21st centuries are characterized by a strong, intensifying link between society and technology. Information technology is considered a powerful instrument for achieving integrated planning and development. GIS technology has been adopted as a tool for the creation of a database for sustainable planning and management of different spatial categories and resources [31].

The database that records climate changes and their effect on urban space and the environment is especially important for the implementation of integrated planning, as well as for measures to protect sustainable and resilient urban space and the environment from harmful effects [32]. Protection against floods in the context of climate change implies making development decisions on the basis of current and potential future risks of extreme hydro-meteorological events [33]. Therefore, some countries in the EU, like the Netherlands, create maps of risk and flood hazards, wind, and other extreme climatic conditions to support planning for resilience.

In addition to creating a spatial information system, it is necessary to continuously update the database on natural processes, disasters caused by climate processes, and anthropogenic activities (soil erosion, landslides, desertification, deforestation, etc.), and processes that are the result of human activities and planning processes (land use, construction, housing, transport, water supply, solid waste, energy and technology resources, education, culture, health, protection of cultural heritage, etc.). Evidence of planning documents and the transition dates of all elements of planning regulation, from the present to a planned state, also represent a part of the planning process and require continuous updating. Using GIS in planning and collecting spatial data and the education of staff in new approaches to planning and urban management are also necessary for an integrated planning process.

Institutional support and regulation frameworks, which are also included in integrated planning processes, are preconditions for sustainable development. That’s why the integrated planning approach is more developed and implemented in the EU than in the Balkan region. Implementation of integrated planning is based on planning methodology, recognized more through theory and less through planning practice. Despite good urban practice in some countries (Germany, Spain, Italy, Netherlands, France, etc.), it is evident that many theoretical assumptions in integrated urban planning have not been achieved in real-world practice [10], which has been the case in former socialist countries since the 1990s. Figure 2. presents a proposed planning methodology in Republic of Srpska in accordance with the law for spatial planning, which consists of the main elements of integrated planning, but which is not yet implemented in planning practice.

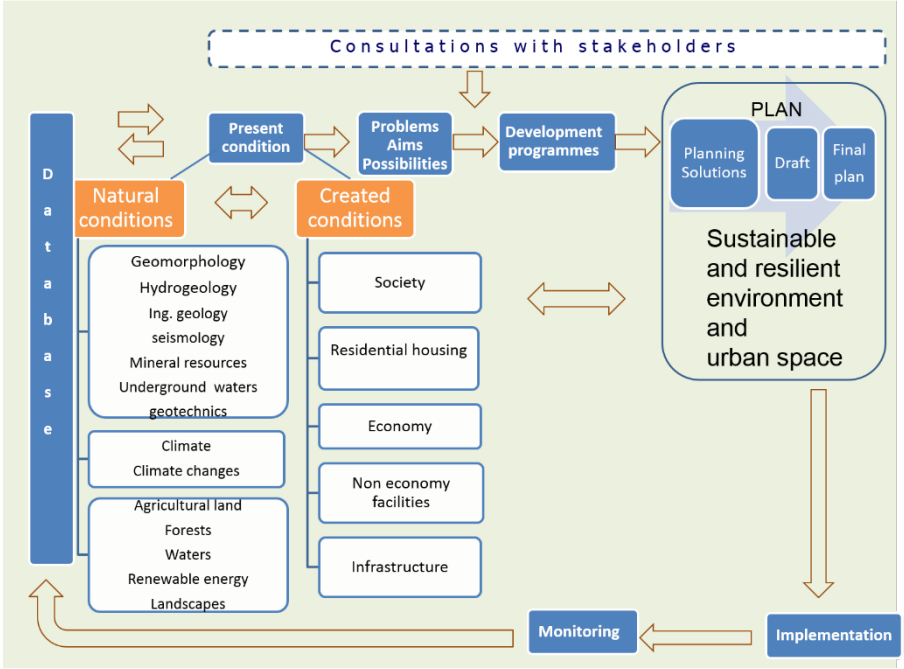

Figure 2. A proposed methodology for integrated planning in Republic of Srpska in accordance with the law for spatial planning and construction. (Image by Milojevic, 2015)

As cities are key actors in development, integrated urban development planning is the new informal planning approach. It is a target–oriented and implementation-oriented strategic control instrument. Committed to serving public interest, equal opportunities, and gender mainstreaming, integrated urban development planning is based on the diversity of local conditions that proclaim the planning process without uniform standards. The content and methods are determined by local challenges and planning practice, supplemented by urban development management. Integrated urban development planning is actually the process that results in integrated urban development strategies that often form the umbrella brand of different modules. This planning approach, adopted by the German Association of Cities (2013) has already been used in many German cities [9]. One of the principal cross-cutting topics of strategic significance is the international outlook and cooperation between European cities.

4. INTEGRATED PLANNING OF EUROPEAN SPACE IN THEORY AND PRACTICE

It is clear that there are different approaches to integrated planning in Europe. They are established through the consideration of the theories of planning [1], [3], [4], and others and the recommendations of UN-Habitat [24], [26] and EU bodies [25], which coordinate many processes by defining integrated development policies, including urban development. The models of integrated planning are also connected with the tradition and practice of each country [14]. They are the result of specific spatial and urban development

at the national level, administrative divisions, regulatory frameworks, planning systems, economic development, organizational and institutional support, and education.

At the municipality level, models of integrated planning are limited by the capacity of the local community to manage urban development in a competent, sustainable, and responsible way, the education process, collaboration with stakeholders, and public participation. In some EU cities, these limits have been overcome to initiate integrated urban development planning as an informal instrument that broadens the system of official planning [34].

Finally, the integrated approach to planning also depends on planners' skills at managing the planning process, accepting the global achievements in planning theory and practice, and developing their own methodological approaches.

4.1. INTEGRATED PLANNING IN THE EU

The establishment of the EU in 1992 had a significant influence on general planning guidelines in Europe. The Treaty on European Union [35], defined the main objectives of the Contracting Parties (Union) as: to promote economic and social progress that is balanced and sustainable; to assert its identity on the international scene; to strengthen the protection of the rights and interest of the nationals of its Member States and to develop close cooperation on justice and home affairs. Integration politics included urban development and integrated planning [36], which were followed by the development of theories and approaches in practice in certain EU countries.

Albrechts [1], states that according to the European Commission [36], more open and flexible EU planning systems were recommended. It was also suggested that land use should not be defined precisely, so it could develop alongside rapid changes in social and economic conditions.

Albrechts wrote: "All the EU member states, except the United Kingdom and the Republic of Ireland, use detailed planning instruments which play a determining role in guiding the location of development and physical infrastructure, and the form and size of development tasks" [1, p.744]. Traditional planning of land use is being replaced with the flexible zoning system, and 'consensus building'. Cooperation and an open dialogue with all actors are advised. Counsell et al. [37] think that the planning system is becoming a mechanism for improving integration policies – horizontal, sector-like, and vertical among political and management levels. They conducted research on the degree of integration of various spatial planning policies in England, Northern Ireland, Scotland, and Wales in 2005.

It has been noted that in these countries, the policies connected with housing, economic development, transportation, sustainable development, biodiversity, and storage of solid waste were highly integrated with spatial planning but not social policies. Education and skills are the least integrated with spatial planning, which opens a wide field of action, including education on integrated planning.

Wider research of spatial documentation at the local and regional levels for the Berlagen area in Sweden [38] showed that the stakeholders were not properly involved in the planning process, and there is room for improvement of integrated planning.

The Association of German Cities promotes a 'new planning culture in German cities' in accordance with 'integrated urban development planning and urban development management'. With the support of the association, 55 projects were realized in 35 German cities – examples of best practice in individual cases where cities have set qualitative standards for their planning goals and their own planning procedures [9]. The renovation

and redesign of public urban spaces for a dynamic urban society, with a variety of functional requirements, were realized in Augsburg, Bielefeld, Hamburg, Hanover, and Leipzig. Adjustment of traffic space to a change in mobility patterns, using energy-saving and low emission mobility, was realized through the projects in Augsburg, Dortmund, Freiburg, Kassel and Munich [39]. New urban quarters were realized in Bremen, Essen, Heilbronn, Munster, Dortmund, Frankfurt am Main, Cologne, Leipzig, Munich, Regensburg, Stuttgart, and Wiesbaden. They promote integrated sectoral urban development concepts for housing, participation, new concepts of funding, etc. [40]. Projects that ensured the quality of urban design, preservation, and reconstruction of urban space were realized in Biberach, Dortmund, Mainz, Munich, Dresden, Halle, Potsdam, Saarbrucken, Siegen, and Wolfsburg [41]. A process-oriented approach and strategic urban development planning were realized in Bremen, Heidelberg, Berlin, Erfurt, Frankfurt am Main, Freiburg, Hamburg, Karlsruhe, Munich, and Schwerin. It is evident that the integrated urban concepts of towns (like the Berlin Urban Development Concept 2030) are based on the old plans, new cross-department strategies and concepts, workshops with key actors, city forums for the public, and events for special target groups. Guaranteeing civil participation in urban development processes is present in most German cities [42].

Six EU countries (Germany, Italy, France, Holland, England and Spain) started creating Smart Cities and Communities in the EU [25] based on topics such as energy efficiency, sustainable energy networks, and transportation. Activities were supported by the European Commission by including new countries and towns in Europe.

It is evident that integrated planning is attracting more interest in the EU among professionals through different topics that target urban development, the final goal of which is an integrated, sustainable, and resilient town.

4.2. INTEGRATED PLANNING IN THE REPUBLIC OF SRPSKA AND PROBLEMS IN THE IMPLEMENTATION

In spite of the different opinions about when transition starts and when it is finished, there is a widely accepted view that the transition is unfinished as long as the composition of output and real fixed assets is distorted and has not yet adjusted to demand, or the standard of living has not caught up with that of the traditional market economies [43]. In the case of B&H, (The Republic of Srpska and the Federation of B&H), the preconditions for a completed transition have not yet been reached. Although integrated planning is mentioned in laws as one of the general principles of planning, there are still no socio-economic preconditions for integrated planning in the Republic of Srpska

This is evident in the lack of regulations, strategies, and harmonized policies at the national level, organizational capacities, and knowledge of integrated planning. Planning teams lack multidisciplinary capacities, which further disables multi-aspect analyses of urban space and environment. Apart from having experts who can deal with the various created artefacts of physical space, it is also necessary to involve professionals in the fields of social sciences and the population as the final users of urban space.

The methodology of integrated planning should be improved with the aim of ensuring more collaboration between professionals and stakeholders, interaction between various planning services, and efficiency in planning procedures. The legislation on flexible planning the law for spatial planning and construction [44], and an updated version [45] - as one of the mechanisms of integrated planning, was adopted in 2010 and 2013 in the

Republic of Srpska. After 2010, zoning was defined in the law as a new regulatory planning document, which offers more flexibility than the regulatory plan but its implementation in planning practice is progressing slowly. There is a necessity to further improve the planning methodology of zoning and to increase professional capacities for new planning practice. Because of this, and other problems in the society, which is still in transition, the implementation of integrated planning has not yet happened. Consequently, guidelines for integrated planning for planners and all other actors involved in the process of preparing, designing, adopting, implementing, and monitoring the plans are needed.

The law on energy in the Republic of Srpska, adopted in 2009 [46], created regulations for energy efficiency but it has not yet been implemented because of the lack of standards and educated professionals. Increasing capacities in this domain and other measures for the mitigation and adaptation to climate change are vital for the implementation of integrated planning.

The Land Registry in B&H has not yet been updated for the whole territory. In this time of climate change, there is a need to have a database on natural spatial features formed under the influence of natural and anthropogenic factors. This refers to geological data on landslides activated after the great floods in 2014, maps of flood risks and hazards, maps of renewable energy resources, etc. This data should be connected to the European spatial data infrastructure and expanded with other sources of information and standards to integrate with INSPIRE. It is based on existing resources at the national and subnational levels, which engage user communities and geographic information stakeholders by organizing them in spatial data interest communities [47].

The education of students, experts, and other stakeholders to enable their active and competent participation in the planning process and the management of sustainable and resilient development, is not yet at a satisfactory level and, therefore, should be continuously improved. All of this implies that integrated planning is not currently present in planning practice to the extent needed to create a sustainable and resilient space and environment.

5. CONCLUSIONS

The nature of integrated planning arises from the complexity and interconnectedness of urban spaces and socio-economic conditions, which tend to develop continuously in space and time. Studies about developing an integrated approach to planning show that it evolved in tandem with the socio-economic development of urban areas and an increasing awareness of the need to create sustainable and resilient environments, which present the highest goals of development on a global, regional, and national level. Integrated planning methodologies have developed especially rapidly over the last few decades, characterized as the age of hyper-dynamic urban context. Urban development involves complex interactions of factors – the natural environment, human-created spaces, the economy, activities connected with socio-cultural and political processes, technology, and planning activities themselves – which all have an effect on the urban space. Integrated planning, as a tool that has developed as the challenges of negotiating these multi-layered interactions have emerged, is one of the most powerful tools for achieving this goal.

Integrated planning methodology is based on the integration of three components – planning, development, and ecosystem sustainability – into a single process. This process can be divided into multiple steps - 8, according to Yigitcanlar and Teriman [28] - which planners can use to work through all the relevant, interacting features of the local environmental conditions, society, economy, and institutional networks to create the plan,

and help to get it adopted by applying expert criteria, collaborating with stakeholders and the public, and applying good negotiating skills. Given the complexity and dynamism of the urban context, integrated planning should be adaptable to frequent changes in space and society; it should also be collaborative, participatory, flexible, and efficient. Flexibility can be achieved by implementing zoning, rather than rigid regulatory planning. Efficiency can be facilitated by ensuring the system is driven by up-to-date databases containing information on land registration, planning proposals and actions, changing local climatic conditions, and so on, as well as by maintaining a collaborative relationship with stakeholders etc. Legislation relating to spatial planning, which is usually made at the national level, should define the need for an integrated approach to planning that takes into account local conditions, effectively making integrated planning a requirement, which has not yet been achieved in the case of the Republic of Srpska.

Integrated planning in the EU, as defined by common regulations on sustainable urban development such as the Urban Agenda for the EU [25], and The European Charter of Planning [48] is present through projects that apply smart city solutions and offer support tools that allow citizens to contribute to the process in a number of European cities. Although the theoretical assumptions of integrated planning have been developed to apply universally, and are, in the EU, underpinned by common legislation, one of the features of the methodology is that it takes into account local conditions. Integrated planning processes are, in practice, also specific to the localities in which they take place, adaptable to the traditions, development models, and practices of each country individually.

This is especially important for the Republic of Srpska, where there are many problems in integrated planning practice. These problems could be mitigated by following the example of many German cities, where efforts are made at the municipality level to promote integrated approaches to creating sustainable and resilient environments. The participation of professional, scientific, and educational institutions in spatial planning activities is of great importance for defining a unified methodology of integrated planning, and training planners to implement it. Civic initiatives are also important for different types of engagement and expression of citizens' interests in urban development. In this way, the initiatives of local communities, citizens, educational institutions, and professional associations can contribute to improving regulation at the national level and strengthen the general socio-economic conditions for the implementation of integrated planning.

ACKNOWLEDGEMENT

The content of this paper was developed as a part of research within the Erasmus+ project 561675-EPP-1-2015-1-XK-EPPKA2-CBHE-JP (2015-3764/001-001) Creating the Network of Knowledge Labs for Sustainable and Resilient Environments (KLABS) funded by European Union.

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24| Оригинални научни рад
Research paper
doi 10.7251/STP1813338R ISSN 2566-4484

УРБАНА ИНФРАСТРАУКТУРА ЗА ХИЉАДУ СТВАРИ. ПРОЈЕКТИ КОЛЕКТИВНОГ КАРАКТЕРА У ЈУЖНОЈ ГРАНАДИ

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Апстракт:

У садашњем социоекономском контексту, а посебно у градовима јужне Европе, један од основних циљева урбанистичког планирања јесте стварање јавног простора као колективног добра који квалификује, обликује и осмишљава урбане функције. У саставу „јавног“ кључна је улога колективних објеката у граду. Рад предлаже и даје одређене базе које би могле помоћи при редефинисању и разумевању објеката јавног карактера у граду. Циљ је да се искорите препознате могућности као и инструменти за њихово правилно инсертовање у динамично урбано окружење, да се сачувају предности од сфере приватног, реактивирају вредности географије и хармонична очитавања која је наследио пејзаж. Све су то аргументи који су изложени и храњени пројектима и искуством планирања у граду Гранади. Они нуде прилагођавање самог значења пројекта и уводе могућност активнијих и кориснијих градских садржаја.

Кључне речи: урбана инфраструктура, колективне форме, пројекат, јавни простор, урбанизам

URBAN FACILITIES FOR A THOUSAND THINGS. COLLECTIVE FORM PROJECTS IN THE SOUTH OF GRANADA

Abstract:

In the current socio-economic context, and particularly in the cities of southern Europe, one of the essential objectives of urban planning is the production of a public space as a collective good that qualifies, shapes and makes sense of urban functions. In the composition of "the public" the role of collective urban facilities is key. A tour of certain bases that could help redefine the understanding of public urban facilities is proposed. The aims are to make the opportunities profitable and the instruments for its correct urban insertion flexible**,** to rescue benefits from the private sphere and to reactivate the geography and the harmonic readings that the landscape inherited. They are all arguments that are exposed and fed by the project and planning experiences in the city of Granada. They offer a readjustment of the meaning of the project and introduce the possibility of more useful urban facilities.

Keywords: urban facilities, collective forms, project, public space, urbanism

1. INTRODUCTION.

It can be said that the city is a conglomerate of urban structures that have developed throughout history. However from its origins, it is clear that it´s structure is far from being an illogical set of elements. If we observe the "urban sculptures" of the sculptor Miquel Navarro, we find a good repertoire of possible 'order between things". Relative position between two or more pieces, repetitions, series, oppositions, creations of concentration points, extensions of low density etc., are directly related to the logical operation of the territory in which the city is situated and in relation to each observational period. This also includes all the contemporary contradictions, where many different types of urban logic overlap and sometimes produce results that are very difficult to read.

By observing cities or ancient foundations, we can take as an example of one of the mechanisms or contrasted logics referred to above, the way in which Miletus (479 years b.c.) organized the structure of the public form in connection with its natural geography [1]. Thus, the reading of its urban map clearly reveals the richness of its concatenated open spaces, and the link that these sets established with the bays of the coastline. At that time, the main public buildings of the city contoured around this sort of "square of squares" that, logically, needed to be located here in order to facilitate possible relationships with other cities that had natural ports.

There are many good examples of cities, real or theoretically planned, that have aimed to suitably locate the main urban facilities by taking advantage of both the natural geography of the area and the geography configured by urban facts.. These cities take into account the shape of the territory and the requirements of the community while allowing an integrated reading of the settlement. We could emphasize here, the benefits of insisting on this approach. For instance, the central position and the way of solving the sloping location of the Garnier Industrial City (1904); the position of town halls, theaters and main libraries, on the tops of the small hills of the new towns designed by Alvar Aalto (Seinäjoki, 1952-1969, Bjoernholm, 1959, Rovaniemi, 1963-1965); the communication between the central roundabout for territorial access and internal main distribution of the city, and the civic center of Tapiola (1951) (that was designed around a semi-open and elevated central plaza. We could also include the interesting symbiosis between Plateau Beaubourg square and the Georges Pompidou Cultural Center in Paris (1977); the relationship between port and waterfront and the central facilities in Trieste, or the same naturality in the Praça do Comerço in Lisbon with respect to the Tejo River, as a city-river connection place, or others waterfront projects like the Alvaro Siza design for the Pendino neighborhood in Naples (1987) or the contest for a new interior port of Badalona (2003) by Manuel de Solá-Morales, etcetera.

In the current socio-economic context, and particularly in the cities of southern Europe, one of the essential objectives of urban planning is the production of a public space as a collective good that qualifies shapes and makes sense of urban functions. In the composition of "the public" the role of collective urban facilities is key. A tour of certain bases that could help redefine the understanding of public urban facilities is proposed. The aims being to make the opportunities profitable and the instruments for its correct urban insertion flexible, to rescue benefits from the private sphere and to reactivate the geography and the harmonic readings that the landscape inherited. They are all arguments that are exposed and fed by the project and planning experiences in the city of Granada.

They offer a readjustment of the meaning of the project and introduce the possibility of more useful urban facilities.

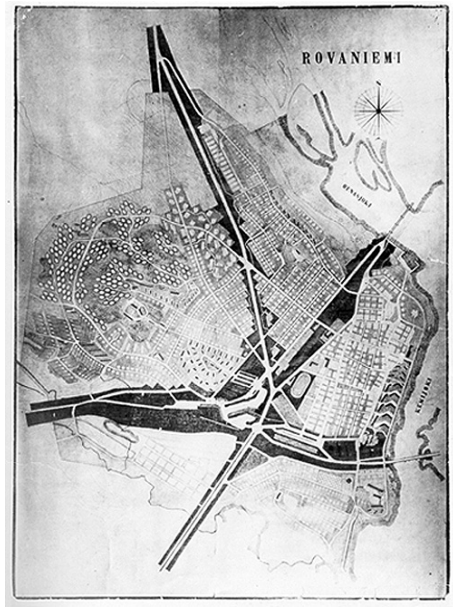

Figure 1. Master Plan for the reconstruction of Rovaniemi, in Finland. Alvar Aalto, 1945. Source: http://julkisetteokset.rovaniemi.fi/teokset/poronsarvikaava1.html

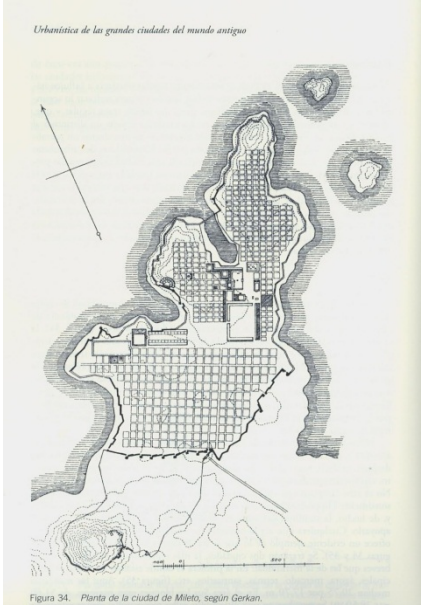

Figure 2. Plan of the city of Miletus, according to Gerkan. Source [2] in http://ciutatmilet.blogspot.com.es/2011/11/introduccio.html

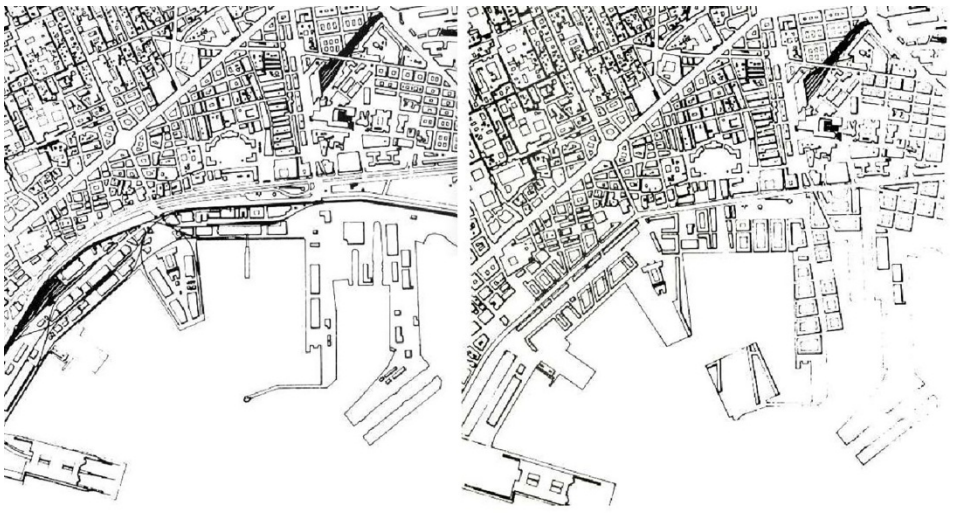

Figure 3. Interventions in the Pendino neighborhood, in Naples, designed by Alvaro Siza in 1987: Previous state / State after the interventions. Source [3].

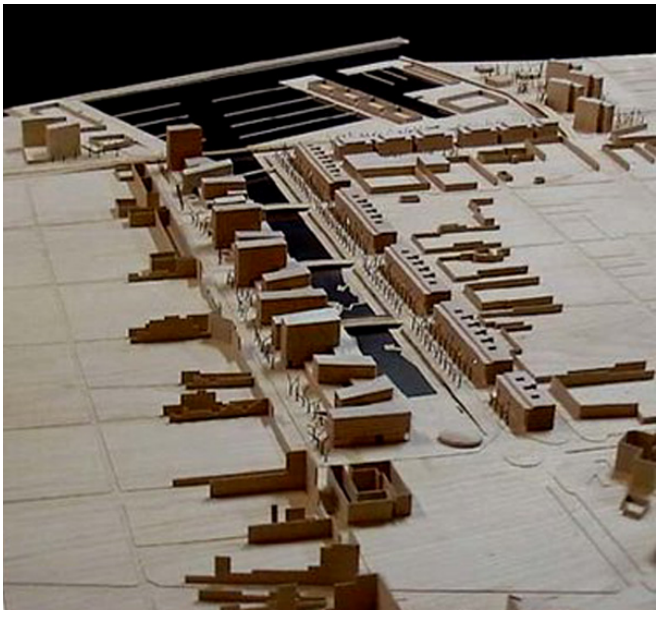

Figure 4. Model for the project of the new urban port of Badalona, by Manuel de Solá-Morales, 1989-2003. Source: http://arquiscopio.com/no-voy-a-hablar-de-la-obra-de-manuel/?lang=ru

Figure 5. Urban project for the communication between territorial access and the Tapiola civic center (Alvar Aalto, 1951). Source: http://www.vaestoliitto70.fi/img-53.html

Figure 6. Hall Twon in Seinäjoki (Alvar Aalto, 1958). Source: http://larryspeck.com/2011/02/02/seinajoki-town-hall/

2. THE PERIPHERY: A TERRITORY FOR ARTICULATION.

The periphery is precisely an urban area that is usually created by the addition of individual projects. Each one of these urban projects has been positioned in a diverse way, producing a sum of different residential systems in terms of size, typology, sections of urbanization, etc. In southern Spanish cities, like in other Mediterranean countries (Portugal, France, Italy, Greece, the Balkan countries or central European countries, among others) a very close relationship was established between the city and its surrounding area.). If we look closely at them all, the first peripheral growth was superimposed on the agricultural tissue (or in coexistence with it). By contrast, this was not the case in the urban growth model represented by the kind of development known as "*los ensanches*", that was led by Barcelona' (Plan Cerdá, 1956), and also implemented in other cities such as Madrid (1860), San Sebastián (1864), Bilbao (1876), or Valencia (1884), among many others in Spain [4].

Taking into consideration a broader vision of the definition of 'periphery', we must overcome its semantic origin as a simple opposition to the idea of 'center' [5]. However we must go further and ensure the meaning corresponds to a concept of “exploding” urbanisation, coinciding with scales of functionality rather than territorial scales [6]. Nowadays the territory is defined as a polycentric, fragmented and discontinuous model, a confused city-region with a varied and changing distribution of functions between the Inner City and the Outer Cities [7]. These 'first peripheries' or 'peripheries of agrarian base' fit into this current definition, and are a feature of Southern European urban settlements.

However, despite the confusion inherent in the periphery as a type of territory -a kind of weakening of the urban space-, referential spaces where the citizen gradually finds his place in the city are contained in the current periphery. This can be seen clearly in the case study of the city of Granada presented in this article. It is more apparent in the Southern District of the city which is a conglomerate of mainly residential neighborhoods located to the south of the River Genil which crosses the city from East to West [8].

In order not to be confused by these consubstantial overlaps in the agricultural based peripheries, it is essential to understand how these areas were formed. In this sense, features of preexisting geography such as roadways and paths, plots, vegetation, crossroads, small agricultural buildings, etc, are preserved. These borders between the urban pieces are, in many cases, responses to the inherited urban traces. Urban interstices, more difficult to define than other spatial stereotypes, have become, paradoxically, the best places to encounter the intensity of the community [9]. This is why this set of internal borders plays a fundamental role in the collective form of these urban areas.

3. SHARED MANAGEMENT OF URBAN FACILITIES.

It is worthwhile carefully reading the reflections on urban facilities written by Portas, Domingues and Cabral [10] with respect to the contemporary territorial and urban situation. Many difficulties in implementing urban facilities are described. These difficulties also have an impact on the objectives that the administration can set when it comes to working with the city's facilities. The text confronts these widespread problems in our cities from different points of view:

The diversity, the specialization, the location, the typology and the quality of the urban facilities, translate into new urban hierarchies and redefine the role of the agglomerations. These processes take place both in the geographical context of insertion of their territories and influential societies, at the national territory level, or at the most extensive level of internationalization.

At a time of deep transformation of the social state the great diversity of institutions are managed directly by the central state, by the municipalities, by mixed formulas, by associations, by private entities, etc. In this context, programs to promote new facilities, at least, have to tackle two different challenges:

Related to the "facilities system", it is necessary to overcome barriers set long ago -through guardianships, for example, or by over-standardizing operating modes - and take advantage of network economies that facilitate the design and operation of transversal projects […].

Nuno Portas, Álvaro Dominguez and Joao Cabral. Text excerpted from their paper "Critical dimensions of territorial politics", [10].

3.1. URBAN FACILITIES FOR MIXING

From the point of view of city behavior, urban facilities are basically for public use. We could say that such public use contains two urban dimensions: one that brings together, on the one hand, the generic characteristics corresponding to its quality for general urban use to serve the collective; and also, on the other hand, that quality which reflects the specific characteristics given by its detailed use, its range and spatial context.

From the sum of its generic quality as a public utility, on the one hand, and its spatial specificity, on the other, we can provide a series of key points to establish its relationship with the urban environment in which it is inserted. These points should be borne in mind for any initiative that tries to implement collective and public uses. They are the following:

1) Firstly, an urban facility -a school, a kindergarten, a library, a theater, a civic center, or hospital, a cinema- must be seen as meeting a social need but also as a project. This means that placing a facility like this in the city is an opportunity to build the city in a better way. It is also an opportunity to generally reflect on the urban condition of this settlement, considering the relationship between place and territory. It must, therefore, comply with superficial parameters. . However it must do more than that. It must be an example of a period of time and a kind of society, a way of understanding social and urban relationships. This means the capability of acquiring sensibilities: environment, accessibility, urban comfort, etc. Requests for new facilities arise during the planning of an urban sector which must adhere to the Master Plan. If they are not part of the master plan they may need to be integrated in a special planning phase as they have an impact on the corresponding projects in the public space related to them.
2) Secondly, facilities must be seen as "containers for urbanity", which means taking care of the possible accesses, areas of arrival and exchange for all kinds of functions and flows; the urban edges, the contact with the limits, the physical and visual relationship to the contours of the city, etc. It also means that they have the ability to connect the urban fabrics and develop the urban identity of the neighbourhood. An urban facility must respond to its

status as a remarkable entity for collective and social use with the capacity to build urban identity. This means taking advantage of the capacity to identify citizens with their environment, from both a geographical and a historical point of view, in relation to the landscape and the natural resources.

3) Thirdly, urban facilities, in general, can, and should, be seen as a powerful urban network. This means that they must be understood from their specific problems but also as a system of linked points. They must become a positive development of the urban condition, transmit information and energy from the public sphere, and introduce their collective functions in the city. In another sense, urban facilities need to incorporate the city in their own spaces. Working on network facilities involves molding each one of them according to its role in the network and recognizing the existence of isolated pieces. The networks are built and improved by interacting with the other city networks and the territory (the network of public spaces, mainly the natural or environmental network, the infrastructural network, the commercial network, etc).

In view of the comparative vision between two sports centers in the southern area of the city of Granada (see figures 7 to 10) we can find examples of the predisposition of the facility to serve many things at the same time. Through urban observation of the functioning of space and of human action, you can check that certain singular spaces can be recognized as "successful places" from a social point of view. A successful place is a space that works in favor of confluence, exchange and the plurality of relationships. In them, citizens are both identified with and represented by the environment, beyond opting for necessary services. From a disciplinary point of view, the project of urban facilities, to a greater or lesser extent, allows freedom of use and appropriation, since the facilities are configurations of urban architecture that contain elements of the past that are of cultural and historical value.

4. GRANADA AND IT´S GROWTH SOUTH.

In order to understand how Granada developed, it is necessary to know the circumstances that influenced its urban growth. Granada is an inland city, to the east of Andalusia in the south of Spain. It is an historic city in the foothills of the Sierra Nevada, on the edge of an alluvial deposit space created by the River Genil valley. For many centuries, Granada remained physically concentrated in this area. It was not until the early twentieth century that the city was forced to grow and cross the rivers.

Three sectors can be recognized in the city: the central historical and cultural sector, a district to the north separated from the center by the Beiro River, and finally, the "Southern District" on the other side of the River Genil.

These lateral districts have been and continue to be the urban growth zones of the city. However, they were urbanised with very different urban typologies. In both sectors, although more intensely in the south, small rural and residential settlements have served as a basis for development in peripheral Granada, and have conditioned, as we will see, the general urban form of the city.

All of this shows a city which is very open and filled with possibilities at both peripheries (to the north and to the south). However, its urban center is very closed and univocal, conditioned by serious prejudices about its own urban form or its future urban evolution.

3.2. THE SOUTH AS AN URBAN STAGE.

The Southern District of Granada was planned urban development out from the city centre, before assuming the sprawl-type accelerated development that has shaped the metropolitan area in many other European cities.

This kind of 'historical periphery', undervalued during its early years, was at the time claimed as a powerful field of experimentation. The Urban periphery was considered to be the stage on which to develop contemporary urban life. It was defined as a space of hope, where there was affordable housing and spacious facilities [11].

The periphery also meant that the city went from being a place completely accessible on foot, to being a space that required other means of transport and new infrastructure in order to move around freely. It became a place with a significant increase in population, a place that needed to incorporate new roles, new uses, new scales and new urban types.

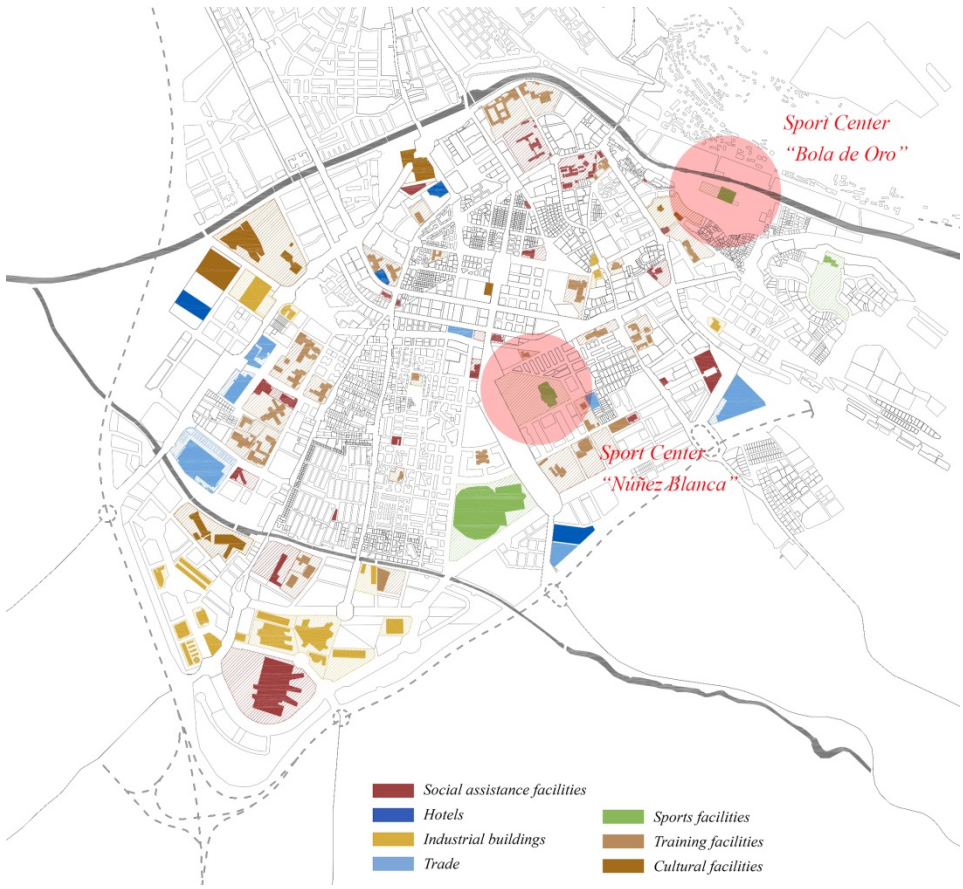

Figure 7. Urban facilities in the Southern District. Location of the two sport centers presented as case studies. Source: Own elaboration.

3.3. THE SOUTH AS AN ARTICULATION OF TERRITORIES.

Beyond a spatial area, this place on the left bank of the River Genil is a kind of city in itself. This type of city in Spain emerged mainly in a historical moment of urban growth that some cities experienced before others. This urban development implied a change in urban mentality where the new development was integrated "into the pre-existing city.

It was the beginning of an urban model where the landscape began to respond to more than one single urban logic. The territory was increasingly more difficult to read: an urban condition compounded by a fragmented landscape, the consequence of a sum of individual projects lacking the necessary cohesion.

Nowadays, the city spreads and disperses through the territory and the periphery acquires a central position. It thus becomes the main space for exchange between the metropolitan area and the historic center, while maintaining its role as a place in transformation.

5. TWO SPORTS CENTERS IN THE SOUTHERN DISTRICT OF GRANADA.

Sometimes deficiencies in urban design can cause rigidity. This is the reason why, paradoxically, the absence of urbanization can facilitate the exchange between urban facilities and the city. In this manner, the citizen's activities can define the spaces around facilities. This arises more naturally in environments that lack definition. Based on this, we could think of our future projects as attempts to imitate the spontaneity with which many of these fragments of periphery have led to a better urban and social cohesion.

In Granada we have an urban area that is basically well-served. Since the arrival of democracy in Spain, four decades ago, and the strengthening of municipal power, municipalities have been claiming equal opportunities for all cities. At the same time, internally, there has been a "democratization" of the different districts of the cities themselves. We are referring here to the emergence of all kinds of facilities and "neighborhood centers", which have served to meet the demands of the inhabitants in each neighborhood.

In general the actions carried out by the local and regional governments are positive: distributing the urban services equally and responding in a balanced way to each area of a city. However, in some cases, when planning has not been accompanied by an integrated vision these actions have become paralyzing elements. In many instances, although the facilities are necessary, they are provided based on the need to meet a compulsory quota of public investment designated for an individual area rather than taking into account a strategic approach for the overall area. In the majority of cases, urban facilities do not take advantage of the spatial and urban potential. They are planned and designed without the required attention to the urban priorities or "key situations" of each context, some of them, opportunities and spaces conquered in past epochs: "*In equal measure to imagination and initiative, changing streets requires eternal vigilance, and hard-won gains must be defended.*" [12].

Figure 8. Ortho-photography of urban context of Sport Center "Bola de Oro". Source: Own elaboration from Google Maps.

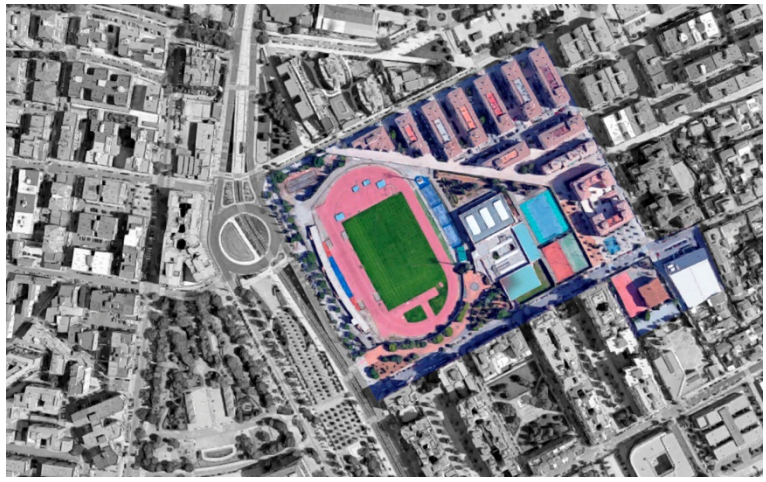

Figure 9. Ortho-photography of urban context of Sport Center "Núñez Blanca". Source: Own elaboration from Google Maps.

4.1. ASSESSMENT OF TWO SPORTS CENTERS IN THE SOUTHERN DISTRICT OF GRANADA FROM AN URBAN PERSPECTIVE.

Sports facilities have become catalysts for activities and collective meetings. They respond to the current social diversity by offering multiple sports activities for all age ranges and profiles of people. This intense activity generates constant comings and goings throughout the day every day of the week. The sports centers open almost all day and stimulate social dynamics not only through their different functions but through the different programs of activities that can be found in them. This is a constant process that generates flows and

needs in the environment and neighborhood. In order to meet these needs (In the case of municipal facilities) a lot of new services arise around them: cafeterias, sports shops, supermarkets, children's games, etc., which develop to meet needs and to take advantage of the collective dynamics that have arisen.

According to the above, the location of these facilities in terms of their plots and the configuration of the exterior space is a crucial factor in being able to develop the urban energy generated around the building and extend it to its urban environment. The combination of activities exponentially increases the interactions, as observed in these two cases described below. Both of them were part of the construction of a system of facilities in an urban area that needed to be developed. The improvement they brought to community life and the gradual increase of more complex community relationships would lead to the transformation of its environment.

The *Bola de Oro* Sports Center is located on the left bank of the Genil River, at the end of *Carretera de la Sierra*, a main street leading out of the city. It was planned on a closed flat space between the hills of the valley and the river itself. It was conceived as an isolated element, avoiding more general urban plans along the banks of the river that the urban planners of Granada tried to carry out a number of times in the 20th century.

Figure 10. General view of the Bola de Oro Sports Complex. Large equipped public space surrounds the sports center on its rear side. Source: Own elaboration.

It is evident that the different factors that influence this area such as neighborhood, riverside environment, leisure and pedestrian atmosphere as a corridor of public space have yet to be understood. In this area we continue playing cat and mouse, without noticing the relevance of improving the quality of space. The conflicts between the different local governments are obvious. Each one of them has wanted to make too many decisions in too short a time frame. In this manner they have placed conditions on the future options, limiting the possibilities of a more general understanding of the banks of the Genil River. The residential buildings placed around it should have been studied and facilities including the sports center should have been better represented and given a more influential role in the organizing of this place.

For its part, the *Núñez Blanca* sports center is located to the right of the old *Carretera de la Zubia* and provides facilities for a series of very dense residential units from different periods of the second part of the 20th century. It is, however, a unique venue that internally distributes the space between an athletic track, open courts, and the central building that

includes multi-sports courts and indoor pools.
This sports center was developed as a singular project and has all its bordering spaces well organised. To the north it allowed for the consolidation of a pedestrian axis that provides access to all the small streets of one of the first social housing developments in the south, the *Mirasierra* neighborhood of the early 70's. To the east, it contains a small square that connects three different streets, all of them the main pathways of three small urban fabrics of different times. The square also connects to the entrance and car park of the biggest supermarket in the area. Finally, access to the sports center is through a wide sidewalk, a kind of public space which provides great freedom of movement and is located next to the athletics track, which is at a lower level and can be observed to the left of the entrance.

Figure 11. Access Square the Núñez Blanca sports center, El Zaidín neighborhood. Source: Own elaboration.

Here we have a project strategically designed to take up a territory and resolve its own limitations. The urban design tries to take advantage of the difficulties to make the implementation of the facility an exercise in conciliation. In this way, the sense of perspective of the pedestrian street is recovered; the relationship between the main access and the squares of dense neighborhood to the east is also defined in a proper way. Finally, the representative public function of the urban facility is achieved and feeds the small rear square and the landscape around it.

6. CONCLUSIONS

The urban plan and urban design of the facilities in a historical periphery like the one that we have explored in Granada could lead to, for example, the renovation of first generation commercial structures; the recovery of basic agricultural roads in the foundation of the urban district; the revitalization of axes of geography; or the revision of foundational urban plots, among other possibilities. These should be the fields of action for urban projects composed of a collective strategy that creates better balance between urban fabrics. In this sense, the reflection on urban facilities goes through an accurate selection of investments, both in terms of effort and capital. The principle aim should be the strengthening of the relationship between urban form and geography. Secondly, it is fundamental to give the key role to certain urban and territorial corners within the city that can act as guides for the urbanization of other neighborhoods in the near future.
We need to present urban plans and projects on neighborhood participation that can be

used to formulate a good set of adequate questions. This would allow a process of reflection on the relationship between the social, political and economic needs of the neighborhoods and cities to start. It would be an opportunity to face new and old challenges. It would be a chance to reveal central places and key elements of urban design that are often hidden under layers and layers of bureaucratic urbanism, but that in essence have been demanding to be seen for a long time.

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25| Оригинални научни рад
Research paper
doi 10.7251/STP1813352M ISSN 2566-4484

INTEGRATED URBAN PLANNING OF BANJALUKA - POSSIBILITIES AND CHALENGES OF NEW URBAN PLAN

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Abstract:

Integrated planning is a modern approach to urban planning aiming at their sustainable and resilient development. It is theoretically based on the need to adapt the planning system of complex processes in the built environment, with comprehensive and integrated analysis, using appropriate planning methodology. Prerequisites for the implementation of integrated planning are institutional, legislative and financial support, the policy for strategic urban development at the national and local level, participation and appropriate education of all stakeholders in the planning process, which often can not be achieved, especially in countries in transition. This paper will address the opportunities and challenges of applying integrated planning in preparation and development of a new urban plan for Banja Luka, which can serve as a model for improving the methodology of integrated planning and planning practices of other cities in The Republic of Srpska.

Keywords: integrated urban planning, urban plan, methodology, implementtion

INTEGRATED URBAN PLANNING OF BANJALUKA - POSSIBILITIES AND CHALENGES OF NEW URBAN PLAN

Rezime:

Integralno planiranje predstavlja savremeni pristup urbanističkom planiranju u cilju njihovog održivog i otpornog razvoja. On je teorijski utemeljen u neophodnosti prilagođavanja planiranja složenim procesima u građenoj sredini, koji moraju biti sagledavani integralno, uz primjenu jedinstvene metodologije planiranja. Preduslovi za provođenje integralnog planiranja su institucionalna, zakonodavna i finansijska podrška, definisane politike strateškog urbanog razvoja, participativnost i odgovarajuća edukacija svih aktera u procesu planiranja, što često nije moguće postići, naročito u zemljama tranzicije. Ovaj rad će se baviti mogućnostima i izazovima primjene integralnog planiranja u pripremi i izradi novog urbanističkog plana Banjaluke, što može poslužiti kao model za unapređenje metodologije integralnog planiranja i planerske prakse drugih gradova u Republici Srpskoj.

Ključne riječi: integralno urbanističko planiranje, urbanistički plan, metodologija, implementacija.

1.

2. INTRODUCTION

Cities are today faced with the major challenges in the field of social, economic and natural processes that are constantly becoming more complex and permanently affect the urban space. Urban transformations are taking place in accordance with the intensity of the processes, but their quality depends on the ability of urban society to deal with processes and to create effective mechanisms to manouver those processes toward the right direction in the long term. Responsible planning and management of socio-economic relations, environmental protection, and the protection of climate change on a local and global level, taking into account the spatial relationships, are the key of sustainable and resilient development of cities [1], [2]. One of the most important mechanisms on that path is the application of integrated urban planning. This approach is based in the integrity of the urban phenomenon that is complex, unique and indivisible. At the same time, urban phenomenon is dynamic, changeable and is a process, not a static form, in which a large number of influencing factors have mutual interaction [3].

Integrated planning is based on the theory, which has been adressed by many researchers [1], [4], [5], [6], [7], [8], etc. It is also supported by the umbrella documents of the UN-Habitat and the EU [9], [10] which define a platform for sustainable urban development as well as guidelines for integrated planning [11], [12]. Thus defined, integrated planning should be the basis for defining integrated planning methodology at the national level which should be defined by each country, in accordance with the specifics of their spatial and urban development, administrative and political organization, legislation, economic development, education, institutional and financial support plan etc. Very often, especially in countries in transition, the processes of urban transformation of the today's cities are not adequately understood character and the role of integrated planning in this process, which is, with limited financial capabilities, weak support for sustainable urban development [13].

The application of integrated planning at the local level is further limited by the insufficient capacity of local communities to manage the process of preparation, drafting and adoption of plans in a participatory manner, lack of strategic planning, funding problems, the education of participants, etc. In some EU cities, problems go beyond of local initiatives that strengthen participation and improve the quality of urban space by promoting informal instruments to strengthen official planning system [14]. The experiences of these cities can provide guidance to strengthen the practice of integrated planning in the cities of the Republic of Srpska. Banja Luka is the city which could promote that approach with improvement of the practice of integrated planning through the process of drawing new urban plan, which will deal with this work. After defining the theoretical bases of integrated planning, presentation planning practice in some European countries, some aspects of integrated planning in Republic of Srpska and present problems, paper will point out some of the possibilities for improving integrated planning of Banja Luka, through the guidelines for new urban plan. The results of this research will be useful in the practice of other cities in the Republic of Srpska, as well as at the entity level in order to create the preconditions for the improvement of national legislation and strengthening the capacities in the field of integrated planning.

3. INTEGRATED PLANNING-THEORETICAL REVIEW

Urban planning in the period of the twentieth century, in which the cities have experienced an intense phase of development at the global level, went through several approaches. The first was rational planning (early thirties) justified by the Athens Charter, which dealt primarily with physical planning of towns, with pronounced zoning and separate work of experts in different spheres of urban space. This access couldn't meet the needs of the complex phenomenon of urban space, where they were, due to focus on the urban economy growing profits, piling up many problems especially in the field of environmental protection, social equality, unemployment, traffic congestion, and so on. [1]. This has resulted in the need to improve urban planning in sixties through a comprehensive approach to planning, with the aim to consider both social and economic factors of development, and environmental protection (comprehensive planning). However, for a long time planning could not create adequate mechanisms for the acceptance of social processes in the planning process, nor a social development framework with its intellectual, political and organizational capacities could creat the necessary conditions for integrated planning [15].

These questions had to be run through the planetary movement as well as the idea of sustainable development and sustainable urban development since the seventies of the twentieth century to the present ([16], [17], [18], [19], the World Summit on Sustainable Development Johannesburg, 2002; Rio + 10 2002 and the Rio + 20, 2012 etc. which basically have an integrated approach to the socio-economic processes and the environment, and planning for sustainable urban development. All this resulted in the New Athens Charter [20] which redefined guidelines for urban development of cities at the beginning of XXI century in accordance with the principles of sustainable and resilient city. General guidelines for integrated planning are defined by the documents through UN Habitat [11], [12].

The task of integral planning is to simulate complex urban phenomenon through the present conditions and vision for future development. It is based on the continuity of planning process in which the space should be seen through all levels of planning documents, from the strategic to detailed ones. Plans must be mutually agreed upon in a way that the lower level plans must be harmonized with higher level plans. Integrated urban planning is based on a unique methodology of planning that clearly defines the planning process from the preparatory phase of the plan to its implementation and monitoring, providing guidance to planners and stakeholders on how to behave and achieve a constructive role in the planning process. In this process comprehensive analysis of all relevant aspects of the urban space in the domain of spatial-physical, functional, and socio-economic characteristics of the environment is very important. [7], [3].

This is achieved by a multidisciplinary planning teams that interact with each other, applying participatory planning. The role of the planners in this approach is changed, from the experts to mediators between the stakeholders [7]. Integrated planning includes the improvement of the methodology of spatial zoning in order to create a planning mechanism for flexible and adaptable planning, which is especially important for post-socialist countries where the regulation plans are kept up to date, as the most common form of regulatory planning [3]. Zoning is recommended especially in non-urban and semi-urban zones, because it offers flexibility in defining the rules of construction, plots and conditionally authorized and prohibited land use. In this way, a dynamic urban

context, which is faced with uncertainty and unpredictability of future events, can be easier accepted through the planning process [21], [22].

Integrated planning is also very important in terms of climate change, the use of renewable energy, energy efficiency in buildings and the increasing need for planning urban areas which are resilient to changeable, not only natural, but also socio-ecoomic processes. Usage of integrated planning in practice is very often not represented enough, or is limited in the sphere of socio-economic, educational and expert capacity, although it is significant mechanism for achieving sustainable and resilient urban development.

4. PLANNING PRACTICE IN EUROPEAN COUNTRIES

The European Union has no formal authority over urban policy, but due to its crisis, cities are becoming a new measure for implementation of urban policies. On the other hand, UN's New Urban Agenda is directly related to cities, both at the level of implementation and actors in urban processes: recognizing cities as development actors, creating livable cities, and achieving integral urban development. Cities are not only responsible for adopting new planning processes, but they also set qualitative standards for core planning goals, priorities for plans and projects in accordance with planning procedures. On the other hand, new city forms, which are dynamic and expanded in the territory, imply the necessity of introducing new approaches to urban planning and planning [23]. Innovative goals and strategies for urban development and planning are prevalent when local politics and administration show courage towards their own research as well as adopt new approaches that have been tested elsewhere. Therefore, the global UN and EU settings need to be tailored to the specific local conditions, and to seek the most appropriate approaches within them. Among many different examples, only a small reflection on the system of planning is here selected, as well as the practice in several European countries including Denmark, Switzerland and Germany.

The system of urban planning in Denmark starts from the statement that planning must equally create and preserve the quality of urban spaces and landscapes. It has to contend with the challenges of change and development, which means that planning regulation and techniques are subject of constant reviewing and updating. Decentralized system with participatory tradition is arranged so it is base on general guidelines, the local community is responsible for the integral implementation of local development and urban planning [24]. In this context, the Danish planning system is characterized by so-called "urbanism of entanglement" [25], which is fighting against unequal development and new urban / rural relations. This approach attempts to harmonize the development of "large Copenhagen" (a coherent area of housing and work that functions as a city centered along the traffic corridors leading to smaller cities, with particular reference to public transport services and common open green spaces that cross the boundaries of local areas) with other parts of the country. Urban design is re-conceived as a practice that mediates in the processes of continuous transformations by acting over the existing, as well as new conditions, ideas and practices. The new methodology is based on the agent-network theory that identifies all factors affecting site performance, geographic characteristics, infrastructure, nature, etc. - regardless of their metaphorical or immaterial status and which analyzes the essence rather than the appearance [25].

Large expert-oriented study on urban planning significantly influenced the change of the planning practice in Swiss cities [26] - Switzerland: An urban portrait, within the ETH Studio Basel University. In the light of population growth and strong territorial

transformation, this study has brought a critical reflection on the urban future [27]. It initiated all institutions from the planning process, which had the status of the holy subjects without being ready to change until then. The system of planning and planning practices has overcome the culture of rejection and prevention of density, height, mass, concentration, new opportunities and other characteristics that are desirable in the city. The result is a new look at Switzerland that questions existing images and explores urban potential through five typologies: urban areas, urban networks, peaceful areas, alpine and adjoining areas and resorts. It is a new urban topography that provokes the Swiss traditional model of social solidarity. While favoring metropolitanization that leads to stronger territorial hierarchical strategies and processes with the aim of spatial condensation of urban services and functions at certain sites, on the other hand, it insists on the well-known concept of the unique "Grande Ville". Further on, the territory of Switzerland is viewed as a continuous urban area or "Horizontal metropolis". Its key idea is the distribution and the increase of the advantages that metropolisation, carried out in accordance with the tradition of decentralization and horizontalism, can bring territory and its population.

This concept exploits different forms of housing and their relationship with infrastructure support. It considers the long-term construction of the "urban territory" as a renewable resource, which means reflection on new life cycles, capitalization of urban and territorial energy, and re-examination of an extensive and diffusive cappital. This could be a valuable resource for adapting future urban growth to desirable forms, maintaining uneven spread as well as currently prevailing ideological, non-selective thickening and polarization [27].

German cities show that current challenges of urban development can be overcomed with innovative approaches beyond everyday routines and traditional planning [28]. However, this example shows that projects for the development of central cities are still the key tasks of German planners with a special focus on public space, communication, new settlements [29] as well as on urban design and identity. In doing so, the planning process pays special attention to adapting these topics to local communities by introducing strategic planning tools, public participation, and respecting the quality standards of both processes and plans. Although the development of participation takes place due to the legitimacy of large speculative projects, a large number of new tools are being created. The integrative approach in interdisciplinary areas of work and informal planning is esepcially significant. Finally, this approach is visible in the urban design itself, moving away from the concept of 'car-friendly' city, raising the comfort of open public spaces and planning new urban settlements that relieve the central parts of cities and allow affordable housing for everyone. This commitment promotes the establishment of partnerships between all actors of urban life and then extensive long-term and phase urban regeneration projects in cities, focusing on energy efficiency, environmental protection, modernization and the environment quality [29].

5. SOME ASPECTS OF INTEGRATED PLANNING IN REPUBLIC OF SRPSKA AND PRESENT PROBLEMS

5.1. REGULATORY FRAMEWORK

Integrated planning is defined in the Law for spatial planning and construction [30] as one of the planning principle which accepted all significant development factors in parallel processes of analysing of dinamic needs and changes in space and resolving

conflict of interest in the space. Methodology framework for planning, defined in the bylaw regulation [31], states that the planning process must observe principle of harmonising natural values with human action through the use of renewable sources of energy, construction of energy efficient buildings, proper selection of a certain purpose by including bioclimatic factors, taking into account climate change and the protection of natural and technical disasters, etc. In generally, the principles of integrated planning are not sufficiently present in the legislation in the area of defining detail methodology and content of plans, multidisciplinarity, participation and flexibility of the planning process, as well as energy efficiency and protection against climate change [32].

In that aim it is necessary to define a methodology with guidelines for the implementation of integrated urban planning and strengthen the education of all stakeholders in this process. The regulatory framework at the entity level is an important precondition for defining integrated planning, but it is not a limiting factor to the local level to develop mechanisms for its implementation and strengthening. They could be achieved, among other things, by using integrated strategic planning and participative and comprehencive urban planning.

5.2. PLANNING CONTINUITY - EXAMPLE OF BANJALUKA

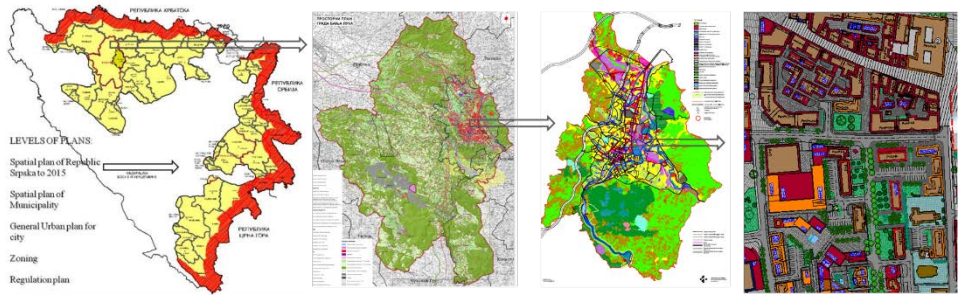

Figure 1. Levels of plans, from left to right: Spatial plan of Republic of Srpska, Spatial plan of Banjaluka Municipality, Urban plan (Draft from 2009-unaddopted) and Regulation plan of centre of Banjaluka (Image by Milojevic, 2015)

The continuity of planning could be achieved by establishing a system of plans across all spatial levels in the same planning period. The Republic of Srpska has a Spatial plan, but many municipalities haven't yet adopted the municipal spatial plan and urban plans of cities that are strategic spatial planning documents. Regulation plans are very often made without previously defined strategic plan, while zoning is rarely present in practice.

Banjaluka has Spatial plan until 2025, but there is no updated urban plan (last was done for the planning period of 1975 to 1990), which has seriously affected the continuity of planning as an important aspect of integrated planning. The activities on the preparation of urban plan at this time are following development of the City Strategy which hasn't been addopted yet. The interaction and overlapping processes of making these two documents represent favorable circumstance in which preconditions for sustainable and resilient city can be created in the future, with the use of integrated and patricipative strategic and urban planning.

6. SOME POSSIBILITIES OF IMPROVEMENT OF INTEGRAL PLANNING OF BANJA LUKA

6.1. THE STRATEGY OF URBAN DEVELOPMENT OF BANJA LUKA

Integral planning in Banja Luka is not yet an established practice. Although this is a major backlog compared to planning practices in developed EU countries and the USA, on the other hand, it leaves the possibility to establish an integral planning system based on innovations [33], scientific research, and the best global practice experiences which need to be adapted to the specificities of the local context of the city and Bosnia and Herzegovina. It is therefore interesting to learn from the from experiences of neighbourhing countries countries, for example Slovenia, as the former socialist republic, which, comparing with other former Yugoslav republics, has gone relatively quickly and relatively successfully through the process of transition of socio-political, economic and cultural system.

The example of Ljubljana [34] shows that the development of local development strategy is important for the improvement of integral planning. It unites vision and city development strategy with a range of model options and scenarios through concrete projects and action plans. However, prior to the vision itself, it is important to understand that the vision should be result of a very complex process of creation. The process should provide a broad professional and public debate that brings together all interested actors, primarily a number of professionals from different profiles, representatives of citizens' associations, institutions, administrations, (...) and citizens. The process should foster mutual understanding and dialogue on the relationship between all participants, by applying innovative negotiation models, an intergenerational and cross-sectoral co-operation. An example of Ljubljana also shows importancy that talks about the urban futures take place in an atmosphere close to the local mentality, to achieve the liberation of free and unrestrained creative thinking that is enriching and forming in interaction with all participants.

This approach to the process of creating a vision of development finally contributes to the citizens' feeling of being active visioners according to the specifics of local urban identity, which are transformed in desirable directions. Then, reaching a broad consensus about the same and finally forming the alienation of citizens who they are identifying with and which will work on its realization.

6.2. FLEXIBILITY AND ADAPTIVITY OF THE PLAN

Given that the city is a living organism [35], the design of urban plan needs to be understood as a process, open to change, flexible and adaptable. Leading the idea that "plan is nothing, and planning is everything" [36], the focus of the urban plan should be on the process rather than on the plan itself. This would mean that the urban planning is based on a real context and that it realizes communication with all the actors of city life, with all active processes and projects that are relevant to development processes. In this sense, urban planning should be open, flexible and adaptable process that accordingly achieves planning documents that are also open, flexible and adaptable, to such an extent that does not endanger the strategic goals set.

Given that flexibility is linked to the provision of policy modification options (including monitoring procedures) and that adaptability is the readiness to accept changes as well as adaptation of planning solutions to justified requirements [37], the urban plan acts as a

mechanism that monitors and directs the dynamics of changes and urban development in the function of strategic directions of development in the real-time.

It enables different types of modification, and subsequent spatial analsis in accordance with dynamic changes that occur almost daily in all segments of society and in all aspects of urban planning. The urban planning thus becomes a kind of open platform that is oriented towards the social capital of its citizens, their needs, different initiatives, ideas, actions, projects and real opportunities for sustainable development.

However, in order that this platform works, it is necessary to be defined structure of the lower plans order, which in the set hierarchy represents a mediator between different levels. In such a setting, zoning plans represent a tool that through a set of parameters allows maximum of flexibility within a strategically defined framework.

The process of integral urban planning in Banja Luka is faced with a few civic initiatives, actions and projects that will likely continue their ways and future trend. For that reason, urban planning should move towards small units, and multiple scenarios enhancing diversity of spatial relationships that those small [spatial] units bring together into the complex structure of city [23]. Those small-scale urban interventions help the community to get involved in the process of adopting a plan, as well as simulating alternative scenarios. Compared to traditional planing tools, small intervention projects also have the ability to adapt to dynamic and unstable contexts [39].

They mostly represent participatory projects close to art performance in the public space [40], which have the ability to visualize provocative alternative scenarios and engage local participants (citizens, workers, associations). This tool meets common project co-operation between planners and local units, which helps strengthen the social network and citizens in the process of strategic urban planning [41] and creates a solid planning base of city. Thus, small interventions require a deeper analysis of inherited urban rules and the establishment of an appropriate legal framework, otherwise they may be unsuccessful or lead to even greater chaos.

Considering the timeframe of the last two decades, small scale urban interventions in Banja Luka have been identified, which had a significant impact on space and community, involving a wide range of actors in the urban intervention process (with the emphasis on bottom-up processes) and innovations [23]. There are recognized few such organizations with different small scale urban projects, which urban planning should consider: Center for Spatial Research (Small SCALE, Delibašino Village, Rasprostor); Helsinki Citizens' Parliament Banja Luka ((O)živimo javne prostore); Naš prostor (Banjaluka naš grad, Građani grade građevinu, Građanska inicijativa Rekreativna zona Banja Luka); Gradske bašte Banjaluka; UAA (Pecha Kucha, FDW - Street Zine); Udruženje Prostor (Krov fest); Flaster (Grafiti) and Protok (a series of projects in the period in the period of 2006 to 2010).

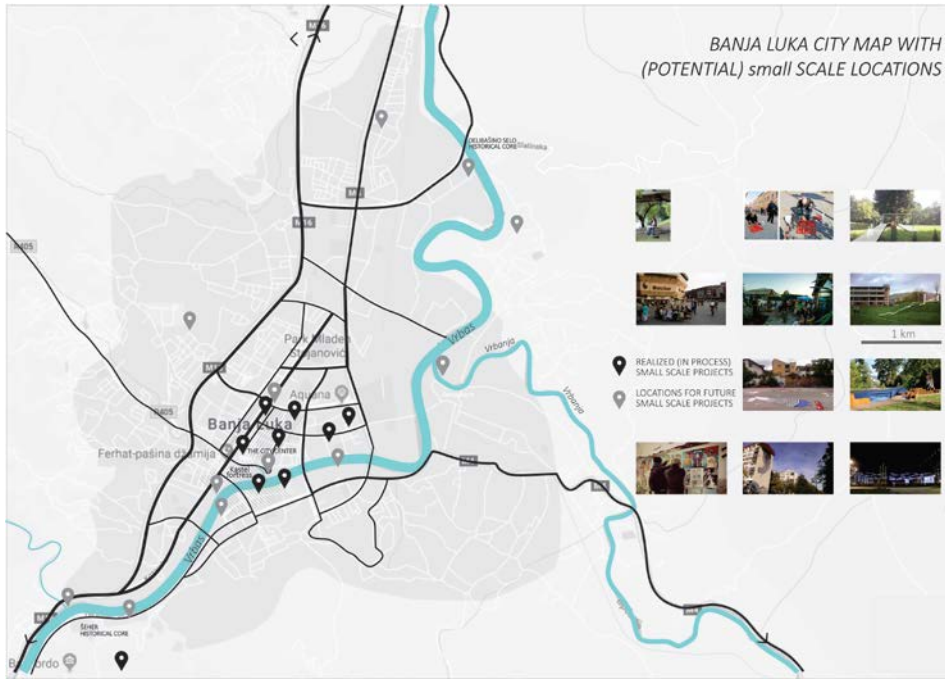

Figure 2. Banja Luka city map showing locations of realized small SCALE urban interventions as well as potential ones (Illustation by the authors, 2018)

Figure 3.

Figure 4. Collaborative and participatory approach in combintion with interdisciplinarity leading to the place making and strengthening of community. Banjaluka's pier, small SCALE project of the Center for Spatial research Banja Luka (Photo by Kristine Tokvam Karlsen, 2017)

6.3. CREATIVE STRATEGIES

UN's Sustainable Development Agenda 2030 [42] recognizes the key role of cities in promoting sustainable development focusing on people, respecting human rights, and stresses that "cities should be inclusive, safe, flexible and sustainable" recognizing culture and creativity as one of the most important levers to act in this context. Although basic schemes and avant-garde urban design in the past were largely a product of economic growth of cities and states, it is now globally clear that a lot of creative work is necessary to develop mechanisms that will enable the realization of economic and many other goals.

On the other hand, it is primarily needed at the local level, where culture and creativity are practiced daily and thus encourage the cultural industries, support creation and participation in culture. It is simultaneously approaching the public sphere with a new perspective in which public administration, in cooperation with the private sector and civil society, can make a difference and support sustainable urban development appropriate to the real needs of the local population [43].

This way, culture and creativity are recognized as the drivers of development and become the basic features of urban policies that are changing rapidly. Because urbanism is not enough. And even good urbanism is not enough. It must be supported by cultural activities [44]. It requires the intensification of the theme of urban-cultural cities-landscapes through housing, education, health, labor, production, in a scale that has never been tempted before. It implies a continuous process of work on the education system on culture, space and space culture.

Creative strategies, based on inherited cultural diversity, represent an important opportunity to improve integral planning [45]. As a significant factor of contemporary society, they lead to the establishment of new forms of cultural life and represent a starting point for creative professional intervention in shaping urban spaces. Particular challenge is construction of a new research-oriented and innovative approach to urban design, starting from the recognition of intercultural dynamics and culturally sensitive values [33].

It is addressed both to traditional education of experts, which requires the development and inclusion of broad knowledge and skills as well as to the local administration from which openness to innovative and creative approaches and solutions is expected, even to citizens of the creative city. The Creative City represents a new method of strategic planning of urban space and analyzes the way people act, plan and think creatively [43]. They also emphasize the importance of social potential, because creative people are the focus of creative city who are encouraged to link their vision with local urban policies.

Contemporary ideas are, in that sense, moving towards the development of a new ideology that should explore ways of integrating urban design and strategicly oriented urban planning. This strategically comprehensive, value-based, process and product-oriented approach to design is aimed to translating public policies that promote cultural integration into quality urban forms and the creation of a characteristic identity of the place, with the assumption that art and cultural strategies alone have the power to create, strengthen, and increase their belonging [45], [46], [47].

6.4. PARTICIPATION AND COLLABORATION

The current approach to sustainable urban development is based on city initiatives through various projects that promote new planning culture focusing on certain topics in urban areas (public spaces, urban culture, urban acupuncture, urban design, smart

transport, energy efficiency ...) processes and strategies of urban development, the participation of civil society in the creation of quality and standards of urban space, etc., which is also a desirable approach for further urban development of Banjaluka. At the same time, it is necessary to undertake activities on system solutions and stages of development that will overcome the present problems and define preconditions for a strategic approach to sustainable urban development.

On the other hand, implicit changes in the collective understanding of social justice are a challenge for civic practices in many European cities [48], and there is no doubt that the strategic planning of sustainable urban development necessarily involves the essential inclusion of citizens without whose contribution it is no longer possible to create or implement plans. In addition to a clear vision for planning sustainable urban development, a participatory and collaborative approach to the process is required, which becomes more important than the urban planning [47] itself. Emphasis is being placed on the process of providing creative milestones for the integration of development sectors and plural interests with significant opportunities in the function of providing a strategic development framework. An integral model of urban design process with an emphasis on rational and collaborative urban decision making becomes one of the basic instances of urban regeneration strategies.

However, participation and collaboration need to be properly coordinated and directed to ensure that the energy of these actions provides the appropriate results as part of a single system rather than individually isolated and eccentric cases without real, disproportionate effects in the process and in the urban space itself. In doing so, the simultaneous development of spatial ideas and organizations is necessary for the design and implementation of decisions, yet it is fundamentally dependent on political will, and then only on resources, whether human or financial. Thus, it is necessary to work on the creation of mechanisms and tools to make the ideas from below really affect the spatial policies of the city [49], [50]. Stil, it is necessary to deal with very carefully because the stimulation of civic initiatives from above is often contrary to the basic principles of grassroots movement [51]. In this respect, zoning plans are imposed as a mechanism that can accept these demands.

Some of the previously recognized mechanisms in the examples of small spatial interventions in the city of Banja Luka represent a kind of a self- proactive actions, strategic networking in direction of transdisciplinary urbanism and scenarios planning.

Self-initiative is a mechanism through which a growing number of professionals decide to deal with the city through the kind of activist-projecting activity [52]. By recognizing the real problems, needs and potential of space, they experiment with the development of new ways of working in urban planning and design processes, applying the best experience from theory and practice globally, respecting the highest standards of quality as well as high professional and social responsibility towards the space [53]. At the same time, they follow the criteria of sustainable spatial development, intelligent and equitable resource allocation, professional ethical approach and equal participation of the public [23].

Transdisciplinary Urbanism [54] implies the concept of networking between different and especially new actors involved in complex processes of planning and construction. These are the order of government institutions at all levels (local communities, municipalities, cities, cantons, regions, entities), business entities, organizations, public companies and institutions, foundations, scientific and research institutions, associations, individuals, citizens and professional public etc. Such participation in processes

contributes to strengthening civic participation, establishing private-public partnerships, building modalities of public interest protection, launching a broad debate on public space issues and finally new concepts of urban development as the last component of the system.

Scenario planning enables exploration of potential outcomes before implementing the plan itself, helping private investors to play an important role in creating cities alive, sustainable and diverse. Scenario planning [55] helps investigate the impact of important and uncertain driving forces on cities. Built into the strategic urban planning process, scenarios planning helps investigate the impacts of important and uncertain driving forces is a form of participative brainstorming that elaborates inputs for SWOT analysis to create alternative scenarios [55]. Finally, all this mechanisms, seen as a unique group, should be set in a system of spatial and urban planning, in which particularly zoning plans are imposed as a tool that can accept all their demand.

Figure 5. Urban café Banja Luka … 2030 … 2040 ... organised by the Faculty of Architecture, Civil Engineering and Geodesy Banja Luka, the City of Banja Luka and the Center for Spatial Research, based on the World cafe methodology. Banja Luka, March 2018 (Photo by Stamenko Mijatović)

7. CONCLUSION REMARKS

Based on the analysis of legislative in the field of spatial planning and construction in Republic of Srpska, it is clear that it does not provide adequate regulatory framework for integral planning in order of comprehensively considering the relevant aspects of natural and created spatial values, nor their methodological-consequential connection is defined at all stages of planning. There is also a lack of strategic, flexible and participative planning as well as professional capacities. In this sense, it is necessary to define the methodology of integral planning which will equally serve to all participants in planning process. It implies expert-oriented approach supported by researches, experimental projects, innovative methods and techniques that are subject of constant reviewes and rethinking cities in relation to the entire territory.

Significant prerequisite for integral urban planning is a strategic planning based on a strategic vision and urban identity, achieved through the process of creation with the

alliance of citizens. Therefore, it is necessary to define the strategic aspects of sustainable development at both local (leading to the integrative approach with new creative tools and urban regeneration projects that improve the life of existing urban structures and create new ones) and a higher level of governance which is not often the case.

Nevertheless, local communities can significantly improve the situation by developing their own mechanisms for integrated strategic and urban planning through enhancing participation, using flexible planning tools, strengthening partner relationships with stakeholders, raising staff capacities, enhancing education, applying for EU grants, etc., which are recognized elements of action in the contemporary context. These are also experiences of planning systems in European countries that show that the EU and UN recommendations with global trends geared to sustainable spatial development have to be adapted to specific local conditions, requiring constant revision and updating.

The process of creating Banjaluka's urban plan for the planning horizon by 2030 represents the city's ability and challenge to improve the situation in the field of implementation of integrated planning. They are reflected in the adequate linking of urban plan with strategic development defined in the City Development Strategy. Urban plan should promote flexible, adaptable and participatory planning with emphasis on vision-oriented processes, a range of model options, and scenarios through concrete projects and action plans. The development of the urban plan of Banja Luka is an opportunity to improve the planning methodology by introducing flexibility, participatory and comprehensive planning process, as a multidisciplinary practice which in the processes of continuous transformation strives to harmonize the relationship between all dimensions, scales and characteristics of the space. Efficiency of the preparation, designing and realization of plan is based on stimulating creative strategies, participative and collaborative approaches that contribute to the transdisciplinary approach with various mechanisms such as small scale actions and spatial interventions, networking of actors, and scenarios planning.

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26| Оригинални научни рад
Research paper
doi 10.7251/STP1813369C ISSN 2566-4484

ИСТРАЖИВАЊЕ ОСОБЕНОСТИ ПРИОБАЉА БАЊА ЛУКЕ У ЦИЉУ ДЕФИНИСАЊА СМЈЕРНИЦА БУДУЋЕГ РАЗВОЈА

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Резиме:

У овом раду истраживан је феномен односа ријеке као природног елемента и урбане средине као људске творевине. Њихов међусобни однос је сагледан кроз теме које се тичу просторно - програмских, перцептивних, естетских и културних потенцијала који у великој мјери одређују идентитет мјеста. Анализиран и приказан је примјер града Бања Луке који је посматран кроз више критеријума: позиционирање урбане структуре у односу на ријеку, морфолошке и топографске карактеристике, развијеност физичке структуре у приобаљу, приступачност, дистрибуција садржаја и насљеђе. У раду су приказани и резултати спроведеног анкетног испитивања корисника простора о идентитету, значају и начину коришћења простора приобаља у нашој средини. У циљу формулисања одређених препорука за унапређење простора приобаља, дефинисане су вриједности које ови специфични урбани простори могу да садрже у себи.

Кључне ријечи: приобаље, урбана структура, приступачност и идентитет

THE STUDY OF PARTICULARITY OF BANJA LUKA WATERFRONT IN VIEW OF DEFINING THE COURSE OF ITS FUTURE DEVELOPMENT

Abstract:

This Study examines the phenomenon of the relationship between the river as a natural element and the urban environment as a human creation.Their mutual relationship is observed through the topics which are related to the spatial - programmatic, perceptual, aesthetic and cultural potentials that largely determine the identity of the place. The example of the city of Banja Luka has been analyzed and presented from the point of view of several criteria: positioning of the urban structure with relation to the river, morphological and topographic characteristics, development level of the physical structure of the waterfront, accessibility, distribution of contents and heritage. The Study gives an overview of the results of the survey conducted among the users of the space with regard to the identity, importance and the way of using the waterfront area. The values which those specific urban areas may contain have been identified in order to formulate certain recommendations intended to improve the waterfront.

Key words: waterfront, urban structure, accessibility and identity.

1. INTRODUCTION

The Study focuses on the established relations between the city and the river. The main morphological characteristics of cities which are positioned next to the water flow or water surface are determined by the relation of the urban structure toward the water and their identity is very often the result of specific values realized in a single space of the waterfront and the aquatoria. [1] The waterfront is specific with relation to other town areas and characterized by a dominant linear shape and longitudinal character of the space which connects various parts of the city. The influence of the water flow on formation of the city pattern is evident but certainly not the only one, there are topography, climate, socio-economic and cultural influences, demography, etc.

In this research, the term coastal area refers to the city coast, which is located in the urban environment. Some of the definitions connect this part of the city to its nature of expansion. Trancik [2] categorizes it as a linear system of open spaces that extend through the city connecting one place to another. According to Hoyle [3], this is a specific space in a city that is very linear, but also very limited, is not elastic and contains much in it. There are coastal definitions that are related only to its port function and mark it as an area of many activities. Perhaps one of the more comprehensive definitions of the urban coastline is that it is a space with a watery edge in cities of all sizes. Water can be a river, lake, ocean, bay and / or canal. The coastline includes everything from a wildlife habitat to a container in the port and a wide range of activities that are contained in a randomly or uniquely built structure, with more or less owners and participants. This area may also include buildings that are not directly on the water, but are visually, historically or within a wider context. [4]

2. ANALYSIS OF BANJA LUKA WATERFRONT

Research of the Banja Luka waterfront was conducted in order to establish the possibility of upgrading the waterfront as the holder of the identity of the city. Identity has been seen through various levels: one refers to the particularity of its physical setting through the natural and the built parts and the other to the level of activities which take place at the waterfront. The stated particularities are considered at the same time as only possible reading simultaneously the special features and character of the area.

Therefore, within the paper, the waterfront of Banja Luka has been singled out as a separate case study which eventually leads to drawing of many conclusions which refer to the waterfront. Additional analysis of the relevance and the way of space utilization was carried out through the anonymous survey of the users of the waterfront on the spot in several places in the Republic of Srpska: Banja Luka, Gradiska, Prijedor, Novi Grad, Zvornik, Trebinje and Derventa. Comparative analysis of the results of the surveys conducted was used to draw conclusions about the current situation and specific relation of the urban tissue up to the water flow.

2.1. PARTICULARITIES OF BANJA LUKA WATERFRONT

The city and the territory on which it stands are not two separate units but complementary parts of one single structure. Whether the settlement followed the natural conditions related to the configuration of the soil or whether the built structures were in contradiction with the morphology of the terrain, their relations generate the main characteristics of the

urban space. Visual identity of the city is determined by its topography as the natural element and physiognomy as the characteristic of the constructed environment. Topography as the natural element has big influence on the visual identity of the city. "The City personality, its identity and the main formative features are born out of this seeming conflict between the nature and the physical, constructed forms of the city." [5]

2.1.1. Natural conditions of the waterfront

The City of Banja Luka and its entire territory is situated in the structural basin of the river of Vrbas. Vrbas river as the right tributary of the Sava river drains the central part of the north slopes of Dinaric mountain massif and generally flows in the direction from the south to the north. Its river banks are mostly steep in the part from the village of Karanovac to the mouth of Vrbanja River into the Vrbas and further to the north. Being the natural flow, the river makes characteristic meanders that create typical zones in each of the stated parts. Urban area of the city of Banja Luka was historically developed in the Vrbas canyon, i.e. in the Neogene basin of the river from the area of Novoselija to Zaluzani. The river of Vrbas, upstream and downstream from the urban area of Banja Luka has always been important natural resource with all its characteristics and has always been the backbone of life. Natural wealth of the river and its waterfront as a resource had never been sufficiently utilized and sometimes even devastated. / Karanovac, the mouth of Suturlija, etc. / Particularity of the river are thermal hot springs of Srpske Toplice spa concentrated on the right bank of the Vrbas river in close vicinity of the river. Those are unique phenomena in the area of entire urban waterfront what makes them the facilities of geological heritage of national importance. Those springs are used unreasonably and are not adequately organized.

Negative impact on the Vrbas River is reflected by the pollution of water with leachate waters whereas sanitary leachate waters of feces type have more dominant effect than pollution with industrial leachate waters. Beside letting in the leachate waters of various origin directly into the river, solid waste of different composition is illicitly disposed into the water. The sewage system partly covers the urban area whereas all utility and industrial leachate waters flow into the Vrbas River. In the past period / the last 15 years / a leachate water treatment facility was not built and there is no central system for treatment of leachate waters. [6]

2.1.2. Historical background

Favorable geographic position and vicinity of the river and the natural resources have led to formation of first settlements on the territory of the city of Banja Luka in the prehistorical times and there are archeological artefacts to support that. Written documents mention the name of the city of Banja Luka for the first time in 1494 in the Charter of the Hungarian King Vladislav II Jagelovic which was issued in Budim in Latin language. During the third decade of the 16th century when it fell under the Turkish rule, Banja Luka was a military fortress with civilian suburbs on both banks of the Vrbas. Since then the city has developed on the principles of oriental community and most intensively during the reign of Ferhat - Pasha Sokolovic as the center of the Pashalik from 1573 to 1639. At that time there were two centers, Upper Seher and Lower Seher which existed on both banks of the Vrbas River.

Cartography documents dating from the 18th century offer pretty clear picture about the urban morphology of the then oriental Banja Luka. "Overview of traffic communications undoubtedly show the dominant role of the longitudinal direction which follows the flow

of the Vrbas River and which was inherited from the Roman times in the course of urbanization. This communication direction in the oriental times and in previous eras represented the backbone which was connected with construction thus creating a linear scheme around which separate parts were distributed." [7] Banja Luka was developed as the administrative, political and cultural center of the area of Bosanska Krajina. In the middle of the 19th century the city had more than 10,000 inhabitants and was the third largest city in the Bosnian Pashalik. Other traffic directions were crucially affected by the position of the Kastel fortress which is located between the Vrbas river and its tributary of Crkvena. The biggest cross communication runs through the fortress itself over the fortress bridge connecting the Carsija near the Ferhad-Pasha mosque with Small Carsija on the right bank of the Vrbas river.

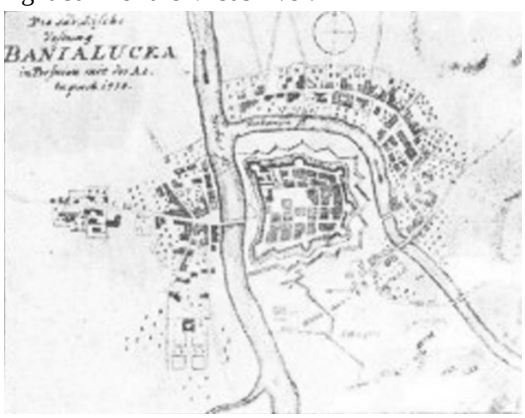

Photo1/ Banja Luka, the Map of the Kastel Fortress at the beginning of the 20th century and geodetic map of the city from 1884 with Big and Small Carsija /Source: https://www.google.ba/search?q=wagner+debes u Husedzinovic, S., Dokumenti opstanka

Travel writers, mostly foreigners who stayed in Bosnia, in Herzegovina and the surrounding areas in the second half of the 19th century observed that the river of Crkvena marked the border between the oriental and the European part of the city. [8] Throughout the 19th century Banja Luka has transformed upon the model of cities of the Central Europe. "The looks of Banja Luka is very interesting. I have not seen a longer or a narrower city anywhere in the world. A line of houses and country cottages stretch along the both banks of the Vrbas river at least six versts. Very often the whole city is encompassed by the width of one street…In Banja Luka there is also an old fortress which is splashed by the waters of the Vrbas river from all sides." [9] Just before the end of the Turkish rule, in 1872 - 1873 an important effort was made which affected the future character of the urban character of Banja Luka. That was construction of the section of railway line Dobrljin - Banja Luka, designed as the part of the future Ottoman Trans-Balkan railways.

With the beginning of Austro-Hungarian rule in 1879, Banja Luka became the center of the county and the area, corresponding institutions have been formed and built and the city center has intensively developed on the left bank of the Crkvena river. Planned elements of the regulations are omnipresent, geometrically regular blocks and wide traffic lines have been built. The oldest lines of trees in the center of the town date back to the Austro-Hungarian administration. [10]

The city center as we know it today was formed during the Vrbas Banate with the arrival of first Ban (the Duke), Svetislav Milosavljevic after 1929. Thanks to him, in between the two world wars, the City got representative facilities which are today the most important holders of the urban identity of the City: the City Hall and the Ban's Palace and in between them the Saint Trinity Church at the Square of the Serbian Leaders, the Hipotekarna Bank and Petar Kocic Park.

2.1.3. The Analysis of the waterfront from the aspect of flood protection

Upstream from Banja Luka two hydro power plants Jajce II and Bocac were built which dictate the water flow of Vrbas River through the city so that daily oscillations of the water level are very high. Bocac accumulation has very important role in transformation of the flood waves and active flood defense of the city of Banja Luka. Minimal levels of water flow are typical for later summer and early autumn months.

Character of the basin of the Vrbas river on the city territory is divided on the basis of its main characteristics. Since its length is approximately 26 kilometers in the city area and taking into account the spatial characteristics, density of population, the purpose of the areas and characteristics of the terrain, three main zones have been established:

- The South Zone which includes the zone of the river flow from the village of Karanovac to Srpske Toplice has the banks deeply cut and in this part there are no 100- year floods. /Photo 2a/
- The Center Zone which includes the river flow from Srpske Toplice to the mouth of the Vrbanja river and the left and the right bank differ by its profile and composition and here also there is no a 100-year flood. /Photo 2b/
- The North Zone which includes the zone of the river from from the mouth of Vrbanja river to the borderline with Laktasi municipality, the banks of the Vrbas river are lower and the river assuems the chatacetr of the inland river. /Photo 2c/

Photo 2 Banja Luka, spatial units: a. The South Zone, b. The Centre Zone, v. The Northth Zone / Source: attachment of the author /

It is a relevant observation that Vrbas River does not flood its basin very often since its banks are pretty high except in the area of Cesma in the sector of the big meander where high water level flood parts of the terrain. According to the data of the Hydrological-

morphology analysis, the size of flooded areas for a 100-year flood rank, is 260.50 ha. [11] Flood protection measures showed to be insufficient during the floods in May 2014 when the quarters of Lazerevo, Dervisi, Kumsale, Cesma, Prijecani, Krmine and Karanovac were flooded and population mostly evacuated. During those floods, the bridge near Vitaminka factory has been damaged as well as the pedestrian bridge in the area of Prijecani and the old bridge in Karanovac what led to the breakdown in water and power supply since the installations that ran over the bridge had been disrupted in Karanovac.

2.1.4. The relation of the city and the river

Different periods in the development of the city resulted in evolution of different urban and ambient complexes. The characteristics of the Turkish period when individual possession of the river bank took place is present in certain parts of the bank even up to the present days. Principles of oriental construction of residential settlements, so called 'mahallas' is characterized by irregular street scheme with land plots and individual facilities placed very close to the river and with economic backyards and backsides of the houses facing the water.

With the arrival of the Austro-Hungarians, new urban complex are built at the end of the 19th and beginning of the 20st century on the left bank of the Crkvena river which flows into the Vrbas river by the Kastel fortress. This complex has the features of the European cultural influence, regular street pattern with wide streets, regular blocks and buildings following the European architectural models. We could state that this complex has developed in the north, next to the railway route and the Emperor's Road at a greater distance from the river and with no significant relation with the water. In the second half of the 19th century the "Marija Zvijezda" Trappist monastery in Delibasino Selo had the major impact. The colony of the Trappist order was an encounter not only with different architectural and construction principles but also had economic relevance. The Trappists build the first electric power plant on the Vrbas River. [12]

After the Second World War development of the city is intense and modern architecture of international style appears with construction of high buildings of the new typology, free from traditional street and block regulation. Residential quarters are built in the waterfront, Obilicevo on the right bank and Borik on the left bank of the Vrbas river. /Photo 88/ scattered structure and irregular pattern as well as picturesque ambiance of the oriental mahalla were replaced by the multi-storey facilities for family residence in an organized regular pattern. Therefore, the most important traffic communications in the city were formed on the opposite side of the urban blocks which lean on the river flow. After the WWII, large scale of demolition and transformation of the existing urban structure was caused, inter alias, by the earthquake that hit the city in 1969 and resulted in a mixed style in the big number of the city parts. [4]

The waterfront of the Vrbas River downstream the Rebrovac Bridge was not particularly interesting for residential purposes but was used for construction of industry facilities. The period of socialist construction is characterized by construction of a big number of industrial capacities in the waterfront/located in the area of the estuary of Vrbanja into the Vrbas river where the Complex of Incel cellulose factory was built which used to be the industrial giant of former Yugoslavia that used to employ 16,000 workers/.

In the last two decades there were individual attempts to build at the waterfront with the changed attitude toward the water. Those interventions are sporadic and mostly of local character. In that sense the residential quarter under construction, Novi Borik, located

downstream the Incel bridge can be singled out. New approach to the waterfront could be expected in the future since the Banja Luka City Assembly adopted the "Regulation Plan Pertaining the Banks of the Vrbas river“ prepared on the basis of the results of the open international urban planning – architectural tender in 2006. Unfortunately, this Plan to a large extent treats only the narrow belt of the bank neglecting the meeting points of the city with the water. In addition to that there is fear with regard to realization of the planned and the possibility of the city services to regulate the existing facilities built in unplanned manner which often downgrades the waterfront. [13]

2.1.5. Functions of the waterfront

Changing character of the function of the waterfront is one of its primary characteristics. Different periods of the city development brought along the change of the waterfront functions what was directly reflected on its shaping and structure. The presence of drinking water and using its power for watermills as supported by many evidence provide us with a clear picture about the first functions of the waterfront related to existence and the supply of water. / Photo 3, Left/

Defense function of the river is evident in the cities which developed within fortifications and in undercities on the water banks. The position of the Kastel fortress at the estuary of the tributary of Crkvena into the Vrbas river, as well as the existence of the water canal around the fort walls indicate the use of water for the purpose of easier defense from enemy. First forms of trading in open markets appear in the 16th century when a cattle fair is organized around the Kastel fortress. In the beginning the Fair was organized once a year and was quite known, then twice a year, then monthly and finally once a week. / In 1935 the closed facility of the City Market was built/. The Market was close to the river what points to the necessity to trade in the areas located in the vicinity of the water flow. /Photo 3, Right/

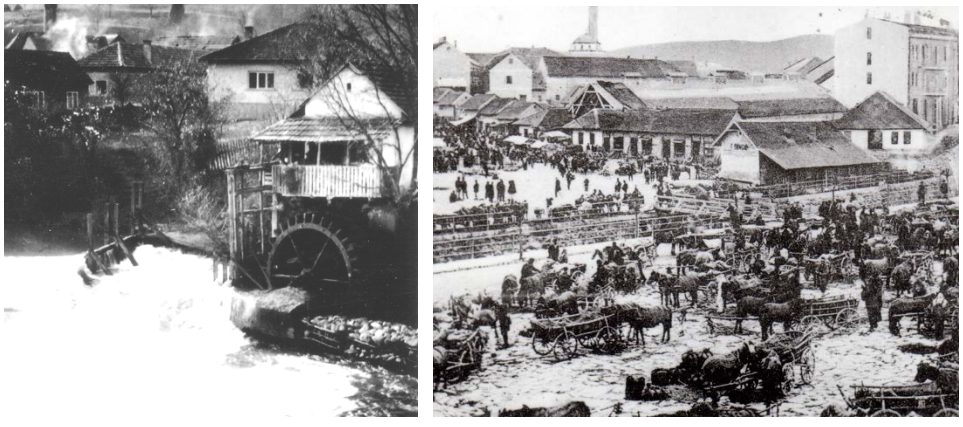

Photo 3 Banja Luka, watermills on the Vrbas River and Govedarica Market, the end of the 19th century / Source: Archive of the Urban Planning Institute of the Republic of Srpska, a.d., Banja Luka/

The manufacturing function in the waterfront becomes evident in the 19th century with the arrival of the order of Trappist who founded their monastery in the village of Delibasino Selo. They built the first electric power plant on the Vrbas river and several

manufacturing facilities. This function of the waterfront was particularly emphasized during the period of industrialization of our cities in the second half of the 20th century.

The natural space of the bank with rich vegetation by the river basin on the right bank in the part from the Venecija Bridge to Rebrovac Bridge is simply arranged but it is accepted by the users and intensively visited as a recreation zone. Recreational purpose is increasingly present through arrangement of separate sport equipment and several public beaches in the city area. Nevertheless, there is no logical continuity of such steps with regard to recreation in the waterfront nor is it followed by architectural framework of the space with necessary contents that would support the active use of urban waterfront.

Today, we talk about different intertwined functions along the city waterfront. The whole belt now is characterized by the new tendencies of exit the town toward the river and is reflected in separate examples of constructing residential and business facilities in the waterfront. The attitude toward the water is gradually changing and the tendency toward opening of the face of the city toward the river is getting more visible.

2.1.6. The bank vegetation

Vegetation as an inseparable part of the waterfront in the urban belt of the river is not articulated nor does it represent sufficiently articulated segment of the city greenery of Banja Luka and the urban space. Organization of this natural belt of the river with the corresponding banks could circle the horticultural complex of the city.

Creation of the landscape architecture facilities did not follow the city development in the adequate way although many plans dealt with the problem. Aspiration to organize the banks of the Vrbas river could be traced back to the earliest town planning documents of the city of Banja Luka. The first of them was the "Proposal of the General Urban Plan of Banja Luka" from 1952 made by Anatole Kirjakov which even though it has never been enacted, contains some valuable data about the city. The author of this Proposal describes the importance of the Vrbas River and its banks which, according to his Plan, should connect many new parks and areas for recreation which have public character. The Programme of Regulation proposes nine guidelines three of which were devoted to greenery, two related to natural features of urban landscape and one to the role of greenery with regard to formation of the identity of the city. [14]

As it is today, the vegetation is the most neglected segment of the city greenery. Due to its specificity that it is neither park nor forest / and certainly not the other part of the horticulture design / but makes a specific phenomenon which must be approached in a complex manner. Since the banks of the Vrbas River are florally and phytology unexplored and since this scientific component is unavoidable precondition for any practical work related to this phenomenon, it is necessary to start preparing the analysis of the situation with regard to vegetation of the river banks. [3] The vegetation of the banks as its inseparable part represents first of all a valuable ecological resource and characteristic environmental reference of Banja Luka which creates many valuable sights and micro-ambient. Unfortunately, the vegetation of the banks has thus far been the most neglected segment of the system of the city greenery thus far that in many parts led to significant downgrading of this area. The exit of the city to the river banks and integration of this precious natural resource with the city should be one of the priorities of urban development in the future period.

2.1.7. Cultural identity

Waterfront is a part of the system of open areas of the city and the way it connects with its most important squares and streets shall define the degree of connectivity of the city with the river. The main pedestrian street, Gospodska Street and the most important squares and parks in the city of Banja Luka do not tie their location to the river bank. We can only state that the main city square, the Krajina Square, partly opens the view toward the Kastel fortress and then indirectly through the market toward the river. As the result of its steep banks and the logic of the construction, the river is perceived only when we leave the city center and step down to one of the city bridges. Peculiarity of the place is set by the Kastel fortress and the City bridge which connects a former Big and Small Carsija and the level of integration of the city and the river and its opposite banks is here intensively realized.

One of the main characteristics of the waterfront of Banja Luka are banks of natural landscape with dominant structures of indigenous greenery. The banks are also known for its city beaches, natural and built beaches which are traditionally used by the local population during the summer months. The shortcoming of those areas is their insufficient accessibility and visibility from the direction of the city.

Cultural identity of the area is defined by the events which take place in its public areas as an expression of the urban way of life in the city. Every year events which last for several days take place which directly depend on the river and represent the most dynamic activities in the waterfront: many sport competitions and races in kayak and canoe type of boats, fishing, etc. when the waterfront gets alive in its role of a public area of the city. The most popular events in the summer period in Banja Luka are held in the open within the walls of the Kastel Fortress. Kastel Fortress is the oldest historical monument in Banja Luka what is supported by many archeological artefacts. „Project of Reconstruction and revitalization of the Kastel Fortress" was made on the basis of the first ranked solution of the international open tender and the works on reconstruction and revitalization of the damaged parts of the Fortress started in 2013. This intervention should create conditions for revival of the capacities of the fortress in future for cultural and tourism purposes.

Extensive and rich construction heritage of Banja Luka has unfortunately been severely devastated in the second half of the 20th century. [4] During the bombing of the city in 1941 during the Second World War and also in the major earthquake which hit the city in 1969, Banja Luka lost many valuable facilities. Beside wars and natural disasters, devastation of historical values was caused by specific approach to urbanization of cities on the territory of the whole former Yugoslavia which urged faster construction of residential blocks and industrial complexes within the city limits without appreciation for the context, urban and architectural tradition. One of the examples of such unthoughtful approach to the matter of urbanization is certainly the covering of the Crkvena River and its transformation into the canal. [15]

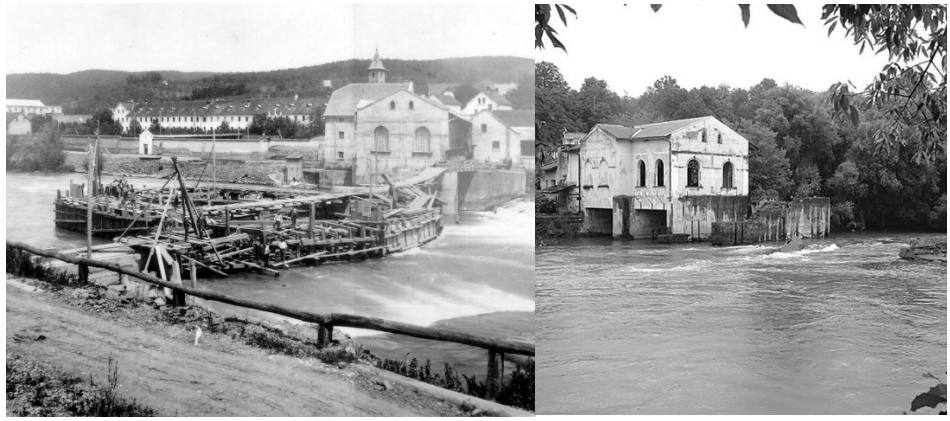

Photo 4, Construction of the power plant in Trapisti and its present condition / Source: Archive of the Urban Planning Institute of the Republic of Srpska, a.d., Banja Luka and photograph of the author /

Cultural – historical goods represent the testimonies of the existence of men and human civilizations in time and space and are very important part of entire men's heritage and therefore the identity. Within the subject of the research the facilities of cultural and historical heritage are included. Certain facilities of the waterfront enjoy certain level of protection whereas most of the facilities which possess architectural, ambient and aesthetic qualities are not under protection. Industrial heritage is not recognized under this term in the Law on Cultural Goods. [16] There is the term Facilities of Technical Culture and industrial heritage facilities on two important locations have been reported in this Paper as such. The first is in the village of Delibasino Selo as a very valuable heritage and legacy of the first Trappist colony: the water tower, the mill, part of the brewery and the first power plant on the Vrbas River. The second protected facility of technical culture is the Steel and Iron Foundry Jelsingrad founded in 1936, now in the industrial zone. / Photo 4 /

3. PROPERTIES OF THE WATERFRONT THAT CONTRIBUTE TO HIGHER SPACE QUALITY

Judging only on the basis of visual observation, we can say that the waterfronts in our cities are underutilized and often abandoned and apathetic. On the other hand, the position of our cities, being one of its basic characteristics, is always naturally related to the river and its banks. It is necessary therefore to point out to the properties of waterfronts which based on their analysis contribute to the higher quality of this interspace, at the meeting point of the city and the river.

3.1. Results of the survey of waterfront users

The survey conducted among the users of the space has been used to determine the importance and ways of using the waterfront in selected cities. Survey of random passers-by in the waterfront was carried out in several towns of the Republic of Srpska in April 2014. [17] The largest number of the respondents live in the city of Banja Luka, 117 of them. Regardless of the condition of the waterfront in their city, the vast majority of people interviewed in all seven cities stated that they were very happy to spend time along the

river bank, 86.3% of them in Banja Luka. The principles of using the waterfront has been analyzed, inter alia, by looking into the way the users move in the waterfront. It is evident that hiking is the basic type of movement of respondents in all cities. In addition to this, the movement by using bicycles in Banja Luka is also represented by 19.08% of those surveyed.

The survey questionnaire measured the identity of the area in terms of recognition and associative images that the inhabitants connect with the waterfront. Rest and recreation are the activities identified by the majority of respondents as the first association of the waterfront in the cities which were analyzed.

Unclear water and low level of equipping of the waterfront are negative characteristics that are recognized as such by a large number of users in Banja Luka. Table 5 gives a comparative overview of the initial associations of the interviewed in the waterfront area of selected cities. The answers obtained varied citing unclear water and river banks, low level of equipment in the area, the occupancy of the area, inability to use it as a public space, the level of flood defense protection, natural character of the waterfront, i.e, its vegetation, activities conditioned by the presence of the water, accessibility of river banks and the river, perception of the architectural framework of the waterfront and events taking place in the waterfront. 40.35% of the respondents in Banja Luka are ddissatisfied with the landscape of the waterfront in Banja Luka.

Natural character of the waterfront, beaches and greenery are seen as the main properties of the waterfront in Banja Luka but also in many other cities. In the case when the town quay is built on the river bank, then it is exactly the quay along the river that is recognizable and the bearer of the identity of the waterfront as the respondents stated in Novi Grad and Gradiška.

Very rarely, the interviewed referred to the facilities of physical structure built in the waterfront as identity bearers. The exception are the gardens of the cafes along the Vrbas banks and the Kastel fortress as the cultural heritage monument in Banja Luka.

The accessibility of the waterfront and the water are important parameters for the use of the waterfront in the city. In cities where the river bank is easily accessible from the direction of the city, the inhabitants saw this as a distinct quality like the respondents in Trebinje. On the other hand, 24.56% of the respondents in Banja Luka determined the inaccessibility of the river bank as a significant deficiency while 34.21% see it as major disadvantage. / Chart 1 /

Chart 1 Comparative overview of the survey results by cities: Inaccessibility of the River Bank / Source: Cvoro, M., Doctoral Thesis: Transformation of Waterfornts Intended to Upgrade the Identity of the Cities in the Republic of Srpska and BiH, Banja Luka, 2015/

The largest number, 87.9% of the respondents stated that the waterfront in the city represented a potential that was not sufficiently exploited. The future appearance of the waterfront, according to the vast majority of the respondents' responses, insist on clean water and natural character of the waterfront and the river bank with high level of urban comfort. / Chart 2 /

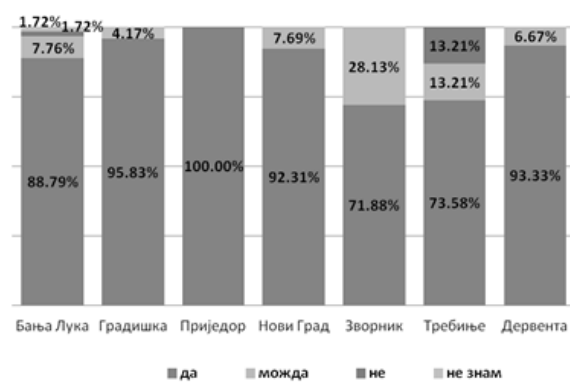

Chart 2 / Comparative overview of the survey results by cities: Waterfront is underutilized capacity / Sourcep: Cvoro, M., PhD Thesis: Transformation of Waterfronts Intended to Upgrade the Identity of the Cities in the Republic of Srspka and BiH, Banja Luka, 2015/

On the basis of the results of the survey and the analysis of waterfronts in the cities stated above, the following conclusions could be drawn:

- Natural character of the waterfornt and emphasis on this quality has been seen by most of the respondents in all cities included in the survey as its essential character. Affirmation and improvement of natural values of the waterfornt is possible only if the primary condition is achieved and that is clean water. By contrast, in case the water and the urban waterfront are contaminated and polluted, the users see it as a significant and major disadvantage.
- The results of the survey indicate a different attitude of the cities included in the survey toward the river, but can generally be divided to those that have turned their "face toward the river" and another group of towns that have "turned their back to the river", the latter group includes Banja Luka. Accessibility to users, as an important attribute of the waterfornt was also recognized during the analysis of the survey results. In case of inaccessibility of the waterfront, respondents identified this as a significant or major disadvantage of the waterfront.
- The interviewed users in the cities included in the survey confirm the assumption that the level of activities which the waterfront has to offer is very low in those cities. Too little contents and too few activities on the river bank is considered by the vast majority of respondents in all cities from the survey to be a significant or major shortcoming in their city. Various possibilities of using the urban waterfornt are precondition for the waterfront to be accepted by the users.

- Vast majority of the respondents stated that the level of equipping the waterfront with basic elements of urban comfort, such as hiking and cycling tracks, benches for sitting, shade and lights was at a very low level. Based on the results of the survey, it can be concluded that when the level of urban comfort was low, users see this as evident and significant shortcoming of the waterfront in their city and vice versa, when a high level of comfort is reached, the value of the waterfront grows in perception of users.
- Free time and recreation are the activities identified by most respondents as the first associative thought connected with the waterfront in the cities included in the survey. Very small number of respondents recognized representative bearers of the cities' identities which represent its architectural heritage as the main association with the city waterfront.

Preservation and appreciation of the heritage should be promoted in the community such as ours in order to increase accountability and raise the awareness of the society toward the values of its architectural heritage which continuity shall enable the inhabitants of the city to identify themselves with their own environment.

3.2. Properties of the waterfront

In order to formulate certain recommendations for the improvement of waterfronts, the following chapter provides the properties which these specific urban areas may have:

- Comprehensibility
- Diversity
- Continuity
- Integration
- Comfort

The comprehensibility of the waterfront is determined by ensuring the quality of readability that will enable us to understand the environment with clearly defined characteristics, elements of a certain identity. By emphasizing the specific nature of the coastal area, its natural and created elements, the user identifies the space and develops awareness and responsibility for the site. The understanding of the waterfront landscape is also seen in a wider urban context, given its constituent role in the formation of the city matrix.

The diversity of activities along the river bank is seen as an opportunity to achieve a high level of contextual integration of the city and its waterfront. The waterfront should offer a wide range of options within which various activities of users would be represented. For the quality and intensive integration of the waterfront and the city, the continuity of various activities along the coast is of key importance.

Continuity achieved through cultural heritage enables the city's inhabitants to identify themselves with their own surroundings. This applies to cultural heritage in the broadest sense including cultural landscapes, movable and intangible heritage as well as architectural and archaeological heritage. Due to the significant role of the waterfront as a productive zone of the city, there are also facilities of industrial heritage that today represent an important resource for the urban reconstruction of cities. By enhancing and emphasizing heritage, we underline the specifics of the city and strengthen its identity in the contemporary scene.

The integration of the city with its river is realized in the waterfront and the prerequisite for quality integration is respecting natural factors as conditions, limitations and potentials

for the development of the city banks. The realized ecological values in the waterfront on one hand enable a higher degree of human recovery in the urban environment and on the other hand improve conditions for survival of other forms of life in the city. Waterfronts shaped as an integral space of natural and the built can contribute to the improvement of microclimate conditions in the city area and can help reduce and neutralize pollution and noise and visual and physical relaxation of the urban environment. / Photo 5 /

Photo 5 Banja Luka, park area in front of the University Complex downgraded by the sewage pipes / Source: Photo of the author /

The comfort and comfortability of a given space is realized through physiological, psychological and physical harmony between the man and his environment. The purpose of creating the urban space should be designing such a place that would provide comfort and safety to the user. One of the main characteristics of the waterfront in terms of comfort is safety and flood protection. The feeling that the waterfront offers protection from the unrestrained power of water increases its usefulness and also psychological value for the men. We should not forget also other physical attributes of the comfort of public space, which will form the scene of opportunities for social networking and contacts in the waterfront. [17]

4. CONCRETE ACTIONS AS GUIDELINES FOR FUTURE DEVELOPMENT

By providing multiple values of waterfronts, its significance / functional, aesthetic, ecological / for the city increases. On the basis of the waterfront characteristics defined, general guidelines which contain recommendations for the methods of affecting the process of transforming the waterfronts have been listed:

- Increasing the accessibility of the waterfront / increasing the access through concrete interventions which must be adjusted to individual cases can make the waterfront closer to the users and open possibilities for its more intensive use. At the same time, the protection and emphasis on attractive sights will provide special values of visual connection of the waterfront with the city/,
- The waterfront as the area of protection of natural values in the urban environment / the importance of protecting and emphasizing the natural phenomenon of the river in

the urban environment as one of the main features of the waterfront is necessary basis for future transformations and can be considered as one of the main recommendations for integration of the city with its river/,

- The waterfront as the place of preserving cultural identity / spatial identity as one of the segments of the overall identity of the urban space is determined by the natural and built structures connected to specific forms during historical development of the city. The structures built during the historical development of the city became an inseparable part of the spatial and cultural identity of the urban area, depicting various social, political, cultural and historical events. Representative bearers of the identity of our cities comprise architectural heritage of our cities. Within the framework of transforming and improving the waterfronts, it is neceessary to prepare strategies to preserve the heritage and also mobilize its economic potential and give it new life/,
- Complexity of functions and content / In this paper, the diversity of activities along the river bank is seen as the opportunity to achieve high level of contextual integration of the city and its waterfront. The waterfront should offer more opportunities within which different needs of users will be met. The conducted survey found that the functions related to recreation of citizens and cultural events were seen as essential for the improvement of the waterfront and its vitality/,
- Improving the integration of the city and the river through development of public space / there is a growing interest for the improvement of the quality of the urban environment precisely through the domain of public space. In this study, the improvement of the waterfronts of cities is seen as a process directed toward the continuous social and cultural development of public space. The waterfront, formed as the public space of the city would contribute to the improvement of the identity of the city precisely through the relation between the city and the river /,[18]
- New physical framework of the waterfront / newly built architectural facilities entails further construction and raises the market value of already existing or reconstructed buildings in the waterfronts of the cities. All this has the effect of increasing the relevance of the entire urban area of the coast: new jobs, better housing, accompanying facilities and events in the area which was neglected. It is necessary that this transformation of the waterfront offers answers to today's needs of the society, but only by adapting to the existing spirit of the place and understanding the historical and natural context of the waterfront in the city. Otherwise, it may be that the development of the waterfront does not lead to its essential improvement/,[19]
- Increasing the level of urban comfort of the waterfront / improvement of the waterfront should be guided by the idea of designing the places that would provide comfort, comfortable and safe environment to the user. The possibility, at least to a certain extent, of conditions that will be acceptable to a larger number of users, implies certain properties of waterfronts. It is particularly important to provide conditions for physical safety of men in terms of flood protection. In this way, the psychological value of the waterfront for men and the value of this space at the city level will be increased in general/.

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27| Оригинални научни рад
Research paper
doi 10.7251/STP1813386K ISSN 2566-4484

NEIZVJESNOST U ODREĐIVANJU VELIKIH VODA U PRAKSI NA PRIMJERU SREMSKE MITROVICE, RIJEKA SAVA

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Apstrakt

Određivanje velikih voda različitog ranga pojave je jedan od najvažnijih zadataka koji se postavlja pred inženjere hidrotehnike. Projektovanje hidrotehničkih objekata i sistema zahtijeva pouzdane ocjene kvantila što nije uvijek jednostavno isporučiti. U ovom radu prikazuje se neizvjesnost određivanja velikih voda uobičajena u praktičnoj primjeni a na primjeru rijeke Save, na stanici Sremska Mitrovica. Na nizu od 42 godine osmotrenih dnevnih proticaja izvršena je statistička analiza gdje je uzorkovanje sprovedeno prema dvije metode: metodi godišnjih maksimuma i metodi pikova. Pri ocjenjivanju neizvjesnosti, uzorci su analizirani prema nekoliko scenarija, tj. mijenjana je dužina uzorka kao i bazna vrijednost oticaja kod metode pikova. Dobijeni rezultati ukazuju na veliku neizvjesnost sračunatih kvantila, posebno u domenu malih vjerovatnoća pojave, a time i na problem usvajanja kvantila u praksi koji obezbjeđuje sigurnost i optimalnu cijenu objekta.

Ključne rječi: neizvjesnost, statistička analiza, velike vode, funkcija raspodjele, kvantili

FLOOD FREQUENCY ESTIMATION UNCERTAINTY IN DESIGN PRACTICE: CASE STUDY OF SREMSKA MITROVICA, SAVA RIVER

Abstract:

Flood frequency estimation is one of the most important tasks for hydraulic engineers. Design of hydraulic structures and systems require reliable estimates of high waters, which is not always easy to deliver. In this paper, uncertainty of flood frequency estimation common in practical use is presented in the case study of the Sava River at the Sremska Mitrovica hydrological station. Time series of 42 years daily flow records are statistically analysed on two samples, comprising annual maxima (AM), and peaks over threshold (POT). For uncertainty assessment, samples are analysed for several different scenarios, i.e. varying AM sample length as well as threshold flow for POT. Results indicate large uncertainty of flood frequency estimates, especially in the domen of low probabilities, as well as problem of adopting final value for practical use that will provide safety and optimum cost of the structures.

Keywords: uncertainty, statiatical analysis, flood frequency, distribution function, quantiles

1. INTRODUCTION

Flood frequency analysis imparts flood frequency estimates (FFE) that play an important role in the design of almost all hydraulic structures and systems such as dykes, bypass channels, bridges, floodwalls, spillways, culverts, etc. Safety of these structures, as well as human lives in the cases of large flood protection systems depend upon the reliability of FFE. On the other hand, estimated design flood must be economically justified, wherefore each country has set the standard design flood return periods for different structure types (e.g. 100 years for dykes, 5-10 years for storm drainage system, 1000 years for a concrete dam spillway, 10000 for earth dam spillway, etc.).

There are three possible methods for design flood estimation, depending on the available data: (a) statistical analysis of the observed flows, (b) statistical analysis of the modelled flow, obtained with hydrological rainfall-runoff model and observed precipitation and (c) by transformation of design storms (obtained from statistical analysis of observed precipitations) into design flows based on a rainfall-runoff model. Here, statistical analysis is assumed to be establishing relationship between the flows and return period or probability of (non-)exceedance with one of the defined theoretical probability distribution functions. In this text from now on, the flow defined in this way is called quantile.

FFE is usually obtained from two sampling methods [1]: annual maxima (AM) and peaks over threshold (POT). Research shows that results of these two methods are quite similar above return period of 10 years [2] or POT is found to be advantageous over AM due to possibility to include more information about floods, i.e. more floods per year instead of only one as in AM method [3], [4].

During FFE in design practice, the uncertainty of the estimated quantiles is very rarely included in the calculation. Uncertainties in hydrological procedures can be classified into three categories [5]: natural or inherent, model and parameter uncertainty. Natural or inherited uncertainty arises from the random variability of hydrological variables (i.e. uncertainty of measured data) while model uncertainties arise from the model structure and approximations made when representing hydrological phenomena. Parameter uncertainty is due to unknown nature, and therefore errors compiled in the methods of parameter estimation. In design practice, usually just one uncertainty source is addressed through confidence intervals estimation. These intervals only deal with data sample uncertainty from which quantile is estimated [6].

Investors, designers and managers usually think that quantile estimated by hydrologist is an exact value while those values, depending on the available data and methodology applied can be found in a very wide range [7]. For this reason, the aim of this paper is to show the possible quantiles range depending on data sample method. This is demonstrated on the Sava River case study, the Sremska Mitrovica hydrological station that records runoff from almost all of the Sava River basin. Similar study [8] shows a wide range of runoff from relatively small catchment, while here, the idea is to see how this range in changed when dealing with large rivers data.

2. METHODOLOGY

2.1. Case study information and data

The Sava River is right and by the discharge largest tributary of Danube, the second longest river in Europe (after Volga River). The river basin area is over 97000 km2 with the watercourse length of cca 990km. The river is formed in Slovenia from the Sava

Dolinka and Sava Bohinjka from where it flows through Croatia and Bosnia and Herzegovina, discharging into the Danube in Belgrade, Serbia. A small share of the river basin is located in Montenegro (7.09%) and in Albania (0.18%).

The Sremska Mitrovica station is located 139.3 km from the Sava river mouth into the Danube. Station controls 87.996 km2 of the basin. The station is founded in 1878 but flow observation commenced not before 1926. Observed flow data available for this paper are for the period 1969-2010.

2.2. Sampling data for statistical analysis

In this paper time series of 42 years daily flow observations are used, which are statistically processed with two sampling methods: annual maxima (AM) and peak over the threshold (POT).

For AM method, samples were formed taking one maximum flow per each year. Because of the relatively short available observation period (1969-2010), here are used three samples with different observation period and different sample length: 1969-2010, 1969-2000 (this way excluding new data after 2000) and 1979-2010.

For each sample, the following theoretical probability distributions are analyzed: log-normal (logarithmic Gaussian distribution), Pearson type III, log-Pearson type III, Gumbel and Generalized Extreme Value (GEV). Review of the fitness of theoretical and empirical distributions is conducted with following tests [9], [10]: Kolmogorov–Smirnov, Anderson-Darling and Cramer-von-Mises. Based on the results of the named tests, log-Pearson type III is accepted as the most adjustable theoretical distribution to the observed data. The statistics of the samples, as well as the parameters of the theoretical distributions, are estimated by the method of moments.

Table 1. Overview of samples analyzed with annual maximum flows method

Label	Observation Period	Sample Length N	Mean Peak Flow of the Sample $X_{max,avg}$ (m^3/s)	Coefficient of Variation C_v	Coefficient of Skewness C_s
AM1	1969-2000	32	4001	0.20	1.05
AM2	1969-2010	42	4020	0.20	0.86
AM3	1979-2010	32	4004	0.19	0.49

Another method used to determine the maximum flow quantiles is POT method, in which samples were formed by taking maximum flows above a certain limit - the threshold X_b. Eight different thresholds are defined from which eight samples within fixed observation period (1969-2010) are extracted. The data samples of maximum flows, shown in the Table 2 are adjusted to the two-parameter Weibull distribution function.

Peak selection for POT method is done by considering independence criteria. General criterion is to use only one peak in one event, while peaks filtration when two (or more) consecutive peaks occur is processed following Water resources Council (USWRC 1982) criteria [16]:

$$\theta < 5 \text{ days} + \log(A)$$
$$\text{Or } x_{MIN} < 0.75\min[x_{s1}, x_{s2}] \tag{1}$$

where

A is basin area in miles,

xs1 and xs2 are two consecutive peak values.
The second peak should be rejected if one of the conditions in above equation is met.

Table 2. Overview of samples analyzed with a peak over threshold method

Label	Threshold X_b (m^3/s)	The Total Number of Peaks M	Average of the Peaks Z_{avg} (m^3/s)	Coefficient of Variation C_v	Coefficient of Skewness C_s
POT1	2500	181	816.6	0.87	1.48
POT2	2600	170	765.5	0.92	1.48
POT3	2750	139	768.7	0.90	1.46
POT4	3000	102	750.5	0.89	1.47
POT5	3250	81	669.6	0.97	1.50
POT6	3500	59	624.1	1.04	1.31
POT7	3750	38	673.2	0.94	1.04
POT8	4000	27	666.7	0.89	0.88

By using these methods for flood frequency estimation, eleven theoretical distribution functions have been obtained. For each of them, confidence intervals are calculated and then their envelopes (aggregate minimum and maximum limit values for each return period) are defined. These envelopes represent uncertainty intervals for quantiles of specific return period, which is the main aim of this paper. Analysed return periods (T) are: 2, 5, 10, 20, 50, 100, 200, 500, 1000 and 10.000 years.
Basic theories of applied methodology is given in the next section.

3. STATISTICAL MODELS FOR FLOOD FREQUENCY ESTIMATION

3.1. Annual maxima (AM) method

Annual maxima (AM) is a statistical model where sample data formed with one maximum flow per year is fitted to a probability function. Therefore, the sample consists of $Q_1, Q_2, ..., Q_N$ data where N is a number of years of observations and Q_i is a maximum flow recorded for i -th calendar year. The basic assumption is that all data in the sample are stochastic value, mutually independent, uncorrelated and homogenous; therefore adequate sample of the population which must be previously tested [1], [11].
There are many probability functions that can be used for fitting AM. In practice, several distributions are fitted and upon test of fitness (i.e. Kolmogorov-Smirnov, Cramer von Mises, etc. [12]) is decided which distribution fits the best to the observed data.
The three parameter log-Pearson type III distribution from the gamma group best describes the flow distribution Q_i for annual maxima series of Sremska Mitrovica station.
The function of this distribution is defined by the expression:

$$F(y) = \int_{\Upsilon}^{y} \frac{1}{\beta\Gamma(\alpha)} \left(\frac{y-\Upsilon}{\beta}\right)^{\alpha-1} exp\left(-\frac{y-\Upsilon}{\beta}\right) dy \tag{2}$$

where:
α (α >0), β (β≠0), Υ are distribution parameters,

$y = logx$,
$x = Q$,
$\Gamma(\alpha)$ is gamma function:

$$\Gamma(\alpha) = \int_0^\infty u^{\alpha-1} e^{-u} du. \tag{3}$$

Since the inverse distribution (the quantile y calculation) cannot be defined explicitly by the expression, numerical approximations (in combination with built-in excel functions) are used. The inverse distribution could be determined via tabulated factor of frequency K_T (which depends on the probability and coefficient of skewness of the series) as well [13]. In that case, the following expression is used:

$$\log(x) = y_{avg} + K_T S_y \tag{4}$$

where:
y_{avg} is mean value,
S_y is standard deviation of the log series.

3.2. Peaks over threshold (POT) method

POT represents good alternative to the AM method since it includes more flood information, i.e. more than one peak in the year [3]. Potential problem here may arise due to uncertainty of threshold determination. Threshold X_b defines the sample data that consists of peaks $Z = x - X_b$, where x is observed flow. There are several recommendations for threshold determination, such as to use minimum annual maxima as a threshold or to find the value on the graphic representation of the relationship X_b and X_b / Z_{avg}. In the later, Z_{avg} is an average of the peaks over threshold and the flow where the distinctive linearity is lost, represents X_b [14].

The theoretical distribution of the number of peaks per year is calculated according to one of the distribution functions for discrete variables. Selection criteria for theoretical distribution is the value of the dispersion index, obtained from:

$$I = \frac{N \cdot S_x^2}{M} = \frac{S_x^2}{n_{avg}} \tag{5}$$

where:
N is the total number of the observation years,
M is the total number of peaks above the threshold X_b,
S_x^2 is the variance of the number of peaks,
$n_{avg} = \frac{M}{N}$ is the mean of the number of peaks.
As the dispersion index for all series of peaks above the threshold X_b formed from observed data for Sremska Mitrovica station is greater than one, negative binomial distribution with two parameters is used. The function of this distribution is defined by the expression:

$$p_i = P\{X = i\} = \binom{b-1+i}{b-1} p^b (1-p)^i \tag{6}$$

where:
b is distribution parameter:

$$b = \frac{n_{avg}}{I-1} \tag{7}$$

p is distribution parameter:

$$p = \frac{b}{n_{avg} + b} \tag{8}$$

The distribution of the height $H(Z)$of the peaks Z is defined with a two-parameter Weibull distribution. The function of this distribution is defined by the expression:

$$H(Z) = 1 - exp\left\{-\left(\frac{Z}{\alpha}\right)^{\beta}\right\} \tag{9}$$

where:
β is distribution parameter that should be numerically calculated from the expression:

$$f(\beta) = \frac{\Gamma(1+2/\beta)}{\Gamma^2(1+1/\beta)} = 1 + C_{vz}^2 \tag{10}$$

α is distribution parameter:

$$\alpha = \frac{Z_{avg}}{\Gamma(1+1/\beta)} \tag{11}$$

The distribution of the probability of the annual maxima $F(x)$ is obtained by a combination of the previous distributions of the number and height of the peaks, in a way that it gives an inverse distribution function for quantile calculation according to Weibull's distribution:

$$Z = X_b + \alpha[-ln(1-H)]^{1/\beta} \tag{12}$$

where:
$1 - H$ is obtained from the negative binomial distribution:

$$1 - H = \frac{F^{-1/b} - 1}{1/p - 1} \tag{13}$$

3.3. Standard quantile errors and confidence intervals

The confidence intervals of the distribution function are determined for quantiles X(T), where T denotes the return period, by defining the upper (u) and lower (l) interval boundaries according to the following:

$$X_{u,l}(T) = X(T) \pm |z_\alpha| S_{x(T)} \tag{14}$$

where:
z_α is a standardized variable of normal distribution for the significance threshold α:

$$z_\alpha = -z(1-\alpha) \tag{15}$$

The significance threshold α corresponds to the confidence interval β:

$$\beta = 1 - 2\alpha \tag{16}$$

$S_{x(T)}$ is the standard quantile error.
The standard quantile error $S_{x(T)}$ represents the square root of the quantile variance and is determined differently depending on the selected theoretical distribution.
For log-Pearson type III distribution, the standard quantile error is defined by the expression:

$$S_{y(T)} = \frac{S_y}{\sqrt{N}} \sqrt{1 + \frac{1}{2} K^2(T)} \tag{17}$$

where:
$K(T)$ is frequency factor:

$$K(T) = \frac{Y(T) - y_{avg}}{S_y} \tag{18}$$

while $Y(T)$ represents logarithmic quantile:

$$Y(T) = logX(T) \tag{19}$$

The determination of the standard quantile errors and confidence intervals for Weibull distribution is somewhat complicated and due to limited space is not given here. However, interested readers may find complete derived expressions in [15].

4. RESULTS AND DISCUSSION

Resulting quantiles for AM method are not in big discrepancy along the different return periods. The lowest quantiles are obtained for the period 1979-2010. The reason for this probably lies in the fact that largest floods on the Sava River recorded at this station occurred in 1970 and 1974, which are excluded from this period. Largest quantiles are obtained for the period 1969-2000, but not with significant differences from the whole period (1969-2010), which is shown in the Table 3.

Table 3. Overview of quantiles obtained from annual maximum flows method

Return period	Quantiles		
	1969-2000	1969-2010	1979-2010
2	3850	3885	3919
5	4580	4616	4591
10	5074	5097	5001
20	5558	5559	5376
50	6202	6161	5840
100	6700	6620	6178
200	7212	7085	6509
500	7917	7715	6940
1000	8474	8206	7263
10000	10496	9948	8337

These leads to conclusion that flood information content within the observation period used for statistical analysis is crucial for quantile estimation. Analysing data where large historical floods are excluded may lead to underestimated quantiles, and excluding periods with less and smaller floods may lead to quantile overestimation. Generally, sufficient length of the sample is maybe the most important in the proper statistical analysis. In this paper, there was not enough data to manipulate with, i.e. to form series of various length, but similar analysis concluded that, for example, parameters of the Pearson III distribution function are getting stabilized as length of the sample gets longer [8]. The problem of short sample data for FFE is not novelty in hydrology. Estimation of quantile of 100 years return period with the data sample of e,g, 40 years is never a good idea. However, in design practice this problem is usual and needs to be addressed with proper inclusion of uncertainty into the FFE.

In the POT method, largest quantiles are obtained with the threshold of 3500m3/s. Fitness of the theoretical and empirical distributions for both methods and for the same observation period is given in the Figure 1.

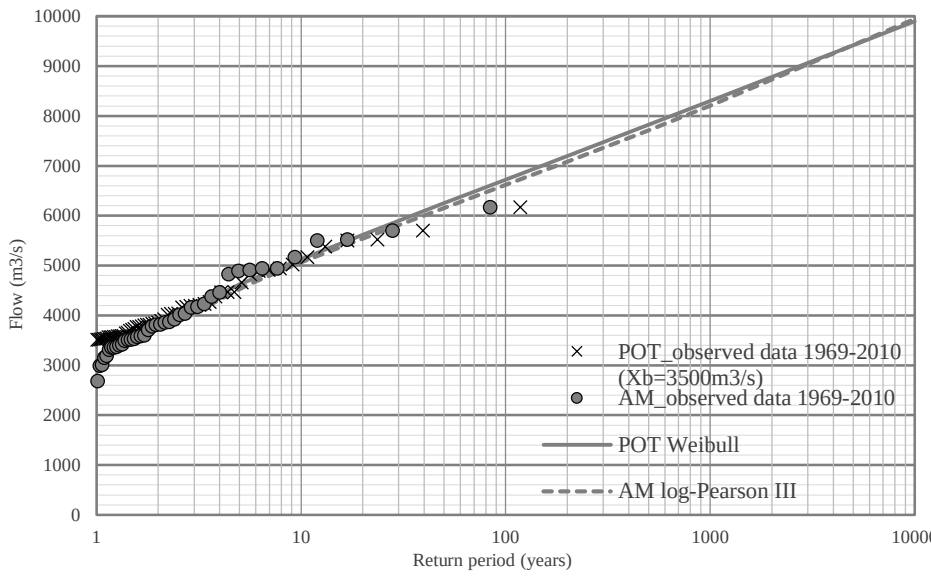

Figure 1. Distribution function plot for AM and POT methods for period 1969-2010

Summary results of all samples by both methods are depicted in the Figure 2. Quantiles obtained by POT are symbolised with dots while the ones obtained with AM are symbolised as squares. Confidence interval envelopes (i.e. boundary confidence intervals for both sampling methods) form upper and lower limits and are shown in the Figure 2 as continuous lines. The value of the significance threshold α used to determine confidence intervals is 0.05.

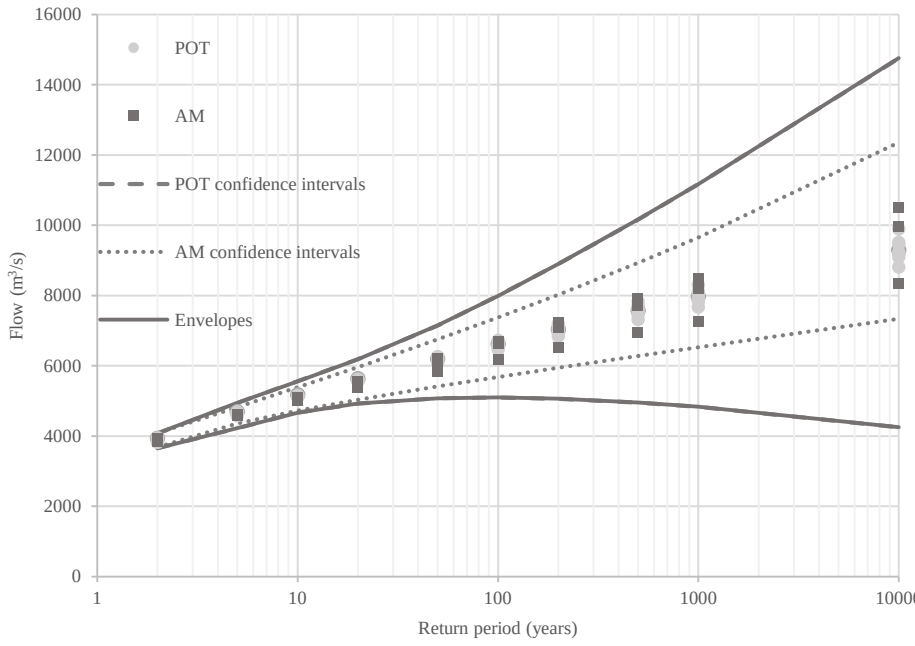

Figure 2. Distribution functions with boundary confidence intervals

For both methods, it is evident that range of quantiles increases as the return periods increases. For instance, defined quantile for a return period of 100 years, for POT method could take any value between 6470 and 6724 m^3/s, while for AM method between 6178 and 6700 m^3/s, depending on the available sample. These envelopes give wide range of possible quantile values, and by increasing return periods, uncertainties in flood frequency estimation increases as well.

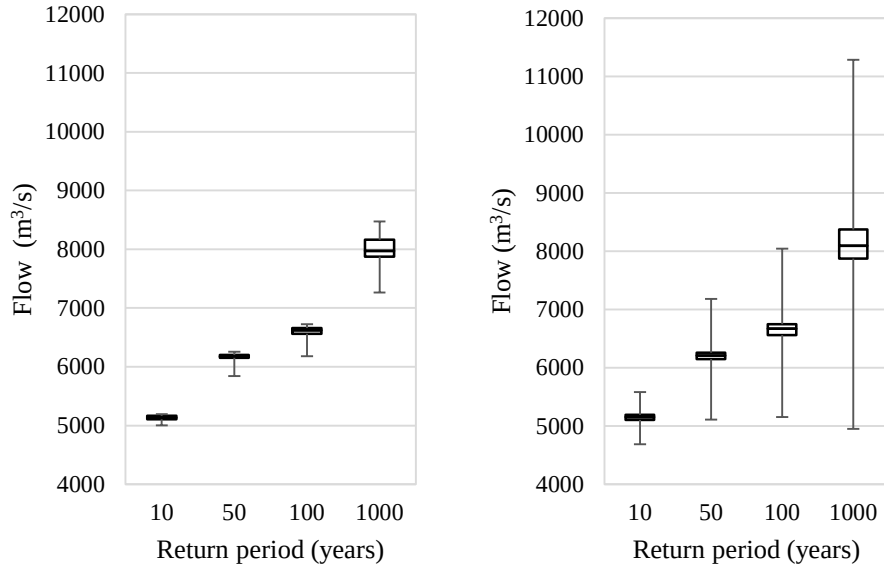

Figure 3. Box and whiskers plot for quantiles determined by AM and POT method (left) and with included confidence intervals (right)

Box and whiskers diagrams show the central value (median) of the series formed from obtained quantiles for both methods and its upper (75%) and lower (25%) quartiles, as well as the lowest and highest values of the quantiles. In this graph, bottom and top of the box are the upper and lower quartiles, so the box spans the interquartile range. A horizontal line inside the box marks the median. The ends of the vertical lines are the minimum and maximum values of all the obtained quantiles.

Introducing only one uncertainty due to the mistake of distribution functions, which in this case are confidence intervals, the range is significantly increased (Figure 3 right). It could be concluded that this range would be even greater, if uncertainty is calculated for output data from the probability analysis of the maximum flows due to other errors (i.e. measurements, distribution function and parameter estimation, etc.).

5. CONCLUSIONS AND RECOMMENDATIONS

Uncertainties in flow estimation occur due to many sources of error: poor data quality, determination of parameters and selection of the statistical model-distribution function, the data sampling method, assumptions about stochastic nature of hydrological variable, problems with water level measurement, equipment malfunction or incorrect cease-to-flow datum, etc. [6]. The best way of improving the data quality of flood flow behavior is to measure rainfall and streamflow – preceding, during and after a flood event. The longer is the period of record, the better the confidence in the flow estimate would be.

The uncertainty of the sample from which information about the maximum flow of a certain probability of occurrence is finally obtained, is mainly considered through determination of the confidence intervals. In this paper, this is extended to uncertainty that depends on sample data used for estimation, statistical model used and method (AM and POT). Still, problem in design practice exists. For example, design flood of 100 years

return period is estimated with mean value of 6577 m3/s. Possible quantiles that can be used in design is ±20% with reference to mean value, including confidence intervals and estimation methodology, which is large span due to large flow values. Comparing results to similar study [8], it could be concluded that great catchments are less sensitive when it comes to the range of quantiles. This range also vary, but in comparison with relatively small catchments, these changes are smaller.

The analysis could be improved: by collecting more observed data to extend analysis, by varying the length of the sample for the peak method, analysing some other sources of error, such as various statistical models and other methods for model parameters estimation (i.e. L-moments). However, it is expected that the future extended analysis will show even more uncertainty intervals, especially under the conditions of changing climate. Still, in practice there is no proper mechanism for solving the problem, i.e. decreasing the uncertainty or methods for dealing with it. This is the topic that should be seriously addressed in order to prevent future designs to be under- or over dimensioned with respect to design floods.

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28| Оригинални научни рад
Research paper
doi 10.7251/STP1813398J ISSN 2566-4484

VREDNOVANJE I OPTIMALNI IZBOR LOKACIJE ZA IZGRADNJU MINI HIDROELEKTRANE NA RIJECI VRBAS

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Sažetak:

Predstavljeni rad je dio šireg istraživanja vezanog za primjenu vode, kao obnovljivog izvora, koji je rađen u sklopu master programa sa temom energetske efikasniosti. Rad analizira aspekte izgradnje mini hidroelektrane (sa instaliranom snagom od 0.5 MW) za energetsko-ekološki razvoj ruralnog područja i primjenu obnovljivih izvora energije bez negativnog uticaja na životnu sredinu. Izvršena je analiza 3 različite lokacije na rijeci Vrbas sa pritokama, pomoću AHP metode i izvršen je izbor one koja je najadekvatnija za izgradnju ovog tipa objekta. Na početku rada opisan je značaj mini hidrocentrale u odnosu na veliki, a kasnije i potencijal za izgradnju objekata ove vrste u širem regionu Republike Srpske i BiH. Cilj rada je da pokaže značaj proizvodnje električne energije korišćenjem vode kao obnovljivog izvora energije i optimalan izbor lokacije primjenom AHP metode.

Ključne riječi: Mini hidroelektrana, obnovljivi izvori energije, AHP metoda

EVALUATION AND OPTIMAL LOCATION'S SELECTION FOR MINI HIDRO POWER PLANT'S CONSTRUCTION ON RIVER VRBAS

Abstract:

The presented paper is part of a wider research related to the application of water, as a renewable source, which was made in the frame of master program with energy efficiency's topic. This paper analyzes aspects of the mini hydro power plant's construction (with installed power of 0.5 MW) for the energy-ecological development of the rural area and the application of renewable energy sources without negative impact on the environment. An analysis of 3 different locations on river Vrbas was performed using the AHP method and a selection of the most suitable location for the construction of this type of facility was made. At the beginning of the paper, the significance of the mini hydroelectric power plant is described in relation to the large, and later, the potential for the construction of facilities of this type in the wider region of the Republic of Srpska and BiH. The aim of paper is to show the importance of producing electricity using water as a renewable energy source and optimal location selection using the AHP method.

Key words: mini hydro power plant, renewable energy sources, AHP method

1. INTRODUCTION

The construction of a mini hydro power plant (MHPP), a flow character, with a centralized electromagnetic network, achieves the production of electricity by using water as a renewable source with a higher degree of environmental protection than large hydroelectric power plants [1],[2]. In addition to the production of el. energy, the goal of the project is the development of a rural environment near Banja Luka, famous for its natural resources. The notion rural development refers to the new modern concept of electric energy, which has not yet been developed in our region. One household, who by constructing such an object, becomes the owner of the energy factory, repays the construction costs and gets free electricity. Households sell electricity to electricity distribution, connect to their network, and forward surplus energy produced. By saving energy costs and earnings from selling assets, they are refunded over a certain period of time. At the end of the household / factory, as an investor, he earns a bonus and earnings. The offered MHPP technology is becoming innovative, because our market is not saturated with such types of projects, thus the technological and design solution is inherently attractive and raises the marking and mapping of the site as important in the environment. The construction of a mini hydroelectric power plant, besides economic characteristics, aims at protecting the environment, reducing fossil fuel emissions, protecting bio systems and microclimate, since the selected flow type of the mini hydro power plant has the least impact on the living world from other types of hydro power plants. In addition, the advantages of building mini hydropower plants are [3]:

- supply of electricity from renewable energy sources,
- water supply,
- watercourse arrangement (regulation of torrents, prevention of deposits, etc.),
- irrigation,
- sports and commercial fishing, and recreation of sports recreation zones.

Figure 1. Appearance of a flow-through mini hydro electric power plant, [3]

Mini hydro power plants has much less harmful impacts on the environment than large hydro power plants. While large hydroelectric power plants influence the change in the micro climate, water flow, fish migration and impact on the biological composition of water, small hydro power plants, especially those of the flowing type (Figure 1), minimize

the migration of fish, the environment and its aspects, as it is not necessary to make artificial accumulation, but use a natural fall. There is noise and vibration, but low intensity. A key advantage of mini hydroelectric power plants is the reduction or completely eliminated of greenhouse gas emissions. The main reason for this is that fossil fuels do not use as a turbine engineer or electric generator. Thus, the electricity produced in hydro power plants becomes more viable, and independent of the price and supply of fossil fuels on the market [2], [4].

In the continuation of work are shown: Criteria, which are important for MHPP's construction, locations suggestions based on criteria and preliminary research, their evaluation and selection of the most adequate solution.

2. DESCRIPTION OF THE CRITERIA FOR MHPP CONSTRUCTION

Criteria, analyzed in paper, are related to the requirements that are necessary for smooth functioning of MHPP. They are defined by urban and technical conditions and law of water use [6], [7]. Urban criteria are related to macro location analysis, e.g. its connection with environment, the distribution and density of population, distance of the existing plants - appearance of competitiveness and distance from urban environment. They are technically most related to micro location and relate to function of plant itself. The criteria on which locations was analyzed are [5], [6]:

- C1 - distance of existing MHP plants from proposed construction sites (greater distance, more favorable option);
- C2 - the existence of a transport infrastructure (this criterion is significant for possibility of access to plant during construction and exploitation, and for a better urban solution that is essential for obtaining a permit);
- C3 - the distance of traffic access from proposed locations (which has closer traffic access to location gets significant);
- C4 - the immediate distance of proposed sites for construction from urban environment (since it is a rural development of a home, the distance from urban environment is desirable, since the construction of such an object is not appropriate for the city environment);
- C5 - the existing quality of household electricity supply at observed sites;
- C6 - development of environment (for development of MHP plants of rural areas, good development of environment is not required, lower development is desirable);
- C7 - population density (a lower population density is desired, but with a concentrated type of object construction, rather than dissolved ones);
- C8 - the velocity of Vrbas River flow (for the MHPP operation it is necessary that the terrain has a fall from 2 to 40m and therefore a higher flow and speed);
- C9 - the distance of planned plant from connection to the mains network (the closer location connection gets to the significance);
- C10 - the consumer's distance from MHP plant (the consumer / investor who builds such an object and supplies electricity is desirable to be in close proximity).

In the wider region of Republic of Srpska, the potential for the development of mini hydroelectric power plants has basins: Vrbas, Trebišnjica, Drina, Bosna, Una and their tributaries [6]. Entity government of the Republic of Srpska has awarded 107 concessions for the construction of similar hydroelectric power plants since 2005, of which 28 contracts have been terminated and seven facilities have been put into operation so far. Of the aforementioned concessions, only one hydroelectric power plant Divič on the Vrbanja River (in 2006) with installed power of 1.4 MW and an average annual 0.25 GWh was built and put into operation [8]. In the Republic of Srpska, there are 7 mini hydro power plants with an installed power of more than 16, 95 MW and an average production of electricity of 68, 14 GWh. At the construction stage, there are two more hydroelectric power plants, while the remaining projects are in the process of preparation or at lower levels of the legal procedure in the process of obtaining the necessary permits and approvals [6], [8].

The main problem for building such facilities is lack of money, insufficient research and problems with local communities. The commission for concessions says that the spatial plans of the municipalities are not harmonized with the entity, so the site is intended for a mini hydroelectric power plant, often a protected area or a planned nature park [7]. Considering that the Vrbas river with its tributaries is characterized as a river with high potentials, which have not been used sufficiently and there are no mini hydroelectric power plants built near Banja Luka municipality, we decided to analyze this catchment in rural city's environment.

3. ANALYSIS OF LOCATION FOR MHPP'S CONSTRUCTION

During the selection of location for mini hydro power plant's construction on the Vrbas and Vrbanja, the criteria set out in the previous chapter have been used. The proposed locations for the construction of a new hydroelectric power plant on the Vrbas river basin are: Rekavice, Vrbanja and Karanovac (Figure 2). It is important to emphasize that our market is not saturated with this solution, and this type of project should not be considered as a competition, since the aim is to increase regional production of electric energy, while using a rational use of natural resources without environment's disturbing. In the territory of municipality of Banja Luka, in Vrbas basin, north of the HPP Bočac, there are no existing projects, while in the southern part of the municipality of Mrkonjic Grad, the project of mini HPP "Medna" is currently being implemented [9].

a) Karanovac b) Rekavice c) Vrbanja

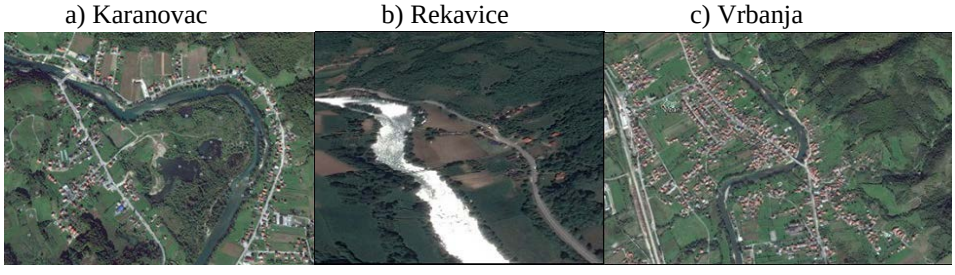

Figure 2. Locations analysis for the construction of a mini hydro power plant, google review, author's work

The construction of this type project is intended for investors, households who are visionaries and have modern thoughts about global problems and achievements in the world of renewable energy source's application. They want to own their own eco-system service and to adapt it to themselves and their needs.
In next chapter, the analytical and hierarchical comparison of 3 different locations and their evaluation according to set criteria were carried out.

4. EVALUATION LOCATIONS USING THE AHP METOD

AHP (analytical-hierarchical process) treats decision-making problem as a hierarchy of elements important for decision-making [10]. This method offers opportunity to explain all problems to problem matrix, with aim at top and criteria and alternatives at lower levels that can be easily understood and subjectively evaluated (Figure 3).[10], [12] It is used quite a lot in field of research because it has a number of its advantages, such as [11]: relative simplicity, intuitive approach, ability to use qualitative and quantitative information in the decision-making process, matrix of comparing system elements by pairs,ability to calculate index of inconsistency, existence of user-oriented software, and simple interpretation of results. The obtained values / results represent weight (priorities) of observed alternatives. Different ways of prioritizing objects are applied in AHP models, such as: the method of own values, the method of additive normalization, the lowest-order logarithmic method, the least-squares method of difficulty, the method of the programming of priorities, etc. [12, 13]. In this paper the method of own values is used. This means that in the analysis and comparison in pairs (Figure 4), for each criterion, values are assigned separately to the criterion (in this case, these values are from 1-9 in relation to priority and comparison). The formula based on this type of comparison is [13]:

$$Aw = \lambda \mathrm{w}, \mathrm{eT} \tag{1}$$

Where:
A is matrix of criteria (Figure 4)
w = 1, is requested priority vector

It is solved so that the maximal own matrix value A is obtained. The maximum own value for an inconsistent matrix can be estimated by successive squaring of the matrix, by normalizing element's sum by type each time and by interrupting the procedure when the difference between the normalized sums in two consecutive calculations is lower than the expected value. Comparison's consistency in pairs and result's quality is checked by calculating the degree of consistency, and the accepted tolerant indicator's value is 0.10. If value of CR (degree of consistency) is CR<0.10 for matrix A is obtained, the values of the alternative (estimating the relative importance of the criterion) are considered acceptable [13].

In the concrete case, the method analyzes 10 criteria, in accordance with required goal "Choosing the best location for SHPP", where they are set in same ranking (Figure 3).

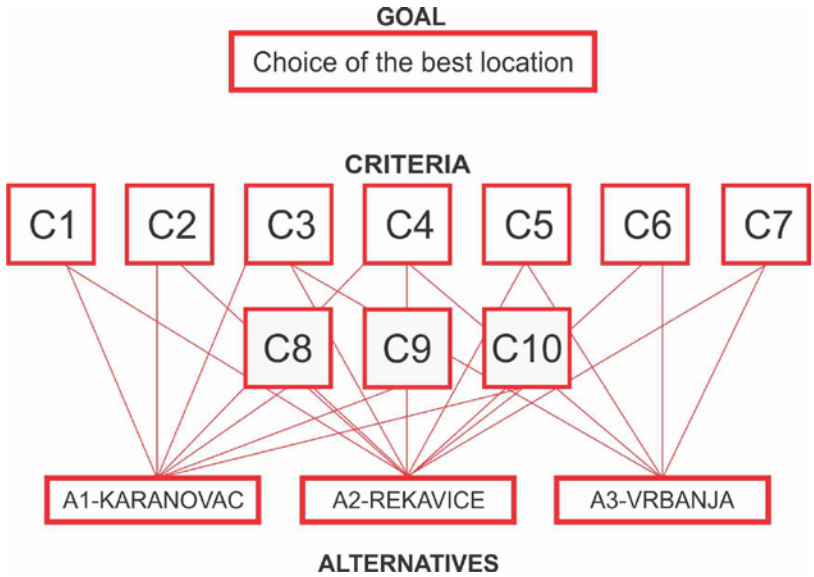

Figure 3. AHP matrix for the presented research - selection of the best location for SHPPs, author's work

Only when comparative analysis of each criterion with each matrix is performed (Figure 4) can the ranged comparison's results of criteria be created [10].

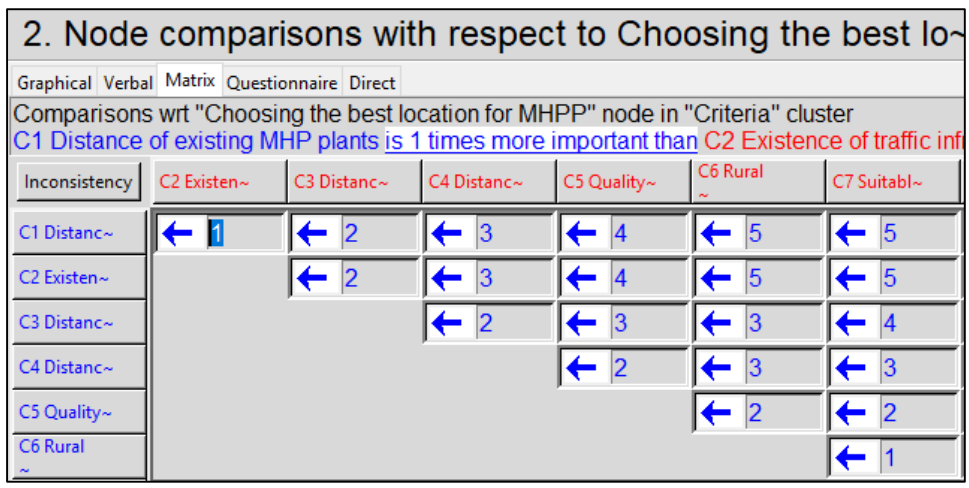

Figure 4. Evaluation and comparison's matrix of criteria in pairs for SHPP's construction, author's work

Based on analysis of the criteria according to the comparison matrix and the results of weight factor for criteria, which program is calculate, it is concluded that the most important criterion is "C8 - Flow velocity", then criteria are ranked by importance: C10, C9, C1, C2, C3, C4, C5, C6, C7.

Criterion	Graphic	Weight factor for criteria	
C1 Distance of existing MHP plants		0.10791	0.053953
C2 Existence of traffic infrastructure		0.10791	0.053953
C3 Distance of traffic infrastructure		0.06871	0.034356
C4 Distance from the city center		0.04639	0.023195
C5 Quality of existing EE supply on site		0.03269	0.016345
C6 Rural development of the environment		0.02411	0.012055
C7 Suitable density of population		0.02356	0.011778
C8 Flow rate of the river		0.25275	0.126377
C9 Connection distance to the mains		0.16799	0.083994
C10 Distance of consumers from MHP plant		0.16799	0.083994

Figure 5. Calculate the local priorities and weight factors of the AHP model criteria, author's work

In next steps, the assessment of alternative locations was made in relation to the offered criteria. First, each location is evaluated for each criterion separately (Figure 6, 7). Also, for each comparison of criteria with alternatives, the degree of consistency (inconsistency) is determined (Figure 7). For shown example - Comparison of C4 criterion with alternative locations (Figure 6) inconsistency is shown in Figure 7.

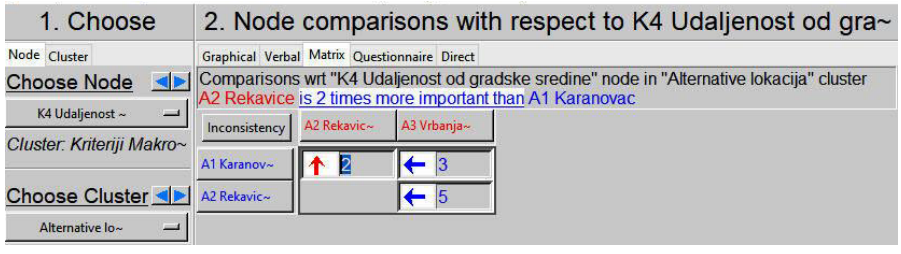

Figure 6. Comparison matrix and the values of local priorities of the criterion C4, author's work

For other comparisons, the consistency degrees are shown in Table 1. The overall degree of consistency, which the program determines based on previous analyzes is
CR = 0, 02395 (Figure 8). This is the total result of the comparison of criteria with alternatives. This value is less than the allowance, which means that the result of the analysis is acceptable and valid.

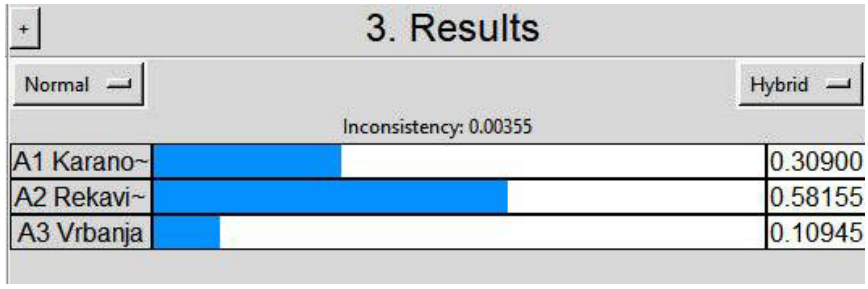

Figure 7. Comparison matrix and the values of local priorities of the criterion C4, author's work

Table 1. Consistency level for each comparation criterion and alternatives, author's work

Comparison of criteria and alternatives	Inconsistency - CR
Comparison of criteria 1 (C1) with all 3 alternatives (A1, A2, A3)	0.00000
Comparison of criteria 2 (C2) with all 3 alternatives (A1, A2, A3)	0.00000
Comparison of criteria 3 (C3) with all 3 alternatives (A1, A2, A3)	0.00000
Comparison of criteria 4 (C1) with all 3 alternatives (A1, A2, A3)	0.00355
Comparison of criteria 5 (C5) with all 3 alternatives (A1, A2, A3)	0.00000
Comparison of criteria 6 (C6) with all 3 alternatives (A1, A2, A3)	0.00000
Comparison of criteria 7 (C7) with all 3 alternatives (A1, A2, A3)	0.00885
Comparison of criteria 8 (C8) with all 3 alternatives (A1, A2, A3)	0.02395
Comparison of criteria 9 (C9) with all 3 alternatives (A1, A2, A3)	0.00835
Comparison of criteria 10 (C10) with all 3 alternatives (A1, A2, A3)	0.00550

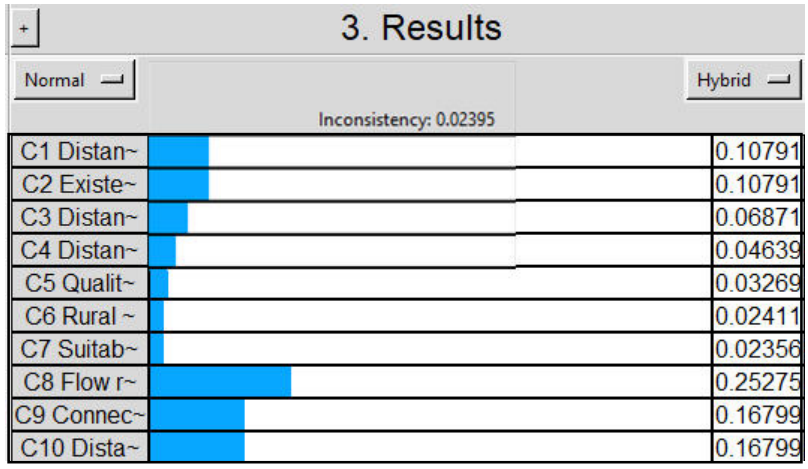

Figure 8. Overall degree of consistency, author's work

In the end, programmatically, all relationships are evaluated and evaluated together, and the final result is the ranking (Figure 9), which represents the ultimate result of the research.

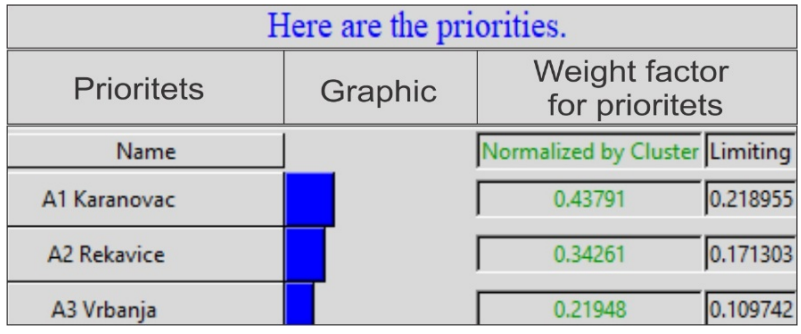

Figure 9. Total calculate priority of observed locations, author's work

The analysis has shown that the highest priority, or the best location for the construction of a 0.5 MW power line, has a Karanovac settlement, then Rekavice and at the end - Vrbanja. When choosing a site for analysis, it was taken into consideration that all three sites are quite good for construction of this type of MHPP and they all have the potential. The location in Karanovac settlement (Figure 10) has good accessibility, it is connected by road, has a relatively fast water flow, proximity to the connection to the network and there are no built MHPPs in the vicinity.

Figure 10. Short view of the location, Karanovac settlement, google review, author's work

5. CONCLUSION

The Republic of Srpska abounds in various forms of renewable energy and the highest potentials are: water, sun, but also bioenergy and wind energy. Climate change, as well as additional costs associated with the change in fossil fuel prices, have spurred a greater interest in renewable energy sources, and thus MHP plants, which should partly compensate for fossil fuels and contribute to environmental conservation. In the Republic of Srpska, there are 7 mini hydro power plants with an installed power of more than 16, 95 MW and an average production of electricity - 68, 14 GWh. If all potentials were used in more than 100 adequate locations with technical possibilities for construction of MHPP from 100 kW to 10 MW, the annual electricity production would increase by about 1400 GWh.

The paper analyzes some of the possible locations for the construction of the mini hydroelectric on the Vrbas with AHP method. Of the 3 locations which are analyzed, the most adequate and favorable position is the Karanovac settlement near Banja Luka. Mini hydro power plant in Karanovac, with installed power of 0.5 MW, would serve as auxiliary device for additional electricity generation and additional exploitation of river potential. By connecting the energy produced in a minihid power plant to a large network power supply system, the energy demand of the selected settlement could be met. What makes the process easier is the existence of a nearby substation and a transmission line system. It was also concluded that the most important criteria for construction are: the speed of the river flow, the distance of the consumers from the plant, the distance of the existing systems and the traffic connections.

Energy efficient constructions and applications of renewable energy sources represent the future, along with the applications of new technologies that enable the collection, absorption and consumption of such forms of energy both in international practice and in the region. This type of design is a complex process, a holistic process, in which different and diverse professions must co-operate, whose co-operation must be integrated into a single compact entity. Environmental awareness and obligations arising from international agreements imply the need to reflect more and more in our region on the increased share of renewable energy sources in the overall energy balance.

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29| Прегледни научни рад
Review paper
doi 10.7251/STP1813409V ISSN 2566-4484

DIGITAL MODELING OF EARTH'S SURFACE RELIEF

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Abstract:

This paper presents the theoretical basis for the development of the Earth's surface relief digital models. The sources and structure of the modeling data, as well as the methods of their processing, are described, depending on the spatial-temporal properties of the Earth's surface. Digital relief models have great significance and wide application in modern geodetic works. Representation of the spatial structure of the relief can be done with different methods of interpolation. In this paper their mathematical foundations are also given. General indicators of the quality of digital relief models are briefly described.

Keywords: digital relief models, Earth's physical surface, interpolation.

ДИГИТАЛНО МОДЕЛОВАЊЕ РЕЉЕФА ПОВРШИ ЗЕМЉЕ

Резиме:

У раду су представљене теоријске основе израде дигиталних модела рељефа површи Земље. Описани су извори и структура података моделовања као и поступци њихове обраде, зависно од просторно-временских својстава површи Земље. Дигитални модели рељефа имају велики значај и широку примјену у савременим геодетским радовима. Приказивање просторне структуре рељефа може се вршити различитим методама интерполације. Њихове математичке основе такође су дате у овом раду. Кратко су описани општи показатељи квалитета дигиталних модела рељефа.

Кључне ријечи: дигитални модели рељефа, физичка површ Земље, интерполација.

1. INTRODUCTION

The relief of the Earth's crust is defined as the deviation of the physical surfaces of the Earth from the geoid, the level surface of the potential of the Earth's gravity acceleration, which can be approximated by the mean sea level [1]. Digital Relief Models (DRM) of Earth's physical surface are sets of digital data, about the spatial structure of the Earth's surface, expressed in vector or raster form. They describe the shape and metric properties of elements of the Earth's physical surface, by parts or as a whole. They represent elementary geospatial surfaces, or their union - sets of material points of different densities, positions, orientations and mutual relations. Often, as synonyms, the terms digital terrain model (DTM) and digital elevation model (DEM) are used, although there is a difference between them [2]. Digital elevation model describes the heights in general, not only of the terrain, but also of buildings and other artificial objects, whereas digital terrain model gives only the heights of the terrain itself.

Digital modeling of the relief includes the collection, processing, presentation, application and research of the accuracy of digital data on the physical surface of the Earth. Data on the Earth's physical surface can be obtained using various techniques and technologies, such as topographic survey, photogrammetry, laser or radar detection and ranging, etc.

Global, regional and national DRMs, as subsystems of the geographic information system, are of a special scientific and practical importance. In geodetic theory and practice, they are especially important data, because they are used for geodetic measurements planning, geodetic networks designing, for calculation of the gravitational influence of topographic masses in the process of geoid determination, for creation and improvement of various geodetic databases, during process of modeling and simulating spatial phenomena, etc. In addition, DRMs are also used in other related fields, e.g. during the design process of line (roads, railways, power lines, oil pipelines, etc.) and other infrastructure facilities (bridges, dams), for calculating the amount of groundworks, then for military purposes (artillery, aviation), etc. It can be said that for each country, relief and heights data, which are sufficiently accurate, with good geographical distribution and spatial resolution, are of key importance for design and construction of capital infrastructure facilities.

2. DATA FOR CREATION OF MODEL'S STRUCTURE

The ability to create DRM is decisively influenced by the sources, the collection, and structure of the relief data. In principle, DRMs are made by using five basic data sources: a) geodetic topographic survey; b) digitized cartographic material; c) photogrammetry; d) LiDAR (Light Detection And Ranging) and e) InSAR (Interferometric Synthetic-Aperture Radar) technology.

Photogrammetry for the purposes of making DRM involves the use of an aerial photographic camera, mounted on a hull of aircraft [3]. After processing, the obtained photo material is used to collect data on objects and phenomena on the physical surface of the Earth. InSAR is an advanced satellite method for DRM production, which uses a radar to measure the phase difference between two recordings. In this way, a sample (interferogram) is obtained, which contains data on the mutual relationship between geometric structures of the images, based on the distance between radar antennas and Earth's surface. LiDAR uses laser beams for measurement, and for the production of DRM, recordings from the airplane are applied. Among other things, combined with the technology of global navigation satellite systems, it enables the formation of precise DRM

in a geocentric coordinate system. Compared to other methods, the entire process is highly automated, making LiDAR currently the most preferred source for DRM data.

The classical geodetic survey for the needs of DRM production is not economically justified, due to the unfavorable ratio between invested time and funds, and the achieved results (in this case, the amount of collected data). However, areas which for some reason are inaccessible to photogrammetric or LIDAR imaging must be measured by conventional methods. Also, the coordinates of photogrammetric control points are determined by geodetic methods.

Digitization of cartographic material, compared to other methods, can be considered as a secondary data source, along with the processing of already existing digital relief data. Basically, on the digitized map, the contour lines (isohypse) are selected, and height values are added to their corresponding pixels [4]. Other sources, such as e.g. different databases of altitudes, altimetric data, etc, represent significant supplemental datasets since they enable complete and accurate expression of spatial-structural properties of the physical surfaces of the Earth. Particularly important are leveling data, used to form the basis of DRM and significant improvment of the basic data structure properties.

3. MODEL STRUCTURE AND ORGANIZATION

In general, points forming a discrete terrain representation are not regularly arranged and can be arbitrarily selected. Therefore, the basis of DRM is usually made up of randomly distributed data, regardless of the conditions of collection, and that is essentially the statistical sampling principle. The density of sampled points can be increased in areas where terrain forms are more variable and more rugged, and especially in the vicinity of characteristic fracture lines, where the surface of the terrain changes orientation (steep slopes, bays). These data are then complemented, edited, gradually modeled, and in this way, the final set of digital relief data is created. The original data are gradually structured through the preparation and harmonization of data from different sources, interpolation, and approximation of lines and elementary surfaces of relief, and forming of the base (reference structure) of DRM. According to the distribution of the base reference points, DRMs are structured (as parts or as whole) as:

- Triangulated Irregular Network - TIN;
- Models of equidistant points, i.e. grid DRM;
- The reference points of the model represent both the vertices of scalene triangles and equidistant points (the so-called universal or TIN-grid DRM).

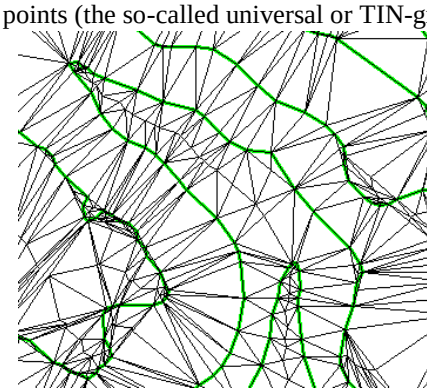

Figure 1. TIN DRM

TIN DRM (Figure 1) are sets of digitized vertices of scalene planar triangular surfaces. They are formed by choosing the characteristic relief points, whose properties are expressed by elementary surfaces, linear and point elements. In this way, it is possible to capture the most important morphometric features of the selected area. Problems can arise in determining the height of mountain pass points, steep sections (canyons, gorge), boundary areas, etc. TIN DRM models are applied for: geoinformation systems (GIS), cartography, geomorphology, geology, geophysics, the formation of reference structures of the grid and universal DRMs, etc. Although handling data is sometimes difficult, this form of structuring allows for better representation of the shape of the relief, with a smaller number of points. Also, if the DRM resolution is variable, TIN DRM provides better results than other methods, because of the size of the triangles changes with the resolution.

Grid DRM (Figure 2) is a matrix of height values of points located at equal distances. Each row or column of a matrix is a special digital record of the material points heights.

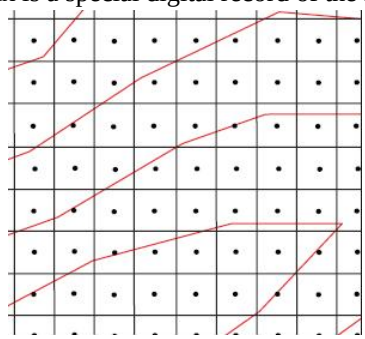

Figure 2. Grid DRM

Grid DRMs are formed directly by sampling data by coordinate lines of the adopted parametrization of the relief, or indirectly, by transforming TIN or universal DRMs. They are well-adapted to the way computers work, so processing large amounts of data is facilitated. The problem of the concurrence of the DRM content and the spatial-structural properties of the relief is solved exclusively by the appropriate density of equidistant points, depending on the morphometry and the required accuracy of the DRM functionals.

Universal DRMs represent sets of points given as elements of rectangular matrices or vertices of scalene triangles. They are reliably expressing the spatial-structural properties of relief, such as elementary surfaces, the unions of elementary surfaces, curves and straight lines, bending points, etc. They are made by mixed data sampling or by matching grid and TIN DRM content. Also in these models, there is a problem of singular points, but it can be exceeded by increasing the density and changing the distribution of data, with the appropriate software support.

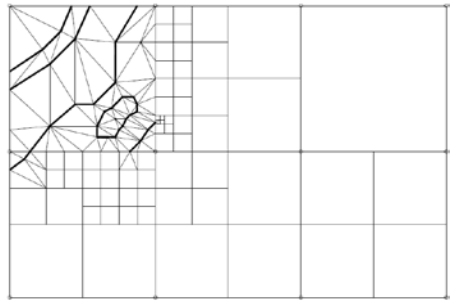

Figure 3. Universal DRM

The interval ($\Delta x = \Delta y = const$) of equidistant points is, in principle, determined if the linear interpolation of heights can be applied to the reference points of the model. If they comprise the necessary area and structural points of the physical surface of the Earth, the TIN-grid DRMs represent the most acceptable and useful digital data sets on relief of the Earth's surface.

4. MATHEMATICAL TREATMENT AND DESIGNING OF DIGITAL RELIEF MODELS

The design process, depending on the scope, purpose, and application of the DRM, can conditionally be divided into "related intervals", but nevertheless significantly different according to content, methods of data interpolation, an approximation of lines and elementary relief surfaces, etc. In the first part of the process, the reference/basic allocation (grid, TIN, TIN-grid) and density of data are formed, based on various and harmonized original data. The main and final part includes a) processing of source data using appropriate software; b) the formation of DRM, until the necessary data sets are created. Then subdivision into subgroups can be performed, along with statistical quality indicators calculation, model adaptation, etc.

In general, using the interpolation and approximation procedure, it is necessary to preserve the quality and accuracy of the original data and to achieve the required DRM quality. The interpolation of lines of the Earth's physical surface is most commonly performed by applying [5]:

- cubic polynomials and spline functions of the third degree;
- linear polynomials;
- Fourier's functional series;
- method of the least squares;
- least squares collocation, etc.

In the approximation of the elementary surfaces of the relief, regardless of the adopted parametrization, the methods of interpolation usually are:

- bilinear;
- bicubic polynomials;
- bicubic spline functions;
- finite element method;
- 2D covariance functions, etc.

4.1. APPROXIMATION OF RELIEF SPATIAL STRUCTURE LINES

The approximation of the relief lines is mainly based on interpolations of continuous functions by polynomials and functional series. Interpolation polynomials, regarding the calculation method, are suitable for analytic expressions of numerical methods for determining the approximate values of continuous functions. The approximations of the continuous lines of the spatial relief structure in DRM construction are mostly based on interpolations of cubic and spline polynomials, and Fourier's trigonometric series. The functions below will be denoted by $H(x)$ since heights are to be determined.

4.1.1. Interpolation using cubic polynomials

If a function $f(x) = H(x)$ has n derivations in point $x_0 \in [a,b]$, it can be approximated by Taylor (Taylor, B.) polynomial [6]:

$$T_n(H, x_0; x) = H(x_0) + \frac{H'(x_0)}{1!}(x - x_0) + \frac{H''(x_0)}{2!}(x - x_0)^2 + \frac{H'''(x_0)}{3!}(x - x_0)^3 + \ldots \tag{1}$$

Continuous function $H(x)$, up to $n+1$st derivation, gives in point $x_0 \in [0, L]$ polynomial:

$$H(x) = M_n(x) + R_n(x). \tag{2}$$

The approximation error ε, of function $H(x)$, by Taylor polynomial $T_3(x)$, depends on the degree of the polynomial and the regularity class of the function, and it follows that the cubic Taylor polynomial is:

$$\begin{aligned} &H(x) \approx T_3(x);\ \left|H(x) - T_3(x)\right| \le \varepsilon;\ n = 3;\ x \in [0, L], \\ &H(x) \approx T_3(x) = a_0 + a_1 x + a_2 x^2 + a_3 x^3, \end{aligned} \tag{3}$$

where:

- a_n, $n \in [0,3]$, coefficients of polynomials;
- x_n, $n \in [0,3]$, length value at an interval $x \in [0, L]$;
- $H(x)$, point height value at distance $x \in [0, L]$.

The polynomial coefficients are determined on the basis of known point heights and their mutual distances. Also, in the interpolation of the functions by Taylor polynomials, significant quantities are the degree of the polynomial n, the length of sampling L, the sampling interval Δx and the error of height approximation ε. They are evaluated during the process of development and application of DRM and may be the initial indicators for the selection and design of the appropriate DRM data structure.

4.1.2. Interpolation using a spline function

The essence of the spline interpolation is that the interpolation polynomial of a higher degree is replaced with more polynomials of the lower degree. If the function $H(x, y)$ is given on an interval $y \in [0, L]$, which is divided by nodes of interpolation [6]:

$$[0,L]: 0 = y_0 < y_1 < y_2 < ... < y_m = L, \tag{4}$$

it can be approximated by the spline function $H_{sp}(y)$ of a different degree m. A set of polynomials $P_m(y)$ and functions $C^{(m)}[0,L]$, of real variables determined on an interval $y \in [0,L]$, is connected by spline polynomial $S_{sp}(y)$, with a defect $k(1 \le k \le m)$ and with nodes (4).

Spline function $S_3(y)$ is cubic interpolation function, of function $H_{sp}(y)$, on an interval $y \in [0,L]$, if on every segment $y_i \le y \le y_{i+1}$ has a value equal to polynomials $S_m(y) = H_{sp}(y)$, or if the function has corresponding third-degree spline polynomial:

$$\begin{aligned} S_3(y) \approx H_{[i,i+1]}(y) = a_{0[i,i+1]} + a_{1[i,i+1]}(y - y_i) \\ + a_{2[i,i+1]}(y - y_i)^2 + a_{3[i,i+1]}(y - y_i)^3. \end{aligned} \tag{5}$$

Coefficients a_m, $m \in [0,3]$ for each individual segment, are determined on the basis of known height points. In addition, equivalences must be satisfied in all nodal points:

$$\begin{aligned} S'(y) = H'_{[i-1,i]}(y) = H'_{[i,i+1]}(y), \\ S''(y) = H''_{[i-1,i]}(y) = H''_{[i,i+1]}(y). \end{aligned} \tag{6}$$

4.1.3. Interpolation using Fourier trigonometric series

If function $H(x)$ satisfies the conditions of the Dirichlet theorem (Dirichlet, G. P.), then, in general, the corresponding Fourier series [5]:

$$H(x) = \frac{a_0}{2} + \sum_1^{\infty}\left(a_n \cos\frac{n\pi x}{L} + b_n \sin\frac{n\pi x}{L}\right), \; x \in [-L, L], \tag{7}$$

has coefficients:

$$\begin{aligned} a_0 &= \frac{1}{L}\int_{-L}^{L} H(x)\,dx, \\ a_n &= \frac{1}{L}\int_{-L}^{L} H(x)\cos\frac{n\pi x}{L}\,dx, \\ b_n &= \frac{1}{L}\int_{-L}^{L} H(x)\sin\frac{n\pi x}{L}\,dx. \end{aligned} \tag{8}$$

For the finite values and wavelengths l_k, the frequency is expressed as the reciprocal value of the wavelength $f_k = \frac{1}{l_k} = \frac{k}{l}$, $k \in [1,m]$. Thereby, the amplitude A_1 has a corresponding frequency $1/L$, the amplitude A_k has a frequency k/L, etc. Fourier series, limited by the finite value $k \in N$:

$$H(x)=\sum_{1}^{m}\left(a_k\cos\frac{2\pi kx}{L}+b_k\sin\frac{2\pi kx}{L}\right),\ a_k=b_k=0,\ \text{за } f_k>f_{\max},$$
$$\mathrm{H}(x)=\sum_{1}^{m}A_k\cos\frac{2\pi kx}{L},\ A_k=0,\ f_k>f_{\max}, \tag{9}$$

enables the representation of spatial-structural properties of the Earth's surface relief. Coefficients a_k, b_k and $A_k^2=a_k^2+b_k^2$ are determined from point heights, during sampling process or through improvements of DRM content with heights of specified points, using, for example, geometric leveling. Because of its specific application, Fourier series are suitable for interpolation of relief lines with diverse morphometry (steep slopes, canyons), but wavelengths must be carefully selected, due to possible mismatch with the spatial-structural properties of the relief.

4.2. APPROXIMATION OF SURFACES OF RELIEF'S SPATIAL STRUCTURE

The physical surface of the Earth is complex and time-varying, due to enduring endogenous and exogenous geodynamic phenomena, processes and forces. Mathematically, it can not be fully expressed, so the approximation of the elementary surfaces of the relief by analytic functions is realized by interpolating the original data in the process of forming the DRM [7].

4.2.1. Interpolation with polynomials

The study of the Earth's surface relief spatial structure can be performed by interpolation using 2D cubic polynomials [5]. Continuous function $H(x,y)$, with continuous partial derivatives of degree $n+1$, can be expanded near point P_0 into functional series:

$$H(x,y)\approx P_n(P)=H(P_0)+\frac{H'(P_0)}{1!}+\frac{H''(P_0)}{2!}+\ldots+\frac{d^nH(P_0)}{n!}+R_n, \tag{10}$$

where R_n is series residual. Cubic 2D polynomial is an approximation function:

$$\begin{aligned}H(x,y)&=a_0+a_1x+a_2y+a_3x^2+a_4y^2+a_5xy\\&+a_6x^3+a_7y^3+a_8x^2y+a_9xy^2,\end{aligned} \tag{11}$$

the coefficients of which a_n are determined on the basis of at least ten known heights of the material points. Interpolation of the point heights is done within the basic DRM field or using the known height of points of arbitrary distribution.

In the interpolation of point heights and the approximation of the physical surfaces of the Earth, the significant application also has:

- bisquare polynomials $H(x,y)=a_0+a_1x+a_2y+a_3x^2+a_4y^2+a_5xy$;
- bilinear polynomials $H(x,y)=a_0+a_1x+a_2y+a_3xy$;
- linear polynomials $H(x,y)=a_0+a_1x+a_2y$.

4.2.2. Interpolation using finite element method

The basis of interpolation with the finite elements is the division of the physical surfaces of the Earth into the elemental surfaces, or the finite quadruple and triangular surfaces [6]. In the network of i points, $k = i - 2$ triangles can be formed, for which three scale factors are determined, and that makes $3i - 6$ unknown variables. A function that approximates the triangular surface:

$$H(x, y) = \sum_{1}^{3} s_i d(PP_i);\ H(x, y) = \sum_{1}^{3} s_i \sqrt{(x - x_i)^2 + (y - y_i)^2}, \qquad (12)$$

in the area $(x, y) \in D \subset R^2$, has joint distances for two triangles, from which follows a condition $d(PP_i) = 0$.

The accuracy of the approximation depends on the spatial structure, density and accuracy of the original data, which can be improved by applying the heights determined by more precise methods, e.g. geometric or GNSS/geometric leveling.

4.2.3. The spherical harmonic relief model

The Earth's global relief, derived from the sums of the mean values of altitudes of restricted areas, can be represented by spherical functions [5]:

$$Y_n(\overline{\varphi}, \lambda) = a_{n0} P_n(\sin\overline{\varphi}) + \sum_{m=1}^{n} \left(\overline{a}_{nm} \cos m\lambda + \overline{b}_{nm} \sin m\lambda\right) \overline{P}_{nm}(\sin\overline{\varphi}), \qquad (13)$$

applying spherical geocentric coordinates $\overline{\varphi}$ and λ. Orthonormal spherical harmonic coefficients can be expressed by the unit sphere:

$$\begin{Bmatrix} \overline{a}_{nm} \\ \overline{b}_{nm} \end{Bmatrix} = \frac{1}{4\pi} \iint_{\sigma} Y_n(\overline{\varphi}, \lambda) \begin{Bmatrix} \cos m\lambda \\ \sin m\lambda \end{Bmatrix} \overline{P}_{nm}(\sin\overline{\varphi})\, d\sigma, \qquad (14)$$

where $d\sigma = \cos\overline{\varphi} d\overline{\varphi} d\lambda$ is an element of a sphere σ, with radius $R = 1$.

In the spherical approximation of the Earth, the physical surface $S\left(R + H(\overline{\varphi}, \lambda), \overline{\varphi}, \lambda\right)$ can be expressed as a spherical harmonic function:

$$H_{nm}(\overline{\varphi}, \lambda) = R \sum_{n=0}^{N} \sum_{m=0}^{n} \left(\overline{g}_{nm} \cos m\lambda + \overline{h}_{nm} \sin m\lambda\right) \overline{P}_{nm}(\sin\overline{\varphi}), \qquad (15)$$

which represents the spherical harmonic expansion of the Earth's surface relief, in whole, or part by part. For the relief of the Earth's continental surface, the orthonormal spherical harmonic coefficients are calculated using the expression:

$$\begin{Bmatrix} \overline{g}_{nm} \\ \overline{h}_{nm} \end{Bmatrix} = \frac{1}{4\pi R} \iint_{\sigma_1} \overline{H}(\overline{\varphi}, \lambda) \begin{Bmatrix} \cos m\lambda \\ \sin m\lambda \end{Bmatrix} \overline{P}_{nm}(\sin\overline{\varphi})\, d\sigma_1, \qquad (16)$$

where σ_1 is a spherical approximation of the continental part of the surface.

The choice of methods of interpolation and approximation of lines and surface elements of the Earth's relief is conditioned by the requirements of application and accuracy of the model. In principle, the formation of the reference structure and the formation of DRM is done using more accurate interpolation procedures (e.g. spline functions), while during

DRM utilization, linear interpolation methods are used. In the formation of DRM reference structure, interpolation and approximation must ensure the preservation of the original data accuracy.

5. INTERPRETATION OF DIGITAL RELIEF MODELS

Since digital relief models are sets of data on the relationships between spatial and structural properties and relief functionals, these data can be studied by analyzing graphical representations (visualization) and by statistical analysis of data sets on the relief or functionals of the DRM application. Interpretation of DRM, for application in geodetic theory and practice, is expressed by indicators [5]:

- completeness;
- reliability;
- susceptibility;
- economic aspect;
- the accuracy of DRM.

The first four elements of DRM interpretation can be considered as general quality indicators, and accuracy estimators express the most significant properties of DRM, indirectly and directly determined by general indicators of the qualitative specificities of digital sets of data on the Earth's relief.

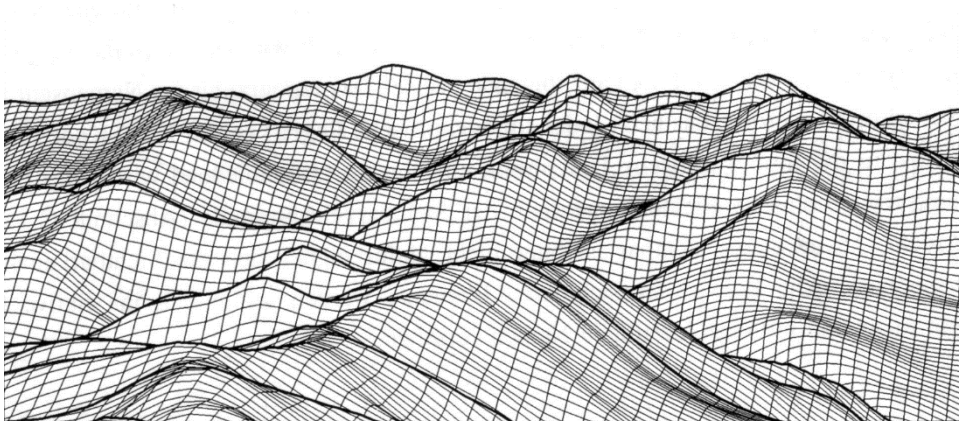

Figure 4. An example of grid DRM

5.1. GENERAL INDICATORS OF DIGITAL RELIEF MODELS QUALITY

The completeness of the DRM is expressed through the level of coverage of the spatial structure of the relief: structural points, lines and surface elements, average angles of inclination and wavelengths of relief variability in horizontal directions. With the appropriate data sampling, interpolation method and approximation functions, the necessary data on the morphological properties of the spatial-temporal structure of the relief are successfully obtained. By statistical analysis, visualization and comparison of source data and created DRMs, the indicators of DRMs completeness are obtained.

The reliability of DRM is conditioned by data distribution and density, completeness, accuracy, geodetic reference system, DRMs application, etc. Reliability indicators are: a) appropriate geodetic reference system, in particular, the height system; b) the ability to access data and to apply DRM; c) compatibility of data distribution and density, and DRM

structure with available software and intended application; d) the possibility of calculating small but statistically significant values of DRM functionals; e) the applicability of the control procedure with more accurate data (e.g. precise leveling) during DRM creation and design [1].

The susceptibility of DRM is expressed by the possibilities of calculating statistically significant values of the relief spatial structure and functionals (inclination angles, relief masses, gravitational potential and isostatic compensation of relief masses, etc.). Especially important susceptibility indicator is the RTMs (Residual Terrain Model) influence, on the physical parameters of the local gravity field, or on the functionals of anomalistic gravity field, e.g. vertical deflections.

The economic aspect of DRMs production and application can be represented by functional models of the required time or cost for making DRM. The time model is:

$$T\left(DRM\right) = a_{DRM}^{t}, \tag{17}$$

where: $T\left(DRM\right)$ - the time period of DRM production; t - time scale; a - digital relief modeling parameter, $0 < a < 1$. The cost model of DRM production is as follows:

$$S = \sum_{1}^{n}\left(k_{0i} + W_i k_i\right), \tag{18}$$

where: S - total cost of production; k_{0i} - costs for the i-th part of the production process; W_i - the number of actions in the i-th part of the production process; k_i - the cost of i-th action of the production process; n - the total number of segments of the DRM production process.

The longest period of time and the highest costs of DRM production are in the procedures of collecting, forming the basis, estimating the quality of DRMs and their functionals. Improving economic aspect can be achieved through standardization of data distribution, density and geodetic datum, timely maintenance of data, application of appropriate mathematical models and software, production of multiuser purpose DRM and use of global, regional and local DRMs.

5.2. THE ACCURACY OF DIGITAL RELIEF MODELS

The accuracy of representation, in the process of digital modeling of Earth's physical surface, is the most important indicator of the qualitative properties of DRM. It is evaluated by mathematical analysis and experimentally, using sets of control points. From a theoretical and practical point of view, a significant advantage is given to statistical analysis [8]. The accuracy of the completed DRM depends significantly on the accuracy of the original data, sampling procedures, interpolation method, approximation function, intended DRM purposes, etc. Therefore, sources of DRM errors and the problem of DRM accuracy estimation, are a specific field of study.

6. CONCLUSION

Digital relief models of the Earth's physical surfaces are digital data sets that describe the metric properties of the spatial-structural relationships of Earth's physical surface elements. They have wide application in all fields of study of geodesy, but also in related scientific fields. The basic data sources for modeling are the classic geodetic survey, photogrammetric images, InSAR and LiDAR technologies and digitized cartographic

material. According to the reference points allocation structure, these digital models can be TIN, grid or universal models.

Presenting a relief with digital models requires the application of a mathematical apparatus that includes different methods of interpolation and approximation of lines and surfaces of the relief spatial structure. It is customary that the DRM reference structure is formed by applying more accurate interpolation procedures, such as spline functions, while linear interpolations are used for the actual application of the model. Interpretation of digital models is done by analyzing the accuracy and general quality indicators: completeness, reliability, susceptibility and economic aspect.

For the successful and economical solution of scientific and practical geodetic and other engineering tasks, as well as for production of geoinformation systems, an organized and institutionalized digital modeling of Earth's surface relief is recommended. It is also necessary to standardize the DRM in terms of geodetic reference systems, structure, data density, and distribution, in order to enable the production of digital relief models suitable for different uses.

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Review paper
doi 10.7251/STP1813421B ISSN 2566-4484

NOVE KOMPETENCIJE U AKADEMSKOM OBRAZOVANJU KROZ REALIZACIJU BESTSDI I EO4GEO PROJEKATA

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Rezime:

Razvoj tehnologija opažanja pojava na Zemlji iz svemira i zraka koje omogućuju intenizivno korištenje prostornih informacija i Infrastrukture prostornih podataka koja uređuje korištenje prostornih podataka, odnosno koncepata kao što su internet stvari, pametni gradovi, precizna poljoprivreda, inteligentni transport i sl., nameću potrebu akademskoj zajednici da redefinira kompetencije kojima studenti širokog spektra studjskih programa moraju tijekom svojeg studija ovladati. U okviru Erasmus+ programa Europske unije pokrenuta su, među ostalima, dva projekta koji imaju za cilj rješavanje ovog globalnog izazova. Na europskoj razini EO4GEO projekt ima za cilj definirati kompetencije za opažanje pojava na Zemlji iz Svemira i zraka, dok BESTSDI projekt na regionalnoj razini definira kompetencije za Infrastrukturu prostornih podataka. Sadržaj ovih projekata, pristup iznalaženju rješenja, metodologija i ciljevi navedenih projekata, odnosno očekivani efekti na studijske programe prikazani su u ovom radu.

Ključne riječi: opažanje Zemlje, Infrastruktura prostornih podataka, kompetencije.

NEW COMPETENCES IN ACADEMIC EDUCATION THROUGH REALISATION OF THE BESTSDI AND EO4GEO PROJECTS

Abstract:

Development of Earth observation technologies from Space and air which are enabling intensive use of spatial information and Spatial data infrastructure which regulates usage of spatial information, respectively also concepts like Internet of things, Smart cities, Precise farming, Intelligent transportation and similar, impose on academic society necessity to redefine competences which students of bright variety of study programmes must overmaster during their study. In the frame of European Union Erasmus+ programme is, among other, initated two projects which goal is to solve this global challenge. The EO4GEO project aim is to define Earth observation from Space and air competences on the European level, while the BESTSDI project aim is to define Spatial data infrastructure competences on the regional level. Content of those projects, solution approach obstinance, methodology and their goals, respectively also expected effects on study programmes are shown in this paper.

Keywords: Earth observation, Spatial data infrastructure, competences.

1. INTRODUCTION

Today, we are at the beginning of a Fourth Industrial Revolution entering the Digital Era. Developments in genetics, artificial intelligence, robotics, nanotechnology, 3D printing and biotechnology, to name just a few, are all building on and amplifying one another. This will lay the foundation for a revolution more comprehensive and all-encompassing than anything we have ever seen. Smart systems—homes, factories, farms, grids or cities—will help tackle problems ranging from supply chain management to climate change. The rise of the sharing economy will allow people to monetize everything from their empty house to their car [1]. This deep and far-reaching change has also tremendous impact on future development of human professions. By one popular estimate, 65% of children entering primary school today will ultimately end up working in completely new job types that don't yet exist.1 In such a rapidly evolving employment landscape, the ability to anticipate and prepare for future skills requirements, job content and the aggregate effect on employment is increasingly critical for businesses, governments, academia and individuals in order to fully seize the opportunities presented by these trends - and to mitigate undesirable outcomes.

One of the plumes of fourth industrial revolution is digital technology, technology dealing with information, more specifically with spatial information. It is well known fact that modern society is relying on effective use of spatial information resulting in concepts which are creating environment for their use and solutions which enable it. Based on Geographical Information System (GIS) development, resulting as a need to standardize collection, organization, access and dissemination of spatial information, Spatial Data Infrastructure (SDI) has been defined, representing today fundamental concept of spatial data use, especially considering segment of public data. Numerous other applicative, how to use spatial data, concepts or solutions on different levels, are developed based on SDI or in parallel with SDI like Smart cities, Intelligent Transportation Systems, Precise farming or Building Information Modelling. The main characteristic of all those concepts and solutions is intensive use of spatial data in an organized and standardized manner increasing value and efficiency of used data.

Recently, space technologies become major source of well defined, georeferenced, spatial data. Earth Observation (EO) via satellites are providing massive amount of data on daily level and Global Navigation Satellite Systems (GNSS) providing reliable positioning and navigation in real-time. European Union is already one of the major global contributors in supply of EO data through the Copernicus Earth observation program, and soon will also become independent satellite positioning and navigation actor, when European GNSS Galileo becomes fully operational. Together with fast sensor development, their digitalization, miniaturization and increase in accuracy, condition has been created in which geoinformatic has become new, fast growing, branch of business. Only in 10 years, revenues of EO companies in Europe have tripled with the annual growth rate of 12% (average EU economy. 0,7%), see Figure 1.

But, at the same time the gap has been created between the offer and uptake of spatial data. Namely, use of geospatial data, including Copernicus, is still difficult for non-experts, what is clearly hampering maximization of socio-economic benefits of Copernicus, Galileo and geoinformatics in general. Having in mind that open data flow of European EO data is guaranteed well into 2030s, two major challenges have been identified as obstacles reducing the benefits of those technologies to the final users:

- most space data cannot be used directly by end users (who do not have the required technical, financial or human resources) and
- Copernicus data and service often need to be combined with other data to bring value (geospatial, socio-economic, digital …).

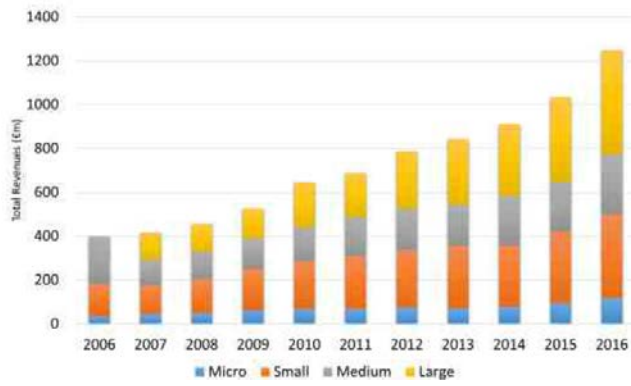
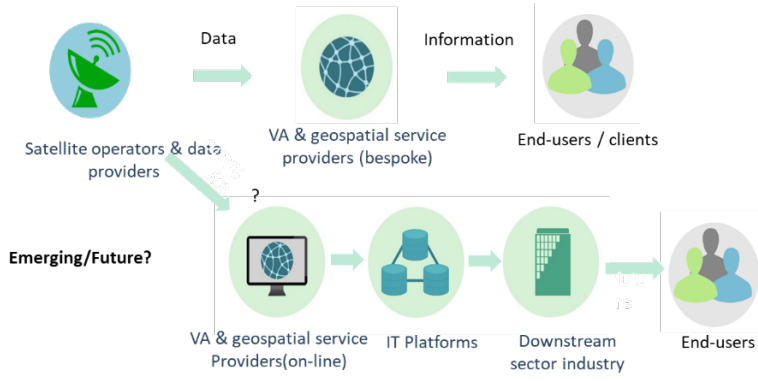


Figure 1. Revenue of EO companies in Europe [2]

Mentioned challenges are clearly indicating the need for new high-level knowledges and skills for professionals in specific sectors, imposing task on education and training institutions to identify those knowledges and skills and offer new profiles of education on levels of education scale. The question looking for an answer is: how will be the future GI services values chain? See Figure 2.



Slika 1. Figure 2. Future EO services value chain [2]

2. LEARNING AND SKILLS FOR DIGITAL ERA IN GEOINFORMATICS

Learning and skills are key contributors to society and the economy. As modern societies and economies are changing due to, amongst others, globalisation and technological progress, a fundamental transformation of education and training (E&T) throughout

Europe is required to deliver the knowledge and skills needed for growth, employment and participation in society. This forms an important part of the Europe 2020 agenda and its various flagships and policy initiatives [3]. In parallel, providing education of adequate and in future looking competences and skills is key challenge for educational institutions, especially academic ones, which should give guidance and lead the process of necessary changes in overall European and national education systems. It is noting strange in the fact that in so many European countries reform of education curriculum is high on agenda of government and society.

Looking on geoinformatics, defined traditionally, which integrates three traditional geosciences (geodesy and surveying, geography and cartography) based on the results of informatics in the frame of rapid evolving computer sciences [4], B. Markus is emphasising that universities are under a pressure of continuous changes, transforming all traditional way of learning, working to prepare our learners for the future. Looking broader, geoinformatics might be referred to the academic discipline or career of working with geo-data in general for better understanding and interpretation of human interaction with the earth's surface. Geoinformatics might be defined in a relatively broad term as a number of different technologies, approaches, processes, and methods to interpreter issue and controversy relating to the earth's surface for collaborative decision making. In this context not only surveying, geography and cartography are influenced by geoinformatics, but also civil engineering, urban planning, architecture, environment engineering, transportation engineering, etc. The bluntest example geoinformatics affecting classical professional disciplines are Smart cities. It is hard to imagine that any of above listed professions will be able to fulfil its tasks in cities and around them without taking in consideration the concepts behind Smart cities and consequently not to implement elements of geoinformatics, being basis for this concept. Considering universities, the pressure on them has recently even increased because universities are forced to implement technological developments which are happening outside or without them with not always sufficient funding or expert capacities.

European Commission and its agencies have therefore developed comprehensive activity which should ensure European citizens to be competitive in future global market and preserve their wellbeing. On broadest level Erasmus+ program has been launched covering the fields of education, training, youth and sport for the period 2014-20201. Education, training, youth and sport can make a major contribution to help tackle socio-economic changes, the key challenges that Europe will be facing until the end of the decade and to support the implementation of the European policy agenda for growth, jobs, equity and social inclusion. The Erasmus+ Programme is designed to support Programme Countries' efforts to efficiently use the potential of Europe's talent and social assets in a lifelong learning perspective, linking support to formal, non-formal and informal learning throughout the education, training and youth fields. The Programme also enhances the opportunities for cooperation and mobility with Partner Countries, notably in the fields of higher education and youth.

In the frame of Key Action 2 of Erasmus+ focus is on high school (academic) education promoting cooperation for innovation and exchange of good practices being materialized through several actions:

- Sector Skills Alliances: ensuring cooperation between education and employment in tackling skills gaps with regard to one or more occupational profiles in a specific sector;

- Knowledge Alliances cooperation between higher education institutions and enterprises;
- Capacity Building in the field of youth supporting cooperation with Partner Countries;
- Capacity Building in the field of higher education supporting cooperation with Partner Countries.

3. BESTSDI PROJECT

BESTSDI project in Capacity Building in field of Higher Education project started in October 2016. The wider objectives of the BESTSDI project is to:

- improve the quality of higher education in Geographical Science and Technology field, SDI and geodesy,
- enhance its relevance for the labour market and society and
- to improve the level of competences and skills in HEI's by developing new and innovative education programs within the field of SDI.

These wider objectives are fully compliant with the priorities of the Capacity Building projects within the Erasmus+ program. The specific project objectives are to:

- develop, test and adapt new curricula, courses, learning material and tools within the field of SDI and
- introduce SDI and related concepts in undergraduate and graduate study programs on academic institutions which profiles are well recognized as SDI users, raising awareness among the students and professionals about the relevancy of SDI and advantages of well-organized spatial data [5].

BESTSDI is 16 academic partners (and 3 associated partners) from Western Balkans countries (Albania, Bosnia and Herzegovina, Kosovo, Montenegro and Serbia) and program countries Belgium, Croatia, Germany, Macedonia and Sweden.

Reaching half of its lifetime, BESTSDI project has carry out comprehensive analysis of existing study materials regarding SDI in Europe and region finding that most of materials are presentation and exercise, there is no project oriented approach to teaching, topics are mainly focused on standards, interoperability, legal aspects and service-oriented architecture, and user aspects are not included in existing materials. Result of those findings is that it is necessary to develop essential part of new SDI curriculum materials [6]. Further, survey among the stakeholders has been conducted aiming to analyse their needs. According to survey competency needs are ranked as follow:

- top: spatial data concepts, land management, cartography and visualization, social competences,
- middle: SDI organizational and institutional aspects and
- low: analytic GIS tools, design, modelling and management of spatial data.

Conducted survey conclusions impose that knowledge and understanding of SDI aspects among stakeholders is rather modest, especially on implementation level, resulting in challenge how to overcome the gap which is presently existing in relation to competences linked to geoinformatics.

BESTSDI project is running now the second phase of the project which should, till mid-2018, deliver following results:

- drafting knowledge catalogue,

- drafting sets of teaching outcomes,
- drafting courses structure and
- drafting teaching materials.

4. EO4GEO PROJECT

EO4GEO is Sector Skills Alliances (SSA) type of Erasmus+ project. SSA are transnational projects which should enable to achieve among others the following objectives:

- Identification of existing and emerging skills needs for professions in specific sectors, strengthening the exchange of knowledge and practice between education and training institutions and the labour market;
- Modernizing Vocational Education Training (VET) by adapting provision to skills needs,
- Integrating work based learning in VET provision, and exploiting its potential to drive economic development and innovation, increasing the competitiveness of the sectors concerned;
- Building mutual trust, facilitating cross-border certification and therefore easing professional mobility in a sector, and increasing recognition of qualifications at European level within a sector;
- Supporting a strategic approach ("Blueprint") to sectoral cooperation on skills, see Figure 3.

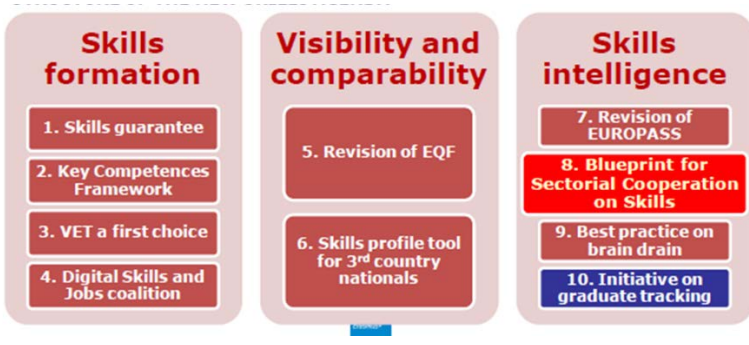


Figure 3. New skills agenda for Europe [7]

The EU Education, Audiovisual and Culture Executive Agency (EACEA) has approved the project EO4GEO - Towards and innovative strategy for skills development and capacity building in the space geo-information sector supporting Copernicus user uptake. EO4GEO is an Erasmus+ Sector Skills Alliance gathering 26 partners (and initially 22 associated partners, looking forward to new adhesions) from 16 countries from academia, private and public sector active in the education/training and space/geospatial sectors. It is coordinated by the Association GISIG (www.gisig.eu) and will run over four years, starting from 1st January 2018. EO4GEO aims to help bridging the skills gap between supply and demand of education and training in the space/geospatial sector by reinforcing the existing ecosystem and fostering the uptake and integration of space/geospatial data and services in end-user applications. EO4GEO will work in a multi- and interdisciplinary way and apply innovative solutions for its education and training actions including: case

based and collaborative learning scenarios; learning-while-doing in a living lab environment; on-the-job training; the co-creation of knowledge, skills and competencies; etc.

EO4GEO will define a long-term and sustainable strategy to fill the gap between supply of and demand for space/geospatial education and training taking into account the current and expected technological and non-technological developments in the space/geospatial and related sectors (e.g. ICT). The strategy will be implemented by: creating and maintaining an ontology-based Body of Knowledge for the space/geospatial sector based on previous efforts; developing and integrating a dynamic collaborative platform with associated tools; designing and developing a series of curricula and a rich portfolio of training modules directly usable in the context of Copernicus (www.copernicus.eu) and other relevant programmes and conducting a series of training actions for a selected set of scenario's in three sub-sectors - integrated applications, smart cities and climate change to test and validate the approach. Finally, a long-term Action Plan will be developed and endorsed to roll-out and sustain the proposed solutions.

To identify needed knowledge and skills initial tasks and outcomes of the EO4GEO project are defined:

T1: Identifying supply of GI / EO education & training at academic and vocational levels - resulting in findings of the analysis of previous relevant studies, results from new survey with metadata descriptions of courses/modules;

T2: Identifying demand for GI / EO skills & occupational profiles - resulting, based on previous related studies and on new survey and interviews in definition of priority occupational profiles for space/geospatial sector;

T3: Analysing trends, challenges/opportunities in GI / EO sector: technology watch - identifying major trends relevant to impact on space/geospatial sector, focusing on the technological (general ICT) and non-technological aspects (soft skills developments);

T4: Assessing skills shortages, gaps between supply / demand - discussing findings, vision, choices / options resulting in assessment of shortages and gaps.

T5: Defining GI / EO sector skills strategy - proposing approach / methods to bridge the gaps and resolve mismatches, describing concrete actions and feed European Skills Panorama.

5. SUMMARY

Developing new competences and skills for new geoinformatic profession based on spatial data as one of building blocks of Digital Era represents great challenge for academic institutions what is recently not jet well recognized among them. Having in mind that it still takes minimum 5 (rather 10) years for full implementation of new profession curricula in academic institutions, while geoinformatic and related industries demand new professionals much sooner, gap is created between supply and demand. This fact has been recognized on numerous levels, and one of the actions undertake is execution of BESTSDI and EO4GEO projects which should reduce this gap and support academic institutions in Europe in development and implementation of new curricula in SDI and geoinformatics, providing for business sector so desperately missing professionals. For academic institutions of technical provenience in Western Balkans region this situation creates, beside challenge, also opportunity to make visible lunge, and adopting new SDI and

geoinformatic curricula, reduce the gap towards business sector, but also towards European academic institutions.

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31| Прегледни научни рад
Review paper
doi 10.7251/STP1813429B ISSN 2566-4484

THE ROLE OF STAKEHOLDERS IN MODERNIZING EDUCATION CURRICULA IN THE FIELD OF GEODESY

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Abstract:

This article deals with the process of modernization the geodesy study program at the Faculty of Civil Engineering University of Belgrade (FCEUB), Department of geodesy and geoinformatics, under the ERASMUS+ European program, which initiate the survey of stakeholders in three partner countries and in accordance to their opinions, BSc and MSc core curriculum were proposed. So far at the Geodesy and geoinformatics program at the FCEUB Department, several new courses and teaching materials were prepared. Additionally, e-learning methodology, has been introduced by installing MOODLE platform which is used as a new learning management system that will initiate more other changes toward this new learning methodology. Also, a problem-based learning (PBL) methodology has been introduced in some of the courses.

Keywords: Geodesy and geoinformatics, Study program improvement

1. INTRODUCTION

The University of Belgrade - Faculty of Civil Engineering - FCEUB is a partner institution in a new Erasmus+ program which started in 2015 and lasts till October 2018. The project title is "Modernizing geodesy education in Western Balkan with focus on competences and learning outcomes". The leading institution is the Royal Institute of Technology (KTH, Stockholm, Sweden). The other partner institutions are: Vienna University of Technology – Department of Geodesy and Geoinformation (TUW, Vienna, Austria), University of Leon (ULE, Leon, Spain) and seven non–EU partners: two from Serbia (University of Belgrade, Faculty of Civil Engineering, Department of Geodesy and Geoinformatics – FCEUB and University of Novi Sad – Department of Computing and Control Engineering – UNS), two from Albania (University of Tirana, Department of Geography – UT and Polytechnic University of Tirana, Department of Geodesy – UPT) and five partners from Bosnia and Herzegovina (University of Sarajevo, Department of Geodesy – UNSA, University of Mostar, Faculty of Civil Engineering – UNMO and University of Tuzla – Department of Geography – UNTZ, Institute of Development Planning – IDPSA, and BNPro d.o.o. – private co.). The official GEOWEB project web site is: http://gidec.abe.kth.se/GEOWEB.

2. PROJECT OBJECTIVES

The wide project objectives are to: 1) modernize higher education in geodesy and geography in partner's countries, 2) facilitate integration of partner countries with EU and 3) strengthen regional cooperation within Western Balkan countries.

The project will last three years and has several activities that contribute the project aims. Planned activities of the project are: 1) Creation of a Balkan geodesy educational database, 2) Establishment of a regional cooperation network, 3) New Laboratories, 4) Four two–weeks courses related to the image processing, GNSS, Geoid and Earth gravity fields and GIS, 5) Core BSc curricula 6) Two new master programs, 7) New teaching materials, 8) New e–learning platform, 9) Problem Based Learning philosophy Introduction.

3. CONCEPT OF SURVEY QUESTIONNAIRE

Under the working package five, University of Belgrade – Faculty of Civil Engineering (FCEUB) with other partners and the project coordinator developed an Internet based survey questionnaire.

The objective and the concept of the questionnaire are:

- to collect information from geodesy stakeholders operating in Western Balkan countries,
- to provide better insight into activities of geodesy stakeholders and their needs regarding surveying and geodesy professionals skills and knowledge, and
- to establish web site and database that will live and be operational during the project lifetime and allow afterwards, so additional input is expected and desired.

The questionnaire (and database) is designed to be as simple as possible, requiring minimal effort to provide requested information; predefined answers offered whenever possible. Project members were asked to invite as many as possible geodesy stakeholders from their countries to take part in the survey. The idea behind internet based questionnaire was to have a live database containing the results of the survey. Each stakeholder is invited

to update his questionnaire as needed. Also, it is expected that more and more geodesy stakeholders will participate in the survey in the future, since other events are planned within the project. Therefore, it is realistic to expect significant increase in number of stakeholders participating in the survey. The results of the questionnaire available are analysed and described, as follow.

Draft version of the questionnaire was provided to all project participants for the review and comments. Comments were analysed and implemented, accordingly. The final version of the questionnaire is provided to all stakeholders at the FCEUB website http://osgl.grf.bg.ac.rs/survey/accounts/login/ (Figure 1).

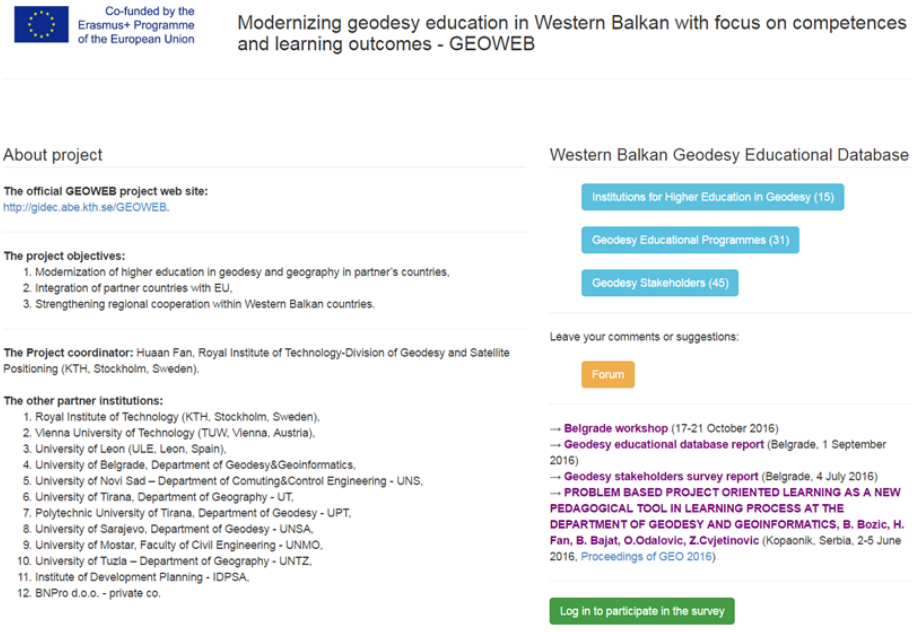
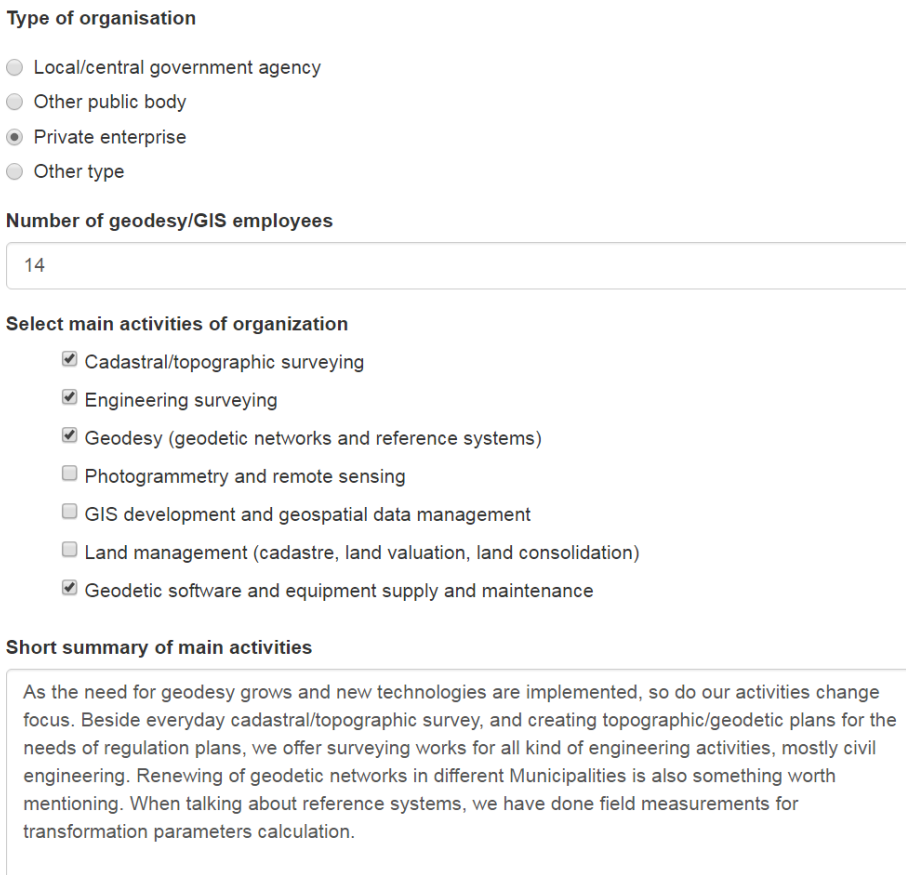


Figure 1. Login page for the questionnaire for the geodesy stakeholders and survey regarding higher education institutions and programmes in geodesy

3.1. Questionnaire content

As it has been already stated, the questionnaire is designed to be as simple as possible, requiring minimal effort to provide requested information. Basic information on geodesy stakeholders have to be filled in using provided web form such as the following (Figure 2):

- name,
- address data,
- information on contact person,
- the type of organization,
- number of geodetic/GIS employees and
- main activities of organization.



Type of organisation

- ○ Local/central government agency
- ○ Other public body
- ◉ Private enterprise
- ○ Other type

Number of geodesy/GIS employees

14

Select main activities of organization

- ☑ Cadastral/topographic surveying
- ☑ Engineering surveying
- ☑ Geodesy (geodetic networks and reference systems)
- ☐ Photogrammetry and remote sensing
- ☐ GIS development and geospatial data management
- ☐ Land management (cadastre, land valuation, land consolidation)
- ☑ Geodetic software and equipment supply and maintenance

Short summary of main activities

As the need for geodesy grows and new technologies are implemented, so do our activities change focus. Beside everyday cadastral/topographic survey, and creating topographic/geodetic plans for the needs of regulation plans, we offer surveying works for all kind of engineering activities, mostly civil engineering. Renewing of geodetic networks in different Municipalities is also something worth mentioning. When talking about reference systems, we have done field measurements for transformation parameters calculation.

Figure 2. Web form for entering basic information on geodesy stakeholders

Whenever possible, representative of the stakeholder is offered to select predefined answers. The option for describing main activities of the stakeholder is provided as well. The second part of the questionnaire was designed to provide desired information on geodesy stakeholders' needs regarding surveying and geodesy professionals' skills and knowledge. The stakeholder is offered to select the type of specialists that are most needed in his organisation and also to specify if retraining of his existing staff is required in some field of geodesy. Also, stakeholder is asked about the possibility to receive geodesy students for visits, practice and/or employment. Finally, the stakeholder is offered an opportunity to give his comments on geodesy education. Section of the questionnaire containing the most significant questions is given in the Figure 3.

Type of specialists which are most needed

- [x] Geodesy (geodetic networks and reference systems)
- [x] Traditional land surveying
- [x] Engineering surveying
- [ ] Global navigation satellite system (GNSS)
- [ ] Laser scanning
- [x] Land cadastre
- [x] Land management
- [ ] Photogrammetry and remote sensing
- [x] GIS and geospatial data management

Other type of specialists. What?

- [x] Organisation can recieve geodesy students

For:

- [x] Visits
- [x] Practice
- [ ] Employment

- [x] Oganization needs staff retraining in the following fields of geodesy

For:

- [x] GIS
- [x] Geoinformatics
- [ ] Photogrammetry
- [x] Remote sensing
- [ ] Global navigation satellite system (GNSS)
- [ ] Land management

Other comments on geodesy education

Technology is constantly growing and improving, and we should follow that. Geodesy students need to be closely familiar with new methods and, and most of all, programming.

Figure 3. Section of the questionnaire for the geodesy stakeholder's survey – Information regarding education and competences of future professionals

3.2. The Results of questionnaire survey

At the time of writing this article the number of stakeholders that participated in the survey was 42 (Table 1).

Table 1. Number of stakeholders per country participating in the survey

Country	
Albania	
Bosnia and Herzegovina	20
Serbia	12
Total	42

Having in mind that, according to official sites of the National Geodetic Authorities in partner countries, there are more than several hundreds geodetic organisations having some kind of licence for practising geodesy/surveying, it is clear that the number of survey participants is rather low. Therefore, it would be irresponsible to state that the results of the survey should be statistically significant. Nevertheless, there are some interesting indications regarding stakeholders' needs and their opinions on geodetic education, so these will be given here briefly.

The summary results of the geodesy stakeholder's survey are given in Table 5. The stakeholders are sorted according the country they are located in. It can be noticed that all three types of organizations are present: private enterprises, local/central government agencies and other public bodies. However, as expected, the largest number of participants is private enterprises (Table 2).

Table 2. Number of stakeholders participating in the survey

Stakeholders according to their type	
Private enterprises	31
Local/central government agencies	8
Public bodies	3
Total	42

It can be easily concluded from the Table 5 that stakeholders are mostly engaged in standard geodetic activities such as: cadastral/topographic surveying, engineering surveying, geodesy (geodetic networks and reference systems) and GIS development and geospatial data management (Table 3). Organisations dealing with photogrammetry and remote sensing as well as those providing geodetic software and equipment supply and maintenance services are, as expected, in minority.

Table 3. Activities of stakeholders

Activity	No.	%
Cadastral/topographic surveying	27	64
Engineering surveying	27	64
Geodesy (geodetic networks and reference systems)	25	60
GIS development and geospatial data management	23	50
Land management	21	50
Photogrammetry and remote sensing	12	29
Geodetic software and equipment supply and maintenance services	11	26

Regarding the type of specialists that are most needed by the stakeholders, it is quite indicative that GIS and geospatial data management specialization is the most needed one. About 74% of stakeholders stated that they need this type of specialization. This is quite understandable, having in mind that geospatial data management and processing is compulsory activity within almost every geodetic project. Also, standard geodetic specializations such as: geodesy (geodetic networks and reference systems), engineering surveying and knowledge and skills from global navigation satellite system (GNSS) are also highly required (50–64%). Laser scanning, as a new technology, requiring still very expensive equipment is, again, as expected, not so required (17%). The needs for other types of specializations are in the range of 33–43% (Table 4).

Table 4. Competences needed

Activity	No.	%
GIS and geospatial data management		31
Engineering surveying	27	64
Geodesy (geodetic networks and reference systems)	24	57
GNSS	21	50
Land management	18	43
Land cadastre	17	40
Traditional surveying	15	36
Photogrammetry and remote sensing	14	33
Laser scanning	7	17

Most of the stakeholders are ready to accept geodesy students for visits and practice, and some of stakeholders are also open for new employees.

It is quite interesting to analyse the information provided by stakeholders regarding their needs in staff retraining:

- Almost all stakeholders from Albany stated that they need staff retraining in almost all offered fields in geodesy;
- Needs of stakeholders from Bosnia and Herzegovina in this respect were quite limited,
- Stakeholders from Serbia showed no interested at all for staff retraining.

Due to rather limited sample, this may not be the real situation regarding this matter. However, the results are quite interesting and they certainly deserve further attention.

Although there is a rather limited input provided by stakeholders, we are giving here a summary of comments provided by stakeholders:

- more practical knowledge and skills is required,
- better cooperation between geodesy stakeholders and educational institutions is required,
- education should be focused on modern technologies, especially geoinformatics (GIS, programming),
- other knowledge and skills required (standards, economy, legislation, etc.).

A complete list of relevant comments is given in Table 5.

Table 5. A complete list of relevant comments

Stakeholder	Cadastral/topographic surveying	Engineering surveying	Geodesy (geodetic networks and reference systems)	Photogrammetry and remote sensing	GIS development and geospatial data management	Land management (cadastre, land valuation, land consoli	Geodetic software and equipment supply and maintenanc	Geodesy	Traditional land surveying	Engineering surveying	Global navigation satellite system (GNSS)	Laser scanning	Land cadastre	Land management	Photogrammetry and remote sensing	GIS and geospatial data management	Visits	Practice	Employment	GIS	Geoinformatics	Photogrammetry	Remote sensing	Global navigation satellite system (GNSS)	Land management	Country	Type of organization	Number of empoyees
1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	ALB	PE	12
2	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	ALB	PE	13
3	1	1	1	1	1			1		1	1		1	1		1	1	1	1	1	1	1	1	1	1	ALB	PE	8
4	1		1	1	1	1		1			1		1	1	1	1	1	1	1	1	1	1	1	1	1	ALB	GA	4
5		1	1		1			1		1	1		1	1		1	1	1	1	1	1	1	1	1	1	ALB	PE	15
6	1	1	1	1	1			1		1	1		1	1		1	1	1	1	1	1			1	1	ALB	PE	3
7	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	ALB	PE	2
8			1	1	1	1		1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	ALB	GA	35
9		1	1					1		1	1		1	1	1	1	1		1	1	1	1	1	1	1	ALB	GA	5
10			1	1	1			1			1	1	1		1	1	1	1	1	1	1	1	1	1	1	ALB	GA	22
11	1	1				1		1	1	1	1						1									BiH	PE	3
12		1						1		1	1					1	1	1	1					1	1	BiH	PE	3
13	1	1	1			1		1	1	1				1						1	1	1				BiH	PE	6
14	1	1	1				1	1	1	1			1	1		1	1	1		1	1		1			BiH	PE	14
15							1									1	1	1								BiH	PE	4
16	1	1	1		1	1		1	1	1	1					1	1	1		1	1			1	1	BiH	GA	4
17					1											1		1	1							BiH	PE	5
18	1	1	1			1				1	1					1	1	1								BiH	PE	8
19	1	1	1	1	1	1	1	1								1		1		1						BiH	PE	5
20																										BiH	GA	5
21	1	1	1		1	1	1	1		1				1		1				1	1				1	BiH	PE	16
22		1			1					1						1										BiH	PE	1
23					1	1	1							1	1	1	1	1	1	1	1					BiH	PE	13
24									1							1										BiH	PB	1
25		1	1		1			1		1						1	1									BiH	GA	3
26	1	1	1					1	1	1						1		1		1				1		BiH	PE	3
27					1			1	1	1					1	1	1	1		1	1		1			BiH	PB	8
28	1	1	1		1	1			1	1	1		1													BiH	PE	4
29	1					2							1			1										BiH	GA	3
30	1	1	1			1		1	1	1				1			1	1								BiH	PE	3
31	1	1																								SER	PE	4
32	1	1	1					1	1	1	1		1		1			1	1							SER	PE	10
33		1	1				1				1					1										SER	PE	1
34	1		1	1	1	1	1		1				1	1	1	1	1	1	1							SER	PE	15
35	1				1	1		1	1	1	1		1	1		1		1	1							SER	PE	10
36	1	1	1		1	1	1	1	1	1	1		1	1		1	1	1	1				1			SER	PE	25
37				1	1										1											SER	PE	5
38	1	1										1			1	1		1								SER	PE	3
39	1	1	1			1				1	1			1												SER	PE	2
40	1			1	1				1	1					1	1	1									SER	PB	30
41	1	1				1				1	1	1														SER	PE	2
42	1								1																	SER	PE	1
Total	27	27	25	12	23	21	11	24	15	27	21	7	17	18	14	31	22	25	17	18	16	10	12	13	13			
%	64	64	60	29	55	50	26	57	36	64	50	17	40	43	33	74	52	60	40	43	38	24	29	31	31			

ALB	Albania
BiH	Bosnia and Herzegovina
SER	Serbia

GA	Local/central government agency
PE	Private enterprise
PB	Other public body

3.3. The response to the results of questionnaires

As a result of survey in Table 6 and Table 7 and in Figure 4 and Figure 5 the structure of BSc and MSc core study program were proposed.

Table 6. ECTS per specific group of courses at BSc level

	General	Surveying	GIS	LM	Final
Mathematics	21				
Physics	8				
Construction Engineering	5				
Theory of Errors	10				
Language	3				
Informatics	5				
Introduction to Programming	5				
Surveying		15			
Geodetic Reference Systems		7.5			
Geodetic Plans		3			
GNSS		7.5			
Satellite Geodesy		3			
Engineering Surveying		5			
Practice (surveying)		5			
Geoscience			5		
Spatial Planning			5		
Geospatial Databases			5		
GIS			10		
Photogrammetry			7.5		
Cartography and Mapping			7.5		
DTM			5		
Remote Sensing			5		
Digital Image Processing			5		
Geosensors			5		
Law and Economy				6	
Cadastre				10	
Land Management - LM				5	
Final Work					12
ECTS	57	46	60	21	12

Figure 4 contains the graphical view of the course structure where it is quite clear that stakeholder request for more GIS was respected. Except GIS modern technology inside the Surveying part of the program was hold as the fundamental part of the surveying profession. The similar conclusion and impact could be concluded in MSc program (Table 7 and Figure 5).

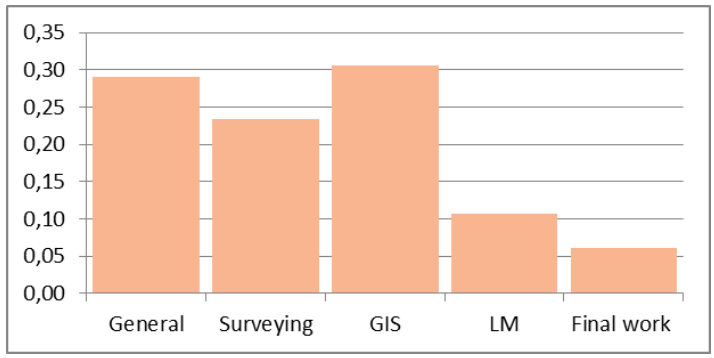


Figure 4. BSc core study curricula

Table 7. ECTS per specific group of courses at MSc level

	General	Surveying	GIS	LM	Final
Advanced programming	5				
Advanced Theory of Adjustment	5				
Applied Mathematics	5				
Project Management	5				
Research Methodology	5				
Physical Geodesy		5			
Laser Scanning		5			
Geodetic Optimization		5			
Reference Systems		5			
Integrated Sensors		5			
Geodynamics		5			
Precise Industrial Measurements		5			
Precise Positioning and Navigation		5			
Geodetic Space Techniques		5			
Spatial Data Infrastructures			5		
Spatial Analysis			5		
Digital Photogrammetry			5		
Geostatistics			5		
Advanced Remote Sensing			5		
Geovisualization			5		
Web GIS			5		
Location based services			5		
GIS in Spatial Planning			5		
Real Estate Investment Analysis				5	
Land Consolidation				5	
Final Work					30
ECTS	25	45	45	10	30

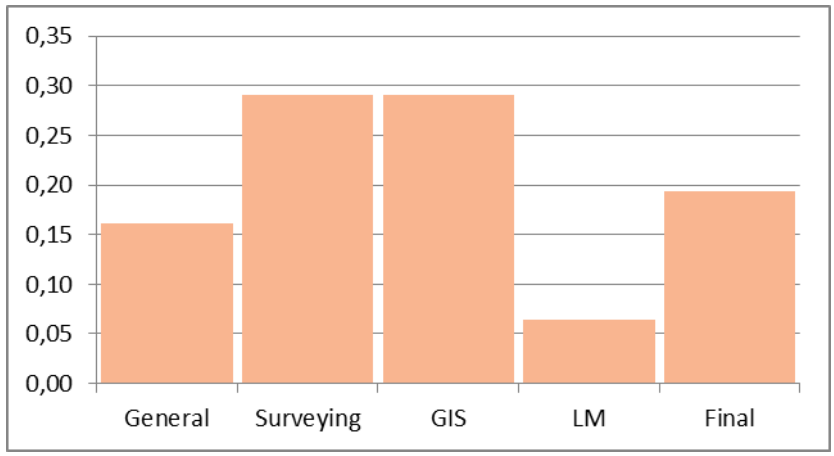


Figure 5. MSc core study curricula

3.4. The MOODLE platform for e–learning – eGeo

For many of the existing courses on Department for Geodesy and Geoinformatics (DGG) of FCEUB that are related to geoinformatics, a large portion of the materials for students (lecture slides, tutorials, assignments, etc.) was already available for download from the courses' web pages. For some courses, (for example, courses in geoinformatics such as: Geoinformatics 1, Geoinformatics 2, Fundamentals of Digital Image Processing, Digital Terrain Modelling), students already had an option to upload all finished work (exercises) for the review by academic staff. The same applies for practical exams, where exams were organized in a computer classroom. Students were downloading assignment in electronic form and uploading results in electronic form also, but much of this different software tools were not so well integrated as it is the case with MOODLE platform for online learning.

Some of the mentioned courses are transferred to the newly established MOODLE platform for e–learning of students of DGG that is called eGeo (website: http://egeo.grf.bg.ac.rs). Now, having Moodle platform installed all of the courses' content are better organized, especially from the basis of integration of students' personal information, exam results, prerequisites of other passed courses on this program etc. Eventually, this will be done for most of the courses at DGG. However, the whole process run gradually depending on the teaching staff involved.

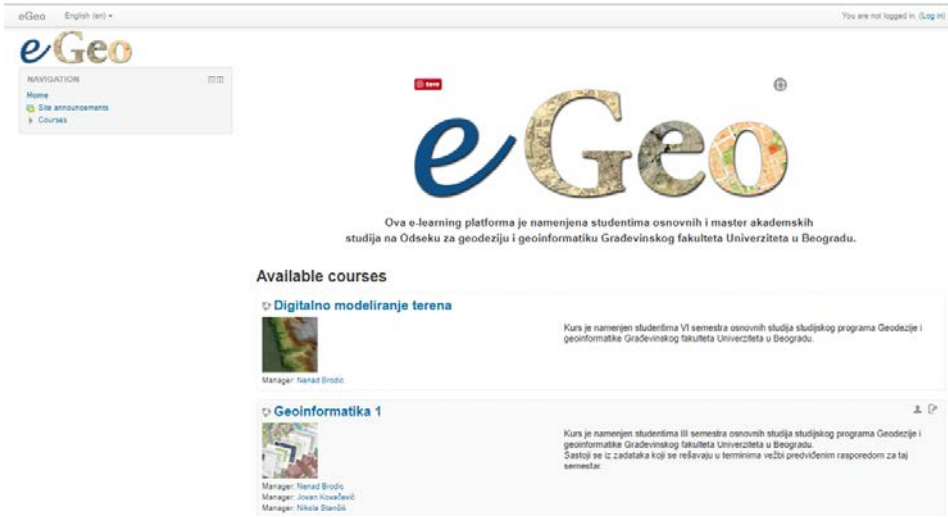


Figure 6. MOODLE platform website for e–learning

Two courses on BSc program: Geoinformatics 1 and Digital Terrain Modelling, and one course from MSc program of Geoinformatics: Digital Photogrammetry, are possible to enrol from eGeo MOODLE website and all of the teaching materials for exercises and lectures are accessible and ready for download (Figure 7, Figure 8 and Figure 9). Certain assignments for each exercise are placed on eGeo, so that students may upload their results for each topic in the designated time. All teaching materials are updated and improved, and in near future quizzes will be created and some examples of practical exams will be posted. Student must earn a proper grade for an assignment within each topic in order to fulfil requirements for passing the courses. Practical exams for mentioned courses will be organized in computer classrooms with upload option of exam results to server for each student. Students that are attending course Digital Terrain Modeling in this semester have their own accounts and are already enrolled while students who take course Geoinformatics 1 will be enrolled in the next semester.

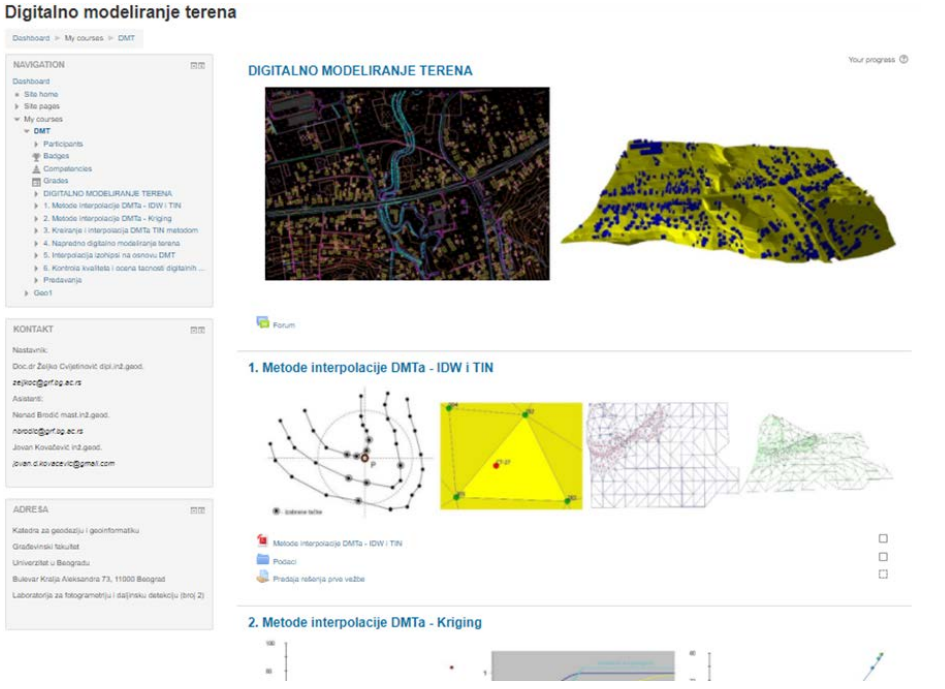


Figure 7. Course of Digital Terrain Modelling

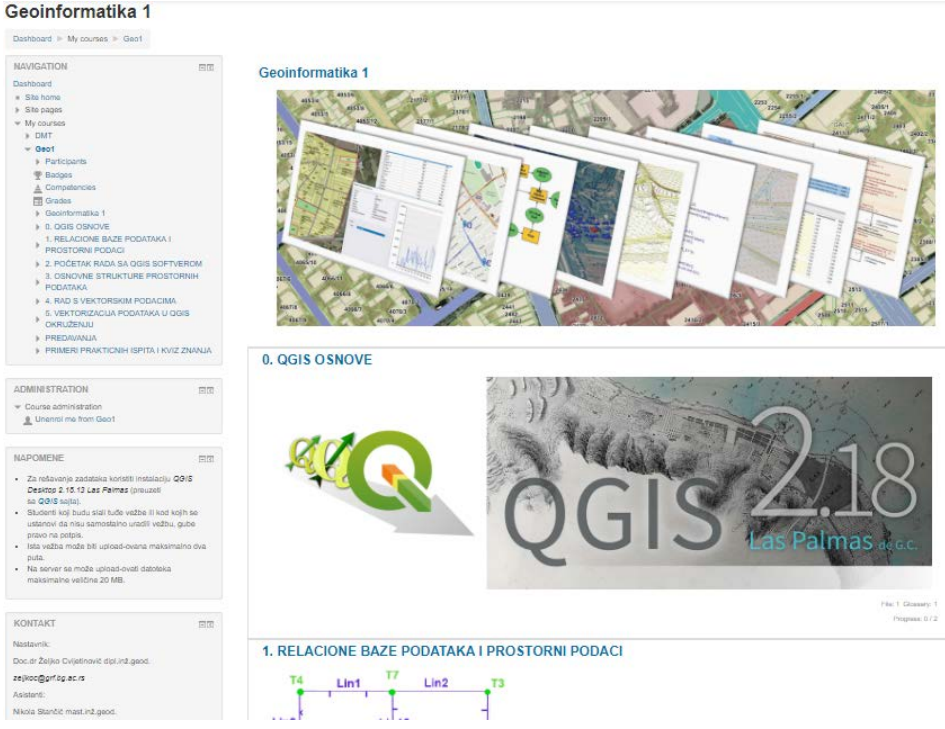


Figure 8. Course of Geoinformatics 1

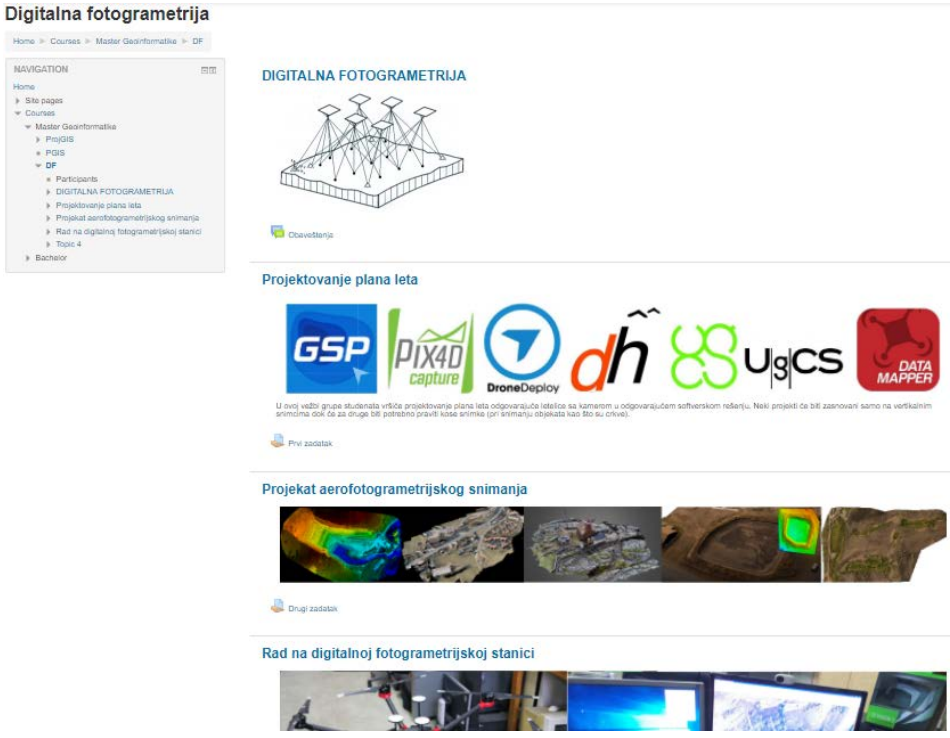


Figure 9. Course of Digital Photogrammetry

As it was planned on this project, Problem–based Learning methodology (PBL) will be introduced within two courses of the Geoinformatics module of the MSc program that are posted on eGeo website. First of these courses is a course Design and Implementation of Geoinformation Systems. Students will get a suitable literature and software (CASE tools, DBMS and GIS software) for the implementation of the project assignment. They will have meetings with teachers where they will have opportunity to clarify some issues from the selected literature and to discuss some problems and solutions related to their assignment. Project assignment will be designed with sufficient complexity so that student has to acquire all the knowledge and skills specified by course objective and content. The second course with PBL methodology is a course of GIS Programming. It was quite reasonable to assume that actual programming for solving some GIS task is a good way for students to acquire knowledge and skills listed in the course content. Everything said for the previous course is also valid for this one. This PBL courses are created on MOODLE platform and appropriate materials are transferred. Students are enrolled in this courses and student working groups are formed for solving different problems.

4. CONCLUSIONS

Taking into account the answers collected from the surveying companies in three partner countries, summary of the results is:

- Mostly students need more practice, more economical topics, industry standards and ethic code;

- Modernizing in geodesy should go through education in modern technology, GIS, Web GIS, Remote Sensing, land management and legislation;
- New teaching methods should be developed and implemented in geodesy study programs with more stakeholders involved and continuous training process practiced;
- The students should be in the focus of curricula development, theory and practice should be integrated, better and Labs need be equipped in a proper way to satisfy all market needs.
- Geodetic engineers should have better skills and knowledge in geoinformatics, especially in terms of solving various problems by programming, i.e. using scripting languages in GIS software or standard programming languages and software development tools, such as Visual Basic, C# and Visual Studio.

The response have been obtained from different stakeholders related to the geodesy education development was of a great importance to the project content and new core curricula. Special attention is paid on PBL philosophy and it's impact on better knowledge transfer and skills development. In connection with that MOODLE learning management system was used as a platform for e–learning implementing everywhere where is suitable to do so.

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32| Прегледни научни рад
Review paper
doi 10.7251/STP1813445I ISSN 2566-4484

ПОРЕЂЕЊЕ УСПЈЕХА СТУДЕНАТА ИНЖЕЊЕРСТВА ИЗ ПРЕДМЕТА НАЦРТНА ГЕОМЕТРИЈА У ЗАВИСНОСТИ ОД ПРОФИЛА СТУДИЈА

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Резиме:

Нацртна геометрија је један од фундаменталних предмета у образовању будућих инжењера архитектуре, грађевинарства и геодезије. Током извођења наставе на овом предмету уочене су одређене разлике у брзини савладавања градива, као и у успјешности студената у односу на профил струке. Да би се прецизније установиле уочене разлике у савладавању градива анализиран је и поређен успјех студената различитих студијских програма АГГФ-а на првом и другом колоквијуму и завршном испиту, разлике у успјеху по профилу студија, као и утицај (корелација) пријемног испита и успјеха у средњој школи на коначан успјех из овог предмета. Посебна пажња је посвећена анализи постигнутих резултата студената архитектуре на тесту перцепције и презентације простора како би се утврдило да ли студенти архитектуре постижу бољи успјех, с обзиром да су кроз припрему за пријемни испит прошли одређени тренинг просторних способности.

Кључне ријечи: нацртна геометрија, пријемни испит, инжењерске студије

COMPARISON OF PERFORMANCE OF ENGINEERING STUDENTS IN DESCRIPTIVE GEOMETRY IN RELATION TO THEIR STUDY PROGRAM

Abstract:

Descriptive geometry is one of the fundamental subjects in the education of future architects, civil engineers and engineers of geodesy. During the course, certain differences in mastering the teaching material have been noticed, as well as the divergence in performance of students in relation to their study program. In order to analyse these differences more closely, we made comparison of the students achievements at the first and second colloquium and final exam, analyzed the differences in relation to the study program, as well as the impact (correlation) of the entrance exam and the success in the secondary school on the final results in the course. Special attention was paid to the analysis of the results of the architecture students in the spatial ability test in order to determine whether the students of the architecture have more success in the subject of Descriptive geometry, considering that they have undergone certain training of spatial abilities through their preparation for the entrance exam.

Key words: descriptive geometry, entrance exam, engineering studies

1.

2. INTRODUCTION

Descriptive geometry is a course in the first year at the Faculty of Architecture, Civil Engineering and Geodesy in Banja Luka. At most other universities in the region, this course is also obligatory in the first year of the above-mentioned study programs.

At the departments of Civil Engineering and Geodesy, this course covers following topics: general elements of projecting; point, line, plane and their mutual relations; transformation, rotation, intersections of straight lines; intersections of planar surfaces and solids both in isometric and orthogonal projection; roofs and terrain leveling. At the department of Architecture, this content corresponds to the course of Visualization and Modeling 1, with the exception of terrain leveling considering the different amount of teaching hours. Students of the department of Civil Engineering and Geodesy study this course in the first semester attending 6 hours/week (2 hours of lectures + 4 hours of theoretical assignments), and students of architecture attend this course in the second semester with attending 4 hours/week (2+2) in total.

The aim of the course is to gain a better perception of three-dimensional space and its graphic representation at the level of the drawing, to understand the graphical transformation and deformation of spatial elements used in Architecture, Civil Engineering and Geodesy as well as to learn various graphical methods for their presentation. The course provides candidates with spatial-geometric knowledge necessary to solve geometric problems in further education and engineering practice.

During the course, certain differences in mastering the teaching material have been noticed, as well as the divergence in performance of students in relation to the study program they enrolled, although the structure of students (origin, age, education) at these departments is homogeneous and uniform. The aim of this paper is to try to determine whether these differences exist and what is the possible cause for this.

Certain percentage of students has already been acquainted with the concept of space or some kind of spatial geometry before they enrolled the University. Students who enrolled the Faculty of Architecture, Civil Engineering and Geodesy come from different high schools and cities. Some of them already attended the subject of Descriptive geometry in high school, and some did not, so it was necessary to start the course with the basic elements of space: point, line and plane.

Exceptionally, students of Architecture were familiarized with spatial geometry earlier, at the entrance exam for the Faculty. In addition to mathematics, freehand drawing and general knowledge test, they had to take the test of spatial perception and presentation, where candidates were expected to demonstrate the ability to mentally manipulate elements in space by noticing proportion, perspective, parallelism and symmetry. Students of Civil Engineering and Geodesy take the entrance exam exclusively in mathematics and physics.

3. RESEARCH AND METHODOLOGY

3.1. AIM OF THIS RESEARCH

In order to determine the observed differences in the mastering of the teaching materials more precisely, we made comparison of the students achievements at the first and second colloquium and final exam, analyzed the differences in relation to the study program, as well as the impact (correlation) of the entrance exam and the success in the secondary school on the final results in the course. Special attention was paid to the analysis of the

results of the architecture students in the spatial ability test in order to determine whether the students of the architecture have more success in the subject of Descriptive geometry, considering that they have undergone certain training of spatial abilities through their preparation for the entrance exam.

The test of spatial ability contains a series of tasks that estimate the ability of mental rotation (Fig. 1), the surface development (Fig. 2), the mental cutting (Fig. 3) or other spatial abilities [3, 4]. This test evaluates the innate perceptual abilities of the candidate, but some experience in solving these types of tasks could increase spatial skills. To prepare for the test students used Annual bulletin for prospective students published by the Faculty containing a collection of tasks from previous admission exams with correct answers attached [8].

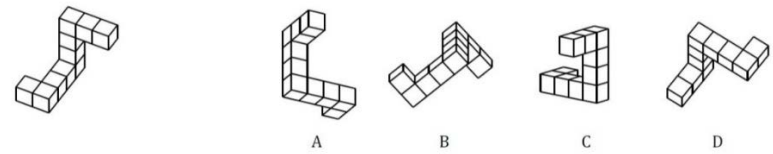

Figure 1. Mental rotation test (Respondents should determine which of the rotated figures offered on the right matches the given object on the left)

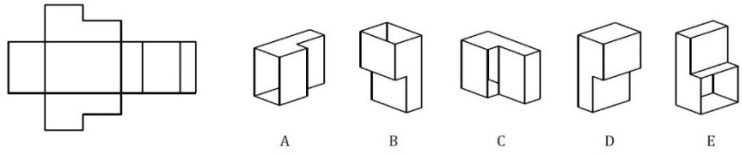

Figure 2. Surface development test (Respondents should determine which of the solids offered on the right matches the unfolded object given on the left)

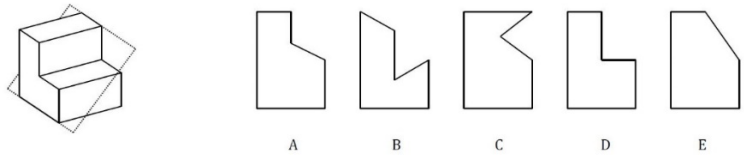

Figure 3. Mental cutting test (Respondents should determine which of the sections given on the right matches the figure on the left cut with the given plane)

The goal is to determine whether the entrance exam to the study program of architecture, due to the spatial test preparation, influences understanding and mastering the subject of Descriptive geometry later during the study, and whether the difference in the amount of teaching hours spent affects student's performance between the study program. Also, it is assumed that students of architecture, by the nature of the study, have a better perception of space. But is that really the case here?

3.2. RESEARCH STRUCTURE AND METHODOLOGY

A total of 223 first-year students during the two academic years (2015/2016 and 2016/2017) were included in this research. Students that took the course of Descriptive geometry for the second time or more were not covered by this research.

Table 1. Number of students by study program

	Number	Percentage
Civil Engineering	65	29.0%
Geodesy	68	30.8%
Architecture	90	40.2%
Total	223	100.0%

For the analysis of the results we used the analytical-statistical software package SPSS v.20 using descriptive statistics for presenting and summarizing data, the nonparametric Kruskal -Wallis test and Mann-Whitney U test, Spearman's rank correlation coefficient [6].

4. RESULTS AND DISSCUSION

Table 2. Avarage results on high school and entrance exam performance of all students

	N	Minimum	Maximum	Mean	Std. Deviation	Median
High school performance	221	27.87	50.00	40.57	5.43	40.71
Entrance exam performance	221	15.00	50.00	25.20	8.53	23.00

Table 3. Avarage results on high school and entrance exam performance by study program

	Study program	N	Minimum	Maximum	Mean	Std. Deviation	Median
High school performance	Civil Engineering	63	27.87	50.00	40.28	5.60	40.43
	Geodesy	68	27.89	50.00	40.27	5.65	40.64
	Architecture	90	30.21	50.00	40.99	5.16	40.74
Entrance exam performance	Civil Engineering	63	15.00	46.00	24.78	9.01	23.00
	Geodesy	68	15.00	50.00	26.71	10.38	24.50
	Architecture	90	15.00	42.00	24.34	6.21	23.00

At the entrance exam, out of a 100 credits in total, 50 credits could be scored with average grades from high school, while the other 50 candidates score at the exam. It is evident from Table 2 and 3 that the average result in the entrance exam (25.20) does not correspond to the average grade in the high school (40.57), which indicates that their level of applicable knowledge from high school is not appropriate. Students of Geodesy

have slightly better secondary school performance compared to the other two study programs.

Table 4. Results on colloquiums in DG

	Study program	N	Minimum	Maximum	Mean	Std. Deviation	Median
Colloquium 1 (passed)	Civil Engineering	36	10.50	20.00	14.88	3.54	13.75
	Geodesy	22	10.50	19.00	15.23	2.70	16.25
	Architecture	33	10.50	19.50	13.46	2.47	13.00
Colloquium 2 (passed)	Civil Engineering	40	10.50	20.00	15.86	3.67	16.75
	Geodesy	43	10.50	20.00	14.36	3.47	14.00
	Architecture	43	10.50	20.00	13.51	3.31	12.00

Each colloquium gets 20 points maximum. To pass colloquium, student must score 51%. For the final grade, points from colloquiums are added only if the colloquium is passed.
Table 4 shows that more students show better success at the second colloquium, a total of 126 students (56.5%) passed, while the first colloquium passed 91 students (40.81%).
In comparison of the first colloquium results between study programs, there is no statistically significant difference in success (Kruskal -Wallis test $\chi 2 = 5.586$, df = 2, p = 0.61), while the second colloquium showed a statistically significant difference in success Kruskal -Wallis test $\chi 2 = 10.025$, df = 2, p = 0.007) (Table 4). Additional Mann-Whitney test showed the difference between students of Civil Engineering (Md = 16.75, N = 40, tab.4) and Architecture (Md = 12.00, N = 43, tab.4) (U = 518.500, z = -3.140, p = 0.002). Students of Civil Engineering have shown better performance than students of Architecture.

Table 5. Results on both colloquium

Study progeram	N	Minimum	Maximum	Mean	Std. Deviation	Median
Civil Engineering	28	21.00	40.00	31.38	6.27	30.50
Geodesy	17	24.50	38.00	31.32	4.90	32.00
Architecture	23	21.00	36.00	29.32	4.04	30.00
Total	68	21.00	40.00	30.67	5.28	30.50

Table 5 shows the number of students who passed both colloquiums 68 (30.5%) in total. It is noticed that students of Civil Engineering have shown better performance on both colloquiums (43.08%), while only 25% of students of Geodesy and 25.5% of students of Architecture passed both colloquiums.

Table 6. Final exam results

	група	N	Minimum	Maximum	Mean	Std. Deviation	Median
Final exam	Civil Engineering	46	22	49	33.82	6.25	33.50
	Geodesy	41	24	50	33.01	6.34	32.00
	Architecture	62	26	50	38.42	7.50	36.00
	Total	149	22	50	35.51	7.22	34.00

The final exam carries a total of 50 points and consists of a written (40) and oral test (10). The oral part of the exam is not required.

The Kruskal-Wallis test did not show a statistically significant difference between groups at the final exam ($\chi 2 = 5.216$, df = 2, p = 0.074).

If we observe only those students who passed the final exam, the Kruskal-Wallis test showed a statistically significant difference between the study programs at the final exam ($\chi 2 = 15.937$, df = 2, p = 0.000). Using the Mann-Whitney test, this difference, at a significance level of 0.05, was discovered between the students of Geodesy (Md = 32.00, N = 41, tab.6) and the Architecture (Md = 36.00, N = 62, tab.6) (U=2249.00, z = -2.198, p = 0.028). Students of Architecture have shown better performance at the final exam compared to students of Geodesy.

Table 7. Final scores in Descriptive geometry

	група	N	Minimum	Maximum	Mean	Std. Deviation	Median
Total score (final exam + colloquium + theoretical assignments score)	Civil Engineering	45	51.40	96.60	66.79	13.64	65.24
	Geodesy	39	51.10	94.74	63.59	12.94	61.40
	Architecture	62	51.00	94.20	61.75	12.72	54.80
	Total	149	22	50	35.51	7.22	34.00

The final grade is the sum of the points earned on the class (through theoretical assignments) - maximum of 10 points, colloquiums - maximum of 40 points, and the final exam - maximum of 50 points.

Using the Kruskal-Wallis test, a statistically significant difference was found in the final scores among the students who passed the exam ($\chi 2 = 6.902$, df = 2, p = 0.032). Using Mann-Whitney test, this difference was discovered at the significance level of 0.05 between students of Civil Engineering (Md = 65.24, N = 45, tab.7) and Architecture (Md = 54.80, N = 62, tab.7) (U=989.500, z = -2.561, p = 0.010). Students of Civil Engineering have achieved a better final scores.

The positive median correlation between the performance on the first colloquium and the performance on the final exam was shown (Spearman's rank correlation coefficient is 0.341 at a significance level of 0.01), as well as between the success at the second

colloquium and the success at the final exam (Spearman's rank correlation coefficient is 0.374 level of significance 0.01).

Observing the final scores (the total sum of points) from the Descriptive geometry, there is a positive correlation between grades in secondary school and final scores (Spearman's rank correlation coefficient is 0.425, at significance level of 0.01) and between the final scores and the performance at the entrance exam (Spearman's rank correlation coefficient is 0.243, at the significance level 0.01).

Table 8. Results on spatial ability test

Study program	N	Minimum	Maximum	Mean	Std. Deviation	Median
Architecture	90	2.00	17.50	9.39	3.98	9.00

The positive median correlation between the results on the spatial ability test and the final scores in Descriptive geometry was found for the students of the Architecture who passed the subject (Spearman's rank correlation coefficient is 0.389, at the significance level of 0.01).

5. CONCLUSION

Based on the obtained results, we see that 69.32% of students enrolled in the Civil Engineering study program, 57.35% of the students of the Geodesy and 68.89% of the students of Architecture have passed the subject of Descriptive Geometry in the current academic year.

By comparing colloquium results, a statistically significant difference in performance between students of different study programs was discovered at the second colloquium, where students of the Civil Engineering showed better performance than students of Architecture. Thus, they are more successful in understanding spatial relations and intersections of geometric solids (both two-dimensional and three-dimensional projections).

Also, most students of the Civil Engineering have passed both colloquiums (43.08%), and only 25% of students of Geodesy and Architecture did the same.

However, at the final exam, students of Architecture have shown better performance than students of Geodesy. It should be noted that the test on the final exam in the study program of Architecture slightly differs from the final test on the other two study program. At the final exam, students of Civil Engineering and Geodesy are tested on drawing methods of solids in orthogonal projections, their intersections with planes and terrain leveling, while students of Architecture are also tested on drawing methods of solids in isometric and orthogonal projections and roofing tasks.

For the final grade in the Descriptive geometry, all points scored during the pre-examination and exam activities are summed. So when we analyzed and compared the overall success of students of different study programs who passed the exam, we came to the conclusion that students of Civil Engineering showed generally better performance than students of Architecture and Geodesy.

Positive correlations between scores on colloquiums and the final exam, as well as between performance in secondary school and final scores, and scores on the entrance examination and final grades, have also been obtained.

A positive median correlation between performance on the spatial ability test on the entrance exam and the final scores in Descriptive Geometry for the students of the Architecture who passed the exam was obtained.

From all of the above, it can be concluded that the students of Civil Engineering are the most successful in understanding and mastering the course of Descriptive geometry, although they do not take the spatial ability test on the entrance exam. The performance in secondary school has proved to be significant; a middle, almost positive correlation between performance in high school and final scores in DG (r_S = 0.425) has been obtained, while somewhat lower, but still, a positive correlation between the results on the entrance exam and final scores (r_S = 0.243). However, one should bear in mind the fact that students of Civil Engineering and Geodesy are taking this course with a total amount of 6 hours/week, while students of Architecture take 4hours/week, with a somewhat reduced amount of teaching material.

In earlier research it was concluded that the introduction of some graphic software in teaching Descriptive geometry could contribute to easier mastering and understanding of this course [1, 7]. Also, there are some dynamic graphic animations as well as video tutorials published on the internet site of the course [9] that students can use. However, it has also been shown that students rarely use this type of didactic material [1], but those who had used it, showed better performance on the exams. It has been shown that even those who have had this subject in high school do not show a better performance at final exam compared to students who did not have Descriptive geometry in high school [2]. And the results of previous research have shown also that students of Civil Engineering are more successful in mastering and understanding the subject of Descriptive geometry [1].

Finally, we can conclude that students of Civil Engineering are more successful than students of Geodesy and Architecture in understanding geometric problems in three-dimensional space and presenting these problems in a two-dimensional plane.

The performance in high school, as well as the results on the entrance exam, is in a positive correlation with the final performance in this subject.

We believe that the difference in the amount of teaching hours could be the reason for the weaker performance of the students of Architecture, and that the intended number of hours spent in the class is insufficient to overcome the planned program of the course, bearing in mind the fact that students work and learn mostly during the class.

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33| Прегледни научни рад
Review paper
doi 10.7251/STP1813455F ISSN 2566-4484

SARADNJA ARHITEKATA I KONSTRUKTIVNIH INŽENJERA U PROJEKTOVANJU SLOŽENIH ARMIRANO BETONSKIH KROVNIH KONSTRUKCIJA

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Abstract:
Istorijat odnosa arhitekata i konstruktivnih inženjera prolazio je kroz niz faza od polovine 19. veka kada je armirani beton počeo da se tehnološki usavršava. Taj odnos je imao svoje uspone i padove, ali je postao posebno važan kada su počeli da se oblikuju veliki natkriveni prostori. I arhitekti i konstruktivni inženjeri teže da armirano betonske krovove učine što atraktivnijim, ali je zato njihovo projektovanje sve kompleksnije. Ta kompleksnost se neposredno odražava na odnos arhitekte i konstruktivnog inženjera, na međusobno razumevanje ideje i mogućnosti da se ona materijalizuje. U radu se detaljnije analizira nekoliko značajnih primera, na osnovu kojih se može izvući zaključak o stanju ovog odnosa u 21. veku i ukazuje na potrebu harmonizacije odnosa arhitekte i konstruktora.

Keywords: arhitekta, konstruktivni inženjer, saradnja, AB krovne konstrukcije

COOPERATION BETWEEN ARCHITECTS AND STRUCTURAL ENGINEERS IN THE DESIGN OF COMPLEX REINFORCED CONCRETE ROOF STRUCTURES

Abstract:
The history of the relationship between architects and structural engineers went through a series of phases from the mid-19th century, when reinforced concrete began to be technologically advanced. This relationship had its ups and downs, but it became especially important when large covered spaces were formed. Both architects and structural engineers tend to make the reinforced concrete roofs more attractive, but their design is therefore becoming more and more complex. This complexity directly reflects on the relation between the architect and the engineer, on the mutual understanding of the idea and the possibility of materializing it. This paper will deal in more detail with this problem by analysing several important examples, based on which a conclusion can be drawn on the state of this relationship in the 21st century and points out the need to harmonize the relationship between the architect and the structural engineer.

Keywords:the architect, the structural engineer, collaboration, RC roof structures

1. INTRODUCTION

Throughout the history, people have been creating different structures with the ability of builders. This term, builders, means both, technical knowledge of construction engineers and architects formal and aesthetic sensibility. Most of the large, stone or brick made, highly aesthetic buildings were invented by such a person. When in the mid-19 century came to a stark division between structural engineers and architects, it was time when it was also open discussion on how to cooperate and who is more important for creating and life of the structure. New materials, especially reinforced concrete, and their application gave a particular advantage to structural engineers at that moment, but soon after that, a period of searching for a modality of successful cooperation emerged. Since the architect is the person who solves the functional requirements through the project and visually shapes them, he, as a rule, expects the structural engineer to design the appropriate structures. This second phase, Felix Candela, a famous Spanish-Mexican designer of bold and unusual concrete shells, witty depicts: “The second design phase….consists of a tremendous battle between the structural engineer and the architect…The result of the struggle is always the same: science prevails and the final design has generally lost the eventual charm and finesse of detail dreamed by the architect”.[1] After this description we could imagine how stressful and yet inspiring the cooperation between architect and engineer can be, and that projects become possible only through a cooperation of those two professions, despite the complex relationship. [2] There are lot of examples which show that the relationship between architects and structural engineers is not always expressed in mutual appreciations. That this is rather a common opinion it can be concluded by reading Pfammater statement when he comes to touch upon another difference between professions: “For an engineer most design effort involves analysis. For architects design is the process of synthesis”. [3] If those start points are harnessed, the integration of those two opposing approaches is the aim of collaboration and the source of its value. Architects are considered the creative ones who always want to create masterpieces and push the boundaries of the physical feasible. In contrast to this, structural engineers are sometime seen as a person who behaves in a way that spoils others' pleasure, especially by not joining in an activity, as “killjoys” or “spoilsports”, who reduce the complex designs, because the design removes structural elements or is much too expansive. But apart from these impressions, the two professionals complement each other perfectly and they can rely on one another. Extraordinary structures of structural engineering have been created only thanks to their cooperation. [4]. A number of references is used in this text, which testifies that this is always a very important topic.

2. CONCRETE AS MATERIAL OF GREAT BUILDING POSSIBILITIES

The first two decades of the 20th century witnessed the wide use and expansion of reinforced concrete as building material all around the world. Nevertheless, there was a small number of architects who realized the sculptural possibilities of reinforced concrete and used it in this way. One of the first to notice this reinforced concrete power was Antonio Gaudi, one of the most celebrated architect of Catalan modernism. One of the most important buildings of Antonio Gaudi is the temple “Sagrada Familia” in Barcelona, still under construction. The first period while Gaudi was author of the building, acting as the architect and as structural engineer lasts from 1883 to 1936. During that period the notion of using concrete was spreading very fast, and Gaudi was familiar with its use. The

Gaudi's attitude about the concrete has been discussed by various authors. The first Portland cement factory in Catalonia was property of his dear friend and supporter Eusebio Güell. That is why Gaudi was well informed and even used it in some of his buildings, but very modest and not for main structures. The design of small building such as the school for the children of the workers employed at the site of Sagrada Familia shows how deeply he understand the geometry of nature's organic forms and managed to find an architectural language to express similar forms in his work.

When Gaudi in 1918 moved his atelier to the construction site of Sagrada Familia he continued to design the rest of the building and that was the moment when he decided to use reinforced concrete discovering good properties of this material for shaping his extravagant pinnacles of the towers of "Nacimiento" (Nativity) façade. These elements are located 110m high and has a structural function as it was confirmed in 1997 after the analyses undertaken to determine the first use of reinforced concrete of this building [5] Gaudi possessed a special ability to model and analyses volumes as well as huge imagination to develop geometric models, especially ruled surfaces like hyperbolic paraboloids, hyperboloids, helicoids and conoids.

Figure 1. School at Sagrada Família in Barcelona, designed by Gaudí. Photograph from 1909. (unknown author)

As the knowledge of the concrete properties became more and more thorough and wider in the vision-focused of modern movement in the 1900s, reinforced concrete started to become a material of choice by well-known architects who used it for many notable buildings. Considering the unusual, stratified forms of its buildings, including their roofs, Antoni Gaudi can be considered as the precursor of a whole series of creators who used reinforced concrete to create unusual and sculptural like roof structures. Not only the concrete industry provide the ability to create a fire-proof structures, but air-entraining agents and other chemical additives, developed in the 1930s increased resistance to freezing and improved workability. These attributes solved a number of technical issues, but the plastic, flexible properties of poured-in-place concrete open the door for new forms of free flowing and expressive of nature. Increasing curiosity and boldness in research of the reinforced concrete building limits allowed construction of thin shell structures and thinner concrete slabs. Some construction companies became known for how efficiently and how well they could "get concrete up in the air." [6]. This possibility of using concrete for incredible roof exhibitions opened a new period of cooperation between architects and

structural engineers. Architectural trends until the 1940s, however, advocated rectilinear and rather rigid forms, mainly with flat, simple roofs.

3. COOPERATION BETWEEN ARCHITECTS AND STRUCTURAL ENGINEERS IN THE DESIGN OF COMPLEX REINFORCED CONCRETE ROOF STRUCTURES

Buildings in which complex roof structures could be applied were, as a rule, of specific functions. Various warehouses, hangars, especially sports and religious buildings, airports, fairs, public houses were among the first to use complex roof structures. The simplest form for which architects began to apply reinforced concrete were the dome. Although domes made entirely from reinforced concrete were not built before 1900, the architectural historians mentioned the church of Saint-Jean-de-Montmartre, which began to be built in 1894 after the design of Anatole de Baudot. It was completed only in 1904 due to distrust in the system developed by the engineer Paul Cattoncin. It is a small brick shell dome with reinforced concrete ribs. In the late 19th and early 20th centuries, the Guastavino family, from United States, developed the masonry dome using layers of tiles in fast-setting Portland cement which allowed mild still bars to be used to counteract tension forces. This model was applied to the dome over the crossing of the Cathedral of Saint John the Divine in New York, built in 1909. It was a part-spherical dome, 30 m in diameter from the top of its merging pendantives and with average thickness 1/25th of its span and still rods embedded within pendentives. After Mainstone this dome “looked forward to modern shell construction in reinforced concrete”. [7]

Figure 2. The Dome of Saint John-the-Divine Cathedral, Guastavino tiles

Methodist Central Hall, today better known as Central Hall Westminster in London was designed in 1904 by architect Edwin Alfred Rickards. The domed ceiling of the Great Hall is reputed to be the second largest of its type in the world. The vast scale of the self-supporting ferro-concrete structure reflects the original intention that Central Hall was intended to be "an open-air meeting place with a roof on". The hall was eventually finished in 1911. [8] Synagogue with a spacious dome of reinforced concrete was built in Augsburg in the period 1914-1917 according to the project of architects Landauer and Lompel. And here, as in the case of the Westminster Hall, an interesting combination of extremely conservative and anachronistic façades and a dome of new material whose qualities are

constantly improving show the strong struggle that architects lead with tradition and the acceptance of innovations. [9]

On the basis of the winner's project of then well-known architect Friedrich von Tierch, the construction of a Festhalle in Frankfurt took place in 1907. The multifunctional hall, which was completed in 1909, was then the largest in Europe. It had the biggest self-supporting dome made in steel and glass. Festhalle in Frankfurt has largely influenced the formation of the Centennial Hall in Wroclaw (Breslau), considered by most historians of architecture as a key building and important example of large-scale dome-shaped structures in reinforced concrete. It was built from 1911-1913 to commemorate the rising-up of Prussian and German people against Napoleon's occupation. The architect Max Berg create cupola in reinforced concrete, with inner diameter of 69m and 42m high, so this was the largest building of its kind at the time of construction. Above cupola there was built lantern which itself is 23m high and was made of steel and glass. In this case, the idea of the structure form was the concept of the architect Max Berg and the main contractors were only mentioned, even Dyckerhoff&Widmann Ag (DYWIDAG), with their engineers Günter Trauer, Willi Gehler, was leading company for concrete structures in Germany.

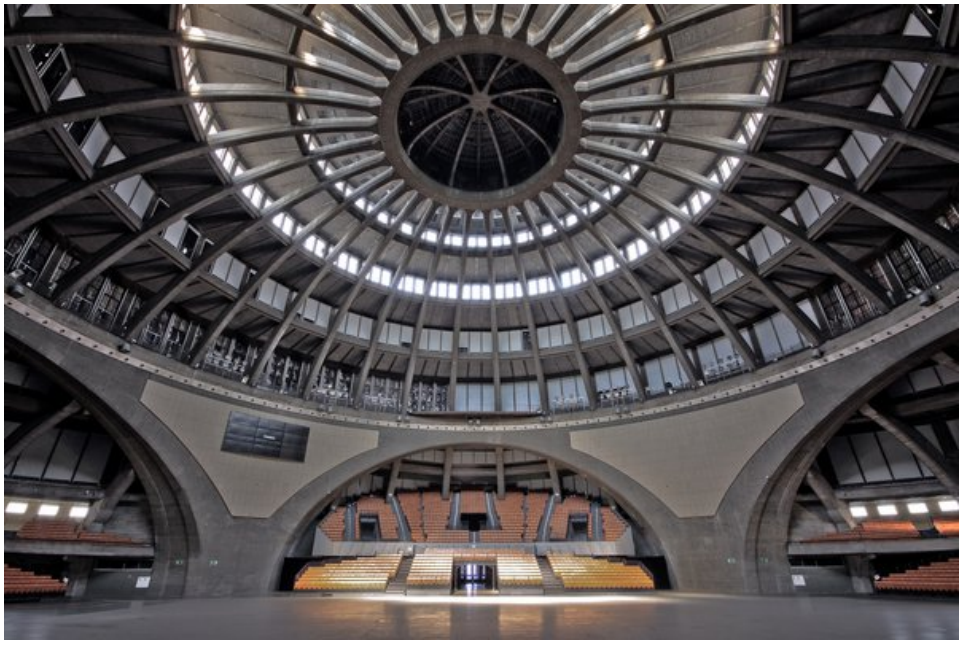

Figure 3. Interior of the Centenial Hall in Wroclaw with RC cupola

The following example, the grandiose Leipzig Market Hall is a reverse case in which municipal architect Hubert Ritter, although designing the building, leaves the initiative to structural engineer Franz Dischinger who designs polygonal shell domes. Shell domes were made using the Zeizz – DYWIDAG patented method. This process involved the construction of a framework of rigid and self-supporting steel bars that divided the desired shape into a number of polygonal shapes, which were wrapped in wire mesh. Workers then spray a thin layer of gunite, a type of concrete, onto this system, with formwork "used as a backing to prevent spray-through". Once the concrete had dried, the formwork was

removed and used for the next section of the shell that was to be sprayed with concrete. The domes of the Leipzig Market Hall only had a thickness of 9 cm [10]

Figure 4. Great Leipzig Market Hall with two RC domes

From the early 1910's until the late 1930's, many structural engineers in Europe try to develop shell structures because they spanned very large spans, used less material, and cost less than other options. This period was dominated by admiration for the shells in reinforced concrete. The easiest way to see their material and cost efficiency is through their ability to greater span distances without the need of intermediate columns, which would require more material. Developments in concrete prestressing and reinforcement, and also the development of stronger steel rebar, were primarily responsible for the newfound ability to design and build these shells [11]. Thin shells were additionally seen as a sound design choice because when shaped correctly, they experienced little to no bending moment, and any compression that was found within the shell was uniformly distributed [12].

But, for this structural shapes the engineer's knowledge was needed and architects have to rely on structural engineers if they wanted to develop fascinated structures. In that case, what was the best solution? The architect and structural engineer in on person!

Known both as architect and an engineer Pier Luigi Nervi (1891 – 1979) explored the limitation of reinforced concrete by creating a variety of imaginative and inventive structural projects. Through his research process he proved that reinforced concrete is the material that will dominate in architecture movements of the coming years. His passionate dedication to the creation of incredible spatial forms, his ambition and ability to recognize opportunity in the midst of challenge made him a person with huge impact on several disciplines and cultures. Continuing the research into the bridging of large interior spaces with reinforced concrete constructions, Nervi carried out two aircraft hangars in Orvieto, between 1935 and 1939. The space was closed with barrel vaults with a reinforced mesh of ribs. Unfortunately, these hangars no longer exist, but Nervi always presented them as paradigmatic examples of a means of intuitive design, capable of challenging conventions, and as one of the first demonstrations of the potentials of reinforced concrete in the design of large-span roofs.

Another challenging project was football stadium in Florence built in 1931. The Stadio Artemio Franchi (originally Giovanni Berta, also called Comunale) is well known football stadium in Florence. The stadium is built entirely of reinforced concrete with a 70-meter tower that bears the stadium's flagstaff. Around the base of the tower, spiral ramps lead from the ground floor to the upper edge of the grandstand.

Figure 5. One of the aircraft hangars in Orvieto, photo before II World War

Another sporty building that Nervi gave his originally seal was Palazzo dello Sport built for competitions at Summer Olympic Games in Rome in 1960. The building corpus was designed by architect Mercello Piacentini in 1957, but its reinforced concrete dome was engineered by Pier Luigi Nervi. Aside the Palazzo it was constructed a smaller building known as Palazzetto dello Sport and its dome was also engineered by Nervi. Today, the complex is renamed in Lottomatica and also modernisation was done in 2003.

Figure 6. Palazzo dello Sport, Rome, by P.L.Nervi

The latest sports structure in which Pier Luigi Nervi took part is the Norfolk Scope in Norfolk, United States, built in 1971. This multi-function complex consists of arena, theatre, exhibition hall, and parking garage. The design of whole complex was done by local atelier Williams and Tazewell, but Nervi was invited to design arena's monolithic reinforced concrete thin-shell dome measuring 134m in diameter and a height od 33.5m. For this, world's largest reinforced thin-shell concrete dome, Nervi was inspired by his own dome of Palazzeto dello Sport in Rome. Norfolk Scope won the Virginia Society of the American Institute of Architects Test of Time award in 2003. Many compliments have been made about this dome, and most often it is said that it is a happy marriage of art and engineering.

Figure 7. Norfolk Scope stadium, RC dome by P.L.Nervi

At the end of his career, Nervi was also involved in designing religious buildings. He was invited to design the saddle roof over the body of the Cathedral of Saint Mary of the Assumption, the principal church of the Roman Catholic Archdiocese of San Francisco in United States. The elementary plan was designed by local architects John Michael Lee, Paul. A. Ryan and Angus McSweeney in collaboration with Pier Luigi Nervi and Pietro Belluschi (at that time the Dean of the School of Architecture at MIT). The saddle roof is composed of eight segments of, one of the favorite Nervi's roof types. [13]

Figure 8. Cathedral of Saint Mary of the Assumption in San Francisco, RC roof structure by P.L.Nervi

Hyperbolic paraboloids were the favourite constructive type not only for Nervi, but also for numerous other creative authors in the 20th century, inclined to sculptural design of architectural structures. Japanese architect Kenzo Tange (1913-2005), with assistance of construction engineer Yoshikatsu Tsuboi, German architect Wilhelm Schlombs, and Swiss architect Max Lechner, developed the catholic Saint Mary Cathedral in Tokyo in 1964. The layout of the church is in the form of a cross topped with eight hyperbolic paraboloids. Using this shape of roof some of building are similar to each other or referred to some predecessors. In this case, the church of Kenzo Tange was build some few years before the Cathedral of Saint Mary in San Francisco.

Figure 9. Saint Mary Cathedral in Tokyo, by Kenzo Tange

In the late years of his career, Piera Luigi Nervi was honoured by personal invitation of Pope Paul VI to build the new General Audience Hall within Vatican City. The project was started in 1963-64 to be completed in 1971. Almost always in the shadow of his ingenious father, this project was signed by Nervi and also by his son, Antonio, an architect. The Hall, approximately 80m wide by 100 m long, with a maximum height of 18m has the vault realized using the same system adopted on many occasions, composed of prefabricated elements used as permanent formwork for the site casting of the ribs. The building glow in white concrete with grains of white marble, between renaissance and baroque surrounding.

Figure 10. General Audience Hall, Vatican City, P.L.Nervi

If we return to the legacy of Antoni Gaudi, we have to mention several authors acting as architects and structural engineers in one. They all admired the architecture of Catalan modernist Antoni Gaudi and in one way or another continue to develop imaginative, brave and unusual building shapes. [14]

Eduardo Torroja y Miret (1899-1996) was Spanish structural engineer and pioneer in the design of concrete shell structures. At the beginning he worked with architect Manuel Sánchez Arcas, a Spanish modernist, sharing his interest in new architectural forms. They designed together an enclosed and semi-spherical shell for the 1932 Algeciras market hall. Market hall was covered with 9cm thick roof of 47.5m height, vaulted and supported on eight pillars. Many historians of architecture consider this roof as Torroja's engineering masterpiece.

Torroja also successfully collaborated with other architect in designing the Hipodromo de la Zarzuela in Madrid in 1930. The architects Carlos Amiches and Martin Dominquez

design the race course and Torroja added the extravagant distinctive hyperboloid roof over the strands.

Figure 11. Market Hall in Algeciras, Spain, E.Torroja

Figure 12. Hipodromo de la Zarzuela, Madrid, E.Torroja

Another world known Spanish and Mexican architect was Felix Candela Outerňo (1910-1997). His major contribution to architecture was the development of thin shells made out of reinforced concrete, popularly called cascarones. Candela was real admirer of reinforced concrete in the shape of a dome or shell like shapes. He took any opportunity to design buildings which allow him to express this affinity. In his career he was always acting as architect and as structural engineer. That is why he has had a great influence on the work of many younger authors. His architecture is simple yet intriguing and complex roofs are designed to be clearly depicted in space, especially in the natural environment. L'Oceanogràfic in Valencia is the largest aquarium in Europe and planet's main marine ecosystems are represented here. The appropriate, but extravagant and avant-guard architecture of the complex is one of the latest works of the architect Felix Candela and the structural engineers Alberto Domingo and Carlos Lázaro, who made the structural design of the concrete coverings of the buildings, opened in 2002. [15]

Miguel Fisac Sema (1913-2006), architect and painter, belongs to the same group of Spanish authors who follow the open minded Gaudi. He started to be interested in experiments with new materials, especially with reinforced concrete. He found that reinforced concrete is material that is adequate to assume its analogies on "bone-beams". With this premises he designed the headquarters of the JORBA laboratories in Madrid in 1967. The popular name of the building La Pagoda refers to the visible structure of the

tower. The original structure of the building consisted of an office tower in which each floor was rotated 450 with respect to the previous one, a feature that made it appear as a pagoda. The transitions between the plants were resolved with a ruled surface in the form of a hyperboloid. This strange building was pulled down in 1999.

Figure 13. Chapel Lomas de Cuernavaca, F.Candela

Figure 14. L'Oceanogràfic in Valencia , F.Candela

Oscar Ribeiro de Almeida Niemeyer Soares Filho (1907–2012), usually known simply as Oscar Niemeyer could be treated in the same way as previous authors fascinated with the possibilities of reinforced concrete. His exploration of the aesthetic possibilities of reinforced concrete was very influential in the late 20th and early 21th centuries. The critics who analyse his opus called him a “sculptor of monuments”. And, really, many of his buildings looks like gigantic sculptures. One of this “sculptural buildings” is the Church of Saint Francis of Assisi in Pampuhla region of Belo Horizonte. It is the first UNESCO listed modern architectural monument in Brazil and consists of four undulating concrete parabolas which exterior is covered with mosaics. The church was finished in 1943, but it was consecrated in 1959 because the Archbishop Cobral opposed both its architectural and artistic forms. If we put aside all huge structures in reinforced concrete

and with shell domes and hyperboloid-paraboloid roofs that Niemeyer had built during his long career, we can proof his genius analysing the small chapel of Nossa Senhora de Fatima built in the city of Brasilia in 1958. The whole roof structure relies on three inclined pillars only. [16]

Figure 15. Nossa Senhora de Fatima, Brasilia, O.Niemeyer

Religious architecture has welcomed many architects to demonstrate their ability to use shell domes and other curved roofs. Le Corbusier express his interpretation of the International Style by using monumental sculptural shapes and row, unfinished moulded concrete while designing church architecture. The Chapelle Notre Dame du Haut, the small chapel in Ronchamp, France, has become one of his most iconic designs. Completed in 1954, the chapel was built for a Catholic church on a pre-existing pilgrimage site. The monumental curved concrete roof is a shell structure supported by columns hidden in the masonry walls. There is also the Church in Firminy which carries special significance, as it was last major work of le Corbusier designed in 1963. It was left unfinished until 2006 keeping his essence alive. For the Church in Firminy he used concrete hoping that this material would also give him control over volume and spaces in his overall goal of giving light a true meaning. [17]

Figure 16. Church in Firmigny, Le Corbusier

We can turn now to the cases with difficult relationship between architects and structural engineers during the necessary collaboration. The Sydney Opera House in Australia, became a mid-century icon of the artistic use of concrete formed into segments of spheres

to produce a dramatic structure that appeared light and airy, like sails on a ship. No project highlights the drama, conflicts, successes and failures of vision for the architect-engineer relationship more than Sydney Opera House. The history of Opera building starts when Danish architect, Jørn Utzon (1918-2008) won the competition with no more than a sketch on a scrap of the paper. Ove Arup, also Danish living in London, congratulate him and give the offer of his company to be involved in structural solutions. At that time, in 1957, Sir Ove Nyquist Arup (1895-1988) was well known structural engineer, leader of the company called Arup and Partners. One of his partners, Ronald Jenkins, was leading authority on the calculation of shell structures. Today, Ove Arup is considered to be among the best architectural structural engineers with deepest impact on the work of many architects and structural engineers in 21th century. The problems started because the construction began before the design had been fully researched. The only hope for resolving the incredibly complex geometries of the roof structure was through an intensive collaboration between architect and engineer, which is why Sydney's Opera is one of, if not, the greatest symbol of 20th century architect-engineer achievement and failure at the same time. The personal similarities and differences between Arup and Utzon were almost immediately visible. However, at first it seemed that Arup's dream of a deeply collaboration between architect and engineer could be realised. But, in 1966, utterly overwhelmed by how complex the project had become, Utzon resigned. In spite of this, the project still gripped Ove Arup. Personally, the whole situation about realisation of the project, left deep impact on Arup. It seems he lost his uninhibited enthusiasm for architect in general and he start to trust only to the architects of his own team. [18]

Figure 17. Opera House in Sidney, J. Utzon

Reinforced concrete was the material that in 1950-1970 impressed almost all architects and structural engineers willing to challenge its possibilities in realisation of most strange curved roof surfaces. American authors were also involved to contribute with their realizations that have also become the icons of modern architecture in the middle of the 20th century. One of the most influenced designers at that time was Eero Saarinen (1910-1961), Finnish architect that immigrated in the United States. His acceptance of reinforced concrete as a formative material was undoubtedly influenced by the fact that he first start studying sculpture in France and then he transferred to Yale University where he took diploma in architecture in 1934. With his own architects' office Eero Saarinen and Associates, he was involved in number of most important works in United States until his early death. The most cited are two airport terminals, the Terminal 5 of TWA Flight Centre and Washington Dulles International Airport, both opened in 1962, a year after Saarinen died in 1961. Saarinen and his team successfully collaborated with civil engineering firm Ammann and Witheney as in both projects the thin shell-shaped concrete roofs were designed over the main interior spaces. Both airports were always highly estimated for its

graceful beauty, but today they are completely changed. But, Kresge Auditorium at MIT is estimated to be one of the best known thin-shell structures in United States. Designed in 1955, it was listed in “One Hundred Years of Significant Building” already in 1956. The elegant reinforced concrete dome comprise one eight of the surface of a sphere and its primarily supported by three pendentives and rising to a high of about 15m and sliced away by sheer glass curtain walls, so that the shell dome comes to the earth on only three points. Thin shelled concrete technology was innovative and the dome is very thin. This project was successfully realised with help of consulting engineers Amman and Whitney. [19]

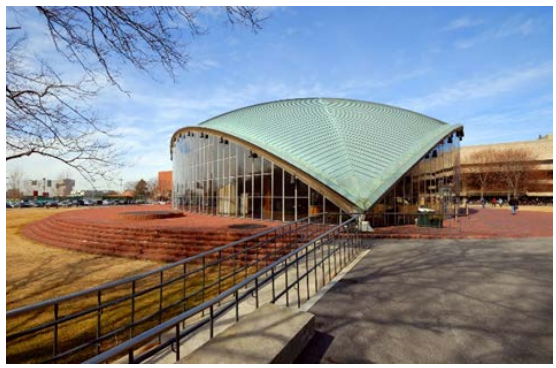

Figure 18. Kresge Auditorium at MIT, E.Saarinen

At the end of the 20th century, there was a change in the form of collaboration between architects and engineers. In some cases, the construction becomes so significant that the architect can not at all realize his idea without the dominant role of structural engineers. Yet, still today there are individuals who are able to independently realize their own ideas,
At the end of the 20th century, there was a change in the form of collaboration between architects and engineers. In some cases, the construction becomes so significant that the architect can not at all realize his idea without the dominant role of structural engineers. Yet, still today there are individuals who are able to independently realize their own ideas,
as is the case with Santiago Calatrava Valls (1951). This extraordinary talented Spanish architect, structural engineer, sculptor and painter in his work is guided with the principle of the early 20th century famous Swiss engineer Robert Maillart (1872-1940), that "with an adequate combination of force and mass, you can create emotion."[20] Although Calatrava is the author of numerous projects, a relatively small number of those are with roof concrete structures. Numerous new materials that enable even more unusual and curved forms than concrete can be used today, and Calatrava uses them frequently for his various realizations.

Figure 19. Palau de les Artes Reina Sofia, Valencia, S. Calatrava

Reinforce concrete as roof material was applied only in some of his projects, such as Bilbao Airport terminal. Another building with “concrete” shell roofing is Palau de les Arts Reina Sofia (Opera House) in Valencia. In form, the building is a series of apparently random volumes, which become unified through their enclosure within two symmetrical, cut-away shells of laminated steel cladded with white concrete.

4. CONCLUDING REMARKS

Undoubtedly, in modern practice, there are still many examples of the application of large and curvilinear roof surfaces, but when analysing the applied building material, it is revealed that it is almost never pure reinforced concrete, but that it is used marginally, and that the dominant is steel and other new technologically advanced materials that are more flexible, easy to install, and can be cheaper. However, there remains one characteristic of reinforced concrete, which is still difficult to overcome, which is its service life. The historical distance is still insufficient to define the durability of new materials with security. Some materials, for which some of the world famous buildings have already been constructed, already show signs of decay and almost parallel to construction are being done repairs and reconstructions. Today, we are beneficiaries of all of the past exploration, technical achievements, and creative experimentation by creative and curious individuals, associations, design professionals and construction companies that have worked with concrete. Further refinements into materials research, engineering, and the science of concrete combined new designed methods and technology have allowed architect to demonstrate innovative and exiting new capabilities.

Yet, the concrete in any of its derivation lost the battle when large span roof shells and other extravagant roof curvatures are planned. A large number of new types of concrete are available and each has a specific use value. Concrete has long been, and continues to be, a significant building material that provides a full range of structural, architectural, and sustainability options. The science and technology of concrete has advanced notably to allow for a range of uses and capabilities that have been proven in countless buildings as well as industrial and infrastructure projects. Combining these capabilities with advances in computerized building information modelling allows entire design teams to work together to achieve designs that are truly representative of 21st century thinking and possibilities. Further, the longevity of concrete means that these constructed designs will likely endure for generations to come. The collaboration of architect and structural engineer is needed now much more than ever, because the vision of entire men surrounding starts to be close to science fiction ambiance and needs to be realised safely and sustainable.

Acknoledgment

This paper has been undertaken after the part of the Project TR36042 supported by Ministry of Education, Science and Technological Development of the Republic of Serbia.

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34| Прегледни научни рад
Review paper
doi 10.7251/STP1813471M ISSN 2566-4484

АРХИТЕКТУРА ШКОЛСКИХ ОБЈЕКАТА У БАЊОЈ ЛУЦИ ГРАЂЕНИХ ИЗМЕЂУ 1878. И 1918. ГОДИНЕ

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Сажетак

Рад се бави архитектуром школских објеката у Бањој Луци, грађеним током 40 година дуге владавине аустро-угарских власти на територији данашње Босне и Херцеговине. Зграде за образовање, од веома малих, основних школа, до великих зграда, као што су гимназије, биле су третиране на различите начине и обликоване у стиловима као што су традиционална архитектура локалног поднебља, псеудо маварски стил, неоренесанса или неокласицизам, па и сецесија.

Овај рад се бави истраживањем оригиналног стања свих зграда, локације у оквиру изворног урбаног ткива, архитектонске и историјске позадине датог контекста, оригинално доприносећи истраживању, анализи и валоризацији ове типологије објеката у Бањој Луци из аустро-угарског доба. Стилска припадности и архитектонске особине су такође анализиране. Поред тога, у раду су изучени и приказани каснији развој свих школских објеката, показујући утицај каснијих политичких режима и у неким случајевима природних фактора на ова важна дјела архитектуре. У закључку, приказан је значај ових објеката за развој окружења и допринос стварању урбаног идентитета Бањалуке.

Кључне ријечи: историја архитектуре, школе, Бања Лука, 1878-1918.

THE ARCHITECTURE OF SCHOOLS IN BANJA LUKA BUILT IN 1878-1918

Abstract

This paper deals with the architecture of schools built in Banja Luka, during the 40-year long Austro-Hungarian rule in today's Bosnia and Herzegovina. The buildings for education, spanning from the basic, very small, elementary schools, to vast buildings, like higher gymnasium, received very interesting set of architectural styles featuring traditional local architecture, Moorish Revival, Renaissance and Classic Revival, as well as Secession.

The paper shows the initial status of all buildings, their location within the original urban fabric, architectural and historical background and specific subject matters, originally contributing to research, analysis and evaluation of this building typology located in Banja Luka, built in Austro-Hungarian era. Their stylistic adherence and architectural properties are analysed as well. Besides that, the paper shows the development and later life of all schools, showing the influences of later regimes, politics and some natural factors to these important pieces of architecture, followed by the conclusion and analysis of the role of these buildings in local development and their contribution to establishment of the cityscape identity.

Keywords: history of architecture, schools, Banja Luka, 1878-1918.

1. INTRODUCTION

With the arrival of the Austro-Hungarian establishment in Bosnia and Herzegovina in summer of 1878, the construction plans for dozens of new buildings were introduced. In majority of cases, new authorities built prevalently buildings for newly opened institutions and facilities like railway stations, industrial and military facilities. Due to very modest educational system in Ottoman Empire, and almost entirely excluded position of non-Muslims within it, buildings for educational purposes were very rare type of facilities in Bosnia and Herzegovina.

In the case of Banja Luka, schools of all kind were constructed, filling the gap in spatial resources and Austro-Hungarian laws that were in power after 1878. However, the versality of architectural styles and building properties is very unique in Banja Luka. New authorities engaged range of architects, that powered different approached in stylistic modelling of new architecture. This paper presents the results of thorough research on Austro-Hungarian architecture and urban development in Banja Luka emphasizing the buildings for education, as one part of building typology that created important influence to later development of local society in general.

2. THE ARCHITECTURE AND HISTORICAL DEVELOPMENT OF SCHOOLS BUILT IN BANJA LUKA BETWEEN 1878 - 1918

2.1. Tsar's school - Volksschule

Building was located near the southernmost part of Kaiserstraße, in Street Ferhadija, southern from Ferhadija Mosque, in the place where Faculty of Electrical Engineering stands today. It is the area between contemporary Street of Patre and Street of Patriarch Makarije Sokolović.

There are several contradictions that are misleading the research work regarding the exact name and date of construction of the Tsar's School; building is also known as Volksschule. Because of a whole variety of primary school departments introduced by Austro-Hungarian authorities, like city schools, public schools and municipal schools, in the same time combined with Muslim, Orthodox and Catholic schools divided between boys and girls, tracing this particular school building is quite hard.

One thing is clear; it was designed to be a public school. Mentioned source leads to a year of design in 1907, but many other relevant sources mentioned [1:94] and also map from 1880-1884 give us enough certain information that it was built 1880-1881. [2:336]

Figure 1. Tsar's school; original site condition. Photograph taken probably after the construction from Ferhadija Mosque's minaret. On the right, western side on the site, beginning of the new section of Kaiserstraße is visible [3]

Two elements are interesting for this project. First is that the actual house was built according to the traditional Bosnian house: ground floor walls were made out of stone blocks, and first floor structure out of half-timbered system mixed with bricks: basic decoration was designed according to simplified Renaissance revival bases. Second, more interesting is garden situated in the courtyard. For a long time, this building was famous for its (Tsar's) gardens designed according to French garden type, with strict geometrical rules, colour combinations and the relationship between elements used.

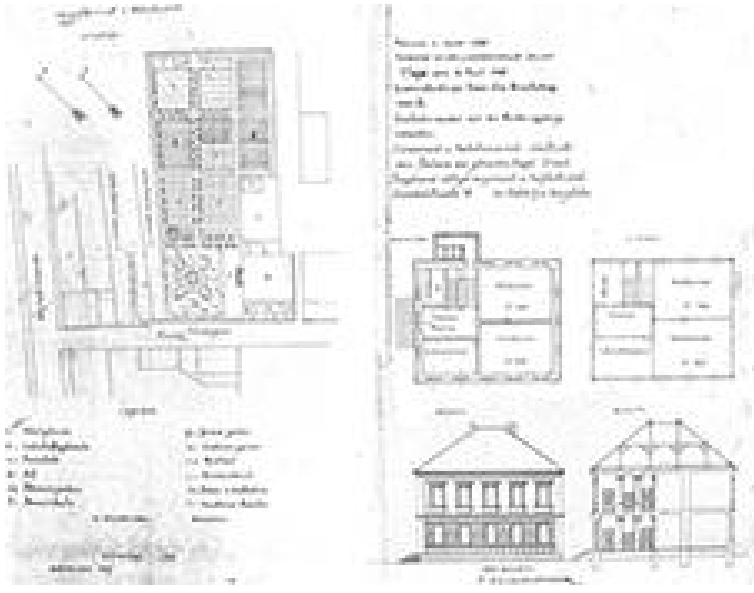

Figure 2. Tsar's school; original project documentation with site plan, floor plans, section and elevation views. Drawings dated in 1907 [3]

The building does not exist today, with very few verified data on its demolition, and one can only assume that it was torn down in the years between WWII and earthquake in 1969.

Figure 3. Tsar's school; photograph taken probably between World Wars [3]

2.2. School in Upper Šeher

Building is located by the main road heading outside the city, through Upper Šeher. This city district is today named Srpske Toplice.

It was erected in 1894 [1:95] and style corresponds to pseudo-Moorish style. It is simple, single volume building with a strong and slightly graded main façade plain. It consists of basement, built in stone, ground and first floor. Floor zones are separated either with different materials or decorative elements. On the main façade, starting from the ground floor, stucco decoration is the dominant element

Figure 4. School in Upper Šeher. View from the southeastern corner. Photograph taken before additional construction works [3]

Ground floor windows are simple rectangular with fake stone architrave decoration. First floor is separated with simple cornice and additionally emphasized with archivolt endings above the windows. Particularly, these elements are important for identifying design with pseudo-Moorish style. Roof zone, barely visible from the street, stretches above the archivolts with a series of wooden elements supporting the roof construction.

Figure 5. School in Upper Šeher. View from the northeastern corner; present condition

The structure is simple: stone basement, brick walls above the ground and traditional massive wooden floor and roof construction.

It has preserved most of the original elements and façade design, but during the time and utilization some add-ons and additional works endangered the original context of the building. This building represents one of the rare examples of newly constructed public buildings in the old city district, as it was quite unusual by new authorities to interfere with old Ottoman architecture, as far as case study of Banja Luka is concerned.

2.3. Real Gymnasium - Ober-Realgymnasium

Building was located in Gymnasium street that passed by the Crkvena River and led to the Gymnasium. That street line direction today corresponds to the Street of Ivo Lola Ribar in its extension. Site was rising above the old market place and set just across the Kastel over the Crkvena. It was not drawn in the plan from 1884, but the street that connects the

Kaiserstraße and future Gymnasium was already there. In that place today is one mega structure, Museum of Republic of Srpska and Children's theatre, that were, along with shopping mall "Boska" designed by team of architects from Zagreb, led by Velimir Neidthart in 1974.

Story behind Ober-Realgymnasium [6:65-83], also referenced in German as Oberrealschule [7:218], in Banja Luka is, as mentioned before, described in dozens of different books and sources with as many background ideas that include political, religious, social, demographic and other aspects of life in Banja Luka at the time. Indeed, not all those sources are completely unbiased, but certainly are really valuable in understanding the importance of this building for wider areas of Krajina region. Consequently, presenting only architectural data about the building where Ober-Realgymnasium was situated is more complicated when one wants to isolate only one part of the story.

Figure 6. Gymnasium in Sarajevo; main façade view [5:52]

Therefore, looking at the wider image of Gymnasium establishment, one has to give at least introductory information about relevant period. At the time of occupation, except the religious Turkish schools, Banja Luka had only School for Serbian boys and girls founded in 1856, although the Ottoman sultan gave the Decree (tur. Ferman) for school opening in 1835, [8:58] as well as the Elementary school for Catholic female children founded in 1872. [9:15] Also, thing that one has not to emphasize specially, Turkish authorities had a whole network of scholar institutions, unfortunately closed for non-Muslim citizens.

As soon as Austro-Hungarian authorities established primary public institutions, they started to found public schools for all children, both girls and boys. [10:41] First school founded by Austro-Hungarian authorities in Banja Luka, covering more than an elementary level of education, was a three-year programme long Trade school in 1885. Afterwards, in 1898, due to several faults in Trade school program, it was thoroughly transformed and adapted to last 4 years. [9:15]

At the same time, Great classical gymnasiums were founded 1879 in Sarajevo and 1894 in Mostar. There was initiative for new Gymnasium opening, but local authorities from Sarajevo, where State's Government was situated, wanted it strictly in Sarajevo. Answer from Vienna was positive, but they recommended Bosnian authorities to found the school in Banja Luka. [11:114]

Ober-Realgymnasium was opened in school year 1895/1896, but sadly, pupils waited until 1898 to move into the new premises. Until then, the school operated in one of the old Muslim schools. Some other references lead to information that school was located in a private building. [8:61]

However, the Gymnasium was opened on 5th October 1895, which was a really important date in Austro-Hungarian Empire, as it was celebrated as a Name day of Tsar and King Franz Joseph. [9:16] Lectures in the new building started in school year 1898/1899.

It was organized according to known system, actually adapted from one Hungarian model, lasting for 8 years. [7:218]

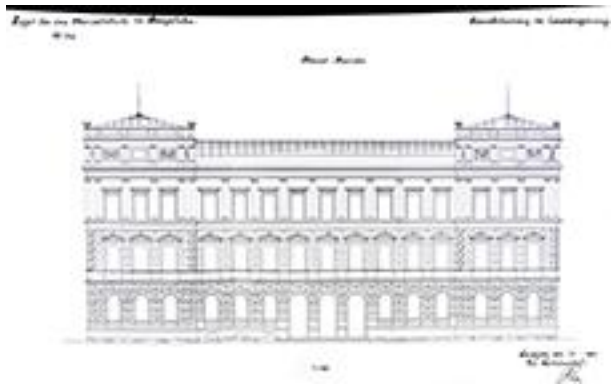

Figure 7. Ober-Realgymnasium in Banja Luka; elevation view from the south, main façade [9:table 2]

Several add-ons were built: first in 1903, then also in 1931. After the partial destruction during the German air force bomb attacks in WWII on 24th and 25th September 1944, building was reconstructed in 1946-1947, under supervision by Ljubica Babić-Goldner. [12:67] The gymnasium was working without problems until 27th October 1969 and the devastating earthquake. It suffered substantial volume of damage and it was completely torn down on 31st January 1970. [13:30-31]

After analysis and thorough research [14, 15, 16, 17, 18] it can be concluded that main project for Gymnasium building is actually an adaptation of a project for Gymnasium in Sarajevo, done by famous architects Karel Pařik, August Butscha and Karl Panek. Karel Pařik had substantial architectural production in Sarajevo at the time of occupation and annexation of Bosnia but also in the time of the Kingdom of Serbs, Croats and Slovenians. [5:52-53]

A floor plan analysis does not give us information about similarities in these two projects because of differences in a backside facilities' design, but a further comparison of the façades and used details to definitely give us enough right to deny the originality of architectural design for Gymnasium in Banja Luka. Also, some other designs were under influence of Karel Pařik, like Higher school for girls in Sarajevo by Karl Panek in 1893 and the School for Serb boys and girls in Sarajevo in 1897 by Ludwig Huber. [19:22]

However, that fact does not degrade the importance of the project and a facility itself. Some authors give higher importance to this building and grade its value higher than the University of Banja Luka founding some 80 years after that moment. [9:16]

The project was done by Austrian architect and technician M. V. Vitzinger and V. Brückner. [12:65] Construction works started in 1892 and were led by Hypolit Pokorný, Chech construction manager. [9:16]

On 1st March 1898 western wing and part of the central corpus were finally completed, but they could hardly handle the number of pupils that were supposed to attend the school. In 1903 central corpus and part of the eastern wing were added on, therefore making the floor plan in F shape. Some authors [12:68] mention architect Josip Blažeković as the

author of the add-on part. The last extension works were in 1931 when eastern wing was completed building finally got, initially designed, E shape. Only the sports hall was not built, and that's the major deviation in comparison to the main project.

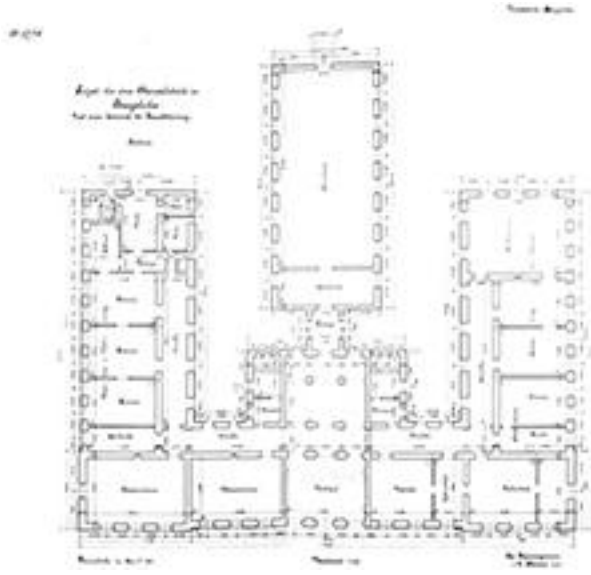

Figure 8. Ober-Realgymnasium in Banja Luka; ground floor plan [9: table 1]

Comparing the Pařik's project from Sarajevo and design in Banja Luka, only a couple of important differences of main façade can be found: different windows in the ground floor, which are rectangular in Sarajevo and completed with an arch in Banja Luka, and attic wall, which has windows in Sarajevo and floral decoration in Banja Luka. The overall atmosphere and impression of proportions, materials and architectural logic are nearly the same.

Figure 9. Ober-Realgymnasium in Banja Luka; view of the southeastern corner after addition of the eastern wing in 1931 [3]

Parts of building that were added later, have completely followed initial idea and implied as the logical extension to earlier phases.

Façade treatment is symmetrical with accents on the side wings, end Avant-corpses, which were pulled out a bit in front of the main façade and finished with a floral decoration on the attic walls. Central volume with entrance was still and uniform, with small accent on

doors in the middle. General design, with rough and fine stone façade plains and windows details, as well with pilaster composition, can be compared to Renaissance revival.

Floor levels were strictly separated and emphasised with the horizontal cornices between each of the levels, making the difference not only between the stories, but also between different materials used on each of the façade planes. Ground and first floor were covered with two different types of stone, and windows were also treated differently. Windows and doors on the ground floor had arch shaped endings with accents on the perimeter of the window. First floor windows were rectangular and had a triangular emphasised lintel with tympanum. Fine carved stone was also visible. Second story had more still design with simple rectangular window but used half-hidden pilasters to emphasise façade's partitions.

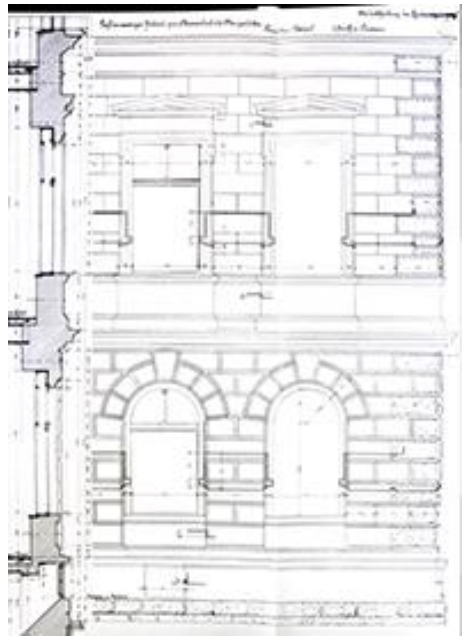

Figure 10. Ober-Realgymnasium in Banja Luka; section detail between ground and first floor with cornices between [9:table 3]

Building was designed with cellar, ground floor and two stories. Sports hall, which was designed in extension of the middle part of the building, was never erected.

Structure system was massive, with the traditional system of construction works realization. Walls were made out of a combination of brick and stone, with wooden beams as the floor structure.

Roof construction was also traditional, made out of wood.

As mentioned, used materials were brick, stone and wood for construction. Different floral decorations and cornices were made in stucco. Roof was covered with clay tiles.

Building was designed and used as a gymnasium. Only at the time of WWII, it was occupied by German forces causing the problems in lecture holding.

As mentioned earlier, it followed general guidelines for gymnasium design in Austro-Hungarian Empire. Floor plans were more or less typical with the usual disposition of classrooms, special cabinets, library, and other service areas like flats for teachers etc.

Figure 11. Ober-Realgymnasium; damages on eastern façade and close-up view of damages on southern façade after the earthquake. Photograph taken 1969 [4]

On 27th October 1969, Banja Luka suffered large earthquake that made substantial damage to many buildings in the wider area. One of those that were partly demolished was Gymnasium. Just like in many other cases, committees were established in order to evaluate the damages, reaching the decisions weather the building should be repaired or demolished entirely. Even though Gymnasium did not suffer as voluminous damages as some other building that were repaired, like buildings in former Herrengasse, it was decided to demolish it entirely in 1970.

Figure 12. Ober-Realgymnasium; demolition sequence. Photograph taken 1970 [4:193]

2.4. Higher school for girls

Original building complex was located in the Street of Banja Luka field, a pedestrian street that was heading towards Military campus Vrbas, just across the Metropolitan Palace. If it existed today, in its full size and shape, an address would be in the Alley of Saint Sava. The remaining parts of the building are located in Street of Simo Šolaja.

Figure 13. Higher school for girls. View of the northeastern corner. In first plan: main façade with entrance zone. Photograph taken in 1905 [20:74]

This school building was erected in obvious Renaissance revival style in 1898, [20:144] but with rather odd proportions and volume disposition of the time built. It had one frontal corpus, torn down after 1969, and back, elongated one, today hardly recognizable and used as a cinema.

Figure 14. Higher school for girls. View of the eastern façade, close-up view of old gym hall; present condition

2.5. Gymnasium of Convent of Sisters of Mercy of Saint Vincent de Paul

The building ensemble of Convent of Sisters of Mercy of Saint Vincent de Paul is located in former Salvatorgasse, later known as Street of Fra Grga Martić, today Serbian Street No 30. The site is in the close vicinity of the Banja Luka Parish Church devoted to the Quest of Blessed Virgin Mary to Saint Elisabeth, which is located just down the street, towards former Herrengasse.

Some contradictions exist regarding the design of Gymnasium building. [21:568-583, 22:140-148] Some authors [1:114-115, 12:89] mention Eberhard Wegnandt as the architect, but some "inside" sources [21:570] are naming Ivan Blažeković. Furthermore, it is unknown if this was the same architect that designed Metropolitan palace for Orthodox church in Banja Luka, there named as Josip Blažeković, considering the fact that in terms of some lingual differences between Serbian and Croatian, names Josip and Ivan are the same.

Nevertheless, data that remain correct for sure are the dates: after buying the construction site in 1907, works started on 29th September 1910, and were finished on 10th October 1910. All construction works and furnishing were completed on 1st November 1911. [21:570]

Building, alongside Convent building in the courtyard, retained its function until the end of WWII, when it was nationalised. Still, scholar functions continued their life in the building; 7th primary school had its seat there until 1992, then from 1992 until 2004 School for civil engineering.

Figure 15. Convent of Sisters of Mercy of Saint Vincent De Paul, Gymnasium building; view of main façade from the northeast. Photograph taken 1910 [21:569]

The process of a denationalization lasted until 1999. In the meantime, reconstruction project for Gymnasium and new project for Convent, that was due to bad condition and damages, torn down, were prepared, which lead to ultimate Gymnasium reconstruction and adaptation works along with new convent building erection. [21:571]

Minor interventions on Gymnasium were undertaken: main structural change was a roof elevation in value of 20 cm, providing conditions for roof area utilization, and façade colour change in grey.

The complex was reopened in 2005, and new Catholic Gymnasium with belonging facilities was founded.

On façade, three zones are visible and distinctive: first zone corresponds to slightly elevated ground floor and cellar that is not completely visible from the outside, second zone is divided from first with a strong perimeter wall, now even emphasised with yellow colour, just like the crown cornice change from second to third, roof zone.

First zone has strong stucco decoration, which is aligned with the firm fence design, making the entrance and link as one whole. Second zone is the interesting one: it has discrete secession decoration vertically displaced between windows, which alongside with small and shallow Avant-corps emphasises vertical guidelines of design. Avant-corps is completed with a decorated gable wall, extending from the hip roof construction.

Also, some small floral and rounded motives can be found in the zone under the crown cornice.

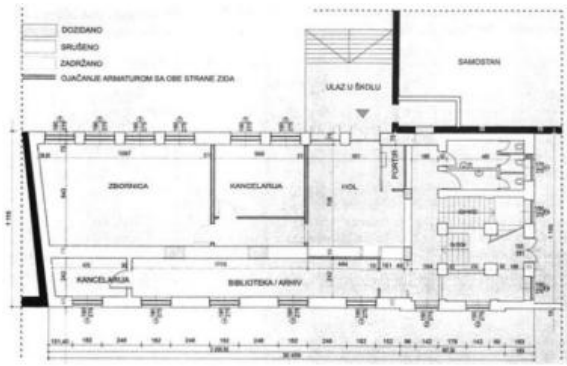

Figure 16. Convent of Sisters of Mercy of Saint Vincent De Paul, Gymnasium building; floor plan of reconstructed building. [12:190]

Some of the decorative elements used here can be found in other designs in Banja Luka, like Evangelistic church and parish house or Banja Luka Stadt Bahnhof, characterized as historicism supporting the Renaissance revival. Interesting is the transformation of the role of the same elements, from situation where they had secondary role, just to frame the outlines and divide the corpses, to design where they make the whole with a floral decoration and other elements emphasizing vertical dimension of the building.

Structure is in the context of the time: massive brick walls in width that exceeds 70 cm. Available documentation does not give us enough information to give conclusions about floor structures, but they are possibly made out of reinforced concrete, due to several reasons: fact that no reconstruction was undertaken on the floor structures in the meantime; visual inspection also confirms assumption and spans are larger than 7m. Some unpublished references state that this building was the first one in Banja Luka with floor structure made out of reinforced concrete.

Roof construction is classic wooden, made out of traditional structural elements.
The first functional concept included rooms for boys in ground floor, girls in first floor and zones for handcrafts and musical education on second floor. Today, function is adapted to new Gymnasium function: on the ground floor are situated common spaces for teachers and administration, while each floor is accommodating three lecture rooms.
As it is presented, brick and concrete are main structural materials. Visible material used for decoration is only plaster: walls are entirely plastered and in recent time coloured with a combination of white and yellow colour. The roof is made out of traditional clay tiles.
present condition After the last reconstruction works, Gymnasium building is in excellent condition and is maintained properly. The convent is in even better, but reasonably, because it is built old not more than 9 years now. Comparing to the old complex design, only sports hall was added behind the school, but it is not interfering with the atmosphere and overall expression due to its "concealed location".
The convent with the school building is on the list of the Provisional National Monuments of Bosnia and Herzegovina. [23]

Figure 17. Convent of Sisters of Mercy of Saint Vincent De Paul, Gymnasium. View of main façade and courtyard side from the northwest; present condition.

2.6. School of Adorers of the blood of Christ

The school building was located in the vicinity of villa Stockmann, where branch named Mary Help of Christians (Mariahilf) had its seat, from 1887. It is the site between former Kaiserstraße and the street today named Street of Petar Kočić, just across the Cathedral complex.

Figure 18. School of Adorers of the Blood of Christ; main façade view. Postcard issued in 1908 [20:186]

Construction works for first convent and school buildings started in 1888. School started working in 1890, and in 1894 first High school for girls was opened. Until 1919 lectures were held in German. [21:594]

The new school building was completed in 1903 and was certainly one of the most prominent buildings in Banja Luka at the time. And of course, one of the best with clear secession design, project that followed all contemporary guidelines. Simple corpus geometry, shallow Avant-corps with emphasized gable wall, everything followed by strong structural decoration with floral motives, which were levelled up from ground zone to the peak in the mentioned gable. Unfortunately, these are the only facts that exist now in available research sources.

The complex was operating until 1943, and on 18th September 1946 due to nationalisation process, building was confiscated and public Gymnasium for girls was founded in it. It was operating until 1969, when it suffered earthquake destruction and was torn down. In its place Army's Centre was built later on, currently being used as a National Assembly.

2.7. Serbian primary school

The site of Serbian primary school, just behind former Orthodox church corresponds to the last part of former Herrengasse, in the vicinity of Military authorities' headquarters in Kaiserstraße. Today, it is the connecting part of Street of Simo Šolaja to the Street of Veselin Masleša. The contemporary address is Street of Simo Šolaja No 1-3.

Figure 19. Serbian primary school. View of the western façade; photograph taken probably before 1969. [22:144]

A new building for Primary school was built in 1907. This school, which was attended by girls and boys together, was founded in 1856, while first Serbian school in Bosnia was opened in 1832. [7:81] Although no clear evidences exist regarding the building in which school operated before 1907, it is sure that it has been just the transfer of the function from one to the new building. [8:58]

Main façade faces the west, and contains all elements needed to understand the concept. Used project is for sure typical and corresponds to dozens of school and administrative buildings built during the Austro-Hungarian period not only in occupied Bosnia, but also in other countries belonging to the Empire. The floor plan is H shaped, with completely symmetrical composition: main volume extending through the whole length of the building is finished with two building parts, extruded in front of the main volume's façade; same move is made in the back-side façade, making the entrance points in the centre more emphasized.

Structural components are simple and include stone walls in the cellar, brick walls in ground floor and wooden construction for floor and roof elements. Walls are plastered and

coloured in ocher colour and discretely decorated with white elements, used around windows and on building corners. Also, some wooden decorative elements are used in contact with roof construction points. The overall experience of the original design is for sure idea of historicism revival, but some contradictions lead to the doubts: stucco decoration, especially floral, is definitely secession influence. This mix can be justified with explanation that the original design and composition was originally from the end of XIX century, but in this particular case it was implemented under strong influence of secession, resulting with this outcome.

Figure 20. Serbian primary school.
View of the southwestern corner; present condition.

The building has a cellar, ground floor and partly usable roof area.

Several changes to original state are recognized: roof ridge straightening, small canopies above the entrance doors and some decorative stucco elements removal.

During the time, the building changed several holders. After the school, Serbian centre was there, and now “Kolo srpskih sestara”, Orthodox kindergarten “Anđelak”, Serbian Choir Association “Jedinstvo”.

Building of “Serbian Primary School” is listed as the Provisional National Monument of Bosnia and Herzegovina. [23]

3. CONCLUSION

As it is indicated in the researched materials and discussed results, the Austro-Hungarian authorities supported the establishment of educational institutions and their belonging facilities after the centuries of educational prohibition for non-Muslims. In some cases, new legal authorities were the initiators and founders of some schools, out of which the most important is the most prominent in the same time, Gymnasium. In other cases, sacred institutions - both Roman Catholic and Orthodox Churches financed the construction of buildings that hosted their own schools.

From the historical point of view, this building typology has very wide stylistic adherence, spanning from local architecture, Moorish revival, Renaissance and Classic Revival to Secession, making it very good showcase of approaches in architecture in Bosnia and Herzegovina during the Austro-Hungarian time. As far as the materials and constructions are concerned, none of these buildings exercised remarkable and elsewhere not introduced properties. It was already established and proven approach of tectonic structural system that used bricks and wood, with rare application of poured and reinforced concrete.

Unfortunately, not all buildings survived later regimes and natural catastrophes. Some of them changed their function becoming the victims of new authorities, while some suffered

damages in earthquake in 1969, and later demolished in order to be replaced by new buildings illustrating the values of newly established society. In contemporary perspective, in terms of heritage, that these buildings and their former sites have, it is important to point out their outstanding potential. It is only to doubt weather harsh conditions in this society are wide enough to let them be recognized and protected from further deterioration. Fortunately, the sites preserved until today are maintained, but it remains questionable if it will stay the same in future. That is why it is important to raise the awareness of the importance of tangible heritage, historical architectural values and built environment that makes our cityscapes so original and irreplaceable.

Undoubted, however is the fact that school buildings erected in Banja Luka during the Austro-Hungarian era left inerasable mark in both local and regional history. It is irrelevant to compare the influence of the schools themselves and their architecture only, but some conclusions can be drawn. Whether the schools got destroyed, or still serve their original function, in the cultural identity of Banja Luka, they are all carved as important milestones for education, culture and prosperity, foremost the Gymnasium, that produced outstanding number of prominent young people that had important role in later historical development of Banja Luka. Moreover, very important buildings are the one that are preserved, and still act as strongholds of national and religious identity of all citizens of Banja Luka, like Gymnasium of Convent of Sisters of Mercy of Saint Vincent de Paul or Serbian Primary School, which even upgraded its role in cultural horizon. When discussing on effects of architecture of these buildings to surrounding streams, it is more appropriate to refer to mutual reflections of general architectural trends in whole Bosnia and Herzegovina, as influences and highlighting projects were easily accessed and used as role models. It is clear and shown that Austro-Hungarian production in Bosnia and Herzegovina did not offer particularly original pieces of architecture, but nevertheless has at least started to fill the gap of the Modern History architecture, that was almost entirely wiped away during the Ottoman time. Unfortunately, upstream that began in 1878, at least when the architecture is concerned, was brutally brought to an end at the dawn of the WWI, later being continued in different social, political and religious circumstances.

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35| Прегледни научни рад
Review paper
doi 10.7251/STP1813487J ISSN 2566-4484

RAZVOJ METODOLOGIJE ZA FORMIRANJE TIPOLOGIJE ŠKOLSKIH ZGRADA U SRBIJI

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Abstract:

Nakon razvoja i definisanja Nacionalne tipologije stambenih zgrada Srbije, isti istraživački tim sa Arhitektonskog fakulteta univerziteta u Beogradu razvio je i metodologiju za formiranje tipologije školskih zgrada. Za ove potrebe, definisan je poseban postupak prikupljanja podataka, kreiran upitnik i sproveden popis školskih zgrada. Dobijeni podaci predstvljaju deo baze javnih zgrada, i korišćeni su za potrebe formiranja tipologije školskih zgrada, kao i procene energetskih performansi javnih zgrada u okviru projekta EmBuild (Horizon2020). U radu su prikazane i objašnjene metodologije formiranja baze podataka i njihovog prikupljanja, kao i metodologija formiranja tipologije školskih zgrada.

Keywords: javne zgrade , unapredjenje energetske efikasnosti, tipologija, školske zgrade

METHODOLOGY DEVELOPMENT FOR CREATION OF SCHOOL BUILDINGS TYPOLOGY IN SERBIA

Abstract:

After development of methodology for formulation of residential building typology, the same research team from the Faculty of Architecture University of Belgrade developed and formulated the methodology for typology of school buildings. For this purpose, specific method of data acquisition was designed and conducted. Obtained data represent part of the public buidling database and were further used for defining typology of school buildings, as well as estimation of energy performance of public buidlings within EmBuild project (Horizon2020 framework). In the paper the methodology of creating this database and gathering information, as well as further work on definition and final typology of school buidlings are presented.

Keywords: public buildings, energy efficiency improvement, typology, schools buildings

INTRODUCTION

As the member of Energy community, Serbia has the obligation to renovate 1% of public buildings stock owned and used by the central government while according to EC Directive it should be 3% for other EU member states. The incentive to research the quality of public buildings was provided by the fact that they, along with residential buildings, account for the largest share of the country's building stock and that their deep renovation can greatly reduce energy consumption and carbon dioxide emissions. Also it is expected that public building refurbishment induces refurbishments in residential sector and includes a whole range of wider benefits: economic savings, better work environment, less health problems, local economy development, raising awareness about energy efficiency etc. Long term investment mobilization in public sector is expected to be defined through National renovation strategy, which was due in October 2017. First public buildings that were investigated were educational buildings - schools and kindergartens, through the method of typology.

The same research team from the Faculty of architecture University of Belgrade that developed the methodology for residential buildings and published several monographs on this subject, this time supported by the researchers from Faculty of mechanical engineering and Faculty of mechanical engineering, developed principles and methodology for the school buildings field survey and typology formulation. As the previous work on typology of residential buildings, this research project Energy Efficiency in Public Buildings was also supported by the GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit). The collected data are also used for Horizon2020 EmBuild project (Empower public authorities to establish long-term strategies of renovation of public buildings) for the development of long term renovation strategies on local level.

Although EU Directive [1] defines the obligation of EU members to renovate the public building stock, no detailed researches about characteristics of public buildings is published yet. An overview of several building stock models and their classification and characterization is found in literature [2], as well as new model proposals [3]. The greatest number of published papers analyses and discusses typologies for residential buildings [4] [5] [6]. Faced with the lack of published public building typologies, the decision of the coordinators of the team was to rely on their own experience in developing different residential building typologies on local and state level [7] [8] [9] [10], and vast literature and legislation research on the characteristics of public buildings, especially educational buildings: schools and kindergartens.

1. SCHOOL BUILDINGS IN SERBIA

The basic condition of any valid statistical analysis, as the basis for typology formulation, is the database with reliable data and with the necessary number of entries. Regarding information n public buildings, there is no uniform and comprehensive list of Serbian public buildings. Regarding educational buildings, there are several databases publicly available:

- The Statistical Office of the Republic of Serbia regularly publishes updates on its activities on its website. School buildings are covered in several sources: as Statistical Yearbook of the Republic of Serbia – Education, published annually, [11] and within the Communiqués: Primary School Education in the Republic

of Serbia and Secondary Education in the Republic of Serbia, [12] published at the beginning and end of each school year.

- The Ministry of Education, Science and Technological Development of the Republic of Serbia also publishes data on schools and school buildings in Serbia [13].

As it was noticed that neither of the sources contained defined building characteristics (characteristics of thermal envelope) and characteristics of mechanical and electrical systems necessary for typology and energy characteristics definition, it was concluded that a comrehensive survey should be conducted.

1.1. SCHOOL BUILDINGS SURVEY

The inventory of school buildings was compiled in 2016 and 2017. For this purpose, Serbia was divided in 6 regions and for each region a group of experts was established. The basic idea was that beneficiaries, public officers and energy managers in municipalities have enough data and knowledge about public buildings on the territory of their municipalities. In practice, the support from the experts was needed on several occasions and some questionnaires were filled by the employees of the public building in question. Such a situation resulted in several questionnaires that were not filled or were filled with incorrect data. Later, the obtained data were entered into a specially created database (not publically available) and then retrieved, processed and searched using custom-designed software.

1.1.1. The questionnaire

The questionnaire consisted of 78 questions divided in several groups:

- The first level of the questionnaire with five questions identified public bodies. In practice, one public body could dispose with several independent buildings on different locations. When school buildings are in question, one school can have several smaller, district schools under its jurisdiction.
- The second level with 14 queries specified the location (address, cadastral parcel municipality, number and sub number) and basic data about the building: when it was built, whether it was purpose-built, whether an energy efficiency study or energy audit were conducted, and whether it was issued the Certificate of Energy Performance of Buildings (energy passport);
- The third and most comprehensive level had 48 questions. It included three sets of questions regarding: architectural characteristics of buildings relevant for its energy efficiency (shape and size of the building, number of floors, type of roof, type of windows, external walls, floors, and ceiling characteristics…), mechanical installations (type of the heating system, type of the boiler, fuel type, boilers for preparation of sanitary hot water…) and which was filled only for schools and kindergartens, and which included the architectural characteristics of the building as well as the applied mechanical and electrical installation systems.
- Special part of the data base consisted of photographs of the school buildings. Those photographs were used for cross checking of the entered data and for choosing the real building which is the representative of the model building.

After the compilation of the inventory, the formation of the database and the validation of the data, it was found that a sample of 1,857 school buildings was formed. As according to the Statistical Office of the Republic of Serbia [11] Serbia has 3890 school

buildings, it was concluded that the number of surveyed buildings entered into the database represents a representative sample and that can be the basis for making valid conclusions.

1.1.2. Size and year class of school buildings

In order to define the basic typology matrix for school buildings several factors were investigated and considered. The research team analysed the development of school buildings in Serbia through history, the regulations regarding design process of school buildings that influenced organizational schemes, regulations on thermal characteristics of the building and building thermal envelope elements. The advancements in construction technology and the development of systems, products, and materials were also considered. Finally, expert knowledge of the progress of architectural thought and styles in the design practice particular to our country was used as a vital criterion in establishing the typology. The basic matrix was defined by four time classes

- before 1945
- 1945—1970
- 1971—1990
- after 1991

and three classes by the school size (gross floor area):

- area smaller than 500m2
- area from 500 to 2000 m2 and
- area larger than 2000 m2

resulting in the matrix with 12 building types.

1.1.3. Cluster analysis

The method of clustering, using the k-means algorithm in cluster analysis has been adopted as the main principle for distinguishing of defining characteristics. Clustering methods groups a set of objects into clusters so that objects in the same cluster are more similar to each other than objects in different clusters according to some defined criteria [14], or in other words clustering aims at finding smaller, more homogeneous groups from a large heterogeneous collection of items [15].

These similarities in the case of building stock assessment are represented by characteristics that influence building energy performance, defining the groups of buildings by their predefined characteristics.All buildings from the sample that belong to a certain type (size class) and period of construction (age class) were grouped according to chosen indicators: size, number of floors, compactness, and type of roof and façade wall predominant material. The number of indicators in cluster analysis is limited, so 5 parameters were chosen that are considered to describe the typical building in the best way. This practically means that within a period of construction and for a size type the maximum of five groups of buildings are defined. Out of the identified groups, the most typical is the one with highest representation (in %). If two groups have the same (or similar) representation than the other set of building characteristics should be considered also and a type and sub type should be defined. In this way, the description of typical buildings is rendered and serves as the model buildings (Table 1).

Table 1. Description of the model school buildings

Period	Analysis parameters	GFA < 500m2	GFA 500-2000m2 type / subtype	GFA >2000m2 type / subtype
Before 1945	1.GFA 2.No. of floors 3.Compactness 4.Roof type 5.Facade wall material	235m2 GF Compact Pitched roof Brick	810m2 /1310m2 GF / GF+1 Compact/partially complex Pitched r. / pitched r. Brick / brick	2890m2/ 3185m2 GF+1/ GF+2 partially com./ complex Pitched r. / pitched r. Brick / brick
1945 – 1970	1.GFA 2.No. of floors 3.Compactness 4.Roof type 5.Facade wall material	145 m2 GF Compact Pitched roof Brick	1160 m2 GF+1 Compact Pitched roof Brick	3010 m2 GF+2 Complex Pitched roof Brick
1971 – 1990	1.GFA 2.No. of floors 3.Compactness 4.Roof type 5.Facade wall material	255 m2 GF Compact Pitched roof Brick	1610 m2 GF+1 Compact or complex Pitched roof Brick	2660 / 5045 m2 GF+1 / GF+2 Complex/ partially comp. Pitched roof Brick/concrete
After 1991	1.GFA 2.No. of floors 3.Compactness 4.Roof type 5.Facade wall material	230 m2 GF Compact or complex Pitched roof Clay block	995 m2 GF+1 Compact Pitched roof Clay block or brick	6200 m2 GF+2 Complex Combined roof Clay block or concrete

1.1.4. School buildings typology matrix

As it was mentioned before, the total number of school buildings in Serbia is 3890. Comparing that number to the number of surveyed buildings and to the distribution of number of buildings in the matrix (in %) it was concluded that for some types there are not enough representatives that will give statistical sample big enough for decision making and for the selection of real representatives. As the benchmark the representation

of 1.5% was adopted and types with smaller sample were deleted from the typology table (Table2).

Table 2. Distribution of schools by period of construction.

Period of construction (year)	Small schools (below 500 m2) %	Medium-sized schools (500-2000 m2) %	Large schools (above 2000 m2) %
before 1945	13.37	6.92	5.58
1946 - 1970	15.30	10.33	12.39
1971 - 1990	7.76	6.32	9.51
after 1991	1.36	1.16	1.77
N/A	1.23	0.62	0.49

By thorough examination of the database, using a software that was developed exclusively for this purpose, school buildings were identified that best corresponded to the descriptions of model school buildings, and they became the real representatives of the model buildings (Table 3.).

Table 3. The typology matrix of the chosen representative buildings.

	1_SMALL <500 m²	2_MEDIUM 500-2000 m²	3_LARGE >2000 m²
A <1945		 	 
B 1946-1970			
C 1971-1990			 
D >1991			

An example of further calculations done for each of 13 identified types are given in figure below (Figure 1). Energy class based on energy need for heating [16, 17] is determined for designed state (0), state after most frequent interventions, like window replacement in the last decade (I), and three levels of improvements (1,2,3). By multiplying specific energy need with the data about distribution of each type in the building stock, data about estimated current consumption and savings after improvement scenarios are calculated.

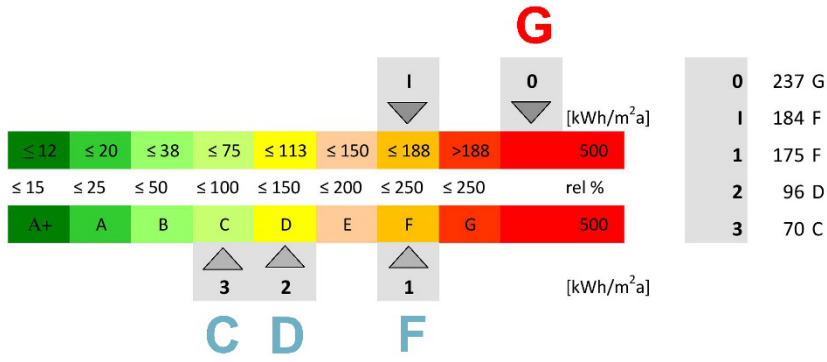

Figure 1.

2. CONCLUSIONS

Building typologies are the method for making the complete overview of the building stock based on the chosen representatives. After National typology of the residential buildings Serbia has developed the school buildings typology, as the first typology of public buildings, which should enable assessment of this part of public building stock energy consumption and improvement potential.

For the purpose of relevant typology it is necessary to have relevant data for sufficient number of buildings. As there is no comprehensive data about public building stock in Serbia, these data were obtained by a vast survey that included cooperation of local representatives, and a three stage questionnaire which was used to obtain all data about building characteristics relevant for issue of their energy performance. Results of the survey form a database which was used for further research, which counts about a half of the entire school building stock in Serbia (about 2000 buildings).

Further steps included typology matrix definition based on cluster analysis of obtained data, and definition of model buildings for each building type. Real representative of model building was then found among analyzed portion of building stock. Energy performance characteristics of each representative were calculated, as well as improvement scenarios. Using the typology tool, with known distribution of each type in the entire building stock, calculation of possible energy savings and CO2 emission reduction in the process of buildings rehabilitation is calculated.

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36| Прегледни научни рад
Review paper
doi 10.7251/STP1813496P ISSN 2566-4484

THE POSSIBILITY OF REVITALIZATION AND PURPOSE ALTERATION OF SCHOOLS IN CRNA TRAVA MUNICIPALITY

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Abstract:

Large migrations in the postwar period have mostly influenced stagnation, and demographic depopulation of the rural territory of Crna Trava. The fate of the village was also shared by educational institutions, there were around 20 them in this municipality. Along with the loss of basic educational functions, the care of the local government for this type of institutions stops. The majority of schools was torn down or is in a very bad condition, and the existing ones are still working with a small number of students. This paper analyses the problem of regeneration of existing buildings that are decaying and losing their purpose. The focus is on examining the possibilities of converting these buildings into some other appropriate purpose in order to save the important historical and architectural material, to create conditions for small business development, cultural events, etc. In general, the institutional capacity of the village would be increased, and thus the conditions of life would be raised to a higher level.

Keywords: schools, Crna Trava, migration, education, revitalization, reintegration

MOGUĆNOST PRENAMENE ŠKOLSKIH OBJEKATA - STUDIJA SLUČAJA, OPŠTINA CRNA TRAVA, JUŽNA SRBIJA

Apstract:

Izražena migraciona kretanja u posleratnom periodu u najvećoj meri su uticala na stagnaciju i delimično ili čak potpuno demografsko pražnjenje ruralnog prostora opštine Crna Trava. Sudbinu sela dele i obrazovne ustanove, kojih je na teritoriji opštine bilo oko dvadeset. Gubljenjem osnovnih funkcija obrazovanja, prestaje i briga lokalnih samouprava o objektima ovog tipa. Većina školskih objekata je porušena ili je u lošem stanju, dok samo manji broj njih radi sa veoma malim brojem učenika.

Rad se bavi problemom regeneracije objekata koji propadaju i ostaju bez svoje funkcije. U fokusu je ispitivanje mogućnosti prenamene objekata u odgovarajuće sadržaje, čime bi bio sačuvan vredan istorijski i arhitektonski materijal, stvorili uslovi za razvoj male privrede, uslužnih delatnosti, kulturnih manifestacija i slično. Generalno, bio bi uvećan institucionalni kapacitet sela, a samim tim uslovi života podignuti na viši nivo.

Keywords: škola, Crna Trava, migracija, školstvo, revitalizacija, , reintegracija

1. INTRODUCTION

Crna trava is a municipality located in southern Serbia, near Bulgarian border. Once famous for its builders, who made impressive buildings all around Serbia, this area today has another label. Nowadays, Crna Trava is one of many municipalities with a distinctively negative demographic structure, a municipality which disappears.

The geographical location of this region, the absence of any kind of production, and the impossibility of employment, make the young people from this place move to larger cities.

With this migration, the population is decreasing and its structure is changing. Although the educational system in this municipality has quite a long history, due to a very small number of children in Crna Trava, only few schools are open with a small number of pupils.

The school buildings are losing their primary function so they are left to a total decay. This paper shows a historical overview of the educational system and schools in this area. It also shows the current state of educational buildings in the Crna Trava municipality. A drastic decrease in the number of children in schools is indicated, and thus the loss in educational purpose of these objects. Would the purpose alteration of these schools at least have the effect of reducing the negative demographic picture and somewhat returning the population to the village? Would, by increasing the institutional capacity of the village by reintegration of abandoned educational facilities, improve the living conditions in the village? Since low quality of life is one of prime reasons for inhabitant migrations from small villages to big cities, would revitalization of these schools create the climate for a temporary or even permanent population recovery?

2. THE ANALYSED AREA

In the south-east of Serbia, 66 kilometers from Leskovac as a center point of the Jablanica district, in the upper and middle basin of the Vlasina river, surrounded by the Grdelica gorge and a valley of Južna Morava in the west, the Suva Planina mountain in the north, the Bulgarian border in the east and the Verdenika mountain and the Vlasina lake in the south, there lies a wide mountain region with the area of 312 km2, named Crna Trava [1]. It belongs to the Jablanica district and it's one of the smallest municipalities in the border zone. The neighbouring municipalities are Babušnica, Vlasotince, Leskovac, Vladičin Han and Surdulica.

Its geographic position makes it isolated from the main roads. The only important communication is its road connection to Leskovac through Vlasotince, and to Vladičin Han through Surdulica, which is, later, connected to the Belgrade-Skoplje motorway.

Crna Trava is a mountainous area with a long history of the settling tradition. According to the population census from 2001, there were 2563 inhabitants located in 25 villages and even more districts - settlements that now hold less than a few households. The census conducted in 2011 provided devastating information. There are only 1663 inhabitants in this municipality [2].

A bit over two thirds of the total number of inhabitants are people living in rural areas. Most of the settlements, which are otherwise fragmented, scattered and compact, with a very unfavourable demographic structure of the population, have fewer than 200

inhabitants. According to the number of people living here, only a few rural settlements stand out in a positive sense: Gradska, Preslap, Darkovce, Krivi Del and Zlatance.

Figure 1. *Geographic position of Crna Trava and the picture of municipality [3][4]*

3. POPULATION

The census was carried out in various time periods, based on which we can carry out demographic and economic analysis of the development of the village. Periods are divided into those that took place before and after the Second World War:

- Censuses that include a period from 1878. to 1931. and
- Censuses that include a period from 1948. to 2011. [5][2]

Table 1. Population according to the census from 1878 to 1931

Year	1878.	1884.	1890.	1895.	1900.	1905.	1910.	1921.	1931.	Change in pop. from 1878.
Number of inhabit.	8864	9044	11284	10098	14770	12065	13537	10825	12651	+42.7%

Table 2. Population according to the census from 1948 to 2011

Year	1948.	1953.	1961.	1971.	1981.	1991.	2002.	2011.	Change in pop. from 1948.
Number of inhabit.	13614	12902	12319	9672	6366	3789	2563	1663	-87,8%

Population is an indicative indicator of the negative development of this municipality. The analysis, so far, shows that the municipality of Crna Trava, in the second part of XX century, was affected by unfavorable demographic tendencies. In the period between 1948 and 2002 a drastic decrease in population occurred (81.2%) on a municipality level, and by the year of 2011 population decreased by 87.8%. In urban areas this percentage is 72.2% and in rural 82.8%. The decline in the number of people in the period between the last two censuses is about 35%, which is a very worrying fact. The main factor in reducing the number of inhabitants is the mass migration of the population caused by a one-sided industrialization process, an unbalanced development policy (neglecting mountainous areas) and poor infrastructure (primarily road), or even the absence of it, and minimal, and in some places no institutional content. To a large extent, there is a negative population growth, which has been in the tendency of decline since the 1960s.

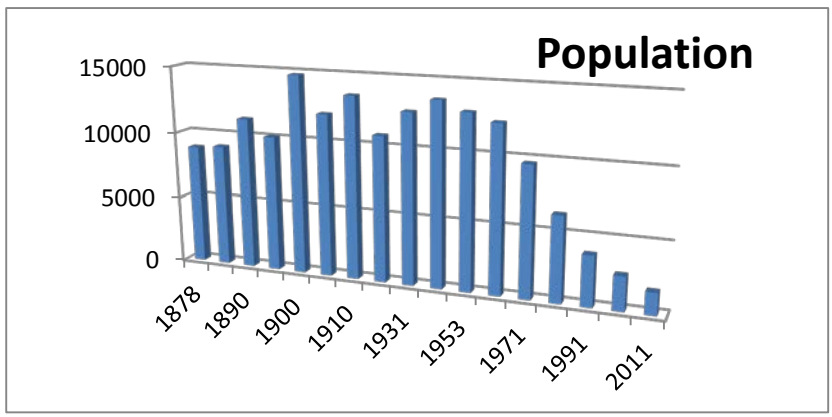

Figure 2. *Migrations in the period from 1878 to 2011 in the area of Crna Trava municipality, based on Table 1 and 2*

Aging, reduction in the number of inhabitants and migration of the young population are factors that have influenced the reduction of the number of fertile population, the decline in the birth rate and the increase in the mortality rate.

Table 3. Change in the age structure of the population in the last 20 years, based on [5]i[6]

	Population		Percentage	
	1991.	2011.	1991.	2011.
0-7 (0-9)	204	66	5,4	4,0
7-18 (10-19)	347	103	9,2	6,2
18-60 (20-50)	2039	759	53,8	45,6
over 60	1199	735	31,6	44,2

The age structure of the population is extremely unfavorable. Proportionally, the majority of the population is over 60 years old, with as much as 44.2%. Youth participation (15-30 years old) according to the 2011 census is 11,72%. Compared to the 2002 census, this population contingent was reduced by 40% [3].

According to the data from the last census in 2011, there were 1,663 inhabitants in the whole territory of the municipality of Crna Trava. Some residents live in other places and are registered in this municipality, which additionally reduces the number of enumerated residents. A part of the elderly population is spending only summer months in this area, and during the winter they reside in the cities with their relatives. If this information is taken into account, the actual picture of the number of inhabitants will be even worse.

3.1. POPULATION PROJECTION

Municipalities, therefore, are characterized by small settlements of predominantly agrarian type, with very unfavorable demographic structure of the population. Among them there is a large number of settlements in which individual districts have been extinct and some have completely disappeared.

For the sake of illustration according to the 2002 census, there were 122 inhabitants in Brod, which is a decrease of 90.6% compared to 1948. According to this trend of declining population, in the coming period, Brod will probably become an uninhabited place. For now, out of a total of 28 districts, even 11 of them do not have a single inhabitant [5].

The analyses related to the population projection for other places according to the so-called tendency projection would give approximately the same results that could be characterized as particularly unfavorable, practically disastrous. Crna Trava has the most favorable position in this area. Here, because of the existence of primary and secondary schools, the vicinity of the post office, the health center, the pharmacy, as well as the available trade facilities, the largest number of inhabitants lives exactly here. According to the population projection, in 2015 there are 1409 inhabitants on the territory of the entire municipality [7]

4. HISTORY OF EDUCATION IN CRNA TRAVA

The first written documents referring to the cultural needs of the inhabitants of this region, as well as the existence of cultural institutions - schools, only originated from the beginning of the XIX century [8]. Jovan Hadži Vasiljević [9] wrote about the advanced school at the beginning of the XIX century, then it is mentioned in the magazine "Prosvetni glasnik" ("Educational Gazette"), "Učitelj" ("The Teacher"), "Leskovački glasnik" ("The Leskovac Gazette") [8]... From these, and many other papers it can be concluded that until the liberation from the Turks, and even later, the school in Crna Trava was an important center of literacy and culture of the entire wider area.

In 1867 the magazine "Srpstvo" wrote about the development of "modern education in Serbia" in Crna Trava. A book, called "Educational and political conditions until the Serbian - Turkish wars in 1876-78" mentions Crna Trava as one of the places in Serbia where new Serbian school started to develop long before 1870 [8].

According to the "Chronicle of the Church in Crna Trava" first schools in this area were private, and according to the magazine "Srpstvo", issued on 15.04.1888., the official opening of first schools took place in: Crna Trava (20.10.1867.) and Ruplje (late 1867). [10]. In the report of military administration of Leskovac a school in Dobro Polje was mentioned in 1878. According to Jovan-Hadži Vasiljević, the school in Crna Trava was opened in 1830. In 1890. Tihomir Đorđević, staying with associates in Crna Trava wrote that school was formed in 1836. and the one in Ruplje in 1860. In the report of the head of the district of Leskovac from 1878, a list of schools from the Crna Trava region that worked during Ottoman domination was given:

- The school in Crna Trava: works in a private building, in one room, without classes. The school has 15 students [11].
- The school in Ruplje: located in a small room in a private, straw house, without furniture. There are 20 students [11].
- The school in Dobro Polje: worked in one of the rooms in a church, but it's closed now.

In January 1881 in the Serbian Parliament, a "Rulebook on the Construction of School Buildings" was adopted, according to which no existing village school was able to work. The rulebook stipulated, among other things, the following: the school must be built by the municipality according to the drawing, the building must be made of hard material, erected in a pleasant place, outside wetlands, roads and kafanas (a type of a restaurant or tavern), in a place with drinkable water and a large plot. Classrooms must be built with thick walls, and the biggest classroom has to have the area of 70 m2 and the volume of 270 m3. In addition to the school building, it is necessary to build a flat for teachers, a shed for storage, the land for the teacher to cultivate, etc. [5].

Because of this law, first schools with satisfactory architecture and hygiene conditions were built. The elementary school in Crna Trava, the construction school, the school in Brod, Mlačište district, are some of buildings that were built with educational function as their primary purpose.

In the territory of the municipality until 1941 there were the following schools: [5]

Table 4. School names by districts with the year of beginning of work, according to [5]

Reg. No.	Place	School name	Starting date
1.	Crna Trava	"Kralj Petar I"	1863.
2.	Ruplje	"Car Dušan"	1867.
3.	Brod	"Princ Tomislav"	1910.
4.	Mlačište	"Kralj Aleksandar"	1920.
5.	Dobro Polje	"Mrnjavčevići"	1920.
6.	Darkovci	"Sveti Sava"	1920.
7.	Jabukovik	"Stefan Nemanja"	1920.
8.	Gornje Gare	"Kralj Petar I Osl."	1922.

A few school were occasionally opened during this period:

- In Preslap, from 1905 in a private building and from 1909 in a newly built school
- In 1931 in Kozilo
- In 1933. in Gradska
- In 1934 in Čuka, Gornje Gare, Jabukovik and Krivi Del,
- In 1935 in Zlatanac and Jovanovce[1]

Therefore, as much as 17 schools existed in this area, before the Second World War.

The number of students in schools was different depending on the circumstances. According to statistics, in every school in municipality, the highest number of pupils was school year 1945/46 because that year the students who stopped school due to World War II also enrolled. In other periods, the largest number of enrolled students was school year 1961/62. 1764 pupils, and the smallest in 2008/09 - 69 students, or 3.91% compared to the school year 1961/62 [5].

Table 5. The number of students in schools from 1961to 2009

		School year 1961/62.			School year 2000/01.			2008/09.
No.	Elementary school	I-IV	V-VIII	Total	I-IV	V-VIII	Total	Total
1.	Brod	68	98	166	1	-	1	Closed
2.	Crna Trava	47	147	194	26	46	72	44
3.	Zlatanci	63	-	63	1	-	1	Closed
4.	Jovanovci	32	-	32	Closed			Closed
5.	Čuka	27	-	27	Closed	-	-	Closed
6.	Obradovci	79	-	79	Closed	-	-	Closed
7.	Todorovci	34	-	34	Closed	-	-	Closed
8.	Ruplje	68	92	160	Closed	-	-	Closed
9.	Pavličine	36	-	36	Closed	-	-	Closed
10.	Dobro Polje	40	51	91	Closed	-	-	Closed
11.	Kozilo	19	-	19	Closed	-	-	Closed
12.	Krstićeve	18	-	18	Closed	-	-	Closed
13.	Sastav Reka	-	79	79	4	5	9	5
15.	Krivi Del	69	-	69	8	-	8	3
16.	Gornje Gare	68	-	68	Closed	-	-	Closed
17.	Darkovce	140	55	195	Closed	-	-	Closed
18.	Gradska	114	89	203	12	23	35	14
19.	Kalna	72	61	133	1	-	1	1
20.	Preslap	71	-	71	2	-	2	Closed
21.	Mlačište	46	-	46	Closed	-	-	Closed
Total		1092	627	1764	55	74	129	69

The mass migration of the population from this area has caused the closing down of most schools so that their basic functions - education and upbringing are realized irrationally because of the small number of pupils, in six schools. Today's educational web consists of 5 elementary schools, of which one is in the biggest settlement - Crna Trava (Elementary school "Aleksandar Stojanović") and the rest (4 schools) are separate departments in Sastav Reka, Gradska, Krivi Del and Kalna [3].

Table 6. The enrollment rate in elementary and secondary school [3]

	2010.	2011.
Elementary school registration	5	4
High school registration	182	175

Technical school (High school) in Crna Trava includes a student dormitory and complete accompanying contents (kitchen, gym, etc.). It also has a pre-school with two educational groups (18 children) [3]. Except for a small number of facilities which kept their function, the rest of the buildings that previously had educational role, are now abandoned. The interest of the local government and the authorities as well as their relation to these facilities is evident by insight into the state of the facilities in the field: the facilities are in a very bad condition, on the border, in the near future, to be totally demolished.

4.1. REVIEW OF SOME SCHOOLS

4.1.1. Elementary school in Crna Trava

Due to previously mentioned law on building educational facilities, in 1886 in Crna Trava, the first school with two classrooms was built, but was demolished in 1915 by Bulgarians. At the same spot, in 1921 a new school was built, with 4 classrooms, 2 offices and a hallway. Unfortunately, this school was burned, also by the Bulgarian army, on 20th of April, 1944. Thus, in 1944, 543 elementary school students in Crna Trava continued their education in private buildings converted to this purpose [1].

In 1949 a new school was opened for the purpose of elementary education. The building had 6 classrooms, 324 m2, with three offices, a large hall, two apartments for teachers and a courtyard [8].

Figure 3. *The school in Crna Trava today, photo A.Momčilović Petronijević*

Today's school is a two-storey building. It includes eight classrooms, offices and a library. Some of the rooms are, considering the number of students, used by a bicycle club "Orlovac".

4.1.2. Technical School in Crna Trava

In 1920/21 in addition to the primary school, Crna Trava also got the Technical School for the improvement of masonry, which was renamed the State construction-craft School in 1930 by the decision of the then Ministry of Trade and Industry [8]. By forming this school, the primary school in the city got its full development.

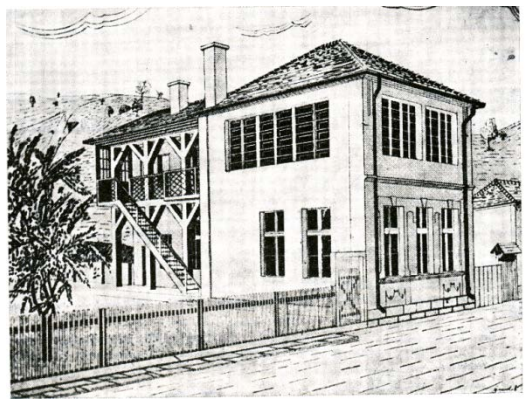

Figure 4. *Ex masonry school in Crna Trava [12]*

Masonry school tradition in Crna Trava lasts for almost one century. Between the two world wars, Crna Trava, among other schools, was almost without a single craft school. After the end of the First World War, by the decision of the Ministry of Trade and Industry, on 5 September 1919, a new masonry-stonecutting workshop was organized, and it worked from 1920 to 1925.

Figure 5. *Technical school today, photo A.M.Petronijević*

In 1927 a new school was opened, and it was operating during school years 1927/28 and 1928/29. In 1930 the state masonry school started but unfortunately it was closed in 1941. After the Second World War, the masonry craft school was renovated, and in

September 1948 it became a secondary technical school. The masonry educational center in Crna Trava is currently located in the Milentije Popović Memorial-school (Milentije Popović was born in Crna Trava). The memorial school is an architectural complex that includes a student dormitory, classrooms, offices, a library, a gym and open field for sports activities. The useful space of the building is 5,400 m² and the same size is open and the area for rest and recreation of students [13].

4.1.3. The school in the Brod district

The school building in Brod was finished in 1909 and it was covering the area of 120 m2. It included one classroom (50 m2), two hallways, a dining room, an office, a two-room apartment for a teacher and a basement that was used as a storage room. In April 1944 this school was burned to the ground. On the foundations of the old building two classrooms and an office were built. One more classroom was added in 1949 along with the teacher's apartments. Due to the increase in the number of students in 1957, three more classrooms and sanitary facilities were added. Prior to this extension, the problem of lack of space was solved by teaching in other districts in private homes [5].

After the reconstruction of the Saint Pantelejmon church in Brod, which is located near the school, wealthy individuals started the initiative for reconstruction of the school and for its new role as accommodation facilities. Inside the school borders were also monk cells, a dining room, workshops, etc. Unfortunately, this idea was dismissed, and the school was completely demolished in the meantime.

Figure 6. *School in Brod today, source http://www.crnatravaprojekt.co.rs/index.php?option=com_content&task=view&id=23&Itemid=37 , accessed may 2009*

4.1.4. The school in the Mlačište district

The school in Mlačište was opened in 1920. It also included the teacher's apartment. The organized charity made it possible for a new facility to be built, which included three classrooms, a hallway, two apartments for teachers and an office. This school was unfortunately closed in 1978 because of the small number of students [14].

Figure 7. *Old school in Mlačište (on the left) and school today (on the right), photo J. Momčilović*

Figure 8. *Abandoned schools - Jovanovci district, photo J. Momčilović*

Other schools in the Crna Trava municipality are similar to these, by the size and the content.

5. CONCLUSION - SOLUTION PROPOSAL

The continuation of such a highly depopulating tendency can only be stopped by the joint action of interested groups for the development of areas: experts, authorities and the local community.

Municipality development program [3][4], research of economic development, tradition and natural predisposition, point to the following activities in the future: agriculture, forestry, water exploitation, small business, hunting and fishing, services and tourism.

Revitalization of schools could bring new educational content for each of these activities. For example, in the agriculture area, where the accent is on "biological cattle breeding" and production of healthy food, these facilities could be used for accommodation for seasonal workers, warehouses, stocks, purchase stations, etc. In the

domain of small business, purpose alteration could clear space for new sections such as purchase, processing and packing of honey, purchase stations for herbs, forest fruits, mushroom dryers. In the domain of services, new restaurants or shops could be opened. In the hunting domain, which has long tradition in this area, it could be a new hunting lodge. When it comes to cultural events purpose alteration could open up activities such as art colonies, music colonies, schools in nature, or even blueberry and mushroom days.

Revitalization of these schools would also contribute to tourism that has almost disappeared from this area, as new mountain cottages and huts.

One more season for revitalization would be preservation of education history in the form of historical and architectural material.

Revitalization examples, although a few, almost always bring positive results. As mentioned, one of the rooms in the school in Crna Trava was given to a bicycle club "Orlovac", which is known for incredible results in and outside Serbian borders. The club uses this room as office space. Some of the classrooms in the technical school were repurposed into a masonry museum, where visitors could learn something about building techniques in this area, old tools which were used and objects that were built.

Figure 9. *A positive example of a partial purpose alteration - the school in Crna Trava and district Zlatanci, phto J. Momčilović*

In the elementary school in Zlatanci, one of the rooms is used as a local community office, and one more is used by the club of beekeepers and as a restaurant, which is opened during the summer.

In the school in Mlačište, the teacher's accommodation space is changed into a shop, but this shop is unfortunately closed because of the very expensive rent.

Figure 10. *Mlačište - ex shop, photo J. Momčilović*

The reintegration of school buildings that are decaying and losing their functions and changing them would increase the institutional capacity of the village that is otherwise in the majority of the settlements below the lowest level, which would raise the living conditions to a higher level and create a real base in the beginning to reduce and stop depopulation, and then for return, temporary or permanent, as well as for restoring certain contents, and then the villages themselves.

Acknowledgment: This research is supported by the Ministry of education, science and technological development of the Republic of Serbia for the project cycle 2011-2017, within the framework of the project TR36042 – "Optimization of architectural and urban planning and design in function of sustainable development in Serbia"
Dedication: I would like to express my gratitude for the creation of this work to my father, Jovan.

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37| Прегледни научни рад
Review paper
doi 10.7251/STP1813510T ISSN 2566-4484

IMPROVING DESIGN OF DAIRY COWS HOUSING IN BOSNIA AND HERZEGOVINA

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Abstract:

Agriculture represents a very important economic field in Bosnia and Herzegovina (BH). The construction and architectural design of dairy cow facilities depend on many factors, primarily the economic and technological conditions, and the geoclimatic features of the area where construction of the agricultural facility is planned. The agricultural facilities must provide proper accommodation for animals, their good production, adequate microclimatic conditions and their presence must not disturb ecological and aesthetic quality of the environment in which they are located. Therefore, special attention should be paid to the design of facades and the design og agricultural facilities. This paper puts an emphasis on clarifying the approaches used in the design of dairy cow facilities in Bosnia and Herzegovina, as well as contemporary approaches of the European Union (EU). The aim of this paper is to indicate how the new approaches apply to design of these types of objects.

Keywords: dairy cow (cattle) facilities, architectural design, Bosnia and Herzegovina

UNAPREĐENJE OBLIKOVANJA OBJEKATA ZA UZGOJ MUZNIH KRAVA U BIH

Rezime:

Poljoprivreda je veoma značajna privredna oblast u Bosni i Hercegovini. Način izgradnje i arhitektonsko oblikovanje staja za muzne krave zavise od mnogih faktora, ali prije svega od ekonomsko-tehnoloških uslova i geografsko-klimatskih karakteristika područja na kojem se planira izgradnja staje. Stajski objekti moraju obezbijediti kvalitetan smještaj životinjama, njihovu dobru proizvodnju, adekvatne mikroklimatske uslove i svojim prisustvom ne smiju narušiti ekološki i estetski kvalitet okruženja u kojem se nalaze. Stoga je posebnu pažnju potrebno posvetiti projektovanju fasada i oblikovanju stajskih objekata. U ovom radu akcenat je stavljen na pojašnjenje dosadašnjih pristupa u oblikovanju staja za muzne krave u Bosni i Hercegovini kao i savremenih pristupa u Evropskoj Uniji. Cilj je ukazati na nove pristupe oblikovanja ovog tipa objekata.

Ključne riječi: staje za muzne krave, arhitektonsko oblikovanje, Bosna i Hercegovina

1. INTRODUCTION

Architectural design can be seen as an eternal quest for an appropriate concept in the infinite richness of the variants offered by a space. The aesthetic level encourages open interpretation and affects stimulatingly to the viewer of architecture (Trkulja, 2013). However, the architectural design of most agricultural facilities is not a dominant trend, as opposed to other 'more attractive typologies'. The reason for this is not that it does not have anything attractive to offer than what is specific: quality animal housing and good production are important, whereas the aesthetics represent a 'tertiary category'.

Animals placed in cattle facilities must feel leisurely. Housing facilities should be comfortable enough for animals to develop and grow normally, to contribute to good production and achieve production capability. In addition, when planning and building agricultural facilities, special attention shall be paid to the application of modern technologies and equipment, as a well-designed and well-structured building and built-in equipment enable high productivity and rationalization of individual work operations (feeding, milking, manure collection).

In order to achieve the best welfare of animals, agricultural facilities must be planned and constructed very carefully and thoughtfully since these types of facilities are expensive, and will prove profitable only if they are used for 25 to 30 years. Modern cattle housing facilities are designed mainly as similar or typical objects, primarily needing to satisfy the economic and technological conditions and principles of design. Manufacturers offer to sell incredible construction, materials and equipment for efficient maintenance and management of these specific buildings. In addition, agricultural facilities must fit the environmental conditions of the space and their presence must not harm their environment either environmentally or aesthetically. Therefore, special attention should be paid to the design of facades and the design of agricultural facilities.

2. OBJECTIVES AND METHODOLOGY OF THIS PAPER

The objective of this paper is to point out to new approaches in designing of dairy cow facilities in Bosnia and Herzegovina. The applied methodology puts an emphasis on field research, i.e. analysis of agricultural facilities in the BH territory, and processing of collected data offered in this paper, providing the narrative and the photo documentation. The method of content analysis encompassed the use of textual and visual sources in order to present contemporary EU approaches to building of agricultural facilities. The conclusions of this paper were assembled and systematized by means of synthesizing method which was applied to all the results of the research.

The principal objective is to clarify the current approaches in the design of these types of facilities. Research issues are related to the development of architectural discourse: the construction and architectural design of dairy cows housing facilities, appropriate microclimatic conditions and ecological and aesthetic quality. The research outputs certainly contribute to understanding of existing approaches in design of these facilities in Bosnia and Herzegovina, as well as contemporary approaches in the European Union. The focus is on the fact that this issue in Bosnia and Herzegovina has not been studied so far, at least not to the extent that would initiate a new approach in designing of agricultural facilities and defining important principles of design. This research is an attempt to use an example of a small country, such as Bosnia and Herzegovina, to point to further development and the evolution of the design concept of milking cattle stalls.

3. ARCHITECTURAL DESIGN OF DIARY COW FACILITIES IN BOSNIA AND HERZEGOVINA

Bosnia and Herzegovina is one of the constituent republics of the former Yugoslavia. It is located in the western part of the Balkan peninsula (Fig. 1). Agriculture represents a very important economic field in Bosnia and Herzegovina. The surface of BH is 51209 km², agricultural land making about 2.5 million ha and 0.7 hectares per capita (FAO, 2012). Cow accommodation and the construction of agricultural objects in BH depend on geographical and climatic characteristics of the area where the construction of these objects is planned. In the south of BH is characterized by a prevailing mild submediterranean climate, with long warm summers and mild winters. The central part of BH is characterized by a mountain-continental climate. In the north, there is a typical continental climate. The various climate and topography of the terrain in BH represent highly favorable conditions for the farming of livestock and breeding food of animal origin (Indigenous dairy products industry in Bosnia and Herzegovina, date unknown).

Figure 1. Administrative division of Bosnia and Herzegovina (Source: FAO, 2012)

The most intensive agricultural production takes place the lowlands, with the biggest farms located there, whereas in the mountains the farms are mostly smaller. Lowlands are more competitive in milk production, primarily due to higher food yield per unit area, dense population and a higher demand for agricultural land. Therefore, the agricultural objects and farms are larger so the cows are more often in loose housing system. On the other hand, agricultural facilities in BH mountains are generally smaller, cows are most often accommodated in tie-stall system. Cows are released to grazing during the spring, summer, and autumn due to abundant pastures in this area (Jovović et al., 2014). The estimated numbers and shares of farms, cattle and cows, for all of Bosnia and Herzegovina, after combining together data from the Pilot Agricultural Census, Master Sample, and statistics on Legal Units, are shown in the Fig. 2.

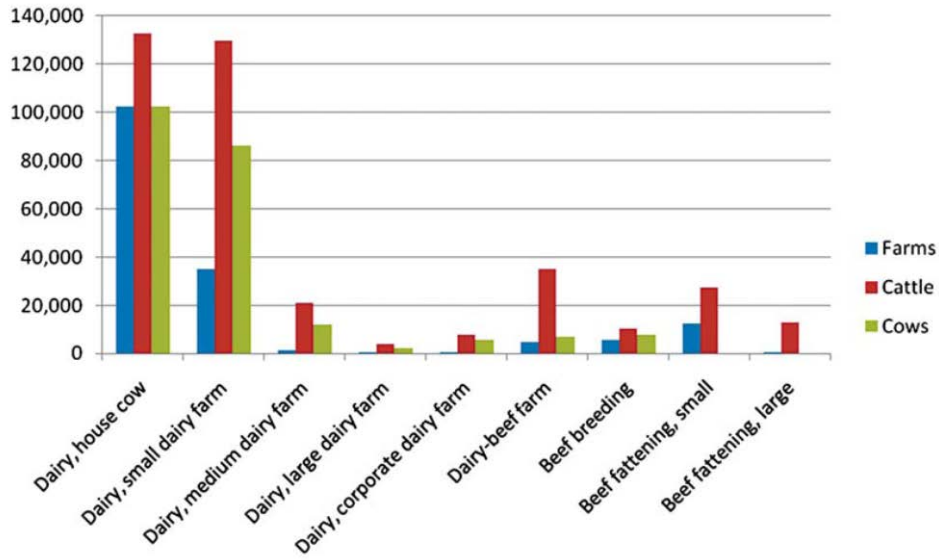

Figure 2. Cattle farms in Bosnia and Herzegovina (Source: FAO, 2012)

In Bosnia and Herzegovina, family farms are the most frequent types of farms. Thus, for example, the total number of households in Republika Srpska (RS) is 414847, and 131586, that is 31.72% categorized as agricultural households (Vaško et al., 2016). The same authors state that over 50% of the milk purchases in the RS comes from small farms holding up to five dairy cows, and that the smallest number of farms have over 200 dairy cows, or a 0.1% of total number. About 1.2% of the total purchased milk is obtained from the large farms (Fig. 3).

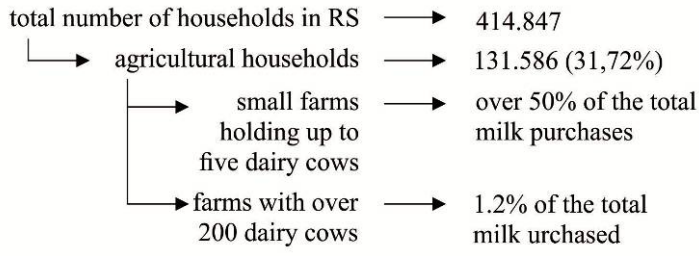

Figure 3. Milk purchases in the RS (Source: Authors according to Vaško et al., 2016)

Different systems of materialization of the objects for farming dairy cows are used for the construction of agricultural facilities. They are mostly prefabricated in order to have the construction of objects as quick and as cheap as possible. The materialization of the milking cattle facilities depends directly on the production and the needs of cattle for its healthy growth. In addition to their functionality, cost/effectiveness, durability, quality of materials used and comfort for animals, the milking cattle facilities should also provide certain aesthetic qualities, which make an integral part of architecture. In addition to architectural design, they are also influenced by the materialization of individual elements of the object.

Masonry farm buildings are widespread in Bosnia and Herzegovina. This method of construction is traditional and recognizable in smaller agricultural facilities, for the

farming up to 10 dairy cattle. The usual roof covering, used in the territory of Bosnia and Herzegovina, is roofing tile (Fig. 4, left). However, it is a characteristic roof covering of old agricultural objects. Lately, sheet metal is the most commonly used roof covering in reconstruction of old roofs and putting up of new roofs (Fig. 4, right).

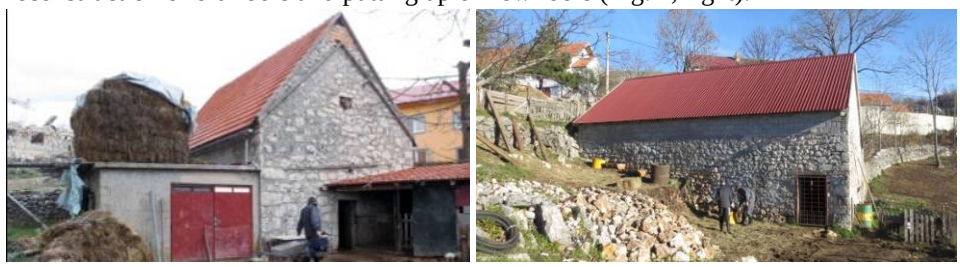

Figure 4. Objects for farming dairy cows in Gacko, BH, 2013 (Source: Authors)

The disadvantages of the smaller objects in Bosnia and Herzegovina are mainly the poor ventilation, insufficient light and poor microclimatic status. Šoch (1998) considers that the microclimate is the basic existential and productive factor in the cattle farming business. The composition of the air in agriculture facilities certainly plays an important role. Cows are adversely affected by the concentration of gases in the stalls. Hazardous gases in the air are carbon dioxide (CO2), ammonia (NH3) and hydrogen sulfide (H2S). Animals produce these gases when breathing or they are formed by decomposition or process of fermentation of organic matter from food, manure and urine. Bad ventilation and poor quality of air in many agriculture facilities in Bosnia and Herzegovina are affected, above all, by closed facades with small windows (Fig. 5) (Jovović, 2015). Buildings with poor ventilation and stagnant air present an unhealthy environment not only for the dairy cattle, but also for the man working in them. Namely, the unfavorable environmental conditions lead to various diseases of cows, and reduce the production and (hygienic) quality of milk (Havranek and Rupić, 2003 in Ostović et al., 2008).

Figure 5. Objects for farming dairy cows in Novi Grad, BH, 2011; Bileća, BH, 2013 and Brčko, BH, 2017 (Source: R. Grubešić, left; B. Rogić, middle; S. Osmanagić, right)

Due to the above mentioned shortcomings, contemporary agricultural facilities have a different design concept. It primarily includes semi-open and open facades, and this is enabled with the use of skeleton instead of masonry construction system. Namely, according to the construction design of the peripheral walls, and taking into consideration the agro-ecological zone and the microclimatic characteristics of the environment where erecting of the building is planned, the facility can be designed with closed, semi-open or open facades (Fig. 6).

Figure 6. Construction of the peripheral walls of objects for farming dairy cows: closed object, Prnjavor, BH, 2014; semi-open object, Trnopolje, BH, 2014 and open object, Prijedor, BH, 2014 (Source: Authors, left and middle; B. Rogić, right)

A closed facility implies a fully enclosed cattle housing space with walls and windows. This type of facilities is foreseen in moderate and colder climatic zones, since it provides ideal protection of cattle against bad weather conditions, but it also requires good ventilation inside the facility. Namely, insufficient amount of fresh air in the agricultural facility leads to increasing of microbiological and pathogenic organisms, which has adverse effects to general health status and productivity of cattle. Full-scale facade construction also entailing investments in ventilation systems, make it the most uneconomical of all.

The semi-open facility includes semi-open space for cows with a facade wall in the shape of a high parapet. The semi-open system is the optimal choice between open and closed systems, but it is closer to the closed system in relation to economic investments. Its advantage entails natural ventilation and good thermal abilities. The semi-open agricultural facility is ideal in Mediterranean and dry climatic conditions.

An open facility implies a completely open space for cows on one, two or all four sides of facade, i.e. covered space with no walls. This type of construction is suitable in dry, warm and Mediterranean climates, with a small number of rainy days per year. It is the closest to the cow's natural environment. Also, such construction system of agricultural facility is the most economical, as it only requires the construction of canopy, so the total expenditures are reduced by approximately 50%.

Areas with lower average annual temperatures are more suitable for the cattle (Erbez et al., 2015; Jovović, 2015), as cows can tolerate low temperatures only if the environment is dry, with no draft. Also, the temperature difference between the outer and inner space of the agricultural facility should not be higher than 10°C during the cold days. Otherwise, warm and humid air will condense in the cold parts of the building. Excessive condensation creates an unhealthy environment for cows (Gay, 1995). High temperatures cause a decrease in milk production and reduction in reproductive capacity of cows. Therefore, in order to obtain desirable production capabilities, cows should not be exposed to direct sunlight during the summer, especially in the afternoon. The metal or white aluminum roof can reduce thermal stress, since it maximizes the reflection of sunlight (Mijić and Bobić, 2012).

Facade walls play a major role in the formation of microclimate inside the facility because their construction is connected with ventilation and lighting inside the object. When planning the system of horizontal ventilation, holes for transverse ventilation are built-in in the facade walls. At the same time, this provides an additional lighting. Facade walls can be constructed of wooden, concrete or brick elements, masonry or may be prefabricated. Mostly masonry stasis are built, because they are long-lasting, and make it easier to maintain hygiene and disinfection (Matarugić and Budimir, 2004).

However, the stalls can be completely open, with birds and other animals' protective netting set up.

Nowadays, experts recommend a horizontal ventilation system with openings on the walls that can be regulated by slotted plastic curtains (Fig. 7). In this case, the height of the hole is up to 3 meters, thus regulating the air supply and transverse ventilation. Protective film, resistant to strong wind, protects animals from draft that can have a negative effect on animals (Matarugić and Budimir, 2004). The drive is controlled by a manual shaft, or by electric drive.

The type of ventilation system depends on the climatic conditions, therefore it is good to combine natural and mechanical ventilation in the areas with high temperatures. In areas with moderate climate, it is good to leave the stall walls open, with windproof nets that allow sufficient ventilation. Tunnel ventilation is best to use in the areas with cold winters and hot summers. Construction of stalls with one open wall (best on the southern side of facility) with windproof net, allows optimal transverse ventilation and precise regulation of the air supply. Alternatively, the longitudinal walls of the stalls have solid parapets and open upper parts of the walls with windproof net set up (Fig. 7). The windproof net is made of special, highly resistant, synthetic materials, which are interconnected in several layers with small perforations. It is resistant to strong winds and can withstand wind blows up to 150 kilometers per hour and almost completely stop it before entering the building (even up to 93%). Also, the windproof net allows constant air flow during the summer and its reduced flow during the winter, thus preventing the draft to which cows are very sensitive. If perforated materials are used, during the year they allow to accumulate particles (because of gases released by cattle) that reduce the open surface of the net and the airflow during the winter. In the spring the net is simply cleaned, enabling the cycle to start over. The system is easily controlled by manual or automatic opening and closing of the net. The use of wind protection nets reduces construction spending (Ivanović et al., 2008).

Figure 7. Wind protection net placed on a stall (Source: WolfSystem)

In the geographical region of Bosnia and Herzegovina, summer months represent a period in which may create conditions that can lead to the heat stress. On the other hand, when it comes to low temperatures, the best way to protect cattle is to adjust the housing facility to the weather conditions. The stall should not be drafty. On the other hand, ventilation should lead to sufficient fresh air and drain the air pollution (Erbez et al., 2015). Due to poor economic conditions, farmers in Bosnia and Herzegovina use a plain nylon or tarpaulin instead of a wind protection net, to cover the open parts of facade in the low winter and high summer temperatures, and thus create a better microclimate (Fig. 8).

Figure 8. Tarpaulins installed during winter to the open parts of the facade in Bijeljina, BH, 2014 (left); Gradiška, BH, 2014 (middle); and Prijedor, BH, 2014 (right) (Source: Authors)

The light coming through transparent roof elements increases the temperature inside the stall, thus creating negative effects. Additionally, in areas with high precipitation, the roofs are covered with snow for several months, disabling the illumination through transparent roof elements. Therefore, this type of roof lighting is not widespread in BH, especially in the mountain regions of BH. It is possible to provide cascading roof lighting by skimming the roof level. Roof cascades are made in order to allow adequate illumination throughout the year (WolfSystem). Triangular and rectangular lanterns are used also for roof lighting, most often placed along the longer side of the stall (Fig. 9).

Figure 9. Zenital lighting through: transparent roof elements, Czech Republic, 2009; openings created by the skimming the roof level, Kozarska Dubica, BH, 2014 and lantern, Trnopolje, BH, 2014, left (Source: Authors)

Facade lighting is allowed by facade openings created on the building, which can be placed on one longitudinal facade (lateral illumination) or on both longitudinal facades (bilateral illumination). Facade openings are shaped in the form of windows, as a continuous opening above the parapet walls or completely open facades (Fig. 10). Nordlund (2003) states that at least 50% of the surfaces of the longitudinal walls must be movable, so they can be removed as needed, which is essential for adequate ventilation inside the facility.

Figure 10. Facade lighting in BH: in the form of windows, Kozarska Dubica, 2014; continuous openings above the parapet walls, Trnopolje, 2014 and completely open facades, Prijedor, 2014 (Source: Authors)

All of the above shows a gradual evolution and development of the design concept of dairy cow facilities in BH, and approximation to EU design concepts. This "design evolution" is initiated by the economic and technological conditions that need to be provided in the stall, as well as by the geographical and climatic characteristics of the area where the facility it is located. However, defining the design concept of facilities is at a very low level, because facilities of similar layout and design solutions are built without the modern design, which should be in line with the local architectural form. Therefore, one can say that in BH these facilities need a new identity, that lays upon the traditional architectural elements and the context needed. Since the objective of this paper is to point to new approaches to the design of dairy cattle housing facilities, the further elaborations provided in the below text provide an overview of several attractive solutions.

4. MODERN TENDENCIES IN DESIGNING DAIRY CATTLE HOUSING FACILITIES

Modern trends in designing dairy cows housing facilities are very much different from the current situation in BH. Design concepts evolved: from classical smaller agricultural facilities (for farming up to 10 cows) to modern concepts of vertical forms. Modern agricultural facilities apply a different design concept which primarily refers to the utilization of different façade materials, but still on the same closed, semi-open or open types of objects (Fig. 11).

Figure 11. Construction and materialization of the facade walls of modern stalles for dairy cows (Source: WolfSystem)

Unlike masonry objects that are widespread in BH, the developed countries mainly use prefabricated skeleton construction systems of laminated wood or steel. They enable fast and quality construction. Additionally, the prefabricated skeleton construction systems offer to designers an unlimited opportunity in architectural design of dairy cows housing (Fig. 12).

Figure 12. Modern agricultural objects with classic steel construction and construction of prefabricated reinforced concrete columns and laminated wood primary beams (Source: Brueninghoff)

More attention is also paid to the ventilation of facilities and facade illumination. Facade openings are formed in the same way as in BH: as windows, as a continuous opening above high parapet or completely open facades (covered space without walls). However, the use of facade materials and architectural shaping of the stalls are incomparable. The EU insists on the use of ecological materials (primarily wood) and mobile wall elements (Fig. 13), just recently being acknowledged in BH, still being in the initial development phase.

Figure 13. Ventilation and facade lighting in stalls in the EU: in the form of windows, continuous opening above high parapet and completely open facades (Source: WolfSystem)

Defining the conceptual solution for the cattle housing in BH and EU cannot be compared. This is best shown by an insight into design solutions of the modern stall facades. For example, a free-stall barn for 30 cows was built in 2005, at the heart of an idyllic landscape of fields, pastures, forests and mountain valleys in Lignières in northwestern Switzerland, (Fig. 14). The client wanted a modern design which meets organic production standards. Architectural studio Localarchitecture was supposed to project a cattle housing facility near the existing farm. In order to design a project that would abide by the development of local architectural form, architects did a detailed analysis of the farm typologies present in the region. By combining typologies, architects synthesized different traditions, thus giving them a new identity. Commitment to sustainable development is reflected in the choice and application of materials, whereas dimensions of wooden elements are adapted to the dimensions of timber available in the nearby forest. In addition to environmental advantages, wooden elements also allow natural ventilation. Stall architecture recognizes the area and the place where it is built and face opens the valley (ArchDaily).

Figure 14. Free-stall barn for 30 cows, Lignières (Switzerland), Localarchitecture (Source: HIC et NUNC)

Integration with the surrounding landscape, without expensive planning, budget and building materials, was the concept of the Agricultural Social Care Project „Grote Heklaantje“, implemented in Bergen, Netherlands (Fig. 15). The design of this wooden

cube, created by the architectural studio Negen Graden Architectuur, confined to simple needs, with the region recognizable construction. The social healthcare farm for mentally and physically handicapped people is built to accommodate eight residents who require the care and the family providing care. In addition to a deep litter for young cattle inside the stable building, there is an educational area where those interested may acquire information regarding the special qualities of this project and the environment. The house and stable have a sturdy wooden facade. Object design and materials are in harmony and create a recognizable unity (Architizer).

Figure 15. Project „Grote Heklaantje", Bergen (Netherlands), Negen Graden Architectuur (Source: Architizer)

The cattle farm in Pratteln (Switzerland) is characterized by the architectural concept aimed to integrate the building into its hilly green surroundings, using natural materials in construction of the wall and installing the greening of the roof. Namely, the designers Georg Schmid and Jonas Wuest used Bauder greenroof system and local hazelnut branches set into concrete as screening around the entire structure instead of the classic wall. The grass on the roof is mown twice a year (Fig. 16).

Figure 16. Cattle farm in Pratteln (Switzerland), Georg Schmid and Jonas Wuest (Source: Greenroofs.com)

At the top of a low ridge, alongside the old forest, there is a barn that represents the entrance to the Cornell campus and a testing ground for students of agriculture. It is the first object that students and visitors get to see, so it is therefore given an aesthetic function. The barn provides an elegant, modern look to the traditional design of cattle barns (Fig. 17). On the other hand, guided by the slogan that a happy cow is a productive cow, priority in a functional organization was given to the comfortability of cows. The cows can move and eat as much as they like. They bed down on sand, a natural deposit that does not support the growth of bacteria. Installed automatic brushes increase the

comfortability of cattle. All this influences that each cow produces an average of 95 pounds of milk per day, so the cattle are milked three times daily (Cerio, 2013).

Figure 17. Dairy barn (exterior and interior) and the experience the magic of automatic brushes (Source: Cerio, 2013)

In the past few years, vertical farming projects are being popular, thus representing modern concepts of a vertical farm. However, the Circular Symbiosis Tower, designed by Lee Dongjin, Park Jinkyu and Lee Jeongwoo for the 2011 Skyscraper Competition, is the first skyscraper that proposes a vertical farm for actual livestock (Fig. 18). The main concept was to create a new habitat to raise cattle within the city. The skyscraper consists of a central tower that carries spiral grazing lawns, enabling free movement of cattle. Healthy and sustainable farm work relies on the symbiosis between cows, chickens and pastures. Namely, after 30 days of habiting the same pasture, the cows move to a higher platform, while chickens use the previous platform (the grass are not the primary source of food for chickens) until the grass is grown again. Chickens feed on worms that grow in the cow feces and thus improve the biodegradation of the feces and growth of pastures. This enables the grass surfaces to which the cows return again after some time to restore, and the whole cycle is repeated again (eVolo, 2011). Vertical farms are a modern concept adapted to areas facing the issue of developing farms in horizontal areas, which is not a problem in BH. The concept of a vertical farm is far from the standards and needs of BH. Also, this concept is far from the proper accommodation for animals and their good production.

Figure 18. Circular Symbiosis Tower, 2011 eVolo Skyscraper Competition (Source: eVolo, 2011)

5. CONCLUSION

In order to enable good production and animal welfare, agriculture facilities must be carefully planned and thoughtfully constructed. Primarily, they must satisfy the economic and technological conditions and design principles, but they also must fit into the environmental conditions of the area and their presence, must not harm their environment, either ecologically or aesthetically speaking. Therefore, the special attention is paid to both the design of agricultural facilities and the design of their facades. This paper, explored the approaches used in the design of cattle barns in Bosnia and Herzegovina, as well as contemporary approaches to this issue applied in the European Union.

The survey showed that family farms (with up to 5 dairy cows) and masonry buildings (for the farming up to 10 dairy cows) are by far the most represented in Bosnia and Herzegovina. Inadequate ventilation, poor illumination and, hence, the bad microclimatic status of these smaller agriculture facilities are being recognized as disadvantageous. Facade walls play a major role in the forming a microclimate in a barn and the poor microclimate conditions are influenced above all by closed facades with small windows. Therefore, newly built cattle barns apply a different design concept: semi-open and open facades with continuous openings above high parapet or with completely open facades.

The study has shown a gradual evolution and development of the design concept diary barns in BH and approximation to the EU design concepts, but only in a domain that initiates economic and technological conditions and geographic and climatic characteristics of the barn's surrounding environment. On the other hand, defining the design concept of barns in BH is at a very low level, with facilities with facilities of similar layout and design solutions, without application of modern design methods. Primarily, this refers to the use of façade materials and architectural design of barns. The EU insists on the use of ecological materials (primarily wood) and mobile wall elements, just recently being acknowledged in BH, still being in the initial development phase. Therefore, one can say that a new identity must be given to the diary barns in BH, respecting the traditional architectural elements and the natural context, and putting into the forefront a natural way of care for and breeding of animals. Adequate design and materialization of the diary barns (objects built from natural materials) undoubtedly contribute to the increase in the comfort ability of cattle and the milk production, as well as to the improvement of the ecological and aesthetic quality of the barn environment.

In relation to all of the above, it is clear that the objective of this research paper has been reached: clarification of existing and pointing to the new approaches for in designing diary barns in Bosnia and Herzegovina. EU approaches are applicable in BH. Therefore, BH should learn from the EU and harmonize its regulations with EU regulations, what was achieved in Republic of Srpska with Rulebook on spatial and technical conditions for housing of farmed animals, buildings and equipment in animal husbandry (Official Gazette Republic of Srpska, No. 100/15) which certainly contributes to the improvement of the design of the housing facilities of dairy cows. The trend of increasing the number of animals per farm and the construction of larger housing facilities is already up to date. Also, reconstruction of existing and construction of new facilities is expected to be in accordance with standards that prescribe the conditions for the accommodation of dairy cows and generally domestic animals.

Well-designed barn serves not only to ensure better animal welfare, but also to facilitate the work of farmers, make systems more applicable for controlling of critical points and with it to improve food security (milk, meat).

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38| Прегледни научни рад
Review paper
doi 10.7251/STP1813525M ISSN 2566-4484

УМЈЕТНОСТ ЏЕКСОНА ПОЛОКА У УРБАНИСТИЧКОМ ПЛАНИРАЊУ И ДИЗАЈНУ - ПОЈАМ "ЖИВОТА" У ГРАДСКОМ ПРОСТОРУ

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Резиме:

Постоје различите дефиниције онога што означава појам „живот“, које као такве иза себе имају одговарајуће теорије: почевши од тога да је све што постоји материја, а живот само њен комплексан облик, па све до витализма, који принцип живота сматра искључиво нематеријалним. Формирање генералне дефиниције живота је одувијек био велики изазов за многе стручњаке, а како је ситуација и даље непромијењена, намеће се питање како у широком спектру различитих идеја и ставова, доказа и експеримената, заузети одређени став када је у питању наведена тема и како исту третирати у контексту урбане структуре данашњице? Да ли је могуће узети мисаону и експресивну структуру сликарства, као специфичне дјелатности која се истовремено заснива на претходно успостављеним принципима и техникама, те на слободи онога ко ствара, као добар примјер за превођење у урбанистички домен? Овај текст истражује везу између "живота", урбане структуре данашњице и сликарства Џексона Полока.

Кључне ријечи: живот, Џексон Полок, градски простор, урбано, процес, догађај, покрет

ART OF JACKSON POLLOCK IN URBAN PLANNING AND DESIGN - NOTION OF "LIFE" IN CITY SPACE

Abstract:

There are different definitions of what constitutes the term "life". The background of most of these definitions is appropriate theories: starting with the notion that everything that exists is matter, and life is only its complex form, up to vitalism which considers the principle of life as purely intangible. Forming the general definition of life has always been a major challenge for many experts. The situation is still unchanged. The question is, how in a wide range of different ideas and attitudes, evidence and experiments, to take a stand when it comes to the phenomenon of life in the context of the urban structure of today? Is it possible to use an expressive structure of the painting as a specific activity that is simultaneously based on previously established principles and techniques, but also on a freedom of the artist, as a good example for translating into the urbanistic domain? The paper explores wide connection between "life", urban structure of today's city and painting of Jackson Pollock.

Keywords: life, Jaskson Pollock, city space, urban, process, event, movement

1. Introduction

In order to better understand art of Jackson Pollock and link it with urban planning and design, it is necessary to know all the opportunities and events within the spatial and time context in which this artist lived and worked. Pollock was born in 1912 in Wyoming, as the youngest of five sons of a farmer and housewife. He died in New York in 1956, as one of the most influential American painters - a representative of the abstract expressionism and originator of action painting. Even from a young age, he had a problem with authority, his mother's ambition, constant moving from town to town and impossibility of making friends, which was manifested in frequent excesses for which he was expelled from the School of Applied Arts in Los Angeles. All off that, as well as the later-adopted lifestyle, were the main cause of his alcohol problems that ultimately led him to death. After Los Angeles, Pollock went to New York to be with his brother within the Art Students League, where he attended classes of a painter named Tomas Hart Benton. Apart from Benton, who introduced Pollock into the theme of rural America (the study of primitive art with an emphasis on American Indians - decorative patterns, totems, etc.), surrealists and symbolists also had a great impression on him (through which he came to essential insights about Mexican painters). Furthermore, the great influence on him had a so-called philosophy of existence (significance of an individual, dramatic nature of the human existence, depression, ecstasy), as well as the Freud's psychoanalysis, the collective unconscious and symbols defined by Carl Gustav Jung. So, abstract expresionism arises after the Second World War in the United States and Europe, as art movement whose representatives wanted to express the feelings of not belonging and inconvenience of artists in society and dominant developmental tendencies. It is no longer important to have a particular style of painting, since the greatest importance lies in the way of thinking and acting that must be spontaneous (to reflect life itself). In an atmosphere that arised from war and post-war events, the artists primarily relied on their personal abilities and capabilities, which actually symbolize the moment when Pollock "get into" the painting. In that way, his actions and gestures gestures were permanently recorded through art. The significance of the very act of creating an artwork (action) becomes more important than the final product itself, which arises as a unique combination of the imagination of the one who creates and expression affected by the surrealist automatism.

In today’s cities (with special accent on the open public spaces representing the inevitable segment of life in urban areas), it is easy to notice the lack of a factor that is not physically represented, but is primarily related to what is meant by the term "experiential". That way, we come to what is represented by "life" in any space within a city. Although the main participants in the process of forming "life" of urban areas are space and its users, as well as the urban planners and designers who previously participated in their creation, it is certainly not a problem with only two or three variables. Namely, it is about the existence of organized complexity that appeared due to the existence of numerous and various factors, which are connected to all the aforementioned participants. These factors are interconnected in layers and their mutual relationship is more important than each of them separately. Previously mentioned way of mutual functioning is what creates the events and "life" in a city, which can be compared with Jackson Pollock’s paintings. Speaking of lyrical abstraction as a movement focused on direct gestural expression, Šuvaković names Pollock as one of the most important representatives, whose specialty is to transform the abstract form into a

note or a sign which denotes the existential drama of a human being. Therefore, his works themselves express the dramatic survival. They esentially refer to the existence of life and humans all through the tools of action, movement and happening [1, pp. 61].

The very common classification of urban design and urban planning into "mechanical" production domain that often exclude creative force of the unconscious, leads to the certain problems that mostly reflect on a human being as a primary user of the urban environment. Therefore, physical city structures often represent the product of a too rigid or inadequate thought, as well as of the interpretation of urban code, which is resulted in absence of "events". All of that, further conditions the level of "life" of a public city spaces. By thaking into account that one of the main characteristics of Pollock's work was gestuality and giving priority to action, emotions and everything that is natural for a human being, this paper will try to suggest a set of aspects that are common to his approach to art and above-mentioned issues from a urban domain. Therefore, through the study of Jackson Pollock's "action painting" and the comparative analysis of questions concerning the "mechanical" (as lack of originality or automatic) open public spaces in cities, this paper will try to reach the certain guidelines for potential solving of the identified problem and form the unique structured mindset. That creative process is based on the principles of logical and intuitive determination of certain aspects and establishing the parametres mutual for Pollock's way of working and urbanistic creative procedure. This is not for the sake of revolutionary ideas, but for purpose of denoting the problems and eventual pointing to possibilities of improving the open public city spaces in the given context.

2. "Life"

Analysing the various literature, it is possible to come across the opposing attitudes concerning the "life" of today's urban sites. Wanting to start a discussion about what the given term actually represents, the further text will analyze the views of different reference authors who have, in their own way, dealt with the cities, open public urban spaces, their users and life - as what they have in common. Christopher Alexander claims that life is neither a limited "mechanical" concept by default nor a reproductive biological machine. It is the quality inseparable from space itself and is related to every brick, stone, person and every physical structure that appears in the space regardless of its kind. Every thing has its own life [2]. If every thing has its own life which at the same time represents the quality inseparable from space, and if that quality is present in every physical structure regardless of its kind, the question is how the physical structures in the cities express their "life" independently? Is it possible for the open public urban spaces, as crucial segments of every urban area, to acquire any level of "life" without involving their users?

Every urban space without people represents nothing but the series of exhibits which eventually decay and fall into oblivion. An example of that is Pripyat, the "ghost town" in Ukraine which was evacuated after the Chernobyl catastrophe. Another good example is the Gunkanjima – the "forbidden island" in Japan, which became uninhabited after the coal mines were closed. Though these locations are still rich in various structures as remnants of formerly active urban areas, it cannot be said that they own or express "life".

Of course, life there exists in the form of flora and fauna, but not in the context referring to the life of urban area dominated by people as intellectual and intuitive beings. The lack of this intellectual and intuitive action of people opposes the work system of Jackson Pollock, as well as the character of his artwork. Pollock's paintings were created gradually, as the product of the idea that every next step should be dictated by the emotional cognition and the potential in the given moment. While explaining the "drops" on his canvas, Pollock defines them as visible energy and movement – memories in space [3]. Beside the intuitive aspect, his artwork implies the results of academic research and intellectual development. The paintings which Pollock exhibited in the Guggenheim gallery during the war continue to show the influence of Picasso, Miró and other surrealists. They also confirm his American roots through the use of Native American or simply American imagery within the European compositional frame [4, pp. 31].

As users of open public urban spaces, people will have a weaker possibility of finding the way to express their own being and emotion through action, in case there are no adequate physical contents in those same areas. It is very common that some city sites are only used when it is inevitable or in the case of emergency, with no longer stay. Though the users of these localities are present, it is brought into question whether that is enough in order to classify a given city space as one which has gained its "life". In relation to that, Jan Gehl says that besides importing the information about the external social world, the opportunity to also see and hear other people can provide the ideas and inspiration for action. We are inspired when we see other people in action. [...] Experiencing other people represents the special and attractive opportunity for stimulation. In comparison to the feelings we have because of buildings and other non-living objects, the feelings that we have for people offer richness of sensual variations. No moment is like the previous or the following one when people circulate among each other. The number of new simulations and stimulations is unlimited. Besides that, all the things mentioned are related to the most important subject of life – people [5]. Therefore, when we talk about achieving the adequate level of "life" in urban areas, it is not enough to have people there only being physically present or passively doing a certain action. They must be animated and actively involved in forming the general picture of a place (stimulation). Just like Gehl claims, in order to get a user of a certain public city space inspired for action, that space must not be monotonous.

Figure 1. Life - open public space vs. Jackson Pollock's untitled painting

Noting down the main characteristics which a certain city site should possess in order to be classified as a space with the satisfactory level of "life", we come to the following conclusion: in order to enable an individual to experience the city space, it is mandatory to get the rest of the users animated and activated. In order for that atmosphere to be realized, it is necessary to provide the adequate space structures and contents, which

leads to the role experts from urban planning and urban design domains. They must have in mind that this need for establishing the "happening", and maintaining its continuity, is conditioned by the successful interaction between a space and its users. The explained issue can be identified with what Pollock managed to overcome in the context of his own work. In his paintings the force was present, a tremendous energy, which often made the paintings look raw and incomplete. But Pollock wanted to achieve that exactly, to go on the other side of beauty, on the other side of usual ambition about what should be illustrated. "Well made" painting and the understanding of the painting as some sort of a great recipe, was exactly what the members of the abstract expressionism wanted to annihilate in the end. There is no doubt that in all that there was a lot of freedom and true stimulus [6, pp. 101]. In the context of including hitherto neglected or completely ignored parameters, denying the "mechanical" principles and forming "non-mechanical" ideas and approaches, the reform of the traditional way of thinking and acting in the context of urbanism represent the potential. This is especially important when it comes to forming the urban spaces that supposed to be adequate for human nature.

3. Event

Tchumi claims the following: "Architecture is certainly not a discipline incapable of reviewing its own structures and foundations. It is a domain which will welcome the greatest discoveries of the 21st century. The event is a factor in which the review and redefinition of various elements of a structure, many of which have resulted in or contributed to contemporary social injustice, can lead to their removal" [7]. Even though considering an event as a very important aspect (which conditions the level of "life" in city space and its quality) has been ignored through a long time, the works of numerous authors show the significant changes in the very approach and indicate that the dissatisfaction with the existing creativity itself should be the motivation to form the new opinions and matrices. With all that given, it is necessary to emphasize that the term "event" must not be taken literally in any case. It represents a complex relationship between the space and the user, which is defined by the line of a various interconnected elements. In other words, it exemplify the state or behavior which is induced by the "communication" between the mentioned factors. Speaking of the "computational complexity theory", as a mathematical method for measuring the degree of biological structure of one organism in relation to the other - the quality of their organization, Charles Jencks points out that the same methodology, applied to art and literature, would signify the measuring of their quality through comparisons with the values necessary for the computer program to reproduce a copy. In case of Jackson Pollock's canvas, the length of a computer description is pretty short [8]. However, although Jencks states that it is all about random Pollock's "scrapings", the importance of Pollock's work is not connected to the final product as much as to the very procedure of its creation.

Figure 2. "Lavander Mist" by Jackson Pollock and physical structure of Rome, Italy - similarity and complexity

Šuvaković states that Pollock's field paintings announce and direct the new practice in art: the artist is not only a creator, but an actor who, with his act in the spatio-temporal continuum (by his happening and performance) creates the work. His paintings can therefore be viewed as documents of his painting existence and rituals, and not only as aesthetic art products. According to this, Pollock's work in the history of modern art of the 20th century is first and essentially innovative [1, pp. 151]. Therefore, the painting process itself, which meant the placement of the painter's canvas on the floor, color dispersion and constant movement over it (i.e. the "entry" into the painting), are the main characteristics relevant to the subject matter. In the given context, the final result is less important than the procedure itself, which can easily be transposed into modern domain of urban planning and design. Namely, the current expert researches suggest completely different ways of city studies in comparison to the "mechanical" principles. Darko Radović explains that the field of urbanism often hold the researches which seek to identify and establish the steady facts, to analyze and to prove them. However, those efforts also carry the risk of losing awareness of the city complexity as an urban environment. As Radović concludes, the event is complex because it goes beyond our capacities and possibilities to understand it. One of the main reasons for this is the fact that urban planners and architects primarily rely on their eyesight and all that is visually conceivable, thus using their other senses less or not at all. However, research and the absolute perception of the urban environment take much more than what a single glance can offer. Since life itself is inclusive, it is necessary to get into the crowd, engage the senses, touch and feel as well [9].

In discussions concerning the general impression of an ambient, a very important role is taken by a parameter that cannot be identified exclusively from the observer context. The trend of compressing theoretical research and engagement within the framework of visualization and "mechanical" production explains the frequent ignoring of the events and "life" of open public urban spaces. The event is not physically tangible, but it can be experienced. The intensity of its representation is constantly changing, and sometimes it may not even exist. The notion that it is something not firmly grounded, precisely defined and clearly framed, which exists in a very subtle manner or is being recognized only as a potential, leads to a question: how to experience nothing? In order to answer this question, Radović focuses on the places and practices of everyday life through his experience, emphasizing that exposure and openness to others provide numerous opportunities to learn about personal creativity. The starting point of identity research

and quality of urban environments relates to a completely simple and routine activity - walking. Sheringham claims that walking plays a key role in exploring everyday life. He considers it a grounded activity that engages the skills of the human body as a practice including rhythm, repetition and non-accumulation. He also sees it as a solid activity, boundless, personal as much as social, limited to here and now, but at the same time able to "embrace" the distant horizons [10]. In accordance to all that, it can be concluded that the recommended tools for researching are compatible with the system that Pollock applied to his painting.

Reflections on possible responses concerning the right way to experience nothing lead to another essential question: how to express that nothing? In today's open public city spaces, the lack of "life" can often be identified as an experiential factor that is not physically tangible even in case of its intense representation. "Life" of the urban sites is conditioned by the "event", as a product of the interaction between space and users. Therefore, it is the absence of factors that unites image and body. In order for communication between the aforementioned participants to be achievable, there is a necessity for certain elements to encourage such a process. For this purpose, as the starting point should be to study, analyze and understand the available sources, as well as the world around us. Before mentioned Darko Radović claims that although philosophers and other experts offer a wide array of inspirational sources, any compression of their thought into concrete and effective tools tends to be dangerous. Therefore, such individuals should be regarded as intellectual provocateurs. Their works should be searched for the new concepts of creativity and indirectly presented phenomena. For this reason and for the purpose of emphasizing the importance of procedure of every scientific and art work, and giving priority to sensuality in relation to the aesthetic, Jackson Pollock’s art served as a source inspiration. Therefore, in order to truly comprehend the functioning of a complex urban environment, it is suggested to deviate from all types of "mechanical" research and pay attention to different aspects of the "non-mechanical" approach.

4. Movement

In the fifties years of the twentieth century, the United States faced the Cold War repression and consumerism vanity, which began to shape the post-war society. In that odd world, abstract expressionists highlighted their desperate aspiration to spontaneity, freedom, and re-discovery of self and human context. Their romantic, anti-capitalist hope, with all its weaknesses and contradictions, voiced them that the values embedded in their art could overcome the sphere of art and transform society. Behind that impulsive energy of immediacy, there was a rigorous life choice that required absolute dedication, which Jackson Pollock confirmed by stating that art is his life. In an attempt to paint the elusive, the radical art that involved into the unknown regarded risk, passion and adventure as the key elements for achieving that [6, pp. 97]. Therefore, it can be noted that, besides all, abstract expressionism came to existence as a response to the atmosphere of vanity that emerged immediately after the Second World War. Also, the lifelessness of open public urban spaces, i.e. the low level of "life" in them, followed as a product of treating the urbanistic activity as a "mechanical" domain of production. City spaces that were formed as a result of the aforementioned "mechanical" approach of thinking and operating are in absolute contrast with livable cities in which, as Jan Gehl

says, people can communicate with each other. Such cities are always stimulating because they are rich in experience. Thus, opposing them are the lifeless cities, in which bad experience and boredom can hardly be avoided, regardless of how much color and variation of the form is implemented into the built structures that compose it [5]. Since every urban ambient with the appropriate degree of "life" contains all the necessary characteristics that condition the achievement of greater liberty of people and their functioning according to their own nature, the main goal of the abstract art representatives was to achieve what is defined as natural and unrestrained. This view is affirmed by Šuvaković, when he claims that the abstract painting of Jackson Pollok (dripping images of Convergence, 1952) or the modernist music of Olivier Messiaen (Sept haïkaï - Japanese sketches for piano and orchestra, 1962) are based on the artist's confrontation (painter, composer) with untouched nature and its driving force for creating art [11].

The presence of parameters that stimulate "life" in the city areas further influences the formation of the overall image of the city and its urban identity. When it comes to strong and significant peculiarities, it must be noted that these are the characteristics that were not missed out in abstract expressionism. Many consider this movement as an art that is existential, since in the entire process of painting, following the idea-process-product path, the constant search for answers concerning questions of human existence, identity and emotions is constantly present. According to Mattick, Pollock's innovation, as he himself often claimed, lies in the use of abstraction in the order of formation of an intense personal emotional content. Abstract expressionists inevitably ruled over the knowledge of past art painting. However, their greatest contribution relates to the unique supplementation of available knowledge through the analysis of their personality and emotion, and the transfer of the aforementioned on canvas [12]. Above mentioned way of thinking and acting is complementary to the principles of the Existentialism, which was originally defined by Friedrich Nietzsche and Søren Kierkegaard in the 19th century. Although these authors had very different ideas when it comes to implementing their own thoughts into actions, the essence is the same - concern about the vulnerable human existence. People seemed to have forgotten their real existence and someone should have warned them. In the context of reflection and action in the fields of urban planning and design, all previously explained can be identified with the need for accentuating personal experiences and sensibilities (real existence of an individual), as well as expressing individual creativity which would contribute to the upgrading of existing methodologies and tools. While we use various tools for varied analysis, we must be aware that all those preferred tools, as well as those we have not decided to use, are likely to be irrelevant. This is why we need approaches and techniques that can supplement (rather than replace) our traditional methods and tools. Although such approaches and techniques may be less useful, efficient, or accurate than the commonly used ones, their ubiquity in the urban planning process is invaluable [9].

As already mentioned, walking is defined as the basis for adequate analysis of the identity and quality of urban space, i.e. as a tool for entering the city and parallel engagement of all senses. The importance of embracing each and every sensation, not only ones related to visual observation, is overly important both in art and urbanistic activity. Jung points out that: We all see, hear, smell, or taste many things, without noticing them at that moment, either because our attention is gone or because the sensory

impression is too weak to leave a conscious impression. However, they are noted by the unconscious and such perception plays a significant role in our everyday life. Although we do not understand it, they affect our reactions to events and people [13]. Sigmund Freud first spoke about the notion of the unconscious, when he divided the psychological life of a human into three parts: conscious, subconscious and unconscious. This classification had a direct impact on modern psychology, but also on the further course of the intellectual thought development, especially in Western countries. Pollock's drawings and paintings are nothing but an attempt to express the inner state, with the emphasis of the unconscious (everything that human is not aware of, which motivates him to act instinctively - physically and emotionally). Everything that senses daily perceive in open public spaces is essential. The main reason for that is the fact that even unconsciously leaves an intrinsic impression on the users and forms their everyday life, future attitudes and patterns of behavior. This approach is equivalent to Pollok’s work methods, which is evidenced by his paintings with clear signs of movement in real space. He placed a lengthy canvas on floor and walked around it or over it. Then he began to spill, throw or spatter paint directly from the bucket, controlling the tracery with his body movement, fists and hands. He worked fast, rolling around the canvas like a "shaman" performing ritual dance, gaining physical grace not seen before. When he used a brush, he most often used it for drawing. Doing so, he splashed the paint from above on the canvas creating dense, flowing and continuous lines and curves, a complex network of colors [4, pp. 47].

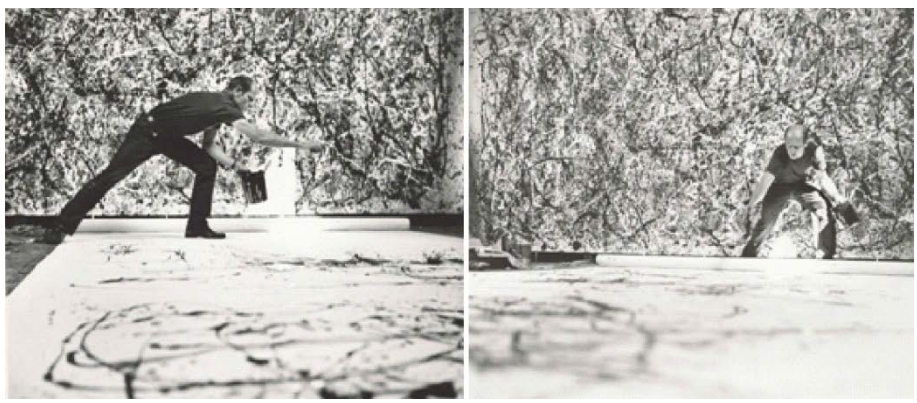

Figure 3. Jackson Pollock's movement during painting in his studio, 1950.

5. Conclusion

Literature fragments that are cited and analyzed through this text represent different attitudes about what the notion of "life" in the cities refers to, and what it depends of. We try to answer whether it is something visible and always present in all physical structures (regardless of whether it is a brick, stone or person), or it is something intangible, such as stimulation and communication mediated by different parameters. By analyzing the reasoned opinions, the main impulses were noted and placed in a certain system. At the same time, the parallel comparison was carried out with terms derived from art - more precisely, the artwork of Jackson Pollock. The concept of this paper proceeded from the

opinion that what is signified as the "life" of a space is impossible to be identified and defined in a homogenous way. A detailed observation, analysis and reflection, which should include the integration and/or overlap of knowledge from various scientific fields in a specific manner, open new possibilities for acquiring the adequate conclusions. Thus, it is not a "mechanical" procedure in the sense of exact science which would produce the same precise conclusion, just as it has become absurd to hold onto the relation from the past with today's urban practice. Innovative ideas and processes need to be set in a way that allows diversity depending on the context, as well as flexibility in terms of further use and development.

The emergence of Abstract expressionism was associated with a series of different influences whose final products (artwork) emerged as a result of their complex overlapping: different primitive cultures, inspiring numerous works of writers, philosophers and psychoanalysts, etc. Growing up in Arizona, attending the Art Students League in New York, studying symbolism in the domains of philosophy and art, certainly contributed to Pollock's interest to American Indians, their expression and culture. Without question, this has contributed to his departure from established forms and styles in painting that were popular at the time. In addition, the question of the unconscious in Freud's psychoanalysis (and later in modern psychology) deepened Pollock's tendency to emphasize individuality, impulsiveness, inner state and emotions.

Although the "life" of certain painting released from an art studio and presented to the public depends primarily on how the audience receives it, it must be kept in mind that its success also depends on other numerous linked factors and complex interrelations. Pollock’s authentic art had numerous supporters even during his active work. However, more important was the influence it had on new concepts, and the orientation towards further flow and development of art (experimental music, "happening", etc.). According to all the above, the main idea of this paper was to refer to different ways of thinking, which imply linking and overlapping the various notions arising from numerous scientific researches and artistic fields. The formation of "non-mechanical" modules of thinking and giving priority (or at least equal importance) to the processes themselves in relation to the final outcome is of crucial importance for further development of urban studies. The reason for that is constantly raising new questions, identifying problems and phenomena, as well as forming new creative concepts as a source of inspiration and intellectual provocation. Previously explained standpoint is in accordance with the statement that if the meanings or primordial impulses which drive artists are different, then any individual integration as part of the creative act is different [14].

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39| Прегледни научни рад
Review paper
doi 10.7251/STP1813536C ISSN 2566-4484

АРХИТЕКТОНСКЕ МЈЕРЕ ЗА ОБЕЗБЈЕЂЕЊЕ КВАЛИТЕТА УНУТРАШЊЕГ ВАЗДУХА У ЗГРАДАМА

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Abstract:

Рад је фокусиран на значај мјера за обезбјеђење ваздушног комфора у градитељству и могућност њихове примјене у архитектонском пројектовању. Обезбјеђивање адекватног комфора у физичком оквиру директно утиче на здравље и радне способности људи и значајно повећава потрошњу енергије. На обезбјеђење одговарајућег квалитета ваздуха, односно ваздушног комфора унутрашњег простора, отпада између 30% и 40% укупне потрошње енергије у процесу коришћења грађевинског фонда. У раду је посебна пажња посвећена анализи мјерљивих утицајних фактора ваздушног комфора: објективним параметрима квалитета и влажности ваздуха.

Keywords: архитектонски простор, ваздушни комфор, објективни параметри квалитета ваздуха, влажност ваздуха.

ARCHITECTURAL MEASURES FOR FACILITATION OF INDOOR AIR QUALITY IN BUILDINGS

Abstract:

This Paper focuses on the importance measures for facilitation of air comfort in construction and the possibility of its application in architectural design. Facilitation of adequate comfort in physical environment directly affects health and working abilities of people and significantly increases energy consumption. Between 30% and 40% of the total energy consumption is spent in the process of using the construction fund in order to ensure adequate quality of air, i.e. air comfort of the indoor space. In this Paper special attention is devoted to the analysis of measurable factors of impact on air comfort through objective parameters of air quality and humidity.

Keywords: architectural space, air comfort, objective parameters of air quality, humidity.

1. ARCHITECTURE AND AIR QUALITY IN BUILDINGS

Construction of functional architectural facilities mirrors the creative spirit of the architect embodied in the process of design which merges several activities that are intertwined and interact and influence each other directly or indirectly throughout all stages of architectural creation. This process is primarily defined by designing the architectural organization and materialization and shaping of the space. At the same time, successful and good design and implementation of measures for achieving air comfort in buildings is inter alia significant characteristic of such a design process which would make the adequate functionality of the facilities impossible to achieve.

Objective factors that directly affect the quality of air in buildings are determined by human activities, construction materials, technological and installation systems, equipment and furniture, uncontrolled entering of atmospheric air into the inner space and other measurable influences. Provision and maintenance of satisfactory air quality in the architectural space is achieved primarily by natural ventilation, i.e. bringing fresh, atmospheric, external air of the required quality and removal of contaminated, internal air from the inner space. Measures for ventilation should provide a sense of comfort in the space in accordance with the basic architectural characteristics of the facility / function, form, materialization, etc. /. When selecting the measures, all air comfort parameters must be adjusted so that optimum air quality is achieved, depending on the purpose of the space and the activities that take place in it.

In that regard, it is interesting to refer to the air quality study in buildings conducted over the past decade by the National Institute for Occupational Safety and Health /NIOSH is the US Federal Agency responsible for carrying out research and preparing recommendations for the prevention of occupational injuries and diseases /, which resulted in producing an overview of primary sources that affect air quality in the space. According to this study, the main causes of air pollution in the architectural space are:

- Inadequate ventilation - 52%,
- Air contamintion as the result of factors inside the building - 16%,
- Air ontamintion as the result of factors outside the building - 10%,
- Microbiological contamination of air - 5%,
- Air contamination caused by building structures and construction materials - 4%,
- Unknown sources - 13%. [1:4]

Based on these research, the National Institute has proposed three basic strategies that can be used individually or in combination in order to reduce the presence of contaminants in space:

- Natural ventilation and control of air quality parameters,
- Forced ventilation and air filtration,
- Directl removal of sources of contamination from the inner space
- Domestic regulatory framework on achieving satisfactory air quality in buildings is provided in the Rule Book on Energy efficiency in the form of recommendations according to which air quality in buildings is ensured through:
- Architectural measures, and
- Systems for air quality control [2:5]

Recommendations of architectural measures are:

- that the buildings should be designed to maximally use natural ventilation whereas the cross ventilation should be preferred,
- The systems of natural ventilation control should be foreseen in order to avoid the negative feeling of drafta.

It is particularly recommended that the air quality control system should have:

- forced / artificial / ventilation system installed with the prescribed number of exchanges in an hour in places where it is not possible to achieve the required characteristics of the air comfort by natural ventilation,
- bringing fresh air by forced ventilation for the purpsoe of regulation according to the real needs of of the situation in time when beneficiaries are using the space.

All existing standards and guidelines for achieving satisfactory air quality are based on the same assumption that ventilation is necessary in order to reduce air contamination in the area to the level which is acceptable. To that end, the main goals of ventilating architectural spaces are:

- provision of necessary air for human physiological needs,
- removal of smells in the space,
- removal of pollutants in the space,
- regulation of humidity,
- maintaining optimal conditions of heat comfort in different weather conditions / mostly in the summer period /.

In accordance with the aforementioned, ventilation of space may be:

- Natural ventilation / functions on the basis of natural charactersistics of air and its influence parameters /,
- Forced or mechanical ventilation / functions with the assistance of various mechanical devices or systems of force /,
- Combined ventilation / functions as the result of application of passive and active measures /.

The remaining part of the Paper shall analyze the parameters, possibilities and combinations of natural ventilation as the main element of architectural measures for the improvement of air comfort of the space.

2. NATURAL VENTILATION

2.1. MAIN CHARACTERISTICS OF NATURAL VENTILATION

Natural ventilation / also in scientific and professional literature the term in use: Free ventilation [3: 6.15] / means controlled air movement through open windows and doors or through designated holes without the use of mechanical devices of force, as well as uncontrolled air movement through holes that exist due to certain imperfections in the building.

In physical terms, natural ventilation implies the change of air that occur as a consequence of natural characteristics of air due to the difference in temperature or pressure, or due to the air flow [4: 1202]. Stimulating mechanisms for natural ventilation are on one hand, the difference in temperature between the internal and external air and chimney effect / and on the other hand, the difference in pressure due to wind strength / wind effect / on the outer shell of the building. [3: 6.15] Figure 1 shows the ways natural ventilation functions. [5: 100]

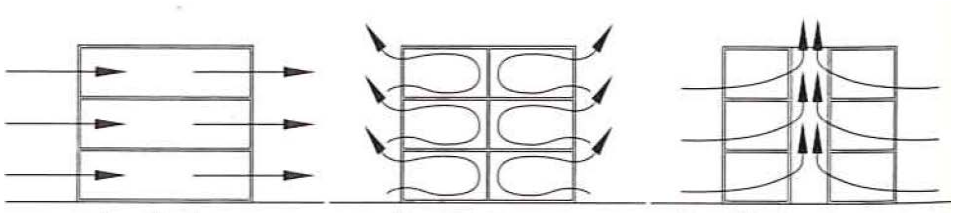

Figure 1. Chart of natural ventilation: 1. Ventilation due to difference in presure / wind effect /, 2. Ventilation due to difference in temperature / chimney effect , 3. Combined ventilation.

The chimney effect is a phenomenon that allows the flow of air through the facility as the result of difference in air temperature between the indoor and outdoor space. Air movement has a vertical trajectory since the density of hot air is lower than the density of the cold air, so the air flow is from downwards up. The wind effect allows air flow through the holes in the building due to the dynamic wind pressure being converted into the static. On the side of the facility exposed to the direct influence of the wind there is a positive pressure difference between the inner and outer space and the negative difference on the side of the curtain, which causes streaming of air in space.

Natural ventilation as a very important and relatively simple technique is intended to contribute to the quality of air in space by reducing the concentration of pollutants, improving the conditions of thermal comfort in space and reducing energy consumption in buildings. The conditions necessary for achieving those improvements in the quality of the environment are:

- the concentration of pollutants in the atmospheric air should be lower than in the indoor space,
- the outdoor air temperature should be within the limits of comfort or in worst case scenario it should not lead to a heat shock for the user of the space,
- Natural ventilation should not cause other environmental and social problems / noise, endangering privacy, etc. /. [6:12]

The quality of air of naturally or partially naturally ventilated building depends largely on atmospheric influences, the microclimatic characteristics of the site, the surrounding natural and built environment and architectural characteristics of the building. With natural ventilation, velocity and direction of the wind are taken into account but also the choice of the appropriate place on the façade of the building where the ventilation openings will be installed. This will affect the amount of atmospheric air that will naturally penetrate into the building and ventilate the room.

In this regard, the quality of natural ventilation depends on:

- Direction and strength of the wind,
- Geometry of the building,
- Surrounding built environment,
- Indoor and outdoor air temperature,
- Type and degree of the porosity of the outer shell of the building. [7:73]

The influence of the wind on the building and the quality of natural ventilation is of highest importance. In the summer period, it has a beneficial cooling effect and reduces the need for forced ventilation, while in other periods of the year and especially during the heating season it significantly increases thermal losses due to higher speed and increased

infiltration through the holes and outer envelope of the building. Buildings should be designed to provide access to the breeze that cools the air in the summer, while reducing the cold effects of the wind in other seasons. [8:58]

Application of measures and system solutions to natural ventilation can significantly affect the living standard of the users of the space. The quality of the building as well as the types of energy, services and systems in the buildings define the role of natural ventilation in accordance with the required air quality in the space. Natural ventilation is sometimes not sufficient in relation to the requirements imposed for certain premises, for example, whether it is a matter of a large number of people being in space or a particular process that takes place in the area concerned.

Natural ventilation, in addition to all its good characteristics referred above also brings certain shortcomings:

- could significantly increase the need for heating under certain conditions,
- causes lack of humidity in the winter time,
- too high temperatures in the rooms in the summer period,
- occasionally leads to appearance of the draft with strong winds,
- occasionally leads to inadequate removal of pollutants in the absence of wind. [7:66]

The oldest way of natural ventilation is through uncontrolled openings, i.e. infiltration, while in most cases it occurs when openings are opened / windows, doors, etc. / on the façade and the roof and provides the best effects of circulation and / or air flow in the room. Channel ventilation, also one of the basic modes, works on similar bases. Today, other contemporary forms of natural ventilation are present, such as, for example, horizontal ventilation through openings, chimney effect, double façades etc.

The main forms or the ways of natural ventilation which will be especially discussed in this paper are:

- Infiltration,
- Ventilation through openings,
- Channel ventilation.

2.2. INFILTRATION

The entry of atmospheric air into the room through unintentional openings / gaps, openings in joints, cracks in walls, floors and ceilings, around the windows and doors / is called infiltration. Infiltration is a natural process that could not be fully controlled in conventional building systems characteristic for the period until the end of the twentieth century and used to be one of the primary ways that caused more or less air flow in space. Thus, by the mid-twentieth century due to the low cost of energy and the need for intensive air exchange, infiltration could almost completely ensure adequate air exchange in the space. In buildings with classic materialization systems in the winter period, the number of air exchange in the space ranged from 0.3 to 0.8 h-1. Contemporary building systems strive to achieve the best thermal characteristics of elements and constructions and air tightness, so the air exchange is below 0.1 h-1.

Modern architectural practice has adopted a number of measures in accordance with the regulations on energy optimization which reduce the possibility of air infiltration to the smallest possible extent in order to save energy, reduce heat losses and avoid moisture formation due to atmospheric precipitation based on the collection of the rose through the insulation in the outer envelope of the building. Therefore, infiltration of air through cracks

in modern buildings designed on the principles of energy efficiency have almost no effect on the ventilation of space.

The rate of air exchange caused by ventilation in cracks is increasing as the temperature gradient increases between the indoor and outdoor air temperature as well as with the increase in wind speed. For that reason it happens especially in winter months that there is excessive air exchange while during the summer months the minimum of hygienically necessary air exchange cannot be reached. Even more important than energy losses is, however, the input of moisture through the collection of dew in the construction when the warm and humid air from the room flows outside through the insulation of the shell. [3:6.15]

The tests found that almost all construction materials are porous and that air leaks. The intensity of the porousness depends on the pressures and the air temperature, the thickness of the layer and the type of material. The water content in structures and materials makes them watertight. Also, the water tightness of the structures and especially the interior surfaces is increased by applying paint / oil based paints almost completely do not let air. Table 1 gives a comparative tabulation of the air infiltration through certain different types of structures and materials. [10:195]

Table 1. Overview of air inflitration by various types of structures and materials

Type of structure	Air infiltration l/h
Gap beneath the door 100/5 mm	54 000
Wooden wall, 10 cm thick	1 100
Roof tiles	720
Keyhole	594
Brick wall, 38 cm thick	280
Concrete	5.5
Brick wall, 6.5 cm thick	4.25
Concrete	0.26

2.3. VENTILATION THROUGH OPENINGS

Ventilation through openings or window ventilation means the exchange of air caused through openings / by opening windows, doors, ventilation openings on the façade, roof extensions, etc. / in the level of the outer envelope.

Ventilation through openings is primarily applicable in areas used by relatively few number of people and with no significant air pollution. The efficiency of the ventilation depends directly on the shape, size and position of the holes on the façade and / or the roof. Ventilation through the openings is relatively quick exchange of the entire air in space but at the same time it is hard to determine the actual speed of external and internal air exchange. The most important parameter of the effect on the achievable air exchange velocity is the position of the opening, i.e. the ways of opening.

In relation to the proper layout, the position and the corresponding surface of the openings, the border cases of setting the openings on the façade and their influence on the ventilation of the space are defined:

- With a low-hole opening located in the central part of the wall surface due to the very small difference in air temperature near the neutral axis, there is no air exchange, / Fig. 2.a. /
- With a low-hole opening located in the upper part of the wall surface, due to the displacement of the neutral axis upwards, the pressure increase and permeability of the opening due to the imperfection of the installation there will be certain air exchange, / Fig. 2.b. /
- With a low-hole opening located in the lower part of the wall surface, due to the displacement of the neutral axis downward, outside the zone of maximum pressure, there is relatively low air exchange, / Fig. 2.c. /
- With a low-hole opening located in the lower and upper part of the wall surface due to the position of the neutral axis in the center and the slots of relatively similar heights in the highest pressure and thrust zones, the best air exchange occurs, / Fig. 2.d. /
- With openings positioned with the entire height of the wall surface due to position of openings in the zones of the highest pressure and buoyance, as in the previous case, there is a very favorable air exchange, / Fig. 2.e. / [11: 8]

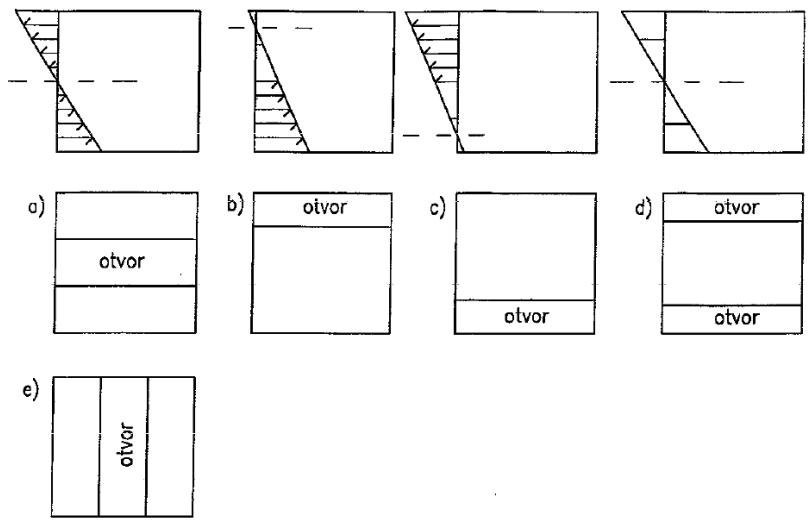

Figure 2. Impact of the position and size of windows on ventilation

In accordance with the way of opening / opening time intervals / there are:

- Impact ventilation / brief opening of the opening /,
- Permanent ventilation / permanent openings [4: 1202].

Impact ventilation is suitable for short-term, relatively fast air regeneration in the winter period with higher temperature differences between the outdoor and indoor air. In this case, when the atmospheric air is significantly cooler than the air in the room, even when there is no wind effect, the atmospheric air flows into the space through the lower part of the opening and leaves the space through the upper part of the opening. / Figure 3. /

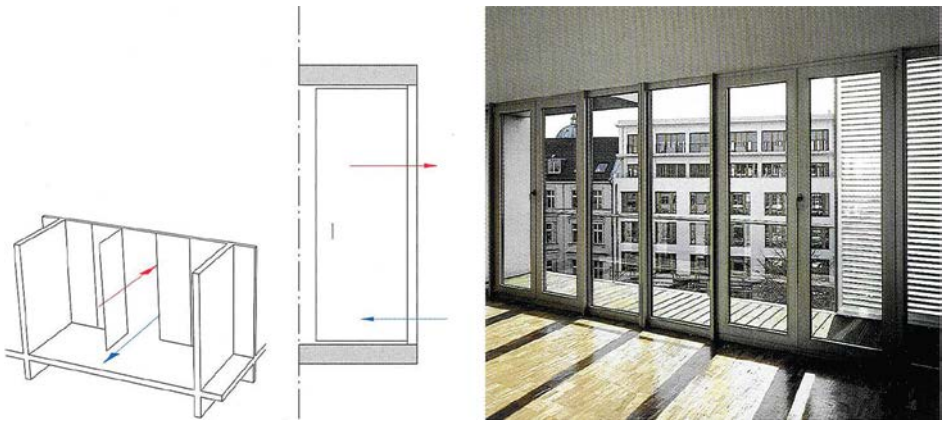

Figure 3. Window ventilation, openings set all over the height of the facade, Residential business building, Gruntuch Ernst, Berlin, 2001

Permanent ventilation is characteristic for the summer period which due to the low temperature differences between the outdoor and indoor air depends to a large extent on the influence of the wind. For permanent or continuous ventilation of space, in contrast to impact ventilation, small openings are preferred, which by correct positioning with the application of the automatic opening and winding system prevent large heat losses, that is, the gain and negative effects of meteorological conditions.

The intensity of natural ventilation depends directly on the orientation of the building. The most common cases, especially for public buildings, are one-sided and two-sided orientation of the space. In the case of one-sided ventilation of the space thermal use is maximized using two openings with as large a vertical distance as possible. In cross-ventilation, the effective use of a thermal buoyance between inlets and outlets of the air is also achieved with as large a vertical distancing as possible. / Figure 4. /

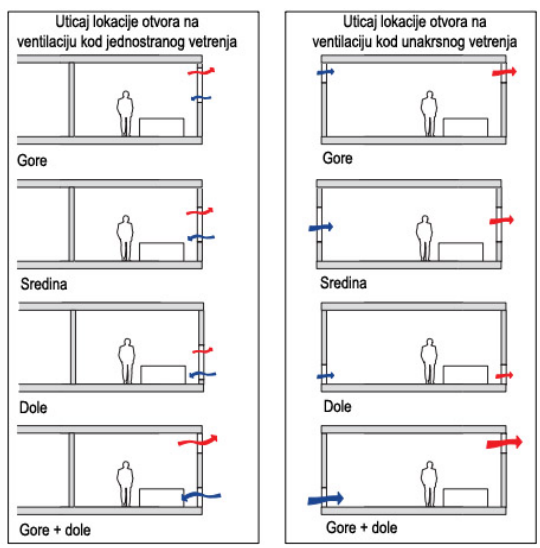

Figure 4. Natural ventilation intensity in a single and double-oriented buildings

The exchange of outdoor and indoor air according to the principle of cross-ventilation is, under realistic bordering conditions, between 50% and 75%. Taking into account the climatic conditions, for complete air exchange in the winter period it takes about 4 to 6 minutes of ventilation and in the summer period in case of inadequate thermal insulation of the building, about 25 to 30 minutes. If a 75% exchange rate is set aside for the ventilation process, then during the winter period, 60 to 90 minutes should last to achieve the minimum required air exchange rate of 0.5 h-1 to 0.8 h-1. In this way, proportionally low heat loss during the day is provided while at the same time good air quality in the room is obtained. By exchanging air through the openings in the night time when, for understandable reasons, the use of permanent ventilation with the opening mode of the window is mainly used, there is often an increase in air pollution, that is, the increased concentration of SO2. [3: 6.17] Table 2 gives an overview of the value of the air exchange coefficients for different of openings. [4: 1203]

Table 2. Overview of the values for feasible coefficient of air exchange with different positions of the openings

Position of the opening	Air exchange velocity / h-1 /
Closed opening	0.0 – 0.2
Tilt and turn windows	0.3 – 3.0
Half open windows	2.0 – 10.0
Completely open windows	5.0 – 15.0
Opposite windows and doors opened	до 40.0

Ventilation through the ventilation holes on the facade works with the constant supply of atmospheric air. During the summer period ventilation is carried out through the opening at the bottom of the wall where the cooler air enters the room and during the winter period ventilation is carried out through higher openings which prevents the entry of cold and humid air with the possibility of regulating the size of the opening. The inlets of fresh air into the building are oriented directly in the direction of the most intensive wind and the outlet is on the roof or on the façade level, contrary to the direction of the supply of outside air.

Special natural ventilation openings are the roof extensions. Ventilation of the space through roof overlays, roof windows or air drainage holes on the roofs of buildings is based on the principle of thermal buoyancy, i.e.when it stagnates at the temperature difference between the outdoor and indoor air. For this ventilation to operate, it is important to bring the atmospheric air that subsequently flows in space when windows and doors are opened.

2.4. CHANNEL VENTILATION

Channel ventilation is applied in cases when the space is located in the central part of the building and when there is no possibility of direct, window or natural ventilation. It operates on the same principles as ventilation of openings, i.e. on the difference in atmospheric and air temperature in the room. The minimum difference in outdoor and indoor air temperatures is unfavorable for air flow and, therefore, ventilation is 5 °C.

With the channel ventilations, a greater air exchange is achieved in the winter period by connecting the air outlet from the room to the window, or the channel that exits to the roof

or facade. The buoyancy in the channel grows in proportion to the height, so that there is bigger subpressure / chimney effect/ in the area.

Suitable openings for the supply of outdoor air with sufficient temperature difference, satisfactory air exchange in the space is achieved. When the outdoor and indoor air temperatures are the same, there is no air movement and in cae outdoor air temperature is higher, the direction of movement is reversed with the possibility of entering warm air through the channel into the room. [4: 1204]

As part of the system solution, channel ventilation involved the use of separate inlet and outlet ducts which are designed and run as single and / or assembly circuits. Domestic building practice has shown that for the natural ventilation of indoor space without windows, the inlet channels of atmospheric air without the use of mechanical air conditioning devices are inapplicable, i.e. that the supply of cold outside air during winter times can cause a feeling of discomfort in space and heat losses. Also, these channels leave the possibility due to the lack of adequate outdoor air and treatment of the same, the supply of contaminated outdoor air into the indoor space.

The channel ventilation system functions as a semi-organized system and modern forms of decentralized ventilation enable organized preparation, insertion and regulation of air in the area with the exhaust of by natural means.

2.5. HYGIENIC - HEALTH ASPECT OF VENTILATION

Ventilation of space is necessary to maintain the normal functions of the human body of persons living and working in those areas. Hygienic and health significance of ventilation consists in maintaining air space comfort at the required level.

Ventilation enables from the health aspect sufficient provision of oxygen for normal functioning of the human body, reduces the concentration of SO2 in space, reduces relative humidity, provides physiological heat transfer, removes unpleasant smell, toxins, gases, microorganisms and pathological bacteria. Among the pathogenic bacteria there are Streptococcus salivarius, Streptococcus beta haemolyticus, Staphilococcus, Pneumococcus, tuberculosis and eggs of pinworm. [12:96]

In case of insufficient ventilation, there are negative consequences, i.e. functional damage, superficial breathing, decrease in productivity, etc. Air flow has several positive effects: its dynamic effect stimulates nerve endings in the skin, tones the vascular and neuro system and causes a pleasant subjective feeling. In case of disturbance of optimum airflow, the human body activity can be reduced and functional disorders, respiratory and viral diseases may occur. In case of complete absence of ventilation, it is possible that disorder of thermoregulation of the human body occurs. In the absence of airflow, susceptible persons feel as if they are choking and adversely affect the general heat exchange of the body. Most authors who deal with this topic consider optimal air velocity in space from the hygienic-health aspect, 0.1 m / s. [12:95]

To perform optimum functions of the human body, it takes about 900 l / min of fresh air, while the smallest physiological limit is 210 to 300 l / min per person. The required amount of fresh air is different for space with different purposes. / Table 3. /

Table 3. Amount of air per person in l / min for different types of space

Quantity of air per person in a l/min	Type of space
140 - 280	Rooms with high ceilings, rooms with no smoke, banks, theatres, cinemas, temples, auditoriums.
280 - 420	Housing units, hotel rooms, barber shops, rooms with equipped with light furniture.
420 - 560	Hospitals, restaurants.
560 - 840	Study rooms, offices, rooms with a lot of smoke.
840 - 1040	Conference halls, bars, smoking areas.

As the consequence of inadequate air quality, certain hygienic and health problems appear in modern architectural facilities primarily related to the characteristics of the applied ventilation systems. This primarily refers to the internationally accepted term, so called / Sick Building Syndrome - SBS/, with difficulties that arise and are primarily characteristic for modern public, mostly administrative and business buildings. Symptoms are unspecific and can be seen in a large number of people in a variety of life situations and because of their temporary characteristics are often not considered as direct illness. It is a collective phenomenon and as such can be qualified. There is a suspicion of the existence of symptoms when more than 20% of people have difficulty or when more than 30% of people complain about the problems of the central nerve system. [4:98]
Possible causes of sick building syndromes are:

- Excessive air flow rate or turbulent air supply to the room,
- Difficulties because of microbial allergens and cellular toxins,
- Defects in field of thermoregulation due to lower or higher air temperatures ,
- Low frequency noise interference / <100 Hz / with central ventilation systems,
- Dispersion of smell from humidifiers and filter sections of central ventilation systems. [7:41]

Table 4. Different Difficulties of Sick Building Syndrome and Possible Causes

Sick Building Syndrome	Possible causes
Draft, inclination to cold, rheumatic difficulties.	Excessive air flow rate, too strong turbulence, insufficient air inflow, too low air temperature.
Irritation of skin, upper respiratory tract and eyes, feeling of dry air.	Microbial allergens / from air conditioners /, home dust, mites.
Fever, difficulties with breathing, pain in the joints, fatigue.	Microbial cell toxins / endotoxins, cytotoxins /, water humidifiers, filters and air exhaust components.
Fatigue, difficulties to concentrate, lack of orientation, headache.	Interference with thermoregulation, low frequency sound, allergens, endotoxins, cytotoxins, insufficiency.

Inadequate air quality.	Odor from air conditioning / technical or microbiological /, insufficient effective air exchange.

The sick building syndrome is characteristic for buildings with total or partly central air preparation that have a significantly higher number of air exchange (> 2 l / h) than conventional buildings with natural ventilation / between 0.5 and 1.0 l / h /. [4: 1204] Numerous studies show that naturally ventilated or occasionally naturally-ventilated buildings cause the least number of disturbances and symptoms of sick building syndrome. A specific form of sick-building syndrome appears in modern facilities where no active ventilation measures are applied. This problem is formally called Tight building Syndrome. Insufficient ventilation / <0.5 l / h / leads to increased concentration of pollutants, nowadays especially various allergens / it is assumed that up to 30% of the modern world population suffers from allergic diseases /, and is successfully resolved by measures of decentralized ventilation of space.

3. CONCLUSION

Air comfort in buildings is one of the basis for planning and designing modern architectural buildings. The provision of air comfort as well as the reduction of negative microclimate effects and the concentration of air pollutants to human health constitute concrete goals arising from the basic settings of the architectural design process and the application of energy, environmental and economic optimization measures.

In this Paper the emphasis is placed on the analysis of architectural measures for the provision of the air comfort of the building. The quality of air in the room is determined on one hand by the quality of the atmospheric air supplied and forms of ventilation and on the other hand, by contamination conditioned by the purpose of space and human activities that take place in it. The movement of air in the space is carried out in accordance with the architectural organization of the space. The aim is to provide a harmonized flow of air in the room with the removal of contamination caused by men who stay and work in the indoor space.

On the other hand, energy-saving construction has a constant need to minimize heat losses caused by ventilation. Air exchange is controlled through hygienic criteria and limits of air quality in indoor spacer. Air quality is appreciated in terms of physiologically desirable air properties and a sense of comfort in space. The air quality in relation to the air composition is characterized by a sufficiently high content of oxygen and the smallest possible content of SO2 as well as other pollutants in the air. Providing sufficient amount of atmospheric air through natural ventilation is necessary to eliminate the harmful effects of pollutants / recommended at least 30 m3 / h per person /.

In addition to all of the above, energy savings between 20 and 50% can be achieved with the application of measures which specifically refers to the improvement of air comfort. Under the current best practices, the following have proved to be extremely effective:

- optimization of the number of people in the indoor space,
- significant improvement of air tightness of the outer envelope,
- improvement of functional and energy performances of natural ventilation openings,

- natural ventilation with modern forms / night ventilation with thermal mass cooling, interior courtyard concept, vertical channels or two-layer facade systems/,
- controlled and decentralized ventilation with air filtration and high heat energy return coefficient,
- automatic regulation of the opening of the outer openings integrated with the central electronic management system / so-called intelligent building /,
- control of the concentration of SO2 in the air of the indoor space. [13]

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40| Прегледни научни рад
Review paper
doi 10.7251/STP1813549K ISSN 2566-4484

SAVREMENI KONSTRUKTIVNI KONCEPTI VISOKIH ZGRADA

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Rezime:

Arhitektura visokih zgrada zavisi od niza faktora, koji uglavnom variraju od inicijalnih ideja, funkcionalnosti projektovanog prostora, percepcije i urbanističkog konteksta, kao i vrste nosive konstrukcije i tehnoloških mogućnosti neophodnih za realizaciju željenog koncepta. Kao jedan od faktora o kojima arhitektonsko rješenje ovisi je svakako nosiva konstrukcija, koja treba da ispuni četiri osnovna zahtjeva: statičku ravnotežu, stabilnost, čvrstoću i krutost. Prekretnica za ubrzani razvoj i izgradnju visokih objekata se desila u drugoj polovini XX vijeka, kada su jake ekonomije razvijenih zemalja poduprle tehnološki razvoj u sadejstvu sa razvojem novih generacija računara i programskih paketa, koji su zajedno doprinijeli razvoju efikasnijih konstruktivnih sistema visokih zgrada. Inovativni konstruktivni sistemi u obliku cijevastih konstrukcija, outrigera (vješaljki) i diagrida (dijagonalnih mreža) i megstruktura su doprinijeli projektovanju i izgradnji visokih konstrukcija kao neizbježnom novom stilu življenja.

Ključne riječi: Visoke zgrade, Konstruktivni sistem, Cjevaste konstrukcije, Vješaljke, Diagridi

MODERN STRUCTURAL CONCEPTS FOR HIGH-RISE BUILDINGS

Abstract:

Architecture of high-rise buildings depends on many factors, which greatly vary from initial concepts, functionality of designed spaces, its proportions to human perception and urban context, and structural support and technological capabilities to support desired concept. Thus, in any analysis of the factors that architecture depends on is its structural support, which has to fulfill four primary structural requirements: static equilibrium, stability, strength and rigidity of the structure. A turnover for fast development in construction of high-rises occurred in the second half of the 20th century; strong economy forced and supported technological developments, and even the new generation of computers and software helped in the development of more efficient structural systems. Innovative structural systems such as tubular forms, outriggers, diagrids and megastructures enabled design and construction of high–rise structures as common thing and inevitable part of new living style.

Keywords: High-rise buildings, Structural system, Tubular forms, Outriggers, Diagrids

1. INTRODUCTION

Race and desire in constructing tall and high exist since periods of early civilizations. The architectural heritage and remains from early civilizations, are undeniable evidences that constructing high and massive is not innovation and reflection of the contemporary society. Whether high–rise buildings function as commercial, residential or educational use of these forms of vertical architecture is becoming more and more popular.

Despite various contemporary requirements and technological developments of high–rise building's structural systems, history and beginnings of high–rises were less complicated and simple when compared to nowadays technology. During the period of the first–high rise building, widely in use and best known were massive load bearing masonry structures, rigid thick shear walls with small perimeter openings with low resistance to lateral forces which are crucial for structural design of high–rise buildings. Masonry structures were replaced with an iron and steel structures which created larger spans between columns, creating more open areas at the building's perimeter for the windows, and it also facilitated the construction. At that time, terms such as load–bearing systems, in shape of rigid steel frames and non–load bearing structural elements, such as separation walls, or fill–in brick non–load bearing walls between the columns at the perimeter of the buildings that were not glass surfaces, were introduced to structural design. [1]

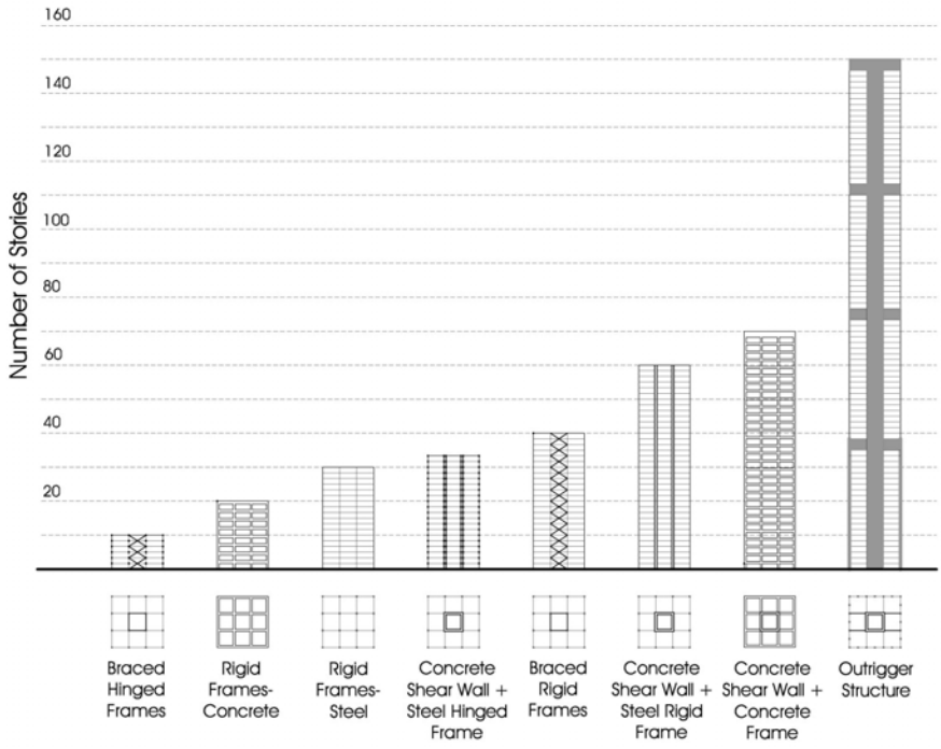

Figure 1. Classification of the Structures of High–Rise Buildings according to Mir M. Ali (interior structures) [2]

Non–load bearing elements and cladding materials were carrying nothing but self–weight and lateral wind load in their areas. Development in this range was more than sufficient for designers and investors to start racing for expansion in vertical dimensions. High rate in increase in height of the buildings was not equally accelerated with technological development of the structural systems and designs.

Notwithstanding fact that major requirements crucial for the structure are to meet equilibrium, stability, strength and rigidity, structures itself are nevertheless in architectural sense becoming an additional aesthetic value for a building supporting the concept. Structural diagrids, tubes, braces of the frame system, space trusses etc., commonly represent structural systems that bring an additional aesthetic value to high–rise buildings.

In 2007, Mir M. Ali developed new classification of structures for high-rise buildings guided by lateral load resisting capabilities. According to Mir M. Ali, each structure had a major structure which was capable to resists lateral actions (wind and seismic actions), and minor one which was not as dominant as major, but did have capacity to resist lateral actions. [2]

If the major structure was placed at the inner part of the building, while minor structural elements were positioned at the perimeter of the building, structure was classified as interior structure (Figure 1). If the major structure was positioned at the perimeter of the building and minor at the interior, structure was classified as exterior structure (Figure 2).

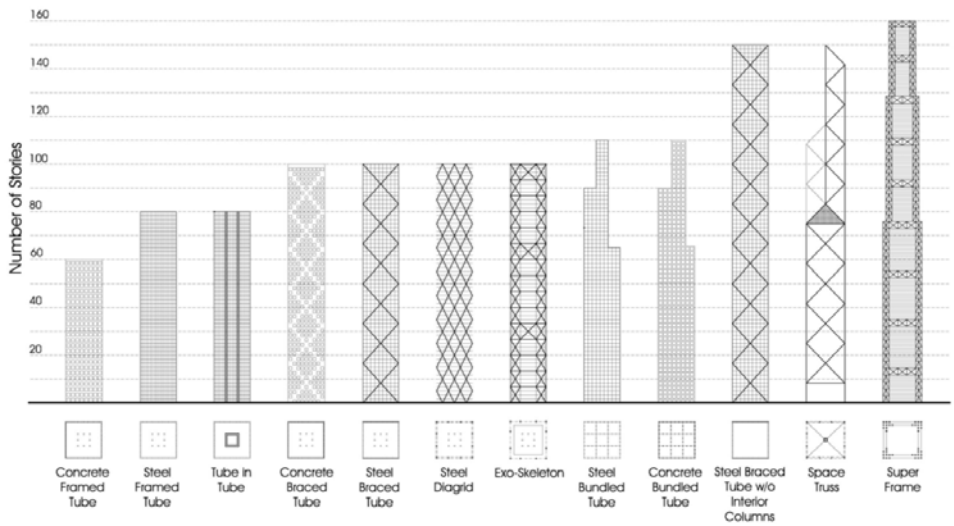

Figure 2. Classification of the Structures of High–Rise Buildings according to Mir M. Ali (exterior structures) [2]

2. TUBE SYSTEM

One of the most spread exterior structures of high–rise buildings is tube structure. Lateral actions in such structure are resisted with the structural element positioned at the perimeter of the building (Figure 3).

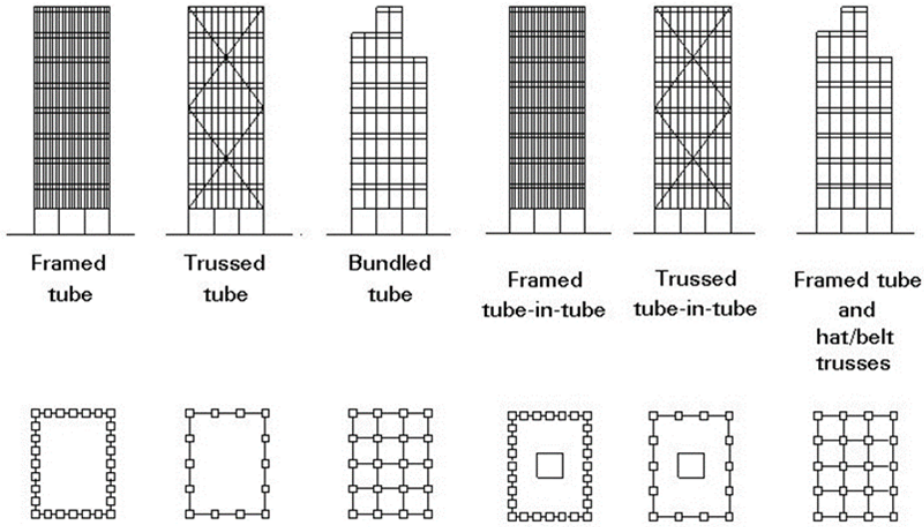

Figure 3. Variation of Tubular Structures [1]

As one of the greatest innovation in the sixties, tube structure was designed by F. Khan back in 1961. [3] It was delivered as an actual structure with De Witt Chestnut Apartment Building in Chicago. Construction was finished by 1963, with 43 storeys height, and in arrangement of framed tube (Figure 4).

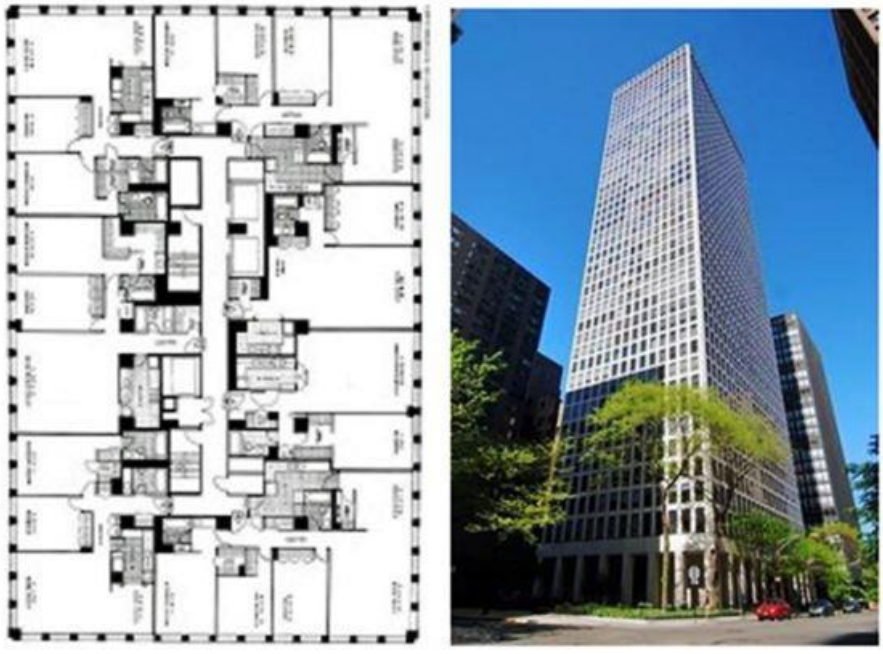

Figure 4. De Witt Chestnut Apartment Building in Chicago [4,5]

Frame tube structure was the first example of tubular approach for construction of in high–rise buildings. It is designed as hollow cantilever, fixed at the foundation to the ground, in order to resist lateral loads. It consists of closely arranged columns, while the span between central axes of columns' cross section is approximately between 1.5 to 4.5 meters and spandrel beams being rigidly connected. The depths of beams vary between 60 and 120 cm. Term framed tube structures is closely related to, shear lag effect, which means that within this type of structure corner columns experience the largest axial forces, which are not distributed linearly along the direction perpendicular or parallel to the wind.

Frame tube can be designed both out of, steel or concrete, with efficiency up to 80 storeys. For architectural functionality or aesthetics such system strongly leads the overall composition, dynamic and geometry of the elevation, while at the same time decreases costs for the additional curtain wall or fill in walls, but also reduces daily light penetration to the building.

A type of tube structure, braced tube, also called truss tube, was first used back in 1970 in Chicago, at John Hancock Centre (Figure 5).

Figure 5. John Hancock Centre, Representative Example of Braced Tube Structure [6]

Such structure developed as newly evolved frame tube. Instead of closely arranged columns, required structural stiffness was achieved by diagonal bracing. Braced tube

overcame the problem of progressive inefficiency in over 60 storey high buildings which was the case with frame tube. With bracing, perimeter frames acted as stiffener and the braces overtook floors' gravity actions. Each joint of the diagonals and columns, in structure of braced tubes, eliminated effect of shear lag by being tubular in framework. Besides structural advantages of braced truss tubular structure, larger spans between columns that were provided by bracings, created larger areas for the openings glass areas increased the interior quality and at the same ratio, the glass areas increases themselves. Also, the braces which were left as visible by design, enhanced and gave a character to each elevation.

Bundled concept, unlike others structure's concepts gives variety of characteristic floor plans in areas, with greater lower storeys and those smaller at the upper storeys. There are different geometrical shapes in grid plan, such as: rectangular, triangular, hexagonal etc., which mould vertical volume of the high–rise tube. Bundled tube structures, efficiency is up to 110 storeys, with possibility of steel or concrete as main structural material. Even though such composition reduces shear lag and enables slenderer structural elements, the configuration of tubes may have created limitation in arrangement of the interior space.

Unlike other tubular structures, bundled tube system, made high–rise buildings structured with this system a vertical play of the various volumes, which differentiated it from the cubic shaped towers. In this variation of tube structural system, couple of tubes were interconnected and acted as one unit. Back in 1974, Sears Tower (Figure 6) was the first bundled structure, with 9 tubes at the base level, which created regular grid of 3 rows and 3 columns, while still following the principle of bundled structure; as the final storey was not cubic (Figure 7). Approach of the bundled structures, concept and the overall design of structure reduced the elements of the lower storeys, slandering lower structural elements, when compared to those that would be required for other type of structure.

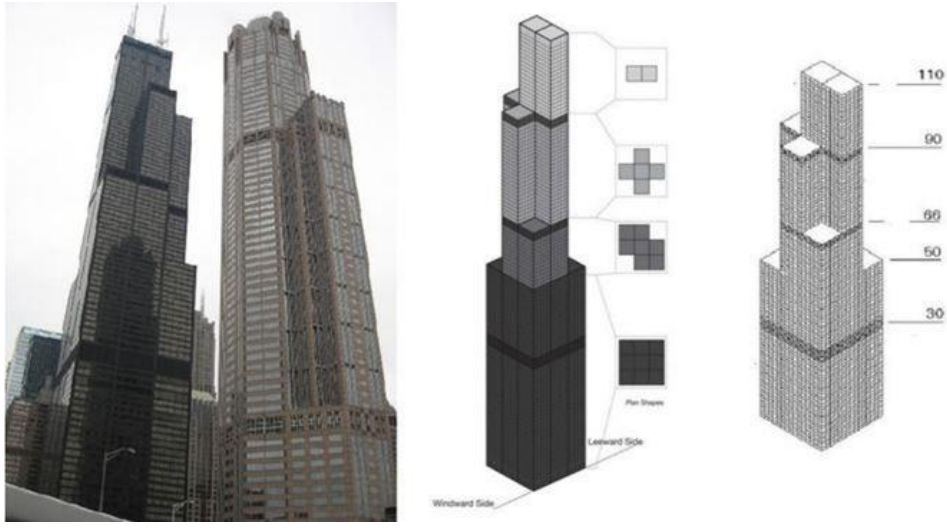

Figure 6. Figure 1. Sears Tower, Chicago (left),
Schemes of Modular Floor Configuration (mid and right) [7,8]

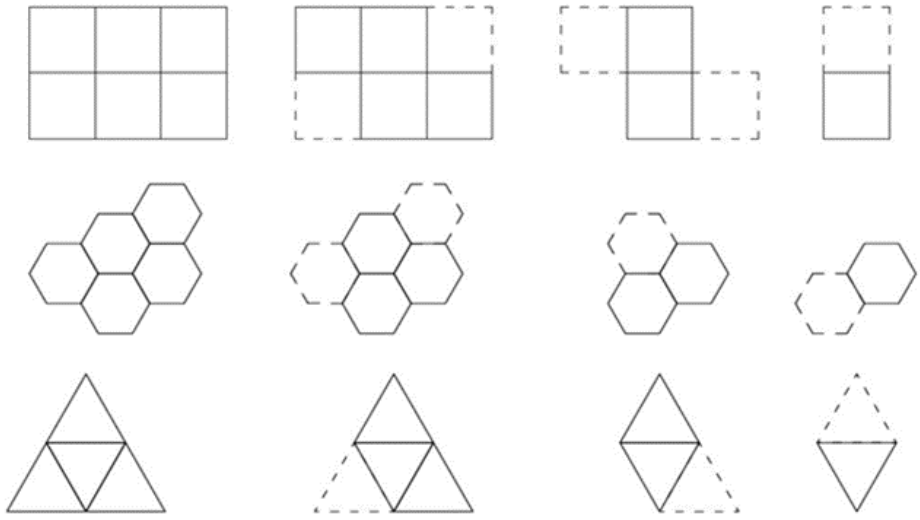

Figure 7. Different Plan Configuration for Bundled Tube Structures [1]

One of the safest tubular structures due to resistance to the impact loads, besides its high stiffness of structure in resisting lateral and gravity loads is tube in tube structure. It is usually composed of two tubes, one larger at perimeter and smaller inside perimeter of building, however it may be designed with more tubes within a tube if it is required due to higher safety and if such attempt and concept shows as efficient.

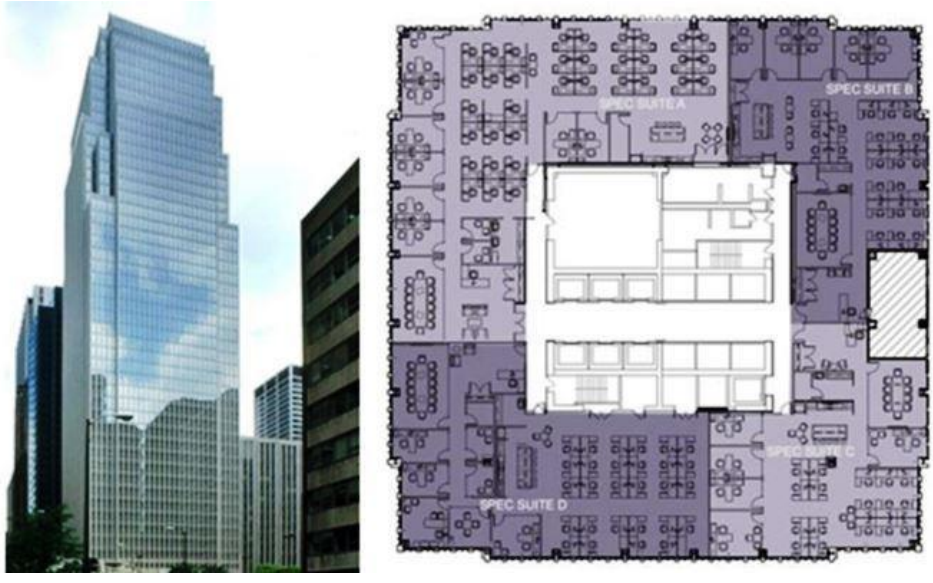

Figure 8. West Madison Street 181, (left), Characteristic Floor Plan (right) [9,10]

An example of tube in tube structure is 181 West Madison Street in Chicago, which has 52 storeys (Figure 8). Such structure effectively resists lateral actions with both tubes due to its system that inner core (inner tube) and outer tube with slabs, which makes both core and cube able to resist lateral actions.

As far as the structural material is concerned, both exterior and interior tubes can be designed as concrete or steel cores or frame tubes. In terms of height, tube in tube system is efficient up to 80 storey high buildings.

However, such structures excludes a high demand for numerous columns in interior design, inner core if not used with specific purpose as elevators, stairs, mechanic installations core, can develop limitation in arrangement of interior space.

3. OUTRIGGER SYSTEM

Outrigger structures are generally a unity of the core, outriggers, belt trusses and mega columns. Shear cores are mostly designed at the axial center of the floor plan; however it is not impossible for it to be located at either one side of the building. Commonly in a form of concrete cores or rarely in a form of steel trusses, shear cores do act as vertical cantilevered beam fixed at the foundation. Outriggers, might be in a form of steel trusses or concrete walls, and depending on the design the outriggers are approximately 1 to 2 storeys deep.

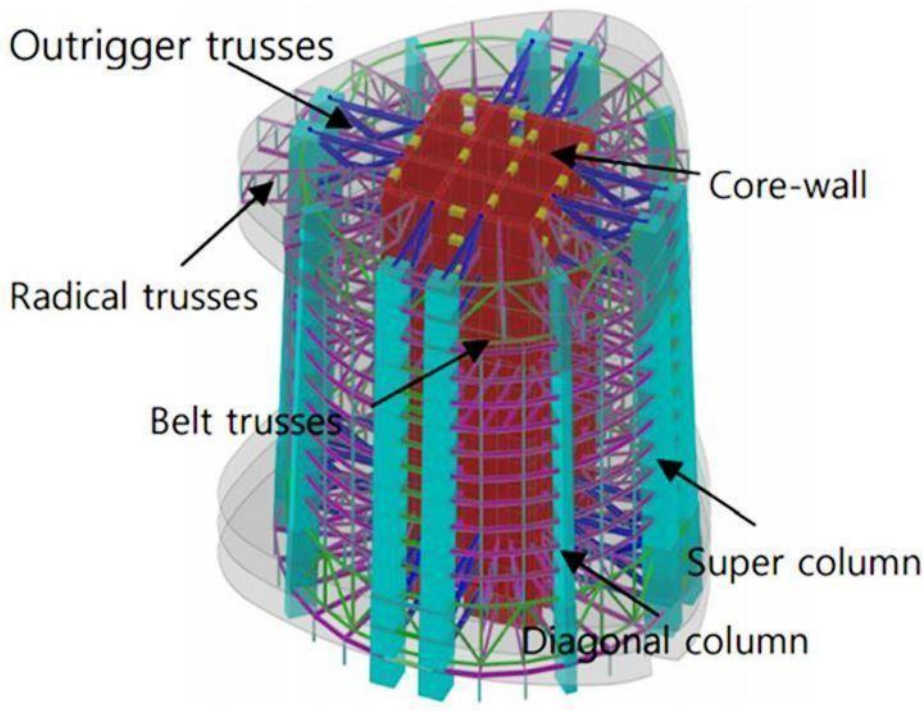

Figure 9. Shanghai's Tower Structural System [11]

Depending on the position of the core, outriggers may extend from both sides if the core is centrally positioned or from one side if the core is placed on one side of the building. The role of the outriggers is to reduce moment in the structure's core by acting as the stiff headers that transfer the moment from the core, to the mega columns generally located at the perimeter of the building by stimulating a tension–compression couple in mega columns. Belt trusses connect the mega columns at the perimeter of the building, reducing the elongations in tensile zone and shortening in compression zone of mega columns, while also being capable to resist a shear load, which can cause bending (Figure 9).

Even though, the columns and belt trusses are capable of taking over lateral actions, the design of major structure is interior core and outrigger, which classifies this structure as interior structure. (Figure 10)

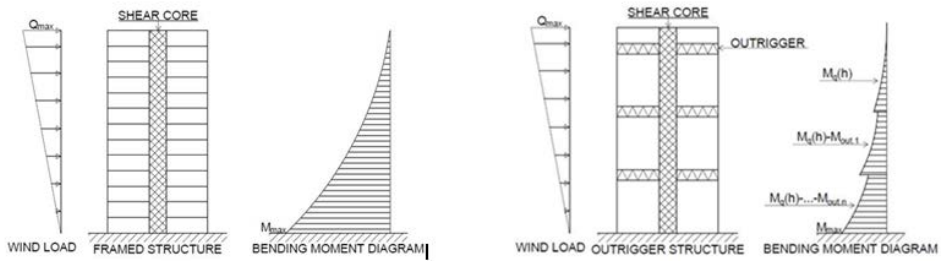

Figure 10. Bending Moment Diagram under Applied Wind Load on Shear Core and Frame Structure (left) and Bending Moment Diagram under Applied Wind Load on Outrigged Structure (right) [1]

Outrigger structures are lately becoming very popular in super high-rise buildings, where outriggers trusses or walls advance shear wall/core system in resisting lateral actions in a form of redistribution of shear forces. With outriggers in buildings higher than 70 storey, bending caused by overturning is highly resistant.

Besides valued advantages, in terms of additional stiffness, stability, higher resistance of the structure to crucial lateral loads, high performance and efficiency in use of the materials and design, the main disadvantage is perceived in occupied rentable space reserved for outriggers.

If consider that 1 or 2 storeys are required per one outrigger, it becomes obvious that the greater height leads to the percentage of occupied stories respectively increasing as well. However if well planned and designed, outrigged stories can be used as mechanical floors; such approach excludes "waste" of space. Considering structural material, this structure might be designed as steel structure or concrete, or in most cases as composite structure. Due to the high fire resistance requirements, cores are mostly designed in concrete, which adds to the safety for occupants of the building in the case of emergency. However, lightness of structural steel makes steel preferable in comparison to heavy concrete for outriggers and belt trusses, such structure and relation between materials and structural elements, is showed as efficient when constructing 150 storeys high buildings.

4. DIAGRID SYSTEM

Diagrid is an exterior structural system used in high–rise buildings, which is even though entirely exposed at the elevation, both in architectural and structural fields of science and art, defined as extremely aesthetic.

Figure 11. Hearst Headquarters Centre in New York (left), and 30 St. Mary Ave in London (right) [12,13]

Unlike, diagrid braced tubular structure, which may be seen as a forerunner of diagrids, it is mostly degraded by expertise and critics. Entirely braced John Hancock Centre in Chicago (Figure 5), was one of the pioneers in braced tube structures; despite the improved structural efficiency, new aesthetic style, innovation, structure exposed through all four elevations was not welcomed.

However, a decade later, newly named form of diagrid, gained full attention. Dating back to 1980's Sir Norman Foster, proposed diagrid solution for the Humana Headquarters composition. Even though diagrid was not a best solution for Sir Norman Foster, Hearst Headquarters Centre in New York and 30 St. Mary Ave in London received praise and become monuments of Sir Norman Foster, and were closely related to diagrid structures (Figure 11).

In diagrid structures, the whole structure depends on diagonal members. Due to stored shear by axial forces in diagonal members diagrid structures reduces and minimize shear deformation. Diagonal members of diagrid were also capable of carrying gravity actions, and its triangulated configuration of diagonals could resist for lateral actions. As structure, diagrid did not seek for shear rigidity cores, because diagrid had high bending and shear rigidity at the perimeter's diagonals (Figure 12).

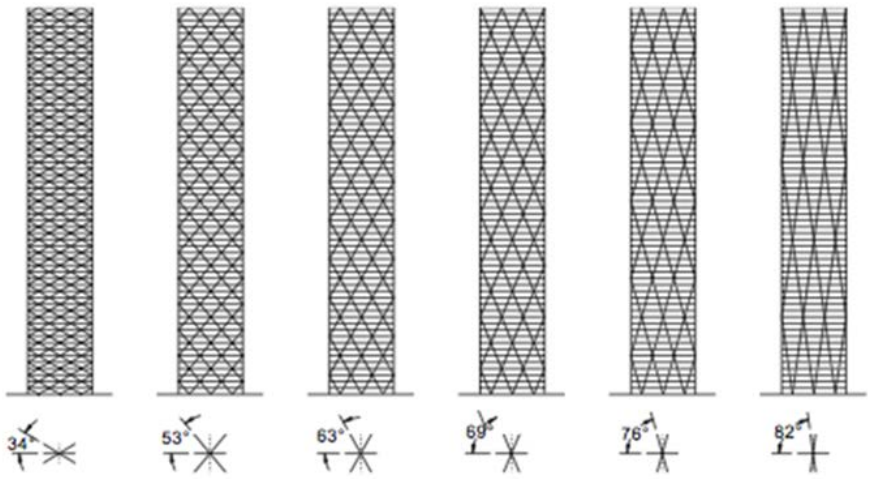

Figure 12. Variations of Diagrid Geometry [14]

Diagrid structures are commonly steel structures, with very complicated joints of the diagonals, however they are efficient in up to 100 storeys buildings, and represent regular geometry in diagrids. Lately diagrids are designed and constructed out of concrete, as main structural material, which is far different from steel diagrid, with more irregular and organic shape, which lead to the new futuristic architectural aesthetics. Concrete diagrid structures, require expensive formwork and the construction. An example of such design is reflected in O–14 Building in Dubai (Figure 13).

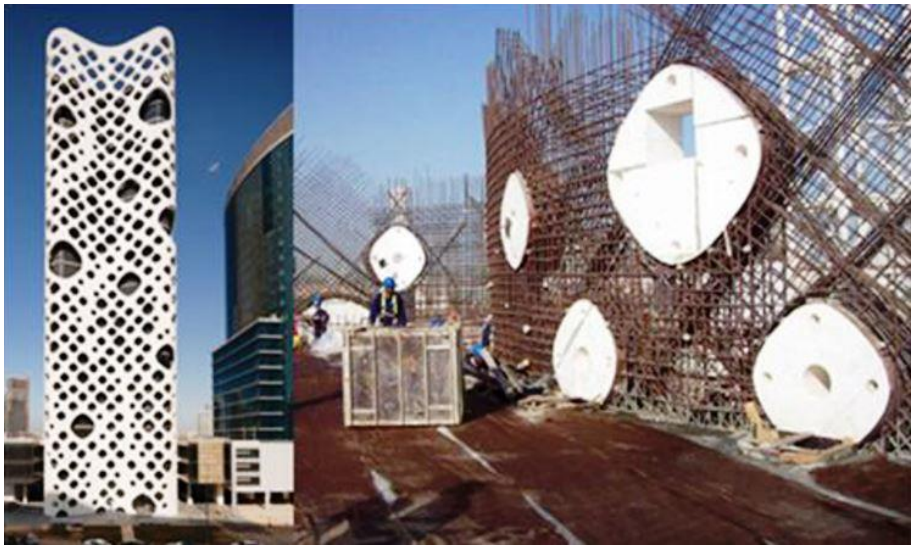

Figure 13. Concrete Diagrid, O-14 Building Dubai (left)
and Construction of Diagrid (right) [15,16]

5. CONCLUSION

High–rise buildings are inevitable part of contemporary living style, and at the same time represent futuristic direction of structural and architectural development. For present societies where there is a constant increase in population number and ratios between constructed land and natural environment, high–rise buildings present new environmentally friendly and sustainable way of living, as they occupy practically small areas of the ground and expand vertically. High–rise building are becoming taller and taller, thus there is a necessity for very careful and detailed design of each structure in order to provide safe, comfortable, stable and resistant structure, and to be trustworthy for potential users and inhabitants of high–rise living. High–rise structures themselves deal with the critical load combinations, where at this specific case of high–rise structures, lateral loads (wind and seismic actions) are crucial in structural design. With these enormous heights, wind acting increases and may cause a noticeable building movement and sway. However, high–rise structures can be of high–quality and detailed architectural, structural and mechanical design with carefully monitored construction process and efficient with the choice of the best suitable, resistant and safe structural material. There are similar and approximately the same structural systems and designs all around the world, which are efficient up to the certain heights, with correspondence to the use of the specific structural materials and ability to resist the critical loads combination in specific environment.

Common types of structures in high–rise buildings are as follows: frame system, shear wall system, outrigger system, tube system, diagrid system, space truss system, exo–skeleton system, super frame and hybrid systems. These structural systems are basics but combined or modified can support any architectural concept and form, while resisting the critical load combinations.

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41| Прегледни научни рад
Review paper
doi 10.7251/STP1813562D ISSN 2566-4484

OTPORNOST NA POŽAR ARMIRANOBETONSKIH PLOČA PREMA EC2 I BRANZ TR8

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Rezime:

Betonski elementi su praktično integralni dio svakog građevinskog objekta. Imaju značajno veću otpornost na požar u poređenju sa elementima konstrukcije izrađenih od drugih građevinskih materijala. Međutim, armiranobetonske ploče su najosjetljiviji armiranobetonski elementi u požarnim uslovima u poređenju sa drugim armiranobetonskim elementima. U tom smislu, ovo istraživanje je usmjereno na određivanje otpornosti na požar armiranobetonskih ploča prema Tabelarnom metodu za određivanje otpornosti na požar betonskih elemenata iz BAS EN 1992-1-2:2017, Eurokod 2: Projektovanje betonskih konstrukcija - Dio 1-2: Opšta pravila - Projektovanje otpornosti konstrukcija na djelovanje požara i BRANZ Tehničkoj preporuci br. 8 - Metodu za određivanje otpornosti na požar betonskih greda i međuspratnih konstrukcija. Požarno dejstvo na armiranobetonske ploče je modelirano Standardnim požarom ISO 834 (BAS EN 1991-1-2:2015). U ovom istraživanju razmatra se otpornost na požar armiranobetonskih ploča statičkog sistema proste grede, različitih raspona, debljina i uz varijacuju debljine zaštitnog sloja betona do armature.

Ključne riječi: Armiranobetonske ploče, Otpornost na požar, Zaštitni sloj betona

FIRE RESISTANCE OF REINFORCED CONCRETE SLABS ACCORDING TO EC2 AND BRANZ TR8

Abstract:

Concrete elements are practically an integral part of every construction project and building. They have significantly higher fire resistance in comparison to elements made of other construction materials. However, RC slabs are the most sensitive concrete elements to the effects of fire when compared to all the other reinforced concrete elements. Therefore, this research focuses on determining the fire resistance of RC slabs using Method for determining fire resistance of slabs BAS EN 1992-1-2:2017, Eurocode 2, Design of concrete structures, Part 1-2: Structural fire design (Tabulated Data) and BRANZ Technical recommendation No. 8 – Method for Fire Engineering Design of Structural Concrete Beams and Floor Systems. A fire action to RC slabs is modeled using standard fire ISO 834-1 (BAS EN 1991-1-2:2015). This research considers determining fire resistance of simply supported RC slabs of different spans and different depths with variations of concrete cover.

Keywords: RC slabs, Fire resistance, Concrete cover

1. INTRODUCTION

This research considers determining fire resistance of simply supported RC slabs of different spans (3, 5 and 7 m) and different depths (12, 15 and 17 cm) with variations of concrete cover ranging from 0.5 to 3 cm. Slabs were previously designed according to the BAS EN 1992-1-1:2017, Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings [1], with permanent action consisting of slab self-weight and flooring of $1.5\,\mathrm{kN/m^2}$ and variable action of $2\ \mathrm{kN/m^2}$. The determination of fire resistance is conducted according to the Method for determining fire resistance of slabs BAS EN 1992-1-2:2017, Eurocode 2, Design of concrete structures, Part 1-2: Structural fire design (Tabulated Data) [2] and BRANZ Technical recommendation No. 8 – Method for Fire Engineering Design of Structural Concrete Beams and Floor Systems [3].

2. FIRE ACTION TO RC SLABS

The International Standard ISO 834-1, Fire Resistance Tests - Elements of Building Construction from 1999, is internationally accepted in Europe, Australia, New Zealand, and other countries, and it defines the standard temperature – time curve for fire modeling or exposure of test samples in test furnaces.
This standard is also accepted as BAS ISO 834-1 [4] in Bosnia and Herzegovina by the Institute for Standardization of Bosnia and Herzegovina, based upon the proposal of its Technical Committee BAS TC 37 – Fire Safety in Buildings. The curve is defined as:

$$T = 345\, log_{10}(8t + 1) + 20 \tag{1}$$

where:

T- average temperature in the test furnace in ºC;
t - test time in minutes.

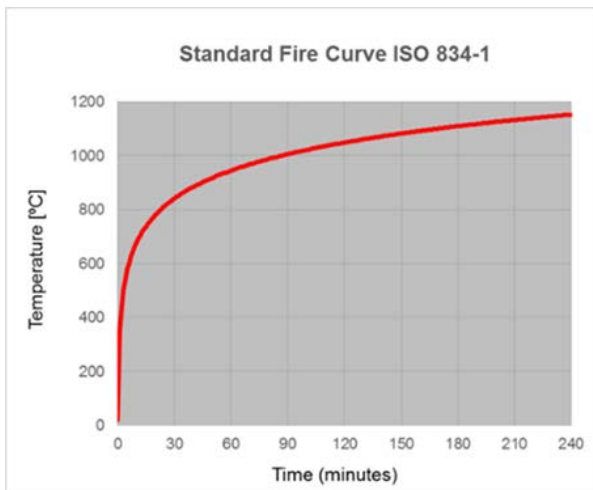

Figure 1. Standard Temperature-Time Curve ISO 834-1 [5]

Table 1 displays values of average furnace temperatures according to the ISO 834-1 temperature-time curve for different test times.

Table 1. Average Furnace Temperatures for Different Fire Test Times [5]

Time (t) [min]	Average Temperature in Furnace $T-T_0$ [ºC]
5	556
10	659
15	718
30	821
60	925
90	986
120	1029
180	1090
240	1133
360	1193

3. EUROCODE 2: DESIGN OF CONCRETE STRUCTURES PART 1-2 – STRUCTURAL FIRE DESIGN - TABULATED DATA

BAS EN 1992-1-2:2017, Eurocode 2, Design of concrete structures, Part 1-2: Structural fire design [2], provides following three methods for determining the fire resistance of concrete structures:

- Tabulated data;
- Simplified calculation methods; and
- Advanced calculation methods. [5]

Fire performance of concrete elements and structures exposed to the nominal fire should be observed through three basic criteria:

- Mechanical resistance, load bearing function (Criterion R);
- Integrity, separating function (Criterion E); and
- Insulation (Criterion I).

BAS EN 1992-1-2:2017 defines that Criterion "R" is assumed to be satisfied when the load bearing function is maintained during the required time of fire exposure. The Criterion "E" (Integrity) is the ability of the separating element of the structure to prevent passing of flame and gases from one side to another side of the element when exposed to the standard fire from one side, thus preventing the occurrence of the flame on the unexposed side during the required time period. Criterion "I" may be assumed to be satisfied when the average temperature rise over the whole of the non-exposed surface is limited to 140 K, and the maximum temperature rise at any point of that surface does not exceed 180 K in consideration of the separating element of the structure when exposed to the standard fire from one side for the required time of fire exposure.

Required criteria for the observed element depend on the element’s function in the building. For example, when it comes to slab, it must meet all three criteria R, E and I, while columns are usually expected to satisfy only the load-bearing function - Criterion R.

Tabulated Data method gives recognized design solutions for the standard fire exposure up to 240 minutes and applies to normal weight concrete (2000 to 2600 kg/m^3), made with siliceous aggregates.

The method is based on the determination of the axis distance of the reinforcement to the fire exposed side of the concrete element, and not on the thickness of the concrete cover, depending on the required period of fire resistance and the required function of the element. The following Figure defines the axial distance "a" from the centroid of the reinforcement to the fire exposed concrete face.

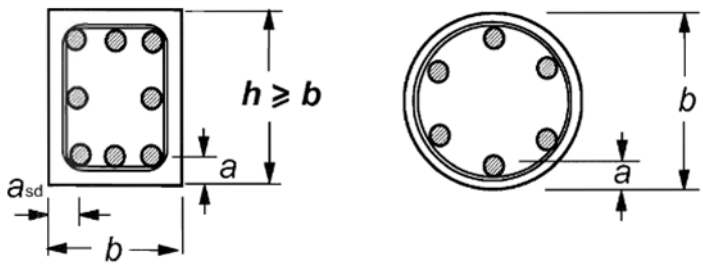

Figure 2. Axis Distance [2]

If calcareous aggregates or lightweight aggregates are used in slabs, minimum dimensions of the cross-section given in tables may be reduced by 10 percent. Minimum requirements tabulated in tables from the aspect of dimensions of the cross-section and the axial distance required to meet Criterion R have their origin from the following equation:

$$E_{d,fi}/R_{d,fi} \leq 1{,}0 \qquad (2)$$

where

$E_{d,fi}$ - design effect of actions in the fire situation; and

$R_{d,fi}$ - design load-bearing capacity (resistance) in the fire situation.

Table 2. Minimum Dimensions and Axis Distance for Simply Supported Concrete Slabs [2]

Standard fire resistance	Minimum dimensions (mm)			
	slab thickness h_s (mm)	axis-distance a		
		one way	two way: $l_y/l_x \leq 1{,}5$	two way: $1{,}5 < l_y/l_x \leq 2$
1	2	3	4	5
REI 30	60	10*	10*	10*
REI 60	80	20	10*	15*
REI 90	100	30	15*	20
REI 120	120	40	20	25
REI 180	150	55	30	40
REI 240	175	65	40	50

l_x and l_y are the spans of a two-way slab (two directions at right angles) where l_y is the longer span.

For prestressed slabs the increase of axis distance according to 5.2(5) should be noted.

The axis distance a in Column 4 and 5 for two way slabs relate to slabs supported at all four edges. Otherwise, they should be treated as one-way spanning slab.

* Normally the cover required by EN 1992-1-1 will control.

Tabulated data are based on the reference load level η_{fi} = 0.7 unless otherwise stated. In order to ensure necessary axis distances in tensile zones of simply supported slabs, Table 3, Column 3 (one way), are based on a critical steel temperature of θ_{cr} = 500 °C. This assumption corresponds approximately to $E_{\mathrm{d,fi}}$ = 0.7 E_{d} and γ_s = 1,15, where E_{d} denotes the design effect of actions according to BAS EN 1992-1-1:2017. The minimum slab thickness h_s given in Table 2 ensures adequate separating function (Criteria E and I).

4. BRANZ TECHNICAL RECOMMENDATION NO. 8 - METHOD FOR FIRE ENGINEERING DESIGN OF STRUCTURAL CONCRETE BEAMS AND FLOOR SYSTEMS

BRANZ – The Building Research Association of New Zealand, Technical Recommendation No. 8 from 1991 [3], provides a model for determining fire resistance of load-bearing beams and slabs made of reinforced or pre-stressed concrete, influenced by elevated temperatures. The basic design procedure was developed and verified through a large number of fire resistance tests of reinforced concrete elements sponsored by the Portland Cement Association - PCA. The significance of this method for determining fire resistance of concrete elements lies in its combination of the principles for determining the fire resistance given in ACI 216.1-97/ TMS 0216.1-97 [6], but also applies the standard temperature-time curve according to BAS ISO 834-1[4], for distinction from ACI 216.1-97/TMS 0216.1-97 which is based exclusively on the standard fire curve according to ASTM E 119 [7].

The foundation of this method is as follows: if the bending moment capacity of the slab is greater than or equal to the maximum applied bending moment $M_\theta^+ \geq M_a$, the slab has the required fire resistance; however, if the bending moment capacity of the slab is less than the maximum applied bending moment $M_\theta^+ < M_a$, then the slab does not fulfill requirements for the required fire resistance period.

Determination of the bending moment capacity M_θ^+ of the slab cross section, given after the required time of exposure to the fire is carried out according to the following equation:

$$M_\theta^+ = A_s \cdot f_{y\theta} \cdot \left(d_\theta - \frac{a_\theta}{2}\right) \tag{3}$$

where

M_θ^+ - bending moment capacity of the slab cross section;
A_s - cross sectional area of tensile reinforcing steel provided;
$f_{y\theta}$ - yield stress of reinforcing steel at the temperature θ;
d_θ - width of the compression stress block (1.0 m for slabs); and
a_θ - depth of the compression stress block.

Based on the nominal temperature of the tensile steel (θ), the yield strength of reinforcing steel at elevated temperatures is determined using the next equation:

$$\frac{f_{y\theta}}{f_y\,(20\,°C)} = \begin{cases} 1.0 & for\ \theta \leq 250\,°C \\ 1{,}53 - \dfrac{\theta}{470} & for\ \theta > 250\,°C \end{cases} \tag{4}$$

Since all methods for determining the fire resistance of reinforced concrete elements assume that the temperature of concrete and the temperature of the reinforcement are identical at the same position, diagram in Figure 3 can be used to determine the temperature of concrete and nominal temperature of tensile steel (θ).

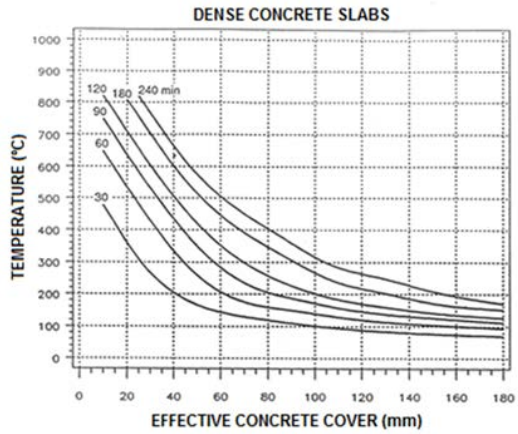

Figure 3. Determination of the Temperature of Reinforcing Steel [3]

Since the compression zone of slabs is not exposed to the fire, the width of compression block is equal to 1.0 m for slabs. The depth of the equivalent rectangular stress block a_θ is:

$$a_\theta = \frac{A_s \cdot f_{y\theta}}{0.85 \cdot f'_{c\theta} \cdot d_\theta} \tag{5}$$

where

$f'_{c\theta}$ - reduced compression strength of concrete at the temperature θ.

For determining the concrete strength at elevated temperatures, the diagram in next Figure can be used, where bilinear diagram “a” is for normal weight concrete and bilinear diagram “b” is for lightweight concrete.

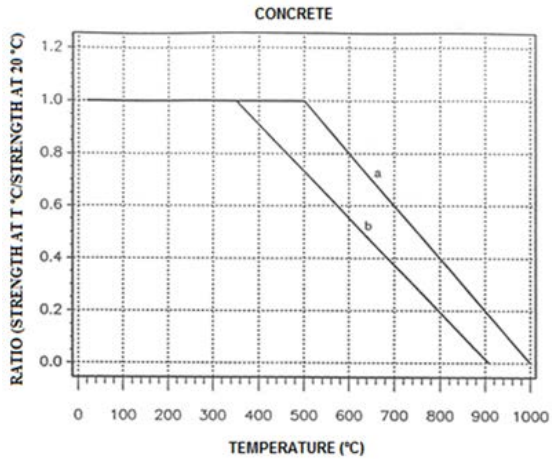

Figure 4. Ratio of Concrete Compression Strength at Elevated Temperatures [3]

According to this Technical Recommendation, but also many other regulations, the partial safety coefficient for permanent action in the fire environment is equal to 1.0. The safety factor for the variable action in case of fire for floors (domestic, office, parking and trafficable roofs) is 0.4; for floors in storages and other structures, it is 0.6, and 0 for non-trafficable roofs. Thus, design action in fire conditions is:

$$w = 1{,}0 \cdot g + \gamma_p \cdot p \tag{6}$$

where:

w - design action of the slab;
g - permanent action of the slab;
γ_p - safety factor for variable action in fire conditions;
p - variable action of the slab.

Then, the maximum applied bending moment to the simply supported slab with uniformly distributed load is:

$$M_a = \frac{w \cdot l^2}{8} \tag{7}$$

where

M_a - maximum applied bending moment to the simply supported slab with uniformly distributed load;
w - design action of the slab;
l - effective span of the slab.

5. FIRE RESISTANCE DETERMINATION OF RC SLABS

For the researching purposes, simply supported RC concrete slabs with spans of 3.0 m, 5.0 m, and 7.0 m were considered. Depths of slabs are 12, 15 and 17 cm respectively. All

slabs were designed according to BAS EN 1992-1-1:2017, Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings [1]. Actions taken into consideration are self-weight of slabs, flooring (1.5 kN/m^2), and variable load of 2 kN/m^2. Different concrete classes were used for each slab: C 20/25, C 30/37 and C 40/50. A concrete cover was also variated for each slab: 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 cm. It should be noted that thicknesses of the concrete cover of 0.5 and 1.0 cm are not allowed for slabs according to Eurocode 2, Part 1-1 [1]. However, given the construction situation in Bosnia and Herzegovina, it is not rare to encounter very thin concrete covers, or virtually no concrete covers at all in the actual construction practice, due to failure of the contractor involved, or poor site inspection of the construction sites, so it is interesting to assess the fire resistance of such slabs.

All slabs were reinforced by welded ribbed meshes made of steel grade B500A, Ductility Class A, Yield = Re 500 MPa, or by straight ribbed bars made of steel grades B500A or St-500-b.

All slabs were exposed to the Standard Fire Curve ISO 834-1 [4] for determining fire resistance according to BAS EN 1992-1-2:2017, Eurocode 2, Design of concrete structures, Part 1-2: Structural fire design - Tabulated data [2] and BRANZ Technical Recommendation No. 8 – Method for Fire Engineering Design of Structural Concrete Beams and Floor Systems [3].

The results of fire resistance of RC slabs according to different methods are presented in Tables 3-11.

Table 3. Fire Resistance of RC Slab, Span 3 m, Depth 12 cm, C20/25

FIRE RESISTANCE OF SLAB depth 12 cm, span 3 m, C 20/25 q_{Ed} = 9.075 kN/m^2						
Concrete cover (cm)	**a_S (cm)**	**$M_{Ed,fi}$ (kNm/m')**	**Reinforcement**	**Bar diameter (mm)**	**EN 1992-1-2 Tabulated data**	**BRANZ TR8**
0.5	0.825	7.14	R 221	6.5	$R_{\varnothing}$	0 min
1.0	1.275		R 238	5.5	R 30	30 min
1.5	1.850		R 257	7.0	R 30	30 min
2.0	2.350		R 257	7.0	R 60	60 min
2.5	2.800		R 283	6.0	R 60	60 min
3.0	3.325		R 332	6.5	R 90	90 min

Table 4. Fire Resistance of RC Slab, Span 3 m, Depth 12 cm, C30/37

FIRE RESISTANCE OF SLAB depth 12 cm, span 3 m, C 30/37 q_{Ed} = 9.075 kN/m^2						
Concrete cover (cm)	a_S (cm)	$M_{Ed,fi}$ (kNm/m')	Reinforcement	Bar diameter (mm)	EN 1992-1-2 Tabulated data	BRANZ TR8
0.5	0.825	7.14	R 221	6.5	R∞	0 min
1.0	1.275		R 238	5.5	R 30	30 min
1.5	1.850		R 257	7.0	R 30	30 min
2.0	2.350		R 257	7.0	R 60	60 min
2.5	2.800		R 283	6.0	R 60	60 min
3.0	3.325		R 332	6.5	R 90	90 min

Table 5. Fire Resistance of RC Slab, Span 3 m, Depth 12 cm, C40/50

FIRE RESISTANCE OF SLAB depth 12 cm, span 3 m, C 40/50 q_{Ed} = 9.075 kN/m^2						
Concrete cover (cm)	a_S (cm)	$M_{Ed,fi}$ (kNm/m')	Reinforcement	Bar diameter (mm)	EN 1992-1-2 Tabulated data	BRANZ TR8
0.5	0.825	7.14	R 221	6.5	R∞	0 min
1.0	1.275		R 238	5.5	R 30	30 min
1.5	1.775		R 238	5.5	R 30	30 min
2.0	2.350		R 257	7.0	R 60	60 min
2.5	2.800		R 283	6.0	R 60	60 min
3.0	3.300		R 283	6.0	R 90	60 min

Table 6. Fire Resistance of RC slab, Span 5 m, Depth 15 cm, C20/25

FIRE RESISTANCE OF SLAB depth 15 cm, span 5 m, C 20/25 q_{Ed} = 10.08 kN/m^2						
Concrete cover (cm)	a_S (cm)	$M_{Ed,fi}$ (kNm/m')	Reinforcement	Bar diameter (mm)	EN 1992-1-2 Tabulated data	BRANZ TR8
0.5	0.950	22.03	R 636	9	R∞	30 min
1.0	1.450		R 636	9	R 30	30 min
1.5	0.195		R 636	9	R 30	30 min
2.0	2.450		R 636	9	R 60	60 min
2.5	3.000		R 785	10	R 90	60 min
3.0	3.500		R 785	10	R 90	90 min

Table 7. Fire Resistance of RC Slab, Span 5 m, Depth 15 cm, C30/37

FIRE RESISTANCE OF SLAB depth 15 cm, span 5 m, C 30/37 q_{Ed} = 10.08 kN/m^2						
Concrete cover (cm)	**a_S (cm)**	**$M_{Ed,fi}$ (kNm/m')**	**Reinforcement**	**Bar diameter (mm)**	**EN 1992-1-2 Tabulated data**	**BRANZ TR8**
0.5	0.95	22.03	R 636	9	R∅	30 min
1.0	1.45		R 636	9	R 30	30 min
1.5	1.95		R 636	9	R 60	30 min
2.0	2.50		R 785	10	R 90	90 min
2.5	3.00		R 785	10	R 90	90 min
3.0	3.50		R 785	10	R 90	90 min

Table 8. Fire Resistance of RC slab, Span 5 m, Depth 15 cm, C40/50

FIRE RESISTANCE OF SLAB depth 15 cm, span 5 m, C 40/50 q_{Ed} = 10.08 kN/m^2						
Concrete cover (cm)	**a_S (cm)**	**$M_{Ed,fi}$ (kNm/m')**	**Reinforcement**	**Bar diameter (mm)**	**EN 1992-1-2 Tabulated data**	**BRANZ TR8**
0.5	0.95	22.03	R 636	9	R∅	30 min
1.0	1.45		R 636	9	R 30	30 min
1.5	1.95		R 636	9	R 30	30 min
2.0	2.50		R 636	9	R 60	60 min
2.5	3.00		R 785	10	R 90	60 min
3.0	3.50		R 785	10	R 90	90 min

Table 9. Fire Resistance of RC Slab, Span 7 m, Depth 17 cm, C20/25

FIRE RESISTANCE OF SLAB depth 17 cm, span 7 m, C 20/25 q_{Ed} = 10.76 kN/m^2						
Concrete cover (cm)	**a_S (cm)**	**$M_{Ed,fi}$ (kNm/m')**	**Reinforcement**	**Bar diameter (mm)**	**EN 1992-1-2 Tabulated data**	**BRANZ TR8**
0.5	1.10	46.12	R 1130	12	R 30	30 min
1.0	1.60		R 1130	12	R 30	30 min
1.5	2.20		Ø14/12,5 cm	14	R 60	60 min
2.0	2.70		Ø14/12,5 cm	14	R 60	60 min
2.5	3.20		Ø14/10 cm	14	R 90	90 min
3.0	3.70		Ø14/10 cm	14	R 90	90 min

Table 10. Fire Resistance of RC Slab, Span 7 m, Depth 17 cm, C30/37

FIRE RESISTANCE OF SLAB depth 17 cm, span 7 m, C 30/37 q_{Ed} = 10.76 kN/m^2						
Concrete cover (cm)	**a_S (cm)**	**$M_{Ed,fi}$ (kNm/m')**	**Reinforcement**	**Bar diameter (mm)**	**EN 1992-1-2 Tabulated data**	**BRANZ TR8**
0.5	1.10	46.12	R 1130	12	R 30	30 min
1.0	1.60		R 1130	12	R 30	30 min
1.5	2.20		R 1130	12	R 60	30 min
2.0	2.70		Ø14/12,5 cm	14	R 60	60 min
2.5	3.20		Ø14/12,5 cm	14	R 90	60 min
3.0	3.70		Ø14/10 cm	14	R 90	90 min

Table 11. Fire Resistance of RC Slab, Span 7 m, Depth 17 cm, C40/45

FIRE RESISTANCE OF SLAB depth 17 cm, span 7 m, C 40/50 q_{Ed} = 10.76 kN/m^2						
Concrete cover (cm)	a_S (cm)	$M_{Ed,fi}$ (kNm/m')	Reinforcement	Bar diameter (mm)	EN 1992-1-2 Tabulated data	BRANZ TR8
0.5	1.10	46.12	R 1130	12	R30	30 min
1.0	1.60		R 1130	12	R 30	30 min
1.5	2.10		R 1130	12	R 60	30 min
2.0	2.60		R 1130	12	R 60	60 min
2.5	3.20		Ø14/12,5 cm	14	R 90	60 min
3.0	3.70		Ø14/10 cm	14	R 120	90 min

6. CONCLUSION

This parallel comparison research for determining fire resistance of reinforced concrete slabs of different spans and depths, made of three different concrete classes, with variations of concrete covers ranging from 0.5 m to 3.0 cm, using two different methods, provided the following results:

- Fire resistance periods of RC slabs considered and determined by two different methods were similar, but not the same. However, maximum difference in fire resistance periods was up to 30 minutes;
- In majority of cases, BRANZ TR 8 had the same fire resistance periods as determined by EN 1992-1-2 Tabulated Data Method. The difference was not more than 30 minutes, but mainly was more conservative when using BRANZ TR8;
- The research also confirmed the fact that concrete class had minor influence on the fire resistance period of slabs, while thickness of concrete cover significantly affected the period of fire resistance of slabs;
- Maximum fire resistance period of slabs observed in this research was 120 minutes.

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42| Прегледни научни рад
Review paper
doi 10.7251/STP1813575R ISSN 2566-4484

EMIPRIJSKO ODREĐIVANJE OSNOVNOG PERIODA SLOBODNIH VIBRACIJA AB ZGRADA

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Rezime:

Određivanje vrednosti osnovnog perioda vibracija armiranobetonskih zgrada predstavlja složen zadatak. Kako bi i u najranijoj fazi projektovanja imali određene podatke o osnovnom periodu vibracija inženjeri se služe raznim približnim metodama pomoću kojih se veoma brzo i jednostavno, ali ipak dovoljno tačno može izvršiti procena traženog parametra.

U radu su prikazani najčešće primenjivani empirijski izrazi koji opisuju zavisnost osnovne periode u funkciji broja spratova, ili visine objekta. Svi ovi izrazi uz veću ili manju tačnost daju procenu tražene veličine što je pokazano kroz veći broj primera. Izvršen je grafički prikaz svih izraza i njihovo upoređivanje sa eksperimentalno i numerički dobijenim vrednostima.

Ključne reči: emirijski izrazi, osnovni period vibriranja, AB zgrade

EMPIRICAL DETERMINATION OF THE FUNDAMENTAL PERIOD OF FREE VIBRATION OF RC BUILDINGS

Abstract:

Determining the value of the fundamental period of vibrations of reinforced concrete structures is a complex task. In order to have certain data on the fundamental period of vibration in the earliest design stage, engineers use various approximate methods, which can quickly and simply, but still sufficiently accurate, provide an estimate of the required parameter.

The paper presents the most frequently used empirical expressions describing the dependence of the fundamental period in the function of the number of storeys, or the height of the building. All of these expressions, with greater or lesser accuracy, give an estimate of the required value, as shown by a number of examples. A graphic representation of all expressions and their comparison with experimental and numerically derived values has been performed.

Keywords: empirical expressions, fundamental period of vibration, RC buildings

1. INTRODUCTION

For most buildings in seismic areas, earthquake represents the strongest load, which is also relevant for structural design. In order to perform the correct analysis, knowledge of the characteristics of earthquakes, but also the object itself, is necessary. Based on the research of seismologists, geologists and geomechanics, in practice designers receive data on potential earthquake characteristics at a given location. However, in the initial design phase, designers do not know the dynamic or any other characteristics of the building. Knowing these characteristics is of primary importance for assessing earthquake effects on buildings.

Since the first tone of oscillation is most commonly dominant in relation to others, it can be assumed that the total mass of the system oscillates only in this tone, and thus the seismic regulations of most countries are based on this tone. Determining the fundamental period of vibration of RC constructions is one of the most important steps in aseismic design and assessment of buildings' behaviour during the earthquake. In order to have certain data on the fundamental period of vibration at the earliest design stage, engineers use various approximate methods, and in recent years simplified empirical expressions are commonly used to quickly and simply, yet still sufficiently reliable, estimate the value of the fundamental period of vibration.

2. EMPIRICAL DETERMINATION OF THE FUNDAMENTAL PERIOD OF FREE VIBRATIONS

The value of the fundamental period of vibration depends on a large number of parameters, such as the choice of the constructive system, dimensions of the building in the base, the height of the building and the number of storeys, the foundation ground on which the object is founded, the nonconstructive elements, the mass of the building, the damping ... Since it depends on many parameters, the value of the fundamental period of vibration can be accurately estimated only after a more detailed numerical analysis has been performed. Despite great possibilities provided by modern software tools, experience has shown that even some numerical models may have some drawbacks, so the final values of the period of vibration can be determined only by experiments.

The great uncertainty that occurs during the determination of the period of free vibration, as well as the need to calculate this value as quickly and as easily as possible, has led researchers from around the world to explore in greater detail the possibilities for estimating this value, and many empirical expressions have been imposed as particularly suitable. Although they are very simple, they can generally include a large number of different buildings and, what is very important, give satisfactory solutions for practical application. By collecting a high volume of experimentally obtained data with numerous numerical studies performed, as well as by a correct interpretation of the results, many authors have proposed their own expressions based on which the values of the fundamental periods of vibration for different types of buildings are obtained. All these expressions give the estimate of the required value, more or less accurately. Some of these expressions also have found their place in the most up-to-date standards, such as the EC or ASCE. All expressions mostly connect parameters such as the constructive system, the height of the building and the number of storeys with the fundamental period of free vibrations. Using empirical expressions, designers can, at the earliest stage of the design, make a choice of certain input data, and then, based on them, perform an assessment of the dynamic

characteristics of the construction. It is recommended to use them for buildings up to 30 storeys or 60 (80) m in height. Some of the best-known expressions describing the relation between the number of storeys and the size of the fundamental period will be shown below. These terms generally present a linear dependence between these parameters and can be written in the following form:

$$T_1 = \alpha \cdot N \tag{1}$$

where:

T_1 is value of the fundamental period of free vibrations

α is coefficient of direction and it is determined experimentally

N is number of storeys

Kobayashi et al. (1987), based on experimental measurements performed on 20 RC moment resisting frame structures with 5 to 30 storeys, proposed the following expression for the area of Mexico:

$$T_1 = 0.105 \cdot N \tag{2}$$

Aničić (2002) proposes a very similar expression for RC moment resisting frame constructions:

$$T_1 = 0.1 \cdot N \tag{3}$$

Expressions proposed by Navarro et al. for the area of Spain and Portugal, which have been modified several times (2002, 2004, 2009), are also represented in practice. These expressions mainly refer to RC constructions with shear walls. It should be noted that practically identical expressions were proposed much earlier by many researchers such as Midorikawa (Chile, 1990), Kobayashi et al. (Spain, 2002), Enomoto et al. (Spain, 1999), Sanchez et al. (Spain, 2002) ...

Most of these expressions range within the following limits:

$$T_1 = 0.048 \div 0.05 \cdot N \tag{4}$$

When expressions that relate the height of the building and the size of the fundamental period are considered, they can generally be presented in the following form:

$$T_1 = C_t \cdot H^x \tag{5}$$

where:

C_t is coefficient that takes into account the type of constructive system

x is determined experimentally

Dunand et al. (2002), based on tests carried out on 26 RC constructions in France, proposed the following expression:

$$T_1 = 0.015 \cdot H \tag{6}$$

Later, the same expression was proposed by Satake et al. (Japan, 2003) by analysing a significantly larger number of buildings, 205 RC buildings with shear walls. Also, Galliopi et al. (Italy, 2009) suggest an identical expression.

After the publication of Eurocodes 8 (EC8), as a comprehensive and one of the most up-to-date regulations in this field, the terms proposed by this Code gain significance. According to the EC, the value of the fundamental period of vibration can be roughly determined using the following expression:

$$T_1 = C_t \cdot H^{3/4} \tag{7}$$

where:

$C_t = 0.075$ for moment resisting space RC frames

$C_t = 0.050$ for " other " constructions (RC constructions with shear walls)

For RC constructions with shear walls, and if there is more input data available, EC alternatively proposes that the aforementioned coefficient can be determined as follows:

$$C_t = \frac{0.075}{\sqrt{A_c}} \tag{8}$$

$$A_c = \sum \left[A_i \left(0.2 + \left(\frac{l_{wi}}{H} \right)^2 \right) \right] \tag{9}$$

where:

A_c is the total effective area of the shear walls in the first storey of the building in m^2

A_i is the effective cross-sectional area of the shear wall "i" in the observed direction in the first storey in m^2

l_{wi} is the length of the shear wall "i" in the first storey in the direction of the forces expressed in m $\left(\frac{l_{wi}}{H} \leq 0.9 \right)$

Since this term introduces the largest number of parameters affecting the value of the fundamental period of vibration, it can be expected that its application will give the most approximate and, in practice, the most useful results. Due to all this, additional attention should be given to it. In order to simplify the calculation, diagrams (Figure 7) have been constructed, from which the values of the fundamental period can be very simply read.

The last expression considered is proposed by the American Society of Civil Engineers (ASCE) and can be written in the form (5), where:

$C_t = 0.047$, $x = 0.90$ for moment resisting space RC frames

$C_t = 0.049$, $x = 0.75$ for RC structures with shear walls

Below is a graphic interpretation of all previous expressions. This method of interpretation is very suitable for comparing the above expressions, and, on the other hand, it can also be used to graphically determine the fundamental period of free vibrations.

In the expressions proposed in the EC and ASCE, two values of storey height were adopted, representing the largest number of common buildings, h = 2.8 and h = 3.3 m.

Figure 1 shows the difference between the formulas proposed for moment resisting frame structures and those proposed for structures with shear walls. The difference between the formulas that include the same type of constructive system is also evident, which is a consequence of the size of the statistical sample, as well as many other specific characteristics of the location and building.

The largest difference obtained by using empirical expressions for constructions with shear walls moves within the boundaries from 0.08s for single-storey building and

gradually increases to 0.15s for buildings up to 30 storeys. With moment resisting frame constructions, this difference is much higher and ranges from 0.08s, but increases with the increase of the number of storeys even up to a maximum value of 1.16s, which suggests a significantly greater uncertainty in the use of these expressions.

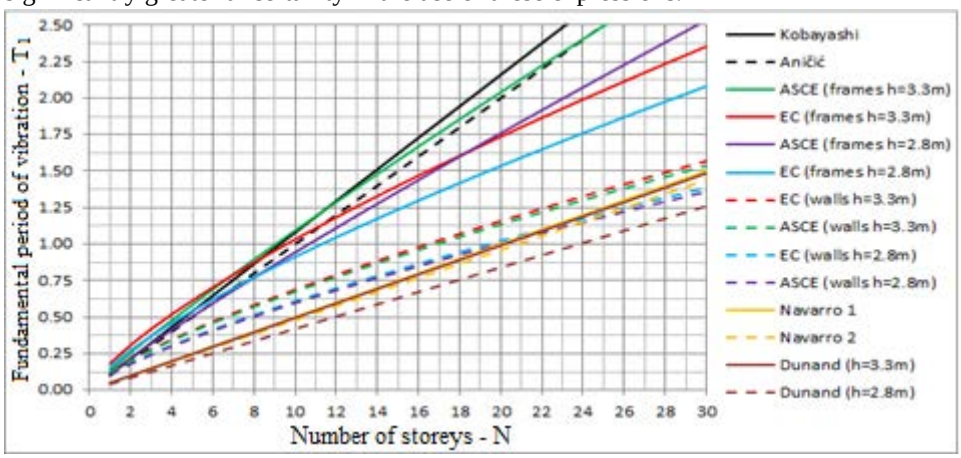

Figure 1. Dependence of the fundamental period of vibration from the number of storeys

3. VERIFICATION OF RESULTS BY NUMERICAL AND EXPERIMENTAL ANALYSIS

This section presents two selected models of buildings with shear walls that were analysed using different softwares. In this way, it is possible to compare the experimental and numerical results with the results obtained using the empirical expressions. In addition, an additional comparison of the experimentally and empirically obtained values for another seven tested buildings was performed.

The first example is a seven-storey building with shear RC walls that was examined on a seismic platform in Japan [7]. The dimensions of the building in the basis are 17x16 m, and the total height is 21.75 m.

The results of the first four experiments are presented:

- No damage - elastic behavior $T_{1,1} = 0.43s$,
- The appearance of flexural cracks $T_{1,2} = 0.55s$,
- Expansion of existing and appearance of new cracks $T_{1,3} = 1.15s$,
- The construction retains integrity with the appearance of major damage $T_{1,4} = 1.36s$.

Numerical analysis performed in the Tower software, which is the most prevalent in our area and is most used in design practice. Four models of different characteristics were analysed, which included the most common approximations that are carried out in practice.

- The first model - the closest to a real construction,
- The second model - increased soil rigidity in modal analysis,

- The third model - introduction of effects of cracks by reducing the shear and flexural stiffness of beams and columns by 50%, according to the requirements of EC8,
- The fourth model - a significant reduction in the stiffness of all elements in the modal analysis

In all models, the variable value of stiffness of the soil was adopted, and the effect of changing this parameter on the results of the modal analysis was analysed.

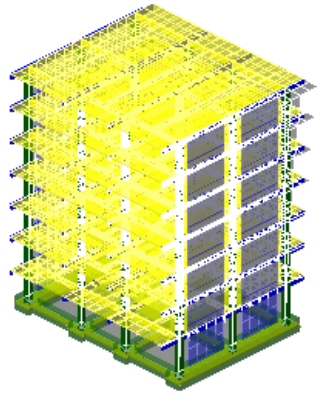

Figure 2. Numerical 3D model of the analyzed building

The results of the modal analysis are shown in the following Figures.

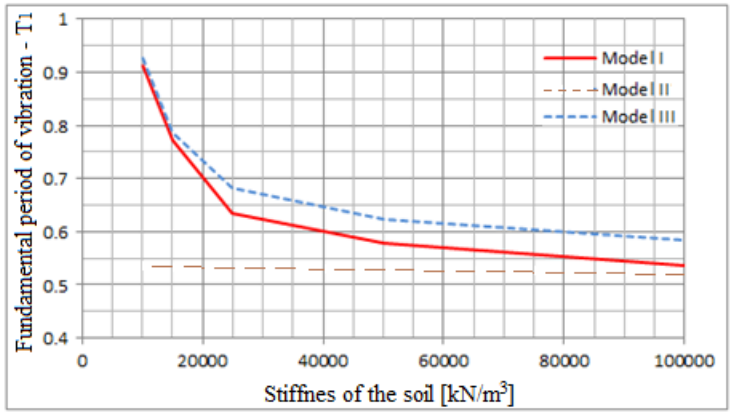

Figure 3. Comparing the values of fundamental period for the first three models

From the previous analysis for the first and third models, the influence of the type of local soil on the value of the fundamental period of vibration is clearly visible. As the effects of the cracks are taken into account in the third model, somewhat higher values of the fundamental period of vibration were expected. In the second model, given the large magnification, soil rigidity is no longer of practical significance to the result of modal analysis.

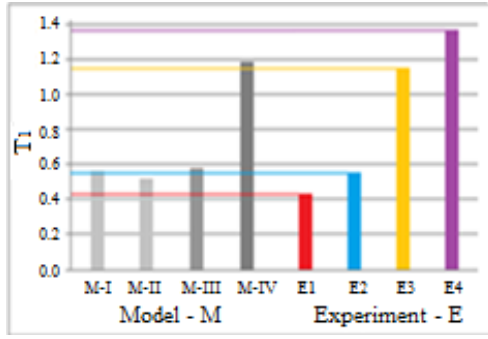

Figure 4. Comparison of values obtained by numerical and experimental analysis

From Figure 4, it can be seen that the values of the fundamental period of vibration in the first three numerical models coincide very well with the results of the first and second experiments. These deviations are practically negligible. The results of the fourth model simulating the appearance of damage coincide well with the results of the third experiment. It is evident that in this case, a significant concurrence was achieved between numerical and experimental results.

For the same building, the values of the fundamental period of vibration were determined using the empirical expressions shown in the previous chapter, and then they were compared with the experimental values. All calculated values are presented in the following figure.

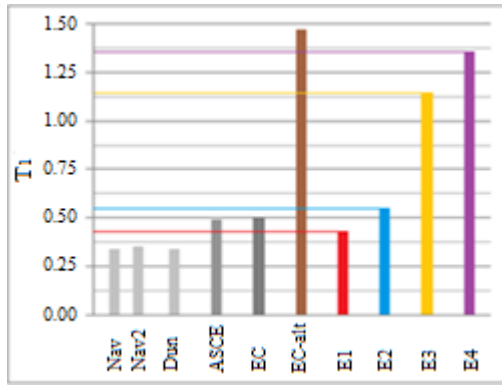

Figure 5. Comparison of empirical and experimental results

Figure 5 shows a good match between most empirically determined values with experimental ones (elastic area E1 and E2). The expressions proposed in the EC and ASCE give the nearest values. For practical application, Navarro's and Dunand's expressions which give slightly lesser value as results, but they are on the safe side. The first impression is that these expressions acceptably describe the value of the fundamental period of vibration. Although the most accurate solution was expected from the alternative (expanded) expression (equations 7-9) proposed by the EC, since it takes into account the largest number of parameters, in this case, it did not provide a satisfactory result and its result deviated too much from the experimental values.

The second example is the eleven-storey building built in New Zealand, which has been tested by ambient and forced vibrations [9]. The structural system consists of columns together with a central RC core. The height of the building is 33.8 m.

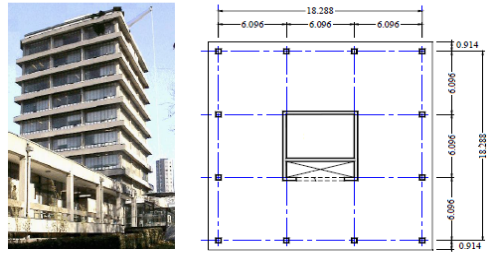

Figure 6. The appearance of the examined building with typical floor plan

Figure 7 illustrates the process of graphic reading of the fundamental period for RC constructions with shear walls according to EC - alternative expression (equations 7-9). The accuracy of the method depends on the precision in operation and reading of the obtained values.

Linear interpolation: $T_1 = 0.98 + (1.21 - 0.98) \cdot \dfrac{33.8 - 30}{40 - 30} = 1.08s$

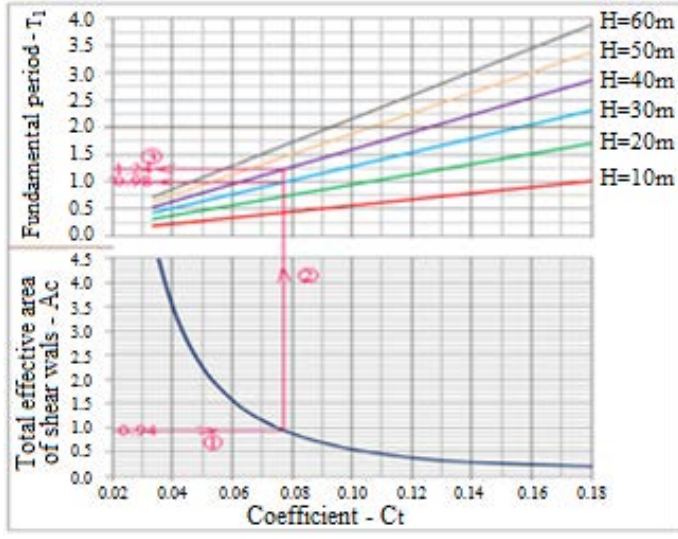

Figure 7. Graphical determination of the fundamental period according to EC

All calculated values are presented in Figure 8.

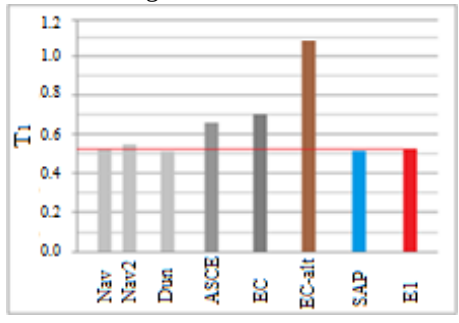

Figure 8. Comparison of empirical, numerical and experimental values

In this case, it should be noted that the values obtained by using the Navarro's and Dunand's expressions were the most approximate, while expressions from the EC and ASCEs gave results which were somewhat higher. Once again, the alternative expression in the EC did not produce satisfactory results. It is important to emphasize that the EC does not make any recommendations in the case of walls of complex cross-sections or walls grouped in the core, as in this case. Whether the effective flange width should be taken into account in the mentioned cases, is up to the designer. It is certainly desirable to do this, but in practice these flanges are most often ignored.

As shown in the previous two examples, the extended expression from the EC, the expectations from which were the highest, did not produce satisfactory results. An additional analysis has reached the same conclusion, suggesting correction of expressions (8) and (9). As a more convenient variant, the correction of the expression (8) is suggested. Two possible corrected curves are shown in Figure 9. Bearing in mind the potential significance of this expression, a more detailed numerical and experimental analysis of all the parameters represented in these expressions should be carried out, and only then can the correct correction be made.

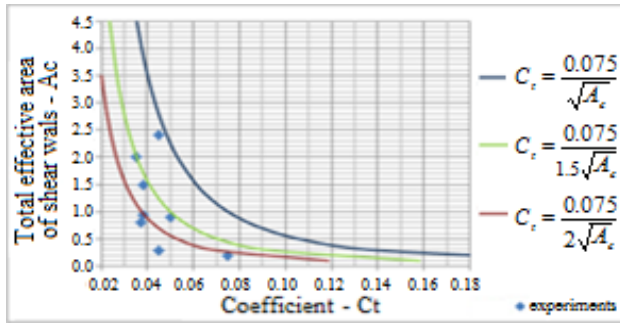

Figure 9. Two possible suggestions for the correction of expression (8)

Figure 10 shows the results of the analysis of additional seven RC buildings of different type.

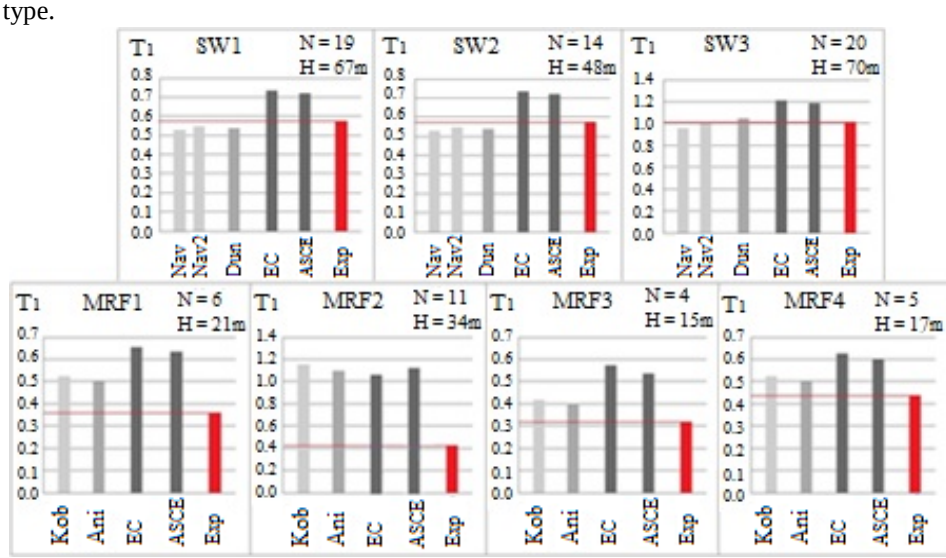

Figure 10. Comparison of the values of the fundamental periods for seven buildings

4. CONCLUSION

Determining the value of the fundamental period of vibrations of reinforced concrete structures is a complex task. Previous analysis has shown that for constructions with RC shear walls the nearest values are obtained using the Navarro's and Dunand's expressions, while the expressions proposed in the EC and ASCE give slightly higher results. It seems that the actual value of the fundamental period is within the limits obtained by using these expressions. It can be said that the value of the fundamental period of vibration for this type of construction can be predicted with great certainty through the application of the aforementioned expressions.

When it comes to moment resisting space RC frames, the scattering of results is considerably higher, so the reliability of these expressions is significantly lower. For buildings up to seven storeys, all of these terms give similar values. For constructions of this type that have over 10 storeys, the expressions proposed by Aničić and Kobayashi represent the upper limit. It is unlikely that the actual value of the fundamental period of the moment resisting frame structures will really be found beyond this limit.

In general, it can be said that most of these expressions adequately describe the value of the fundamental period of vibration. It should be remembered that despite the high reliability of individual expressions, they all represent only rough approximations, and they should be used accordingly.

In the construction practice of our region, RC constructions with shear walls are predominantly present; the RC moment resisting frames are used for buildings with a small number of storeys, so it can be said that the presented expressions are a good engineering aid in the initial design phase. In some cases, they can also serve as a control of numerical models. If a large difference between these values is obtained, this may indicate potential errors in modelling.

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43| Прегледни научни рад
Review paper
doi 10.7251/STP1813585U ISSN 2566-4484

POUZDANOST REZULTATA PRORAČUNA U FUNKCIJI ODABRANOG MODELA TLA

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Rezime:

Pouzdanost geotehničkih proračuna, opšte je poznato, u funkciji je kvaliteta ulaznih parametara, kako po pitanju opterećenja, tako i fizičko-mehaničkih svojstava tla. Pored navedenog na pouzdanost rezultata geotehničke analize utiče i odabir konstitutivnog modela tla. U radu se opisuju modeli tla i analizira pogodnost modela na realnom (izvedenom) geotehničkom projektu.

Ključne riječi:Model tla, geotehnički proračun, pouzdanost rezultata.

RELIABILITY OF THE RESULTS OF THE CALCULATIONS IN THE FUNCTION OF THE SELECTED SOIL MODEL

Abstract:

The reliability of geotechnical calculations is, as it is generally known, in function of the input parameters quality, both in terms of loads, as well as the physical and mechanical soil properties. In addition to above mentioned, reliability of the results of geotechnical analysis is also influenced by selection of constitutive soil model. This paper describes soil models and analyzes the suitability of the model on a real (implemented) geotechnical project.

Keywords:soil model, geotechnical calculation, reliability of the results

1. INTRODUCTION

The model is an attempt to show the natural phenomenon, physical process and other occurrences in nature in a manner that enables their behavior to be predicted. In soil mechanics, there is a great need for the development of a model that will describe soil behavior when changing the stress state. The calculation of deformations in the soil, which are caused by the external load or by internal forces, is an important task that needs to be solved because the safety of the building depends on the deformations that occur during its construction and duration. Classical soil mechanics distinguish two separate states of soil behavior under load:

- the state of minor deformations, which do not cause the fracture of the soil, is studied by using the theory of elasticity;
- the state of major deformations, which cause the fracture of the soil, where the stresses in the soil are such that their small increase causes major deformations at constant velocity, is studied by the method of boundary state of the plastic balance.

The elasticity theory is used in the study of stresses and deformations of soil at work level load, where the value of ground fracture has not been reached. Solutions are obtained by linear elasticity theories. The states of the progressive collapse is the middle between the elastic behavior and the boundary state. The progressive fracture theory studies the elastic-plastic transition from the initial, linear-elastic state to the boundary state of the collapse with plastic deformations. The basis for obtaining a solution in a progressive fracture is the stress - deformation relation, i.e. constitutive term for the soil. For practical applications, within the load sizes, the soil is neither linearly elastic nor completely plastic. The real behavior of the soil is non-linear, very complex and variable depending on the conditions to which it is exposed, and this has a great influence on the selection of soil parameters for geotechnical calculations (Atkinson, 2000). In the last thirty years, a scientific approach to the constitutive soil modeling has been developed. The concept of critical soil condition was developed at Cambridge University in the 1950s by the ideas of Roscoe and asc. (1958, 1968). Further developments were contributed by Schofield, Wroth and Palmer (according to Chen 1975). Although the behavior model is originally developed for normally consolidated clays and slightly over consolidated clay, it is believed that with some adjustments, it can be used to describe the mechanical behavior of all types of soil. Idealization is needed to obtain mathematically simple constitutive models for practical application. A time factor is excluded in order to apply the theory of elasticity and plasticity. For the fracture, a plastic model is applied, and for conditions well below the breaking level, the elastic model (Maksimović, 2014). The criterion for evaluating of the model should consider the balance between the demands from the continuum mechanics point of view (theoretically), demands from real presentation of soil behavior (based on field and laboratory testing - experimentally) and demands for the simplicity of applying the model (numerically). These are the three basic criteria for evaluating the model in soil mechanics. Constituent equations are necessary in all soil mechanics methods: planning and evaluating laboratory and field testing, analytical and numerical prediction, or reverse strain and deformation analysis within the soil itself. All materials, including soil, have limited strength that limits the range of possible stress states. The stress - deformation relation for soil behavior is extremely nonlinear, inelastic, depends on the previous stress and deformation history, and depends on the rate of deformation, boundary conditions, and other factors (Ishihara et al., 1975).

2. CONECTION BETWEEN TENSION AND DEFORMATION

The connection between tension and deformation represents the Model material or its constituent equation. Models of soil and rock materials are generally presented as a relation between infinitesimal changes in the value of the effective stress and the infinitesimal change of deformation values. This relation can be presented in the form (Tymoshenko, Gudier, 1962):

$$\dot{\vec{\sigma}}' = M \cdot \dot{\vec{\varepsilon}} \tag{1}$$

where M is the matrix of material stiffness.

3. SOIL MODELS AT STATIC TEST CONDITIONS

The elastoplastic model gives a more realistic picture of the deformations formed before the final plastic fracture (Figure 1.) The real ground approximately corresponds to the model of ideally elastic materials, only for the limited range of application of the main stresses. For the problems discussed so far, satisfactory solutions were provided by the theory of elasticity and solutions using the oedometric soil model.

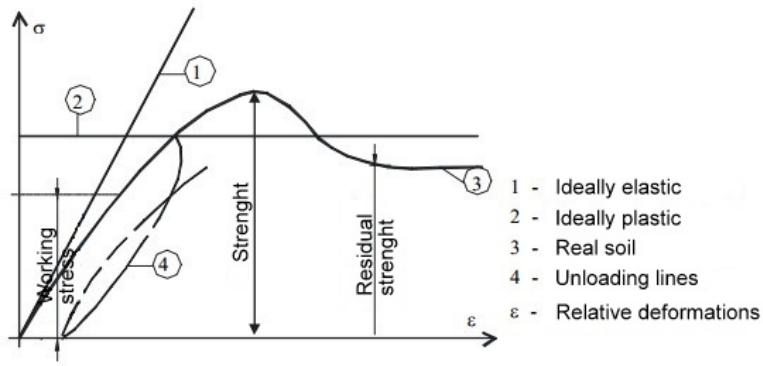


Figure 1. Stress - strain curve

When the ratio of the main stresses exceeds a certain range, deformations begin to increase much faster than the strain and eventually become very large. This is the boundary state of the plastic balance, in which a plastic flow with significant deformations begins. Soil behavior depends on the stress and deformation relation in the given conditions. The most commonly used, oedometric model, is a curing model as well as three-side models with lateral pressure. In shear tests with major deformations, models with softening to fracture occur. The most commonly used laboratory test to obtain the relation between stress and deformation is an oedometric test.

$$M_{k(\tan gent)} = \frac{d\sigma'_z}{d\varepsilon_z} \tag{2}$$

The strain of the deformation Δε_z, due to the increase in stress Δσ'_z, for the initial stress, p_o, is:

$$\Delta\varepsilon_z = \int_{p_0}^{p_0+\Delta\sigma'_z} \frac{d\sigma'_z}{M_k(\sigma'_z)} \tag{3}$$

The solution of integral depends on the shape of the functional link between the compression modules M_k and strain σ'_z. There is a great deal of attempts to improve the concept of the model, which increases the number of parameters, some of which can be determined, and some are assumed to get good agreement between a mathematically determined model and data obtained by tests. And when a model simulates the test well, which is a prerequisite for its acceptability; there are number of other tests that need to show that it will behave satisfactorily by arbitrary stress strains in various practical problems. The constituent equations in the continuum mechanics represent an analytical expression of the relation between the instantaneous stress state at a material point of the continuum and the history of deformation states through which the close environment of that point has passed. Through these equations, the mechanical properties of the material are included. For now, there is no constituent equation that describes the complexity of the mechanical behavior of the soil for the various conditions in which the soil can be found.

4. ELASTIC MODEL

These models include: Linear-elastic model, Duncan-Chang model (nonlinear hyperbolic elastic models) and anisotropic elastic model (cracked rock model).

4.1. Linear-elastic model

One of the simplest soil models is a linear elastic model in which stress is directly proportional to deformations. This model is most commonly used in the calculation of the settlement in soil mechanics because it corresponds to the assumption that the ground behaves in a linear resilience in minor deformations. The interpretation is shown in Figure 2 a).

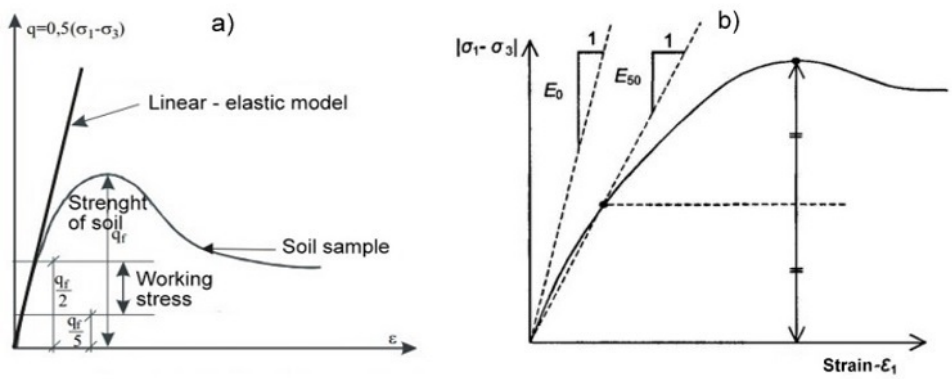


Figure 2. a) Explanation of the assumption of linear soil behavior; b) Definition of modules E0 and E50 for standard drained three-axis test (Yong, Townsend, 1980)

The linear elastic model is based on Hooke's law. There are four parameters of material for an elastic model: Young's modulus of elasticity E, Poisson's coefficient v, coefficient of volume deformation K and shear modulus G, and only two are required for the full description of the material. The proportionality constants are Young's modulus of elasticity E and the effective Poisson coefficient v. Young's module is used as the basic stiffness module in the elastic soil model. Special attention is needed for the adoption of stiffness parameters in the calculation, because it is shown that the assumption of linear soil behavior in minor deformations is often incorrect. Namely, the materials demonstrate nonlinear behavior at the very beginning of the load. Typically, the initial inclination of the deformation curve is marked as E_0, and the value of the secant module at 50% strength is marked as E_50 (Figure 2 b)). For materials with a larger scope of linear elasticity, it is more realistic to use E0, but the E_50 is generally used for soil loading. Considering the problems of unloading, such as tunnel excavations, etc., it is necessary to use a parameter that can be determined at the return deformations, i.e. the release (Figure 1, line 4), E_ur instead of E_50. For the soil, both the E_ur release module and the load modulus E50 tend to grow with increasing pressure. Therefore, higher stiffness can be expected in deep layers of soil compared to shallow layers. The rigidity is much higher for relieving and reloading than for the primary load. When a model with a constant modulus of elasticity (compressibility) is used to represent the soil behavior, a value corresponding to the level of stress and the corresponding strain of stress must be selected. Poisson's coefficient is by definition the ratio of longitudinal and transverse deformation:

$$\nu = \frac{\varepsilon_{\text{transversal}}}{\varepsilon_{\text{longitudinally}}} \tag{4}$$

In the soil, this ratio is not nearly as simple as code, for example steel rod or concrete cube. When considering Poisson's soil coefficient, one should always keep in mind that only the pores are deformed in the soil, while the solid particles, according to the basic assumption, do not change their shape for the level of work stresses. Deformation occurs by mutual sliding and rolling of particles at the expense of pore loss. Since the lateral expansion is prevented in the oedometric test, this is the lateral deformation ε_b = 0, which leaves only an upright deformation ε_z, and from the equation 4 it follows that for such a Poisson model the coefficient is ν = 0. In the drained tri-axial test, the Poisson coefficient ν can be determined for each of the specially selected stress levels, i.e., the incremental stress Δσ_z as well as the secant and tangent module, according to the:

$$\nu = \frac{\Delta\varepsilon_z - \Delta\varepsilon_v}{2\Delta\varepsilon_z} \tag{5}$$

ε_z - upright, axial deformation;

ε_v - volume deformation.

The choice of the Poisson coefficient value is simple when elastic model or a Mohr-Coulomb model of soil is used, in contrast to other cases when it is much more complex. The relation between Young's module E and other stiffness modules, such as shear modules G, the compression module K, and the edo-modulus module E_oed, is given by the following equations (Hill, 1950):

$$G = \frac{E}{2(1+\nu)} \tag{6}$$

$$K = \frac{E}{3(1-2\nu)} \tag{7}$$

$$E_{oed} = \frac{(1-\nu)E}{(1-2\nu)(1+\nu)} \tag{8}$$

4.2. Nonlinear elastic soil model

A nonlinear elastic soil model was suggested by Duncan and Chang 1970, analyzing the deformations of embankments and dams. The model parameters can be obtained from the results of a three-axis test. The stress-deformation curve is hyperbolic, which connects the deviator stress (σ_1-σ_3) and the axial deformation ε according to the expression (Konder, 1963, Konder et al., 1963, 1965):

$$\frac{\varepsilon}{(\sigma_1 - \sigma_3)} = a - b\varepsilon \tag{9}$$

Depending on the stress state and the deformation trace, the model contains three soil modules: the E_i starting module, the E_t tangent modulus and the load modulus - Eur listed in Table 1.

Table 1. Modulus of elasticity in non-linear elastic soil model

$\mathrm{E}_i = K_L p_a \left(\frac{\sigma_3}{p_a}\right)^n$	E_i - initial tangent module; K_L - modular load number; P_a - atmospheric pressure (p_a = 100 kPa, used as a reference parameter); σ_3 - minor main stress n, the exponent determining the impact of lateral pressure on the initial module. Where n and K are numbers (constants) derived from the results of the drained tri-axial laboratory tests.
$\mathrm{E}_t = \left[1 - \frac{R_f(\sigma_1 - \sigma_3)(1-\sin\varphi)}{2c\cos\varphi + 2\sigma_3 \sin\varphi}\right]^2 \mathrm{E}_i$	φ - angle of internal friction; c - cohesion; R_f - ratio of asymptote of hyperbole and shear strength (from 0.75 to 1.0), but can also be determined from the results of the drained three-axis test; σ_1 - maximum main stress; σ_3 - minimum main stress.
$\mathrm{E}_{ur} = K_{ur} . p_a \left(\frac{\sigma_3}{p_a}\right)^n$	Unlike the tangent module, the load-relief module is not dependent on the state of shifting stresses. This module can be calculated directly from the curve of the results of the drained three-axis test, based on unloading - reloading (line 4 in Figure 3).

Poisson's coefficient of nonlinear elastic soil model can be considered as a constant, not depending on the state of stress; from the equation (5) or it can be calculated from the volume change module, which depends on lateral stress. The volume change module is given by the following expression:

$$B_m = K_m p_a \left(\frac{\sigma_3}{p_a} \right)^m \tag{10}$$

B_m - modulus of volume change;
K_m - Module number;
m - the exponent of the volume module.
The relation between the volume module and the Poisson coefficient can be determined by the theory of elasticity, so hence:

$$\nu = \frac{1}{2}\left(1 - \frac{E_t}{3B_m} \right) \tag{11}$$

Such module can be obtained by testing in the hydrostatic state of stress.

5. THE CONCEPT OF THE THEORY OF PLASTICIFITY

It consists of three basic links: the condition of relaxation, the law of relaxation and cure and the condition of fracture. Plastic constitutive models differ according to the assumed function of release. The stress and deformation ratio assumes that the material is acting linearly elastic before the relaxation in accordance with the elastic parameters E and ν determined in the model and perfectly plastic after release. The total deformation or ratio of deformation components is:

$$d\varepsilon = d\varepsilon_e + d\varepsilon_p \tag{12}$$

dε - total deformation;
dε_e - elastic deformation;
dε_p - plastic deformation.
Basic plastic models:

- Mohr-Coulom model,
- Drucker Prager model,
- Von Mises model,
- Tresca model,

of which the simplest and most extensively applied in geotechnics is Mohr -Coulomb model. Figure 3 gives graphical representations of the main stresses in the space for classical fracture theories.

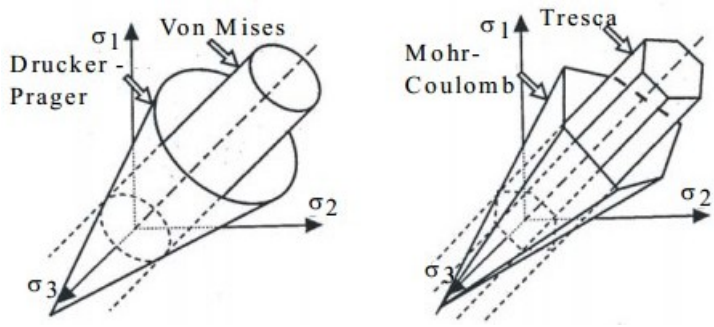
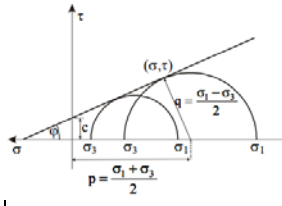
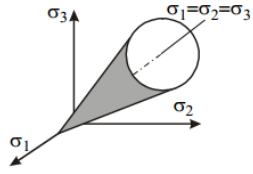
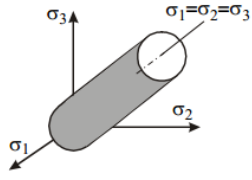
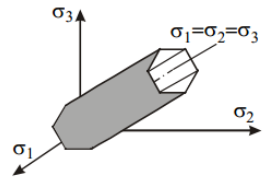


Figure 3. Classic fracture theories in the main stress area

Table 2. Overview of basic plastic models

Model	Graphic display	Fracture criterion	Description
Mohr - Coulomb's criterion for fracture for a straight state of stress		$\tau = c + \sigma * tg\varphi$ A criterion written in the form of the maximum and minimum major stress, can be written for a general stress state in the form of three stress invariants.	τ - shift strain; σ - normal stress; c - cohesion material; φ - angle of friction.
Drucker - Prager model is given as a function of relaxation		$f = 3\sigma_m \sin\phi + J_2 - c = 0$	σ_m - main stress, J_2-second stress invariant, c, φ - maximum or peak cohesion and friction angle of the material
Von Mises model		$f(J_2) = \sqrt{3J_2} - \sigma_0 = 0$ li $f(J_2) = \sqrt{\sigma_x^2 - \sigma_y^2 - \sigma_x\sigma_y + 3\tau_{xy}^2} - \sigma_0 = 0$	σ_o -equivalent uni-axial stress determined by tests, J_2 - second deviator invariant of stress.

Tresca model		$f = 2q \cdot \cos\theta - k = 0$	f - function of relaxation q - second stress invariant k-maximum or peak uniform pressure compressive strength of the material.

6. ELASTIC - PLASTIC MODELS

This group of models includes:

- Ideally elastic - an ideal plastic model,
- Cam Clay and modified Cam Clay model,
- Deformation-softening model.

6.1. Ideally elastic - an ideal plastic model

Typical stress-deformation curve of linearly elastic - ideally plastic models is shown in Figure 4. The stresses are directly proportional to the deformations until the point of delivery is reached, and after the point of release the stress-strain curve is horizontal.

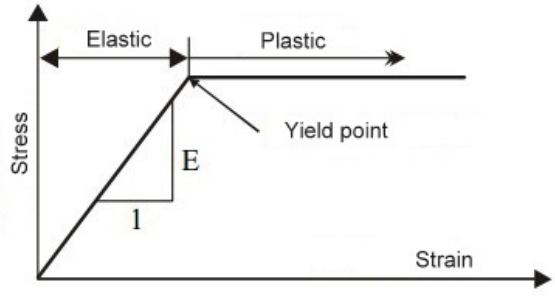


Figure 4. Elastic - an ideal plastic model

The elastoplastic theory, which describes the behavior of Figure 4, consists of the following elements:

Relative deformation is disassembled, on elastic and plastic component:

$$\{d\varepsilon\} = \{d\varepsilon_e\} + \{d\varepsilon_p\} \tag{12}$$

The elastic component of deformation can cause changes in stress. Elastic constituent equation has the form:

$$\{d\sigma\} = \{C_e\} + \{d\varepsilon_e\} \tag{13}$$

The relaxation function is defined by the form:

$$f = f(\sigma_x, \sigma_y, \sigma_z, \tau_{xy}) \tag{14}$$

or in matrix form:

$$df = \left[\frac{\delta f}{\delta \sigma}\right]\{d\sigma\} \tag{15}$$

If f < 0, the function describes the elastic property of the material. When f = 0, it describes strength or plasticity law. The plastic potential function takes the form:

$$g = g(\sigma_x, \sigma_y, \sigma_z, \tau_{xy}) \tag{16}$$

The direction of the plastic deformation increment is determined by the law of flow:

$$\{d\varepsilon_p\} = \lambda\left\{\frac{\delta g}{\delta \sigma}\right\} \tag{17}$$

Where:

g - the function of the plastic potential

λ - plastic scalar factor

The dλ must always have a positive value, and it is obtained from the condition that the function of relaxation is constant when fracture.

In geotechnics, Mohr-Coulomb's Law of Strength is most often used for the law of release:

$$f = \frac{\sigma_1 + \sigma_3}{2}\sin\varphi - \frac{\sigma_1 - \sigma_3}{2}\cos\varphi + c \cdot \cos\varphi = 0 \tag{18}$$

Usually the Mohr-Coulomb function of release is used for the plastic potential function, where the angle of internal friction φ is replaced by the angle of dilation ψ. Tangens of dilation angle is the ratio of increment of plastic volume deformation and plastic increment shear deformations (GeoSlope).

6.2. Cam Clay and a modified Cam Clay model

Cam Clay and modified Cam Clay models are in the group of elastoplastic models with curing (Atkinson and Bransby, 1978 and Britto and Gunn, 1987). Figure 3 explains the procedure of choosing an edometric test or isotropic compression test as one that can provide satisfactory data for modeling the Cam Clay model. Figure 5 (a) shows the ratio of the effective stress p' and the volume change ν, where ν = 1 + e, a, e, is the porosity of the sample. Figure 5 (b) shows the same pressure ratio shown on the natural logarithm scale, lnp'. Further simplification can be done when the hysteresis loop that occurs when unloading and reloading is replaced by the direction. The approximation is sufficiently accurate for the needs of further calculations. This view describes the actual state of the soil during over-consolidation, unloading and reloading. The direction of over-consolidation and the direction of normal consolidation show the properties of an elastic - plastic hardening curve of stress - deformation relation. The direction of over-consolidation corresponds to the linear-elastic part and the direction of normal consolidation to the plastic-curing part.

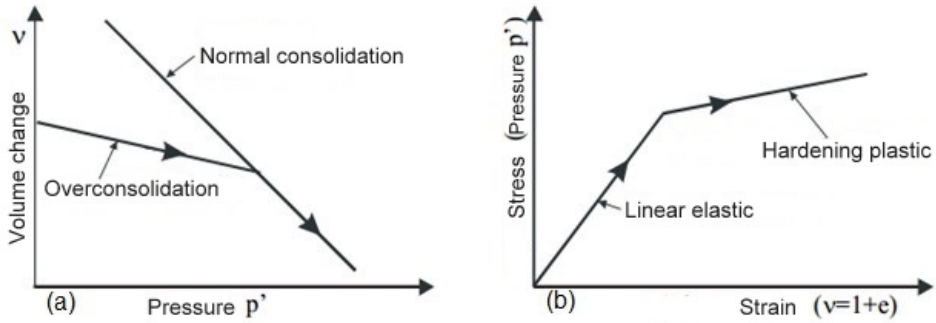


Figure 5. Consolidation and stress ratio

6.2.1. Release function in the Cam Clay model

Plastic hardening means the possibility of expanding the surface of the release. The description of the expansion of the release surface is achieved by introducing a variable for the plastic deformation into a function of release. In Cam Clay models this is a variable volume deformation ε_pv so that now the function of release has the form:

$$f = f(\sigma_x, \sigma_y, \sigma_z, \tau_{xy}, \varepsilon_{pv}) \tag{19}$$

In both models, the associated law of flow is assumed. In the Cam Clay model, the release function is given by the expression:

$$f = \frac{q}{M \cdot p'} + \ln\left(\frac{p'}{p'_x}\right) - 1 \tag{20}$$

while in the modified Cam Clay model it is given by the term:

$$f = \frac{q^2}{p'} + M^2 p' - 2M^2 p'_x \tag{21}$$

where:

p' - average effective stress;

$$p' = \frac{1}{3}\left(\sigma'_x + \sigma'_y + \sigma'_z\right) \tag{22}$$

q – stress deviator;

$$q = \sqrt{\frac{1}{2}\left[\left(\sigma_x - \sigma_y\right)^2 + \left(\sigma_y - \sigma_z\right)^2 + \left(\sigma_z - \sigma_x\right)^2\right] + \tau_{xy}} \tag{23}$$

M – Parameter of the material as a function of the angle of internal friction φ or direction gradient of the critical state when this is displayed in p'- q coordinates.

$$p'_x = \exp\left(\frac{\Gamma - \nu - k \ln p'}{\lambda - k}\right) \tag{24}$$

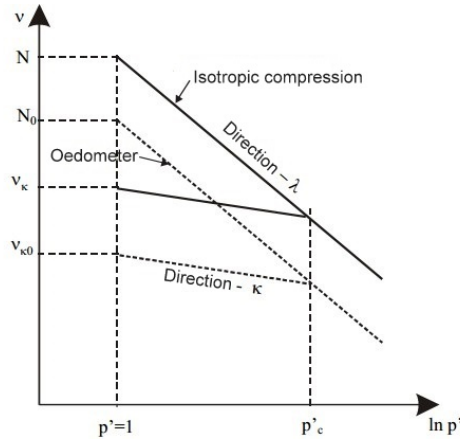


Figure 6. The results of laboratory tests of isotropic compression and uniaxial compression (edometric test) shown in the diagram ν - specific volume / ln p'- pressure

Parameters from the picture:

ν - the specific volume, defined by the pore-coefficient e, ν = 1 + e;

λ - the direction slope that represents the relation of the specific volume ν and the natural logarithm of average effective stress ln p', during isotropic compression of normally consolidated soil and

κ - the direction slope which represents the ratio between ν and ln p' in the elastic region

N and N_0 in Figure 6 are specific volumes of normally consolidated soil at the pressure p'= 1 kPa, and ν_k i ν_k_0 are of the specific volume of the over-consolidated samples when p' = 1 kPa. The position of the possible κ-forms is not unambiguous, but depends on the stress of the over-consolidation p'_c. Figure 7 a) and b) show Cam Clay models in the coordinate system p'- q.

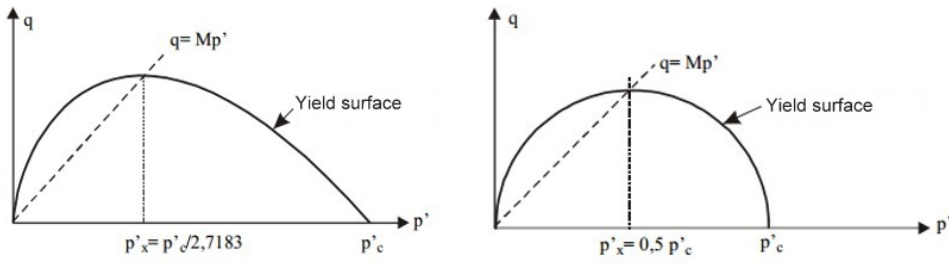


Figure 7. a) Cam Clay model b) Modified Cam Clay model

If pc' denotes the over-consolidation stress, i.e. the intersection of the direction slope κ and the direction slope λ, then in the Cam Clay model, the dimensions p'_x and p'_y are related by the expression:

$$\ln p'_x = \ln p'_c - 1 \tag{25}$$

and in the modified model:

$$p'_x = 0.5 p'_c \tag{26}$$

The size Γ denotes the specific soil volume on the line of critical states, for p'= 1 kPa, or ln p' = 0 (corresponds to the values of N in Figure 6). The line of critical states is given by the expression:

$$v = \Gamma - \lambda \ln p' \tag{27}$$

and represents the state of the material with expansion angle of ψ = 0.

6.3. Deformation-softening model

This model is elastic - softening - plastic and consists of three linear parts. The linear part grows to maximum shear strength, a softening part, in which the shear strength decreases from maximum to residual strength and the part in which the strength does not change (residual strength, Figure 8).

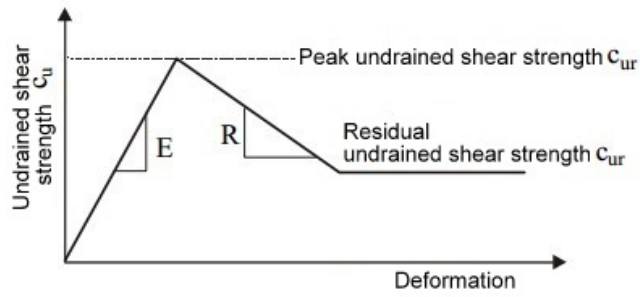


Figure 8. Deformation - softening model

The release function for this model is given through the positional stresses q and the undrained strength of c_u:

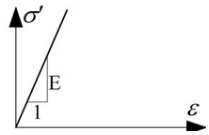
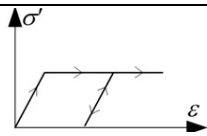
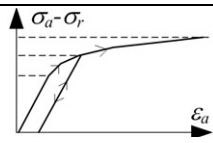
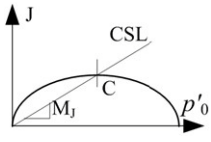
$$f = f\left(\sigma, \varepsilon_p\right) = q - \sqrt{3}c_u \tag{28}$$

The fracture at the shear strength c_u is equal to (σ_1 - σ_3) / 2. Shear stress q can be expressed over another invariant of stress J_2, q = 3J_2.

Each of these models has advantages and disadvantages, which are substantially limiting their usability for numerical simulation of structure and soil interactions. Basic characteristics of constitutional soil models available in commercial computer programs for the calculation of geotechnical structures are shown in Table 3.

Table 3. Basic characteristics of constitutional soil models for calculation of geotechnical structures

Model	The basic curve	Elements of soil behavior	Deficiency	Application

Linear - elastic		- linear elastic behavior	- unlimited strength; - no dilatation occurs; - Unique stiffness for load /unloading - dependence between volume and shear stiffness	GSU (monolithic rocks)
Ideally elastic - plastic		- linear elastic behavior to fracture; - a unique fracture surface; - unique dilatation in case of fracture	- Unique stiffness for load / unloading -unique stiffness depending on the state of stress and deformation	Robust load control
Hardening		- shearing curing; - stiffness reduction depending on the state of deformation - dependency of starting stiffness from the stress condition	- lack of peak strength reduction - lack of critical condition - additional rules for unrelated behavior	Sand gravel rigid clay
A critical state model		- critical state; - isotropic cure; - reduction of peak strength	- critical condition	Soft clay

7. PHYSICAL MODEL

The reliability of the results in the function of the selected constitutional soil model was analyzed on the physical model. In the natural slopes after the excavations, the soil mass movement has occurred, which was observed over time by using an inclinometer, on the inclinometer borehole IBK 11 (Figure 9). The determined soil parameters for all layers on the engineering-geological profile (Figure 10) are shown in Table 4.

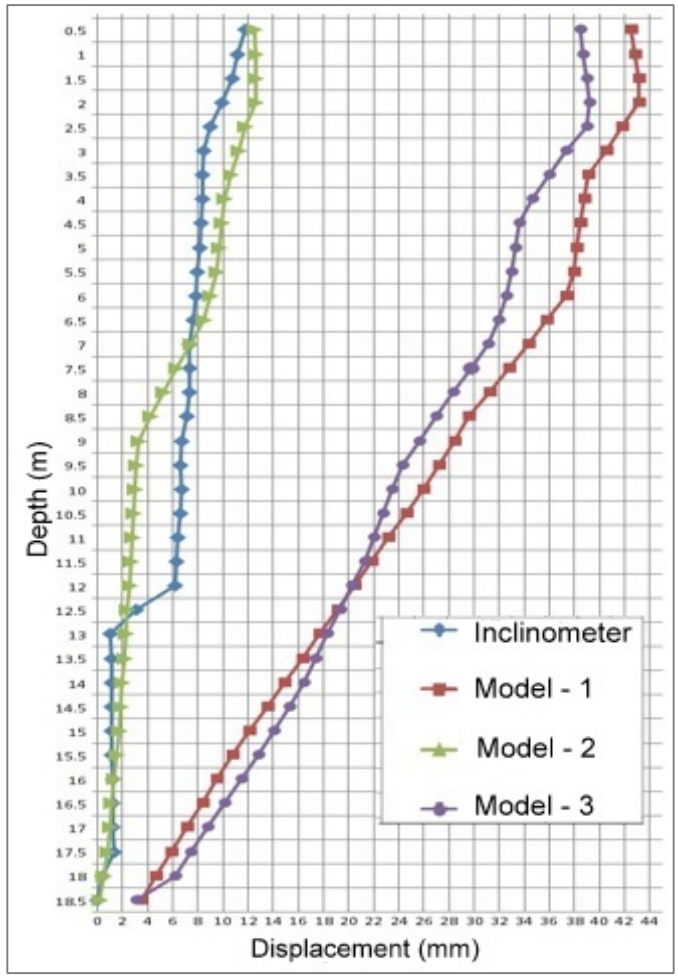


Figure 9. Movements on inclinometer IBK 11

Soil model number 1 represents Mohr-Coulomb model, isotropic stiffness, Mohr-Coulomb model, orthotropic stiffness, is represented by soil model number 2 and modified Cam-Clay model, isotropic stiffness, is represented by soil model number 3 in the Table 4.

The results of the movement were obtained using a software package Rocscience Phase 2 v.6.0., based on the finite elementh methode (FEM).

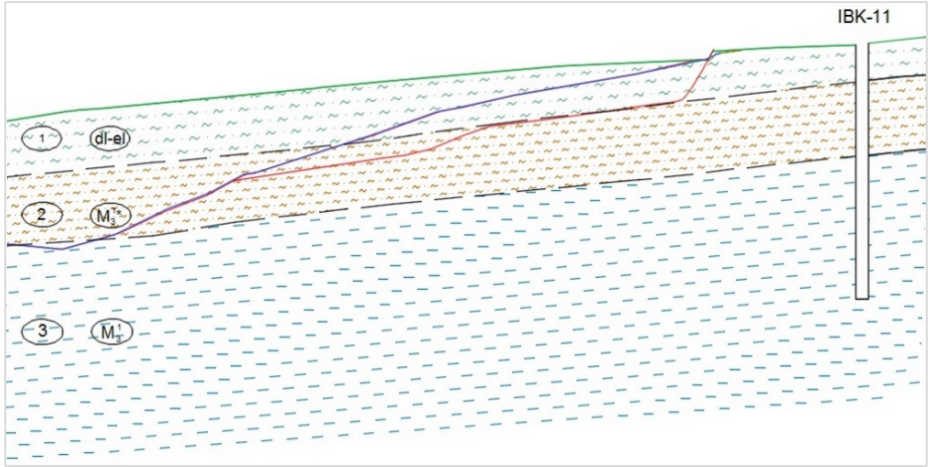


Figure 10. The engineering-geological profile

Table 4. Input parameters for soil models obtained by testing

Soil models		1			2			3		
Soil		1	2	3	1	2	3	1	2	3
γ	[kN/m3]	16.5	19.5	20.0	16.5	19.5	20.0	16.5	19.5	20.0
ϕ	[□]	16 (10)	16 (11)	18 (12)	16 (10)	16 (11)	18 (12)			
c	[kN/m2]	15 (3)	25 (5)	40 (8)	15 (3)	25 (5)	40 (8)			
M_v	[MPa]	5.4	13.1	22.8				5.4	13.1	22.8
ν	[-]	0.40	0.36	0.34				0.40	0.36	0.34
E	[MPa]	2.52	7.79	14.81				2.52	7.79	14.81
G_12	[MPa]				2.00	4.41	44.78			
E_1	[MPa]				4.00	8.30	87.00			
E_2	[MPa]				6.00	12.5	130.0			
E_z	[MPa]				5.00	12.0	120.0			
α	[□]				3	3	3			
N_12 =ν_2 =ν_2z	[-]				0.40	0.36	0.34			
M	[-]							0.59	0.37	1.21
λ	[-]							0.1	0.052	0.096
κ	[-]							0.03	0.01	0.02
ν	[-]							0.40	0.36	0.34
OCR	[-]							1	1	1

8. CONCLUSION

While solving geotechnical problems, we are able, by using computers, to apply some of the listed soil models included in the programs. Most computer programs, using the finite element methode, are able to determine the state of deformation and displacement, which is not possible by the limit balance method. Determination of the state of deformation and displacement is of crucial importance in most geotechnical engineering problems. Using the FEM (Finite Element Method), a more realistic estimation of the stress, deformation and shift distribution is possible, as well as finding the local fracture zone during the construction of the building. In addition, it is possible to more realistically look at and describe the geotechnical environment as heterogeneous, anisotropic, discontinuous, and changes in the conditions of equilibrium of the excavations. The reliability of the established geotechnical parameters has the greatest influence on the success of the geotechnical calculation. But the applicability of the soil model (Figure 9) also has a major impact on the results of the geotechnical calculation, and this should be given special attention.

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44| Претходно саопштење
Preliminary report
doi 10.7251/STP1813602Z ISSN 2566-4484

PAVEMENT STRUCTURES AT THE INTERSECTION AREA

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Abstract:

From the very beginning of the application of modern pavements, it was known that with increasing load on the pavement structure, more attention should be paid to the details during design and construction in order for the pavement structure to reach the planned lifetime. Heavy, slow vehicles that stop, stand, rotate and accelerate transmit the largest possible load on any pavement structure. These phenomena are most frequent at intersections, but also occur at traffic lanes on increased longitudinal slopes, weighing stations, bus stations and stops, parking lots and rest areas, and the like. Due to the need to equalize the characteristics and behavior of all elements of the road, the areas exposed to increased and non-characteristic loads must receive particular attention during design.

Keywords: pavement structures, load, intersections.

KOLOVOZNE KONSTRUKCIJE U PODRUČJU RASKRSNICA

Rezime:

Od samog početka primjene modernih kolovoznih konstrukcija je bilo poznato da se s povećanjem opterećenja na kolovoz mora obratiti više pažnje na detalje tokom projektovanja i izgradnje kako bi kolovozna konstrukcija dostigla planirani životni vijek. Teška, usporena vozila koja se zaustavljaju, stoje, okreću i ubrzavaju prenose najveća moguća opterećenja na bilo koju kolovoznu konstrukciju. Ove pojave su najčešće kod raskrsnica, ali se javljaju i kod traka na povećanim podužnim nagibima, stanicama za vaganje, autobuskim stanicama i stajalištima, parkinzima i odmorištima i sl. Zbog potrebe ujednačavanja karakteristika, odnosno ponašanja svih elemenata puta, površinama izloženim povećanim i nekarakterističnim opterećenjima se mora obratiti posebna pažnja prilikom projektovanja.

Ključne riječi: kolovozne konstrukcije, opterećenje, raskrsnice.

1. INTRODUCTION

Heavy, slow-moving vehicles that are stopping, turning, or accelerating expose intersections to some of the highest stress levels found on pavements. High-stress locations also include climbing lanes, truck weigh stations, rest areas, and other low- or zero-speed areas. That is why some intersections need special attention to ensure that these areas deliver the same outstanding performance as other asphalt pavements.

While asphalt has continually proven to have superior life-cycle cost-benefits, special attention should be focused on intersections to ensure the same outstanding performance. Braking, accelerating and turning movements that occur put additional stress on the pavement surface. Engine fluid drippings and heat exhaust increase with slower traffic and has a softening effect on asphalt. In addition, load repetitions at intersections are sometimes double that of mainline pavement due to the dross flow of traffic. Together, those are the reasons that intersection pavement need to be treated differently [1].

2. EFFECT OF TRAFFIC LOAD ON PAVEMENT

Static and dynamic effect of traffic load, i.e. of the real vehicle, is transmitted to a pavement structure through a vehicle's tires. Tires represent a complex structure, mainly made of natural or synthetic rubber, and as such, they have characteristics of rubber as a material.

The static force from the vehicle shaft is transferred to a smaller or larger pavement-tire contact surface (Figure 1) depending on the: size of the axle load of the vehicle, tire pressure, type and characteristics of the tire and speed of the vehicle.

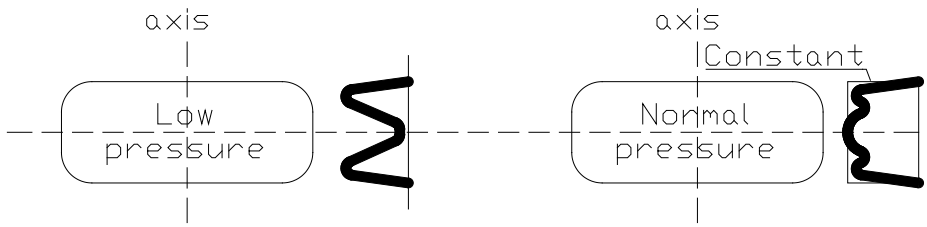

Figure 1. The contact surface of the tire-pavement depending on the air pressure in the tire [2]

The tire pressure on the pavement surface is not constant, i.e. evenly distributed on the contact surface, and as such equal to the internal pressure in the tire, however, for the needs of the calculation in designing of the pavement structure, a big mistake isn't made if it is adopted for a constant, i.e. that the tire pressure is approximately the same as the pressure on the contact surface.

Normal pressures at the contact between the tire and the pavement surface are not the only forces that are transmitted through the tire to the pavement structure. In the case of the vehicle braking and accelerating, which is particularly pronounced in the area of the intersection, horizontal forces also act on the pavement.

It should be emphasized that even when there is no sudden change in the speed of the vehicle's movement or when the vehicle is stationary, there are forces that act on the pavement surface. It is very difficult to calculate the values of these shear forces (tangential shear on the pavement), however it must be noted that their role is of great

importance. The consequences of these forces can often be seen in poorly designed, poorly constructed or inadequately maintained roads in the form of rutting, shoving etc. These forces occur as a result of tire deformations caused by load on an imaginary undeformed and deformed, but unstretchable rubber element of a circular shape (Figure 2).

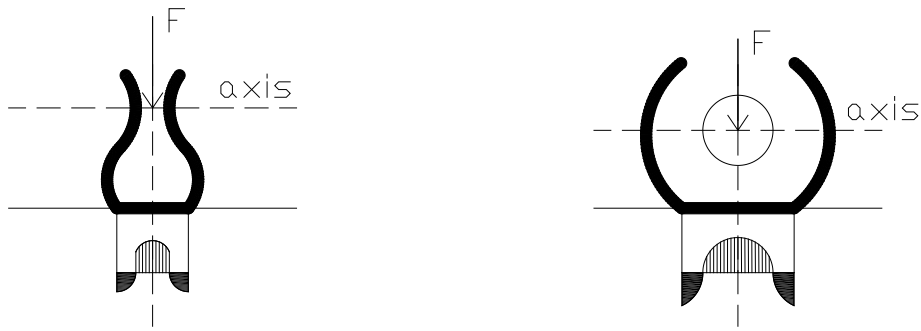

Figure 2. Display of the shear under the tire
(left: longitudinal shear under the tire (meridian plane);
right: longitudinal shear under the tire (equatorial plane)) [2]

Because the tire can be deformed, the tire causes shear, not skidding, i.e. horizontal force which depends on the vertical force and the friction coefficient μ (Fx, y = μ · Fz). The layout of the longitudinal shear on the contact surface in the case of vehicle movement is shown in Figure 3.

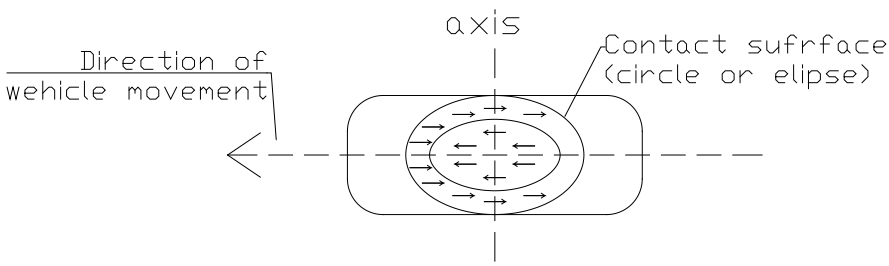

Figure 3. Distribution of longitudinal shear [2]

For designing of the pavement structure, when calculating the static traffic load (all the aforementioned phenomena of shear force are significant), the axial load of the vehicle is of particular importance, especially when the dimensioning is carried out using the analytical method. The static load can be relevant for designing of the pavement structure in all cases of stationary traffic (traffic on urban roads, often disrupted free flow outside urban areas, etc.).

Dynamic impacts on vehicles moving along the road can be viewed from two aspects: comfort when driving, and secondly, the impact on the dynamic components of the vehicle force in the pavement structure, which may be significant, and as such should be included in the design analysis of the pavement structure.

Comfort or driving cosiness is a serious preoccupation in the construction of the vehicle and is conditioned by many factors that define mechanical, i.e. dynamic performance of the vehicle. One of the most important factors affecting the comfort is the level of the

roughness of pavement surface. This factor is very often researched and analyzed, and based on it, normatives that define comfort conditioned by roughness of the road are defined very often.

2.1. MUTUAL INFLUENCE VEHICLE-ROAD

Features, characteristics, models, etc. of driving with a motor vehicle, except driver factors, are mainly conditioned by the interaction of vehicles and road. Influences from the vehicle on the road are transmitted directly through the pavement structure (superstructure), indirectly to the substructure of road. However, the characteristics of the road and structures on the road, to a considerable extent, determine the driving, and above all, the surface characteristics of the pavement structure.

The forces that occur during the movement of a vehicle and transmitted to the pavement structure include: vertical forces (Q, P), tangential (longitudinal) forces (Z, Pk, T), transverse forces (C, W), suction forces, and impacts due to repetitive traffic loads (Figure 4).

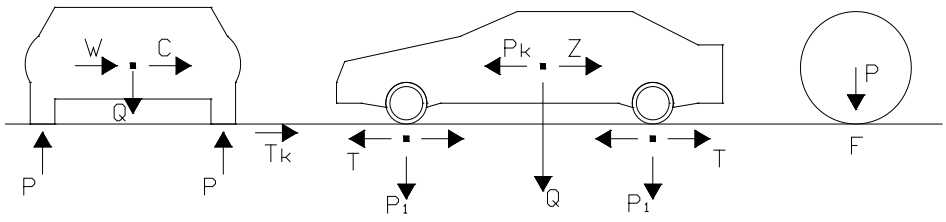

Figure 4. Impacts that occur when driving a motor vehicle on the road [2]

Of all these influences, the tangential and transversal forces are characteristic and significant for movement in the roundabouts, as a result of the movement in the curvature and frequent braking and acceleration of the vehicle.

2.1.1. Tangential (longitudinal) forces

In the longitudinal direction (horizontal path without the influence of the wind), there is an active and reactive force: the driving force Z, the braking force Pk and the adhesion force T (Figure 5).

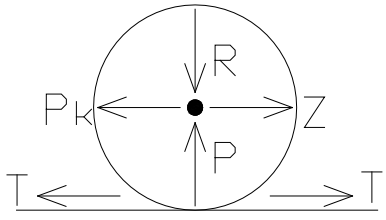

Figure 5. Tangential (longitudinal) forces acting on the pavement structure [2]

From these forces tangential stresses between the substructure and superstructure occurs, between the layers of any structure or, within one layer, and as a result, there is a tendency for shearing the pavement structure or its part.

The largest force that can be transferred from the drive wheels to the pavement is:

$$\max Z = \max P \times f_a \tag{1}$$

The specific stress (tangential τ) due to the tangential force is:

$$\tau = \frac{T}{F} = \frac{\max Z}{F} = \frac{3,6N}{V \times F}; \left(Z = \frac{3,6N}{V} \right) \quad (2)$$

where:

V is a vehicle speed,

Z is a tractive force,

F is vertical force,

N is engine power.

2.1.2. Transversal forces

Transverse force is a horizontal force that occurs as a result of a centrifugal force when vehicle moves in the curvature. These forces also are added the side wind force. Leaving out the influence of wind W, the greater part of the transversal force is:

$$C = \frac{m \times V^2}{R}; m = \frac{Q_p}{g}; Q_p = Q \times i_p \quad (3)$$

where:

C is a transversal force,

R is a radius of curvature,

m is a mass of the vehicle,

V is a vehicle speed,

Q is a weight of the car,

i_p is a cross slope of a road.

2.2. INFLUENCE OF TANGENTIAL AND TRANSVERSAL FORCES ON A PAVEMENT STRUCTURE

The forces transmitted from the vehicle's tires to the tire-pavement contact surface have a significant impact on the pavement structure. These forces also include transversal and tangential forces [2]. They also make a real traffic load (the equivalent axle traffic load is just an approximation). The special significance of these forces is in the case of flexible pavement constructions, i.e. pavement with a surface course constructed of bitumen-bound materials. Together with these forces, hydro-meteorological effects also affect the asphaltic concrete surface course.

In cyclic repetition of loads, the shear tensile stresses occur in the surface course made of bitumen-bonded materials (asphaltic concrete). In cases where these tensions exceed the permissible tension for a particular material that is embedded in the surface course, cracks occur. With this in mind, it is seen that the tensile shear strength is a very important parameter in design. It is very important to determine experimentally (laboratory) the tensile shearing strength of the material from which the bitumen bonded layers (wearing layer, bond layer, etc.) will be constructed. That has to be performed for test specimens in a certain shape and at the predefined loading rate.

Tangential and transverse forces can be the cause of the occurrence of undesired phenomena, and in cases where the shear strength is not relevant, i.e. in the case where

the wearing layer is laid over rigid Portland Cement Concrete Pavement (PCCP) or reinforced concrete and similar pavement structures. In this case, a pure tension strength and adhesion between the wearing course and base course may be relevant. This phenomenon should be specifically investigated in the case of tangential forces caused by vehicle movement (braking, acceleration). In this case, and not only in this case, but also in the previous one, the appearance of cracks in the wearing layer, reflecting cracks, rutting, etc. can be prevented or improved by applying special types of asphaltic concrete wearing courses or using synthetic polymer mesh for reinforcement of asphaltic concrete.

Transverse forces cause transverse stresses in the pavement structure and cause transversal shear between the layers of the pavement structure, resulting in damage to the pavement. They also influence the intensification of the wear of the surface layer of the pavement structure, which requires a more frequent reconstruction of the pavement construction.

3. DISTRESS OF PAVEMENTS AT THE INTERSECTION AREA

Asphaltic concrete and Portland cement pavements at intersections and their approaches, where traffic is required to stop and start, exhibit several types of distress. Research in this area has shown that leading causes of pavement failures at these locations are primarily materials related [3]. Meaningful amounts of funds allocated for maintenance operations are exhausted each year to rehabilitate intersection pavements that have become safety hazards as a result of simple traffic action. Significant savings may be realized if intersections and their approaches are designed and constructed to accommodate the shear stresses as well as fatigue to which they are subjected.

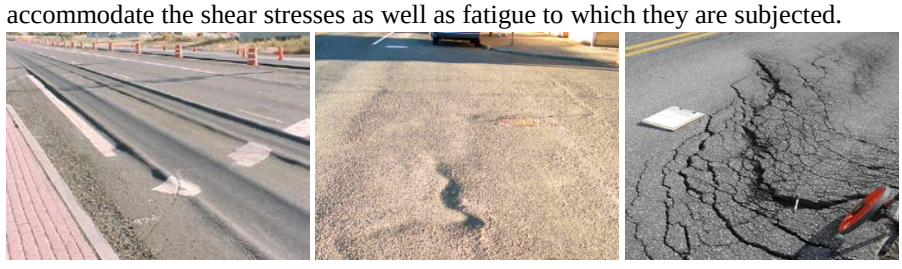

Figure 6. Distresses of pavement at the intersection area (left: rutting, middle: shoving, right: slippage cracking)

In regard to the wide range of distresses that can occur as a result of the impact of traffic loads and the environment, as well as other factors that can affect the pavement construction, the following specific types of distresses occur at intersections (Figure 6) [4]:

- Rutting - surface depression in the wheel path, caused by improper mix design or manufacture, inadequate pavement structure or insufficient compaction of layers during construction.
- Pushing, shoving and severe wash boarding - a form of plastic movement typified abrupt wave across the pavement surface perpendicular to the traffic direction, most often due to insufficient stability of the mixture and poor bonding between the layers;
- Slippage cracking - crescent or half-moon shaped cracks generally having two ends pointed into the direction of traffic, occur on surfaces exposed to sudden

changes in the turning point (braking, starting or turning), caused by a low-strength surface mix or poor bonding between the surface layer and the next underlying layer in the pavement structure.

Average daily traffic and the percentage of trucks do not necessarily indicate whether an intersection will or will not have an Asphaltic Concrete Pavement (ACP) rutting problem. Factors that can affect rutting include the starting and stopping of trucks, roadway grade, climate and mix properties combined with the average daily traffic, truck percentage, and Equivalent Single Axle Loads (ESALs) [5].

By repairing damaged surfaces and depressions, the required slope and required roughness are established. Damaged surfaces can be fixed with flattening, which can be done on small, medium and very damaged surfaces. A little damage to the surface does not have to be repaired, but must be monitored to prevent serious destruction. It is also possible to fill slippage cracking to prevent water penetration and further destruction of the carriageway surface. Delays in taking these measures can lead to much more serious damage and even higher costs of repairs.

It is possible to use the reinforcement procedure - "overlaying" of the pavement, which increases the strength of the structure in which certain displacements (rutting, etc.) have occurred. Care must be taken not to mix materials, that is, never reinforce PCCP structures with bituminous bonded materials [6].

At some roundabouts, the problem can be cracks, especially around the outer edge of the circular flow, near the outer curves and dividing islands, so special attention should be paid to provide the necessary relief [7].

4. GENERAL COMPARISSON OF PAVEMENT STRUCTURE TYPES FOR USE AT INTERSECTIONS

Pavement structure in areas of turning, such as the intersection area, curves on road and roundabouts, is exposed to very severe shearing forces from the vehicle's tires, especially the trucks.

Horizontal loads that are transferred from tire to the pavement during a narrow maneuvering angle are as large as 80% of the static load. These loads cause the wear of the surface layer and the shear between the layers of the pavement structure. As a result, the traditional ACP structure in the area of the intersection or the roundabouts eventually wears out and requires regular reconstruction, sometimes every five years, and even more often. The cost of maintaining these pavements is therefore very high.

In order to function well, flexible (asphaltic concrete) pavement structures at intersections must first of all have adequate thickness and density in order to meet the traffic needs. It is necessary to carefully select the bitumen binder to provide the desired functionality in the long run. At intersections binders that are more resistant to wear and tear should be used. As is it important to select the appropriate binder, it is also important what kind of aggregate will be used in the mixture for pavement structure. The structure of the aggregate must be able to withstand the load and develop a high degree of blocking between the stones that will withstand shear. Both the coarse and fine particles of the aggregate must be of an angular shape in order to provide the blocking required for shear resistance. It is important to limit the use of rounded particles and non-crushed sand. The purpose of the design of the pavement mix is to select the appropriate materials and in an appropriate proportion in order to withstand the shear.

Experience shows that the amount of voids of the mineral aggregate is very significant. Low void mixtures may be susceptible to relatively small changes in the total content of the fluid (asphaltic binder, moisture and small fill). Small fluid's increase can cause rutting and shearing of these mixtures under load. On the other hand, mixtures with high void content produce a thick asphalt protective layer around aggregate particles, which can serve as a lubricant allowing particles to reorient under traffic. Quality control of the asphalt mix is crucial and preliminary tests are necessary in order to identify all the necessary volumetric settings.

PCCP (rigid) at intersections and roundabouts will prevent shear between layers of pavement structure, to which particular attention should be paid at ACP structures. In areas with high traffic loads, where safety is a priority, PCCP will withstand heavy traffic. PCCP do not require periodic rehabilitation, as required by ACPs. An advantage with PCCP is that 40-year design life, with minimal or no rehabilitation required. In addition, the drainage characteristics are preserved over time, because the concrete will not leak and there will be no holes.

Advantages of PCCP for heavily loaded intersections (intersections with crossing of traffic streams or roundabouts) are:

- They do not compact and do not collapse during turning maneuver of large vehicles, i.e. they are resistant to the appearance of depressions and rutting (as opposed to ACPs), and therefore are much more durable;
- They are the cheapest option at intersections where the traditional flexible ACP structure works poorly;
- The traffic congestion due to the maintenance of the PCCP is minimal because the repairs are less frequent and to a lesser extent;
- They are generally thinner than ACPs, and it is therefore necessary to dig out less material during reconstruction. This has a particular advantage in urban areas, where it is necessary to move the buried technical infrastructure, or when the depth of excavation is limited in order to avoid this infrastructure;
- PCCP are suitable for part-to-part construction in limited urban areas where large rollers required for ACPs cannot be effectively maneuvered due to spatial constraints;
- Good skid resistance, more reflective materials of a lighter color for paving;
- PCCP are ecologically more acceptable because concrete can be recycled and the materials used for its production are natural and can be recycled (stone, water, cement), as opposed to asphalt which uses some expensive non-renewable materials (oils);
- Portland cement concrete mixes can be easily painted and textured to differentiate and to be visible areas of intersection.

Because the intersection carries traffic from two or more roads, it may be necessary that the thickness and density of the concrete slab be greater than the thickness and density of the access roads. For pavement structures at intersections, the usual thickness of concrete is 12,5 to 25 cm. The exact required thickness will depend on the expected traffic, local conditions, etc.

Based on the excellent performance of the concrete sections observed during some studies, the use of Portland cement concrete is strongly recommended whenever maintenance expenditures at intersections are excessive. Further, PCCP should be considered for use at newly constructed intersections and their approaches.

The adoption of geosynthetic for pavement aims to improve long-term bearing capacity and performance of the road [8]. The use of high-strength, polypropylene grids can be regarded as one way to reinforce an ACP to diminish the distressing effects of traffic such as rutting and shoving. Observations indicate that high-density plastic geogrids placed in the asphalt layers provide some resistance to long-term permanent deformation. However, the key to using these high-strength materials efficiently for ACP reinforcement lies in the ability to suitably install the grid in a manner that it can provide the added tensile strength as designed. It is recommended that high-density plastic reinforcing grids be considered as a rehabilitation option if it can be determined that the geogrids can be suitably installed with minimal difficulties [3].

The major disadvantage with PCCP intersections is the initial construction cost. However, a life cycle cost analysis of PCCP intersections versus ACP reconstruction and future inlays shows that PCCP intersection construction competes with and can be less expensive than rebuilding with ACP [5].

Because budget constraints have often dictated the choice of construction, ACP was the dominant choice, largely due to its lower initial cost. Life cycle cost analyses between ACP and PCCP reconstruction typically are not done. An additional reason for not considering PCCP reconstruction was related to constructability and concerns about accommodating high traffic flows through urban intersections. Rehabilitating urban intersections with ACP requires rotomilling and inlaying with ACP to remove wheel rutting. This work can typically be done at night, in a short period, and with minor inconvenience to the public. Rehabilitating intersections with PCCP, on the other hand, involves the complete disruption of the intersection, as construction for specific areas sometimes must be staged over several days [5].

With rising prices and intense labor costs for concrete pavement construction, the cost of an asphalt intersection is often half the cost of a concrete intersection, sometimes as low as 30% [8]. The reason is simple - asphalt is less costly to build and maintain than concrete pavement, and asphalt is environmentally acceptable since it is recyclable, so it is the life cycle cost solution.

A great advantage of using hot mix asphalt is that it takes significantly less time to construct than concrete. Intersections can be open to traffic within minutes after construction. This results in much less delay and impact on motorists and businesses. In addition, asphalt paving can be completed at night, further lessening the impact of construction on the motoring public and businesses.

Through the use of improved materials and mixture designs developed by the Superpave system, mixes can now be designed for very high traffic level intersections. These new designs and premium mixes can withstand the loadings and conditions that have resulted in rutting, shoving and cracking in the past.

Asphalt street cuts for underground utilities are easier, quicker, and less costly to make - resulting in quicker repairs and less traffic delays than are necessary for concrete intersections. Street cuts often damage electronic traffic detection loops - which are more quickly re-installed in asphalt, lessening traffic flow disruptions [8].

Asphalt provides superior driver visibility for pavement markings, especially at night and during wet pavement conditions. This enhances safety for drivers, bicyclists, and pedestrians. White and yellow stripes show up best against smooth black surfaces - helping drivers to be more aware of crosswalks, stop bars, turn lanes, and off-set line stripes at intersections. In addition, asphalt provides superior skid resistance without special grooving. There are no joints, saw cuts, or grooving required in asphalt

pavements, so asphalt intersections can be built smoother than concrete and much quieter. Asphalt is a flexible pavement that can be made to easily conform to the grade changes which occur at intersections.

5. HIGH-PERFORMANCE INTERSECTIONS WITH FLEXIBLE PAVEMENT STRUCTURES

Pavement engineers have adopted a four-point strategy to ensure good performance for intersections and other high-stress applications. A basic intersection strategy consists of four steps [1, 8, 9, 10]:

1. Assess the situation

Two types of pavement evaluations are normally conducted: a functional evaluation and a structural evaluation. A functional evaluation considers the surface characteristics of a road, including certain types of cracking, surface smoothness, noise, and surface friction characteristics. A structural evaluation is used to determine the ability of the pavement structure to carry current and future traffic. A structural evaluation typically requires detailed information about pavement layer thicknesses, paving layer material properties, subgrade support conditions, traffic, and the response of the existing pavement to loading.

2. Ensure structural adequacy

To perform well, an intersection must first have adequate thickness to provide the structural strength to meet traffic needs. Whether new or existing, the thickness of each component of the section must provide structural integrity and be sufficient so that, as a combined unit or pavement section, it will carry the anticipated loads and higher stresses resulting from slower moving traffic. Key factors to consider when ensuring structural adequacy: subgrade strength, frost depth, subbase and base thickness, asphalt thickness, traffic type and loading, drainage [8]. For existing pavements, it is critical that the structural adequacy of the in-place material be evaluated. The key elements of a properly designed intersection include various combinations of quality materials (modified subgrade, geo-synthetic fabrics and mats, aggregate subbase, aggregate base, drainage systems, recycled construction materials, hot mix asphalt). Any failed or weak pavement layers identified during the evaluation process must be removed. Simply paving over existing failed material will likely result in recurring failure.

3. Select high-performance materials and confirm the mixture design

Current technology, known as the Superpave process, provides engineers the necessary tools for improving the performance of asphalt intersections and other high-stress locations. The performance-graded binder system is used to select the proper type of liquid asphalt to bind the aggregate particles together in the finished pavement. This selection is based on each project's expected climatic and loading conditions. One of the provisions for selecting the appropriate performance-graded binder recognizes the need for a stiffer binder for slowed or stopped traffic associated with intersections. This provision, commonly called "grade bumping," rounds up one grade higher for slow-moving traffic or two grades higher for standing or stopping traffic.

While the asphalt binds the pavement together, waterproofs and gives additional stiffness, it is the aggregate structure that actually carries the load. This makes aggregate

selection and blending a critical step. The Superpave aggregate requirements (coarse aggregate angularity, fine aggregate angularity, flat and elongated particles and clay content) are used to characterize the aggregates being considered. As the expected traffic loading on the pavement increases, the individual aggregates and aggregate blends must meet higher standards. A successful blend of aggregate must have high internal friction to develop the degree of interlock needed to resist shearing or rutting. Crushed, angular aggregates are a necessity, while rounded aggregate must be avoided in both the coarse and fine portions of the mix.

The purpose of the mix design process is to develop an economical and constructible blend of component materials that will satisfy the engineering requirements of the application. For intersection mixtures, it is particularly important to use a mix design that produces stone-on-stone contact or aggregate interlock. Strong, durable aggregates are a necessity to avoid fracturing the individual aggregate particles.

4. Use proper construction techniques

Use of proper construction techniques is of course important for all pavements and it is critical for high-performance intersections. Three aspects are worth special mention here: proper compaction, avoidance of segregation and proper joint construction.

Proper compaction is vital for long-term durability. The mixture must be properly compacted to resist additional compaction under heavy traffic. Proper compaction also reduces air and water intrusion that could cause accelerated aging which reduces the long-term durability of a pavement.

Segregation occurs when different-size aggregate particles separate in the loose mixture during handling and placement, creating a weaker, more open-textured pavement that is less durable. Best management practices to prevent segregation must be followed closely in intersection work; otherwise, problems may occur.

Proper joint construction techniques, both transverse as well as longitudinal joints, must be executed to prevent the intrusion of air and water at the construction joints.

The quality of a completed project is not only dependent on proper design and good quality materials, but also on using quality workmanship. Issues to be address to ensure quality workmanship are [7, 8, 11]:

- Process control plan - All details of construction, including control of materials and their transportation and placement, need to be covered. A complete schedule of construction activities should be included;
- Compliance with project specifications - Materials delivered to the intersection construction project should be sampled and tested before placement to make sure they are of high quality and in compliance with project specifications. Additional sampling and testing should be performed again during placement and upon a completion of each phase to ensure that they are still in compliance and have been placed or installed properly;
- Utilities - A utility study should be performed to determine if utilities being proposed, or that are already installed, are adequate in size to handle the projected growth within their service area;
- Production and placement - At the start of paving, the volumetric properties of the plant produced material should be re-evaluated. Adjustments should be made to the plant produced material as necessary, so that all of the volumetric criteria remain within the specification limits required for the job mix formula (mix design). During hot mix asphalt paving, it is vital that the contractor

practice proper construction techniques and pay attention to details (achieve target density; avoid the use of diesel fuel in truck beds; do not overheat the mixture; thoroughly clean milled areas; avoid segregation during production, transportation and placement; proper joint construction is important to prevent the entrance of water).

6. RECOMMENDATIONS FOR RIGID PAVEMENT STRUCTURES

Some experiences with constructing PCCP intersections convinced engineers that design and construction details were important [5]. Resulting random cracking and construction difficulties provided valuable learning experiences. Recommendations and conclusions for the use of PCCP at urban intersections are:

1. Construction costs

Full-depth PCCP reconstruction at urban intersections costs approximately 25-30% more than full-depth ACP construction. Construction costs have been lower when urban intersection construction has been included as part of larger ACP resurfacing projects. Traffic control costs typically run 4-5% of the project subtotal when intersection construction is included as part of a larger ACP resurfacing project, and 12-17% of the project subtotal when intersections are constructed as a separate contract.

2. Life cycle cost analysis

The 40-year annualized costs for intersections with and without user delay costs show that full-depth PCCP intersection reconstruction typically costs less than full-depth ACP reconstruction with future ACP inlays when intersection reconstruction is necessary. When user delay costs are used, studies showed that PCCP reconstruction cost is 5,5-14% less than ACP reconstruction. A comparison of the 40-year annualized costs for reconstructed PCCP intersections with and without user delay costs to ACP inlays at four-, six-, and eight-year cycles showed that ACP inlays will always cost less than reconstructing with PCCP at an urban intersection. However, with ACP inlays, the state or local agency must decide whether inlays meet the expectations of the public. The public's view of rehabilitation of the same section of roadway at four-, six- or eight-year-cycles does not reflect well on the agency, even if the section needs rehabilitation because of the distress present. In addition, the public does not appreciate delays during roadway rehabilitation.

3. Traffic management

Reconstruction of PCCP intersections is faster when some type of closure has been used. Intersection projects with minimal or no detours have required 30 to 42 days for the PCCP reconstruction. Allowing at least some type of closure (such as closing minor legs) can shorten the number of construction days to 15 to 20. Full closure of the intersection facilitates the fastest construction period. It is also possible to reconstruct intersections during weekend closures.

4. Design considerations

A key element of constructing PCCP intersections is the planning of transverse and longitudinal joints. Often, state and local agencies are not prepared to make on-the-fly

jointing decisions once intersection construction is under way. Therefore, joint planning is necessary to prevent distresses such as sympathy cracks, random cracks, and misalignment of joints with manholes and valves. It is strongly recommended the preparation of jointing plans to be included in contract documents.

5. Construction considerations

PCCP intersection construction requires the same care and consideration as any other PCCP project. However, PCCP intersections require special jointing considerations, especially around curb radii and utility fixtures. Field adjustments are often needed to avoid random cracking. As mentioned under "4. Design considerations", the best way to avoid random cracking is to provide PCCP jointing plans in the contract documents. Even with the best of jointing plans, field adjustments will still be needed, and project personnel need to be aware of the options.

7. CONCLUSION

Most intersections, roundabouts and intersections with crossing of traffic streams, are built using ACP. PCCPs generally have a longer lifetime and are better maintained under heavy traffic (trucks, etc.). However, experience shows that the occurrence of rutting is not a problem with well-constructed ACPs, which is often emphasized as one of the advantages of applying rigid pavement structures (PCCP).

ACPs can be economically maintained to preserve superior ride quality over long periods of time - and smooth roads keep the traveling public happy. Proper design, combined with quality materials and construction workmanship can make hot mix asphalt a long term construction solution for even the most heavily trafficked intersections [8]. When choosing a pavement type, constructability should also be considered. Although PCCP structures are recommended for heavy load areas, with particularly tangential and shear forces, ACPs can be effectively applied if an intersection must be built under traffic, as it can quickly be put into circulation. The decision to use an ACP or PCCP will depend on the local advantages and the type of pavement construction of the access roads.

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45| Претходно саопштење
Preliminary report
doi 10.7251/STP1813616S ISSN 2566-4484

ECOLOGICAL ASPECTS OF SNOW AND ICE CONTROL ON ROADS

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Abstract:

In all countries where, with regard to climatic conditions, the occurrence of ice on the roads is possible, great efforts are made to minimize the loss of friction on the pavement surface, thereby ensuring continuity and safety of traffic and minimizing human casualties and material losses. Modern road maintenance in the winter period is based on finding a solution to reduce the freezing point of water by creating chemical solutions and breaking the bond between ice and pavement. However, the use of various chemicals and abrasive materials, especially in uncontrolled quantities, can have serious environmental consequences. This paper presents the most commonly used materials for preventing ice, as well as underlines negative impacts and recommendations for mitigation of environmental threats.

Keywords: snow, ice, control, environment

EKOLOŠKI ASPEKTI KONTROLE SNEGA I LEDA NA PUTEVIMA

Rezime:

U svim zemljama gde je, s obzirom na klimatske uslove, moguća pojava poledice na putevima ulažu se veliki napori da se gubitak trenja na kolovoznoj površini svede na minimum i na taj način omogući kontinuitet i bezbednost saobraćaja, a ljudske žrtve i materijalni gubici svedu na minimum. Moderno održavanje puteva u zimskom periodu se zasniva na pronalaženju rešenja kojim bi se snizila tačka mržnjenja vode putem stvaranja hemijskih rastvora i razaranja veze led-kolovoz. Međutim, primena različitih hemijskih supstanci i abrazivnih materijala, posebno u nekontrolisanim količinama, može imati ozbiljne posledice po životnu sredinu. U radu će biti prikazane najčešće upotrebljavane materije za sprečavanje poledice, te naglašeni negativni uticaji i preporuke za manje ugrožavanje životne sredine.

Keywords: snow, ice, control, environment

1. INTRODUCTION

In all countries where, with regard to climatic conditions, the occurrence of ice on the roads is possible, great efforts are made to minimize the slipperiness of pavement surface, thereby ensuring continuity and safety of traffic and minimizing human casualties and material losses. The number of traffic accidents due to the loss of friction at the contact point between the wheel and the carriageway in the world is very high, and in the region this problem is very highlighted.

Qualified road, safe in all weather conditions is of big importance, not only for the inhabitants, but for the society in general. Today, life could not be imagined without passable road communications during the winter, in narrow geographic area as well as at the international level.

Excessive amount of spreading material that roughens the pavement, or chemicals used to melt snow and ice is not generally acceptable for environmental and cost impacts, yet, in the other hand, in principle it is not acceptable to overcompensate the speed of driving in such disadvantageous conditions due to waste of time and higher fuel consumption.

Today is undoubtful that the only way to preserve the roads with heavy traffic without snow and ice is to use the dissolving agents. Such a way of maintenance is the only one, in general, that ensures unhindered driving in winter conditions.

However, there is still a great deal of safety responsibility on drivers' side as well, since it is necessary to be ready for surprises in changing conditions on winter roads. First of all, it is necessary to change the driving mode and this is much easier to do than to change the condition of the pavement.

2. ICE

2.1. PRINCIPLES OF ICE FORMATION

Ice represents a solid aggregate state of water, which is reached at temperatures equal to or less than 0°C (point of frost). Due to the specific spatial distribution of the molecules of water at that time, the ice has a lower density of water (for about 8.5%) and floats on its surface. When frozen, the volume of water increases for about 11% [1].

Specific temperature of ice is twice lower than water in liquid condition. Because of this, ice is relatively quickly formed on the surface of the water cooled down to a temperature of 0°C, and for its melting it takes a much smaller amount of heat than for evaporation of liquid water. Increasing salinity reduces the point of water freezing.

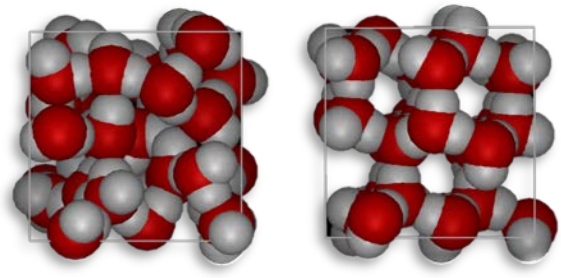

Figure 1. The volume of water (left) and ice (right) [2]

In ice, each oxygen atom has four neighbouring hydrogen atoms - two from its own molecule, and two from closest molecules (Figure 1). This structure is not the most dense possible packaging of water molecules. As the temperature rises, melting of the ice and the weakening of hydrogen bonds occur. This results in a density increase which is at the maximum at 4°C [3].

2.2. ICE ON THE PAVEMENT

Ice on the pavement occurs in the form of black ice. This is the occurrence of smoothness of the pavement with reduced adhesion, which is influenced by weather conditions. The black ice is formed by freezing of water and moist on the pavement. Given the type of formation, the following forms are distinguished [4]:

- Compacted snow is a black ice that occurs when snow sticks to the pavement and by stepping on and freezing of compacted snow due to driving vehicles or by freezing the snowy slush or the remains of snow;
- Snow frost occur due to freezing of moisture from the air on the pavement;
- Black ice is homogenous layer of ice, formed on pavement due to freezing rain precipitation on the cold pavement. Super frosty water drops automatically turn to ice, with additional freezing of water due to snow melting, as well as other water that appears at the pavement (from access roads, berms, slopes and gutters).

3. LOWERING THE WATER FREEZING POINT

Modern winter road maintenance is based on finding a solution for lowering the water freezing point, creating chemical solutions, decomposing the Na-Cl bonds, as well as ice-pavement bond all of which should be achieved in a "smart" way.

Salt is a universal agent for lowering the freezing point. That is only a shorter form of the expression “agent for lowering the water freezing point to the temperature lower than 0°C”. In the field of winter maintenance, a substance that postpones forming of ice is a very useful and good thing.

There are many alternative chemicals that can be used to lower the water-freezing point, but the salt is still the best solution because it costs much less than other alternatives, is easier to handle and is very reliable in achieving safe driving conditions.

The snow accumulates on road and becomes compacted due to traffic. Then it begins to bond with the pavement causing the problem because of the impossibility of removing it with mechanical means. The only way to break the ice-pavement bond is by using chemical means, such as road salt.

During the action of ice removal, it is applied at the top of the compacted snow. If there is a sufficient amount of moisture and heat, which most commonly occurs as a result of a combination of sun, traffic and higher daily temperatures, the road salt will dissolve and form a solution. The graines of salt that turn into the solution will penetrate through the compacted snow towards the pavement surface, by providing the melting along the entire path. As far as the melting conditions are concerned, the heavier crystals of salt must exist, powerful enough to perform melting all the way till the road surface. Penetration depth of salt solution (salty water) depends on the density.

The amount of time needed for salt to get into the solution and start melting snow or ice is determined by the temperature and humidity, and the total amount of the salt solution used must be spread over the surface of the road by transverse fall or through movement

of traffic. Change of pavement temperature will accelerate or slow down the chemical reaction. The characteristics of the salt used also influence the reaction time and the melting effect [4]. The road salt is effective up to -21°C, but its application is not recommended below -10°C. Effect of salt on melting of water can be assessed on the basis of data given in Table 1.

Table 1. Kilograms of ice melted by 1 kg of salt [4]

temperature [°C]	one kilogram of NaCl melts
-1	46.3 kg of ice
-4	14.4 kg of ice
-6.7	8.6 kg of ice
-9.4	6.3 kg of ice
-12	4.9 kg of ice
-15	4.1 kg of ice
-18	3.7 kg of ice
-21	3.2 kg of ice

With a decrease of the pavement surface temperature, a higher salt concentration is needed to prevent freezing. However, as snow and ice melt and dilute the salt solution, the freezing point of the solution increases, and freezing is possible.

Depending on the local conditions and the policy, the scope of application of road salt may vary between 80 and 600 kg/km at the two lane road.

4. SUPPLEMENTS AND ADDITION TO THE ROAD SALT

Depending on the climate characteristics of the area, quantity of salt to be applied is determined. However, regardless the quantity of salt used in a particular region, it can probably be used less in a more efficient way, i.e. with more accurate selection of procedures depending on the conditions.

The best way to optimize the quantity of road salt used is replacement or addition of other chemicals. Five most frequently used chemicals for removal and prevention of ice forming are three “road salts” and two “alternatives”. Some other chemicals used have a high harmful effect on the environment (urea), can be toxic to humans and the animal world if swallowed (glycols), volatile, flammable and toxic (methanol) or have not been sufficiently tested to reliably determine the safety and usefulness of their application (sodium formate) [5].

4.1. CALCIUM CHLORIDE ($CaCl_2$): VERSATILE AND EXOTERMIC

One of the advantages of calcium chloride (Figure 2) is that it reacts at lower temperature than others. It is exgotermic, it absorbs moisture from atmosphere and releases heat when it passes into the liquid state. It can prevent freezing of the pavement and provide moist required for the salt to transform to a solution.

It takes effect at a temperature of -15°C or lower, which means that it is superior to salt for a few degrees. It can be used as previously moistened agent while mixing with sand to avoid freezing. It can also work well in combination with salt.

It is naturally liquid, but it can also be found in solid state, in the form of grains or small plates. Since it draws moisture from the air, it is an advantage in certain conditions and can improve the ways of managing traffic problems during the humid conditions, but it can slow down the process of reaching the clean roadway after the snowfall.

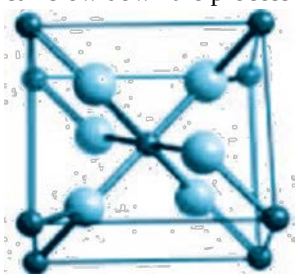

Figure 2. Molecular mesh of calcium chloride [4]

It is also an effective anti-dust agent on gravel roads during the summer.

4.2. MAGNESIUM CHLORIDE (MgCl2): ROAD ANTIFREEZE

Magnesium chloride (Figure 3) originates from the Great Salt Lake, in the state of Utah in the United States of America. It represents a hygroscopic substance, takes and retains moisture regardless of the origin of the same (from air, from carriage, snow, ice). Prevents bonding of snow for the pavement and prevents forming of glaze and black ice.

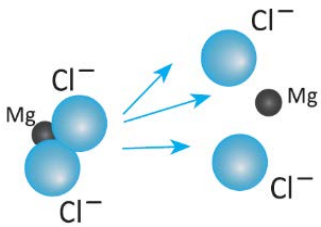

Figure 3. Composition of magnesium chloride molecules [4]

It is used by spraying in liquid state on the roads before snowfall; its eutectic point is -36.6°C. It acts as anti-freeze for roads, lowers the temperature of water freezing and prevents the appearance of ice that creates a strong bond to the road. When used, the road cannot become slippery, security is improved, and the number of accidents is reduced.

It prevents the appearance of black ice and is also used in case of rain that turns to ice. If used as a sand moisturizing agent, it affects the better bonding of the abrasive to the compacted snow.

Magnesium chloride is one of the rare chemicals which can gradually destroy concrete. Some tests showed that with proper application there are no negative effects for ground and surface water or vegetation.

4.3. CALCIUM MAGNESIUM ACETATE (CMA): VINEGAR AND OAT FLOUR

As a chemical compound (Figure 4), calcium magnesium acetate (CMA) is a dolomite limestone rock and acetic acid. For 25 years it is applied as an agent for the control of snow and ice on the roads. It can be used in a liquid form or combined with salt and sand. To prevent the formation of ice, it is used as a liquid.

CMA does not melt snow and ice, but turns it into oat-flour texture. This allows easy cleaning and removal, and if road traffic is very intense, it has the tendency to remove the slush aside very efficiently. However, in that case it must be applied at the beginning of snowfall prior to the accumulation of large amounts of snow, because it is more effective in preventing the formation of ice than in eliminating the already formed ice.

Figure 4. Molecular grid of calcium magnesium acetate [4]

It prevents the transformation of the compacted snow into ice and its subsequent bonding to the pavement, but once ice is created, another chemical should be used to break the bond.

Over 30 years of testing and use showed that it has no impact on the soil because it is biodegradable. It has very little mobility, does not penetrate the soil deeply, so it can not reach the groundwater. It smells like vinegar and therefore is not as attractive to animals as the salt. In Scandinavia it is used in the areas where there are many deer, in order to prevent traffic accidents involving vehicles and animals.

It is less corrosive for metal than salt. It does not contribute to the grinding and peeling of new reinforced concrete.

4.4. POTASSIUM ACETATE: SMALL BIOLOGICAL OXYGEN DEMAND

Potassium acetate (Figure 5) was created by reaction of acetic acid and potassium carbonate. Previously, it was primarily used as an agent for removing ice, but also for keeping the railway track switches open, preventing the icing of lids on the manholes, even as a water antifreeze in the toilets.

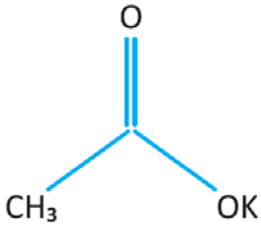

Figure 5. Chemical structure of potassium acetate [4]

It is applied at the extremely low temperatures. If applied at the beginning of snowfall it can prevent the formation of ice-pavement bond. As an additional advantage, it is underlined that it leaves sediments on roads, which is important in preventing the formation of ice during the next snowfall, so that it can be considered to have a prolonged effect.

It is biodegradable - it degrades to potassium and acetate. As it changes to carbon and water, it needs an insignificant amount of oxygen. This process is called “biological oxygen demand”. It has been found that it is toxic to fish in growing concentrations.

It is considered to be non-corrosive, but it must not come into contact with galvanized metals.

Must be stored in clean and sealed container. Otherwise, it could start biodegradation prematurely and expose itself to biological growth.

4.5. SODIUM CHLORIDE (NaCl): OLD, GOOD SALT

Sodium chloride (NaCl) (Figure 6) is natural product. It can be hundreds of millions of years old, or it can be just created a year ago in a solar salt basin. Road companies have been applying it for over 60 years. It is the most studied and the most comprehensible of all chemicals used to eliminate ice.

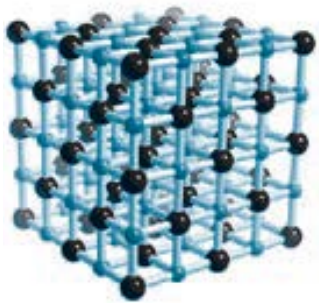

Figure 6. Molecular grid of sodium chloride [4]

Most snow and ice occurrences take place in the range of temperatures where sodium chloride has the best effect, i.e. above -9°C. At this temperature there are no significant differences in the effects of all the chemicals described. They all work equally fast.

Since most of snowfalls is accompanied by a decrease of temperature, modern practice of preventing formation of ice, which assumes application of means for direct removal of ice, prior to or in early phase of the snowfall, makes NaCl a very attractive alternative.

When the temperature is too low to be used alone, it has excellent effect when previously moistened with some of better ice removing agents. It is far cheaper to use a previously moistened NaCl than using only some of the more expensive alternatives.

Temperature of the pavement surface is probably the most significant variable, and NaCl lowers it. This effect is less than 1°C and the duration is 5 minutes or less, after which the effect disappears. Some other agents increase the temperature of the pavement, but this effect also disappears very quickly.

To start acting, it needs moisture from snowfalls. Therefore, it is increasingly used as a pre-moistened or as a salt solution, so it shows the effect immediately. However, after the end of the rainfall, it helps to dry the road surface by returning it to a state of safe conditions. Unlike that, some hygroscopic agents continue to take moisture retaining in that way moist conditions on the road.

It can be purchased in liquid form, or it is possible to make a solution at the construction site, which is much cheaper. Its great advantage is that it is much cheaper than other agents, but it is not a good solution for extremely low temperatures.

5. ENVIRONMENTAL IMPACTS

Melting agents cause damage to the road, buildings, vehicles and road surrounding area. Some of the examples of negative effects include:

- corrosion of vehicles and reinforcement at the facilities and in buildings with bad or damaged anti-corrosion protection;
- damage to the vegetation due to contact in direct vicinity of the road (Figure 7);
- damage to the vegetation and parts of vegetation as consequence of receiving excessive quantities of sodium chloride materials from the soil;
- damage to the fish due to short-term saturation of water with chlorides after the rain.

Figure 7. Damage to plants along the road due to the use of salt [6]

Reducing the spread rate, especially with the use of wet salts, improved spreading technology and enhanced protection measures, can provide less damage to the road environment. In the cases where salt continues to be a problem, there are several precautions that can be taken to avoid negative effects on vegetation, and as a result of collecting droplets of salt for defrosting on leaves and branches.

Planning and designing roads should avoid areas with vulnerable vegetation and agricultural crops. The salt should be used in an optimal amount to prevent ice-bonding for the pavement, and the electronic controllers should be used to control the regulation of quantity. Also, modern road meteorology should be used to obtain reliable weather information and apply salt only when necessary. In hazardous areas, it is necessary to apply known techniques of snow cover control to minimize the amount of snow on the roads, which will also reduce the need for salt.

As for planting, the plants resistant to salt should be considered in zones subject to spreading salt. Vegetation is planted in groups for maximum protection, and in line with the existing vegetation at the terrain. Vulnerable species should not be planted within the boundaries of spreading salt and in the vicinity of streamflow collection zones, such as depressions. If this has to be done to fit into the existing road environment, the planting

should be done at places that are elevated compared to the surface of the pavement or in the areas physically protected from salt. In order to protect the vegetation from the solutions saturated with salt, it is necessary to pay sufficient attention to the design of the drainage system, as well as to its regular maintenance.

For long-term survival of vegetation in urban zones, newly planted softwoods should be protected by raising the coating from coarse cloth during the winter months, the use of agents that prevent drying and evaporation at weak offshoots of vulnerable plants, protect naturally formed/regulated zones from salt spraying by planting salt resistant species as a buffer. Where feasible and cost-effective, it is necessary to consider the use of snow fences to prevent snow accumulation on the roads or to collect dispersed salt to prevent further spreading.

As for the trees next to the road, the aggressive effect of spreading agents is best tolerated by wild chestnut, blue spruce, Austrian pine, hops, white oak, red oak, black carob, etc. More sensitive species are amur maple, Manitoba maple, yellow birch, paper birch, white ash, black cherry, etc. The following sensitive trees should be avoided next to the road: fragrant dishes, red maple, sweet maple, silver maple, black walnut, red pine, white pine.

If the field and nutrient crops are planted near the road, then it should be high or thin wheat grass, because they are the most resistant. Wheat, barley, oats, alfalfa and sweet cloves can be planted as well. The most vulnerable are soy, white beans and red clover.

Spreading material for roughening has no chemical effect on the road and its environment, but can be spread by the traffic over the edge of the road to nearer areas. This causes the following effects:

- clogging of drainage devices;
- pollution of surfaces that can be used for farming;
- pollution of green surfaces and rise of berms;
- damage to parked vehicles and driving vehicles;
- creating dust.

Ecological consequences of usage of large quantities of abrasives are often considered as higher than consequences from using salt. Some regions have completely switched to the use of salt to avoid accumulation of sand in collecting basins and sewage systems [7].

Among the other ecological issues caused by abrasive means are damage to the vegetation along the roads and their accumulation in watercourses, basins and lakes.

If one considers the financial aspect, it can be said that the ton of salt is about five times more expensive than the ton of stone material for spreading, but for the same surface it takes five to ten times more stone material than salt.

Ecologists believe that stone material mixed with oil, mud and dirt (accompanying elements of the road) represents a significant environmental burden. If the increased use of salt is analysed from the aspect of road safety, experts have concluded that stone material is equally dangerous during the rain as black ice.

6. NEW TECHNOLOGIES AND ALTERNATIVE MATERIALS

New materials and technologies enable achievement of significant improvements in many fields of science. Also, by using some of the modern elements of the road and road equipment, it is possible to have a significant influence on the improvement of traffic conditions, as well as to increase the level of traffic safety. Application of new materials,

elements and equipment, besides all the advantages and time and money saving features, contributes to increase of environment protection.

In order to gain an efficient and economical system that reduces the risk and allows traffic to take place on all key road directions within the road network, it is necessary to establish a quality system of winter road maintenance.

In developed countries, a complete system for preventing the formation of black ice on the surface of the pavement has been developed. The core of this system is the network of Road Weather Stations (RWS). Using the probes in the pavement, these cells measure the temperature condition of the pavement surface and together with the meteorological sensors determine the parameters of the local microclimate. These data are then processed in a computer center.

RWS also enables automatic control of certain alarm systems depending on road conditions. Based on the data processed and the given parameters, the system notifies the winter maintenance service about the need for intervention, but the intervention of mobile teams is often endangered by the conditions of traffic and possible traffic jams on the road.

6.1. FIXED AUTOMATED SPRAY TECHNOLOGY

Fixed Automated Spray Technology (FAST) systems (Figure 8) are automatically controlled by ice early warning systems and they spray the road surface with a chemical solution before ice can form. During snowfalls, this prevents the accretion of snow in a compact layer on the road surface; the snow remains sufficiently soft for removal during standard winter maintenance operations. The de-icing agent is sprayed in a uniform manner onto the road surface using spray nozzles at the side of the road, spray discs in the road surface or by means of the innovative Micro-FAST technology [8].

The automated sprayer has a reaction at the optimum moment, a significant precision of spreading and use of the agent, including reduced adverse effects on the structure, which prolongs the lifespan of the structure and allows the use of various types of defrosting agents in the appropriate amount, which also affects the road environment.

Figure 8. Automated spray technology systems [8]

6.2. SOLAR SYSTEMS

The future of winter pavement maintenance and preventing the formation of ice on them are the solar roads. Their profitability is high, as cities could have a significant reduction in the cost of removing snow off the pavement, and pollution problems caused due to the use of chemicals (CaCl2, NaCl, etc.) could disappear.

It is also estimated that the number of accidents caused by black ice will be reduced. This method of road maintenance is already being applied successfully in Toddington (England), as well as at the Hiroshima Airport (Japan) [9, 10].

The solar system (Figure 9) compiles two solar collectors that are integrated into the surface of the pavement (presented in orange) and two thermal storages (presented in blue). The energy collected in this way during the summer is stored in thermal “banks” and it directs to defrosting of the pavement during the winter when the pavement temperature drops below 0°C.

The successful demonstration of this project in Toddington was carried out by the United Kingdom Highway Agency in cooperation with the Road Research Laboratory. The system is designed in such a way that heat, accumulated in pipes beneath the carriageway, is activated when necessary, defrosts the pavement and thus creates adequate conditions for unhindered traffic without danger of black ice.

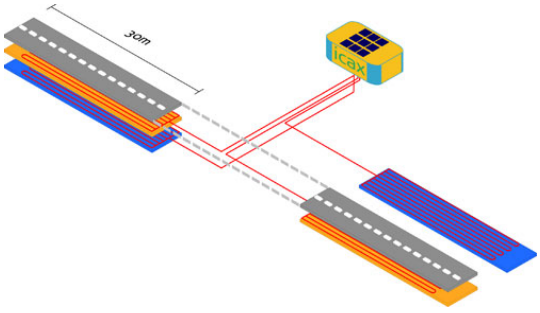

Figure 9. Solar systems on roads [9]

An inter-seasonal heat transformer can be used to remove snow and ice from the pavement, public squares, parking and airports. In this way, accidents are prevented and life is preserved, but also, the durability of the pavement is prolonged, as its heat is controlled during the summer and winter. It reduces the consumption of salt and its adverse environmental impact, and therefore reduces the cost of road maintenance and repairing of maintenance machines. Favourable effects related to the level of service on the roads reflect in the reduction of crowds and traffic jams, and the time for possible road repair is prolonged [10].

Another very successful example of using solar energy for maintenance of traffic surfaces was used in Japan at Hiroshima Airport (Figure 10). The aforementioned defrosting system prevents the formation of ice on the landing and take-off field, runways, taxiways, and aprons. Costs and time required for maintenance of chemical spreading machines are reduced, and thus the life of the traffic surfaces at the airport is prolonged.

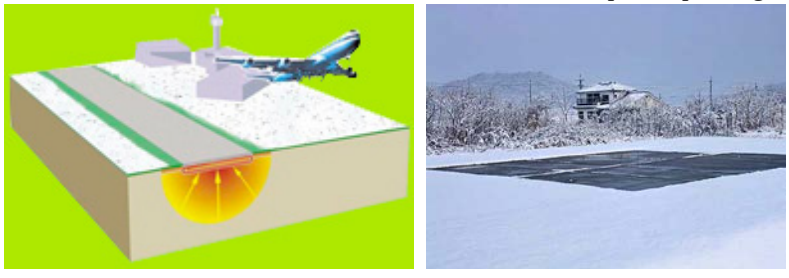

Figure 10. Application of solar systems at the airports [9]

The system allows unhindered traffic to be carried out at the airport without the discharge of harmful substances into the environment. After determining the outside temperature, it is self-activated to prevent ice forming.

6.3. HEATING PANELS

One of the innovative technologies of snow and ice control is installation of heating panels (Figure 11), mostly used on bridges. According to the report of the Federal Highway Agency in the United States of America, three heating technologies are usually used: hydraulic, thermal and electrical [11]. In a hydraulic heating system, the heated liquid is pumped through a pipe mounted in the plate. In the heat pipe system, the operating fluid contained in the steel pipes is evaporated and condensed due to passive heat transfer. In an electric heating system, heat is generated by electric resistant cables placed in the plate near the surface [12].

According to Conger [13], the operating costs of the heat pipe system are lower than the electrical or hydraulic systems. The report on the use of heating panels concludes that the available technologies for pavement heating do not represent any problem for the structure and no adverse effect on durability of bridge was observed. The NCHRP report concluded that the technology of the heating panels is feasible, that it does not pose a problem in the construction and that there is no adverse effect on the load capacity of the bridge. However, it is indicated that the error of one sensor may cause the whole system to malfunction and that selection of the proper working fluid for the heat of the pipe is important [13].

Figure 11. Heating panels [14, 15]

6.4. ALTERNATIVE SOLUTIONS

If considerations include high costs and problems caused by traffic accidents almost on a daily basis (especially during the winter period), it is justified to use new materials and technologies during the process of planning, design, reconstruction and maintenance, as well as the introduction of a system for monitoring and analysing traffic. Therefore, special

attention should be paid to the application of new materials and technologies, as their application has multiple effects on maintenance savings, safety and traffic flow.

NaCl is effective, but its use causes corrosion of reinforcement, corrosive damage to cars and soil contamination due to increased NaCl concentration along the road, as well as in the waters. In the last few years there has been a lack of this material, causing the increased costs and renewed interest in alternative materials that can be used to defrost the pavement.

In an effort to increase the efficiency of the removal of ice from the pavement and reduce the corrosive effect of NaCl, new alternative solutions have been developed, which differ in their mode of operation, operate under different conditions and have a different impact on human health and the environment [3].

Some of these materials are:

- CG-90 (so called surface saviour) [16] - Resistant to the corrosion, used in the form of sprayer and has wide application. It is applied directly on ice and acts 1.5 times faster than sodium chloride. The advantage is that it prevents damage to the road surface, and it has better effect against corrosion both from NaCl and CaCl2. The only danger is possible dissolution over time into its components - chloride, salt and magnesium that can cause corrosion. A small amount of phosphorus in salt acts as a stimulant for plant growth. As it represents a type of salt, it is necessary to take care of the protection in order to avoid skin irritation;
- CMS-B, also known as MoTech, is a sugar beet processing product whose defrost properties have been recently discovered and are still in the testing phase. Sugar beets are used to produce sugar, giving various by-products. Water from sugar beet is separated during the processing process for obtaining different compounds. Of the processing residues, 10% make NaCl in the solution itself. It has been noticed that it has positive effect as defrost agent up to -23°C. It is used as spray, and it is added to the sand with whom it gives good results.

Experiments on environmental impact have not been made since basic substance is NaCl, so the effects are the same as well. As far as the man is concerned, NaCl irritates the eyes, skin and can create abdominal disturbances. Protective clothing and gloves are recommended. It is very slowly decomposed at temperatures below zero.

In the domain of the research of the defrosting agents, products that originate from by-products from agricultural raw materials, including corn, wheat and rice, also draw considerable attention. There is currently little information about the production process, since most of the manufactured materials are owned by producers - farmers or processors. Some of the existing agricultural products that can be used for defrosting are: mono-acrylic esters, processed agricultural by-products, wet grinding maize, beer by-products, plant material particles, monovalent and polyvalent alcohols, reduced sugar, various types of salts, etc. [3].

Their use is being tested in laboratories, test and evaluations are performed, and recommendations are defined, but mostly remaining at that level. Many of these products are biodegradable, and therefore they represent minimal concern for vegetation, for human and animal health compared to other types of defrosting agents. Moreover, small concentrations of phosphorus and ammonia in organic lubricants can provide nutrients for faster plant growth.

Research in the world has led to the selection of several alternative defrost agents based on agricultural raw materials, whose further development, i.e. use, makes sense.

The selection is made taking into account: the likelihood of defrosting, usability, possible effects on the environmental resistance, the anticipated price and availability, the damage caused to the vehicle, the possible effects on the environment.

Comparison was made with respect to NaCl whose effect is well known. By combining any of these substances with NaCl it is possible to achieve the same or better effect than it can achieve itself, and less pollution of the environment.

Geomelt 55 (formerly known as ICE BITE 55) [17] is an anti-icing fluid, a natural, agricultural product, obtained from renewable sources of sugar beet and has proven to have ice control performances, the same or slightly better than traditional solutions. It is suitable for use in environments where the impact on environment is important. It is a product of molasses (high fructose corn syrup) (Figure 12).

Figure 12. Molasses [18]

Also, two types of biofuel were approved for further laboratory testings. Their commercial names are BioOil and E310, and they have not been examined as defrosting agents before.

BioOil is derived from the conversion of biomass in Canada, dark brown, liquid, with the same odour as plants it was derived from. It was created in the process of pyrolysis where biomass, such as forest residues (bark, sawdust, shavings, etc.) and agricultural residues (sugar cane, waste in its processing, wheat straw, etc.), is exposed to a temperature of 400-500°C in the environment without oxygen. It is generally used as a fuel for a boiler.

E310 is obtained from corn in cereal processing plants. It is obtained in the process of converting corn into ethanol, where E310 appears as one version of this powder product.

Another type of agricultural product is glycerine. It is colourless, odourless, liquid, low toxicity, has great application in the pharmaceutical industry, personal care, food. Glycerine (molecular formula C3H5(OH)3) (Figure 13) has three hydroxyl groups that are responsible for solubility in water. It is a central component of many fats and lipids.

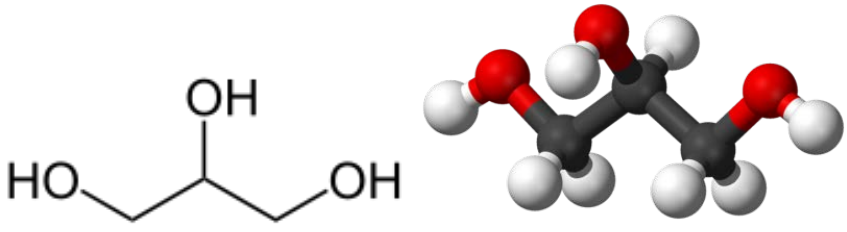

Figure 13. Chemical structure and molecular grid of glycerine [19]

Glycerine appears as a by-product during saponification of animal fats in treatment with sodium or potassium hydroxide in the production of soap. It is also obtained as a by-product in the production of biodiesel through the treatment of animal fats and various

vegetable oils with methanol in the presence of a catalyst of basic organic compounds in a process known as transesterification. Glycerine is very soluble in water. The minimum freezing point is about -37.8°C and it refers to the concentration of glycerine in the water of 60-70% [20].

By researching these products, their freezing points, the possibilities of defrosting, resistance and viscosity, the following conclusions were obtained. The ratio of 80% glycerine and 20% NaCl proved to be the best to defrost the roads [20]. When considering other factors, such as corrosion, dilution of NaCl reduces this effect, while the addition of glycerine does not increase the risk of corrosion. Impact of glycerine on vegetation is minimal.

The biggest concern when using this combination and its application is on the sidewalk due to its viscosity and possible effect on movement of pedestrians. Therefore, the ratio of 80% glycerine and 20% NaCl is accepted as the best because in this ratio the viscosity can be controlled in water.

In practice, it is used as a defrosting spray in various concentrations.

On the basis of the above, it can be concluded that in the future it is realistic to expect increasing use of defrost agents based on agricultural by-products. Further research is necessary in this field, but better results are certain and adverse environmental impact is minimized.

The most advanced and the boldest research related to the means for removing ice from the pavement today is taking place in the field of nanotechnology. Scientists are working on the development technology that would prevent the formation of ice on road [21].

A drop of water, when falling on the surface of pavement, splashes into millions of nanoparticles, then aiming to re-collect. During the course of this re-collection, the formation of ice occurs. If the success in acting on the particles at the time of the fall, when they begin to re-group and produce ice ia achieved, the formation of ice on the pavement would be completely prevented. For this purpose, “smart” nano-materials would be used to keep the particles at a “safe” distance.

Environmental damage would be reduced, the costs of the winter service would be reduced to a minimum, as well as the number of accidents on the road due to the frozen pavement. This possibility is still at the level of theoretical considerations and laboratory testing, but there is hope that in the not too distant future the idea will be put into practice.

7. CONCLUSION

Each year winters are getting stronger and removal of ice from the pavement demands more and more efforts and modern means. Control and removal of ice from the pavement is becoming one of the most important factors in winter road maintenance.

Currently, the best results in fighting against black ice are achieved by various types of salts, which have the widest application. The experience of the United States of America, as one of the countries with the most developed road traffic, according to numerous surveys conducted across the country, indicates the necessity for use of salt for winter road maintenance.

Nowadays, when the eco-awareness of the world population is growing, harmful effects of salt on the environment have been discovered. Many studies have been carried out in the hope that a suitable salt replacement will be found and will not have a harmful effect. Unfortunately, most of these studies ended with the conclusion that, for now, in the case

of large scale black ice, the only solution that gives quick and efficient results is the spreading of various types of salt on roads.

In addition to all the positive characteristics of spreading salts, scientists are trying to improve some alternative spreading materials and develop new methods that will eliminate ice in a faster and more efficient way. Their ecological justification and economic viability are also the aims that should be achieved.

New materials and methods will give better results, but the goal always remains the same, which is better functioning of traffic and reducing the number of accidents.

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46| Претходно саопштење
Preliminary report
doi 10.7251/STP1813632L ISSN 2566-4484

KONSOLIDACIJA POMOĆU VERTIKALNIH DRENOVA

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Rezime:
Izgradnja nasipa saobraćajne infrastrukture (puteva i železnica) zahteva što bržu i kvalitetniju gradnju. Jedan od problema koji se najčešće javlja u ostvarivanju ovih ciljeva je konsolidacija koja se često odvija još dugo nakon završetka izgradnje, a usled čega nastaju naknadna sleganja i oštećenja saobraćajnica. Zbog toga se primenjuju mere da se konsolidacija ubrza i završi za vreme građenja nasipa.
U okviru ovog rada se prikazuje jedna od metoda ubrzanja konsolidacije pomoću vertikalnih drenova. Pored teorijskih razmatranja konsolidacije daje se i jedan primer primene ove metoda.

Ključne reči: infrastruktura, nasip, konsolidacija, sleganje, vertikalni drenovi

CONSOLIDATION WITH VERTICAL DRAINS

Abstract:
Building the embankment of traffic infrastructure (roads and railways) requires faster and more quality construction. One of the problems that often occurs in achieving these goals is the consolidation, which often occurs long after the completion of construction, resulting in subsequent settlements and damage to the roads. Therefore, certain measures are being implemented to accelerate and complete consolidation during embankment construction.
In this paper, one of the methods of accelerating consolidation, using vertical drains, is shown. In addition to theoretical considerations of consolidation, one example of the application of this method is given.

Keywords: infrastructure, embankment, consolidation, settlement, vertical drains

1. INTRODUCTION

In cohesive materials, especially if their pores filled with water, subsidence are not present but may develop months or even years. In the paper on seepage and seepage effects it was assumed that the volume occupied by the water per unit of volume of the soil is independent of the state of stress in the soil. There is no real soil which strictly satisfies the continuity condition, because every change in the state of stress produces a certain change in the volume of voids per unit volume of the soil. Yet, if the soil is very permeable and not very compressible, the change of the porosity due to a change in the state of stress in the soil can usually be disregarded.

Bearing in mind all this, the ground where time consolidation is a problem for the dynamics of the construction of, in particular embankments, apply measures to accelerate consolidation and finishes during the construction of the embankment.

2. THEORY OF CONSOLIDATION

The application of total stress (or a load) to an unsaturated soil can result in the generation of excess pore-air and pore-water pressures. The excess pore-air and pore-water pressures will dissipate with time and eventually the pore pressures return to the equilibrium values that existed prior to loading. The dissipation process of pore pressures is called “consolidation” and the process results in volume change as excess pore pressures are dissipated. It is also possible for excess pore fluid pressures to be generated as a result of changes in boundary conditions. For example, the infiltration of rainwater at ground surface can initiate water movement into the soil along with associated soil swelling or soil collapse. Water moves into the soil because of a difference in the hydraulic head (or pore-water pressure) at ground surface and the hydraulic head immediately within the soil mass. The drying of a soil from the ground surface also initiates moisture movement that can be accompanied by volume decrease. The drying of the soil can be visualized in terms of a moisture flux at ground surface or a change in the pore-water pressure boundary condition.

The “swelling” process is usually associated with a change in moisture flux boundary conditions whereas the consolidation process is usually associated with a change in the externally applied total stresses. In the case of a swelling process, the pore pressures (i.e., pore-water pressure, pore-air pressure or both) are below the equilibrium state and therefore will increase toward an equilibrium state. The consolidation

process has a decrease in pore pressures with time while the swelling process has an increase in pore pressures with time. The consolidation and swelling processes are essentially equivalent and opposite processes from a theoretical standpoint. However, the swelling process is not usually initiated through a change in the total stresses (i.e., unloading of the soil). Rather, it is usually environmental changes related to precipitation that directly change the pore-water pressure conditions at the ground surface and initiate a process of pore-water pressure changes throughout the soil mass.

If the load on a layer of saturated soil such as clay isincreased, the layer is compressed, and excess water drains out of it. This constitutes a process of consolidation. During the process the quantity of water thatleaves a thin horizontal slice of the soil is larger than thequantity that enters it. The difference is equal to thedecrease in volume of the layer; thus the continuity condition expressed by Eq.1 (since the volume of water in the element is n dx dy dz, where n is the porosity, the equation of continuity) [1,2]:

$$\left(\frac{\partial v_x}{\partial x}+\frac{\partial v_y}{\partial y}+\frac{\partial v_z}{\partial z}\right)dx\,dy\,dz=-\frac{\partial}{\partial t}\left(n\,dx\,dy\,dz\right) \qquad (1)$$

The added pressure or load per unit of area that produces the consolidation is known as the consolidation pressure increment. At the instant of its application, it is carried almost entirely by the water in the voids of the soil. Therefore, at the beginning of a process of consolidation, there is an initial excess pressure in the water almost exactly equal to the consolidation pressure increment. As time goes on, the excess pore-water pressure decreases, and the effective vertical pressure in the layer correspondingly increases. At any point within the consolidating layer, the value *u'* of the excess pore-water pressure at a given time may be determined from

$$u' = u - u_s \qquad (2)$$

in which u is the total pore-water pressure and u_s is the reference static or steady-state pore-water pressure in the consolidating layer. At the end of primary consolidation the excess pore-water pressure u' becomes equal to zero, and the entire consolidation pressure increment becomes an effective stress transmitted through the structure of the soil.

The Darcy equation in terms of excess pore-water pressure is:

$$v_z = -\frac{k_v}{\gamma_w}\frac{\partial u'}{\partial z} \qquad (3)$$

Assuming that the coefficient of permeability k_v is the same at every point in the consolidating layer and forevery stage of consolidation, and expressing the porosity n in terms of void ratio e, we obtain

$$\frac{k_v}{\gamma_w}\frac{\partial^2 u'}{\partial z^2}=\frac{1}{1+e}\frac{\partial e}{\partial t} \qquad (4)$$

Equation (4) is the hydrodynamic equation of onedimensional consolidation based on the assumptions that the coefficient of permeability is constant and the strains are small during consolidation.

Even in the absence of time-dependent changes in total stress and groundwater level or reference pore-water pressure, the compression of saturated soils is time-dependent because it is the result of two separate mechanisms, each of which is time-dependent. This can be illustrated by the following basic equation relating void ratio, effective stress, and time

$$\frac{de}{dt}=\left(\frac{\partial e}{\partial \sigma_v'}\right)\frac{d\sigma_v'}{dt}+\left(\frac{\partial e}{\partial t}\right)_{\sigma_v'} = a_{vs}\frac{d\sigma_v'}{dt}+a_{vt} \qquad (5)$$

where the subscripts v, s and t denote vertical, stress, and time, respectively.

If we assume that the time lag of the compression is caused exclusively by the finite permeability of the soil,so that in Eq. 5 $a_{vt} = 0$, and if we assume further that in Eq. 5 a_{vs}

is equal to - a_v , which is the same at every point in the layer and for every stage of consolidation, then Eq. 5 becomes

$$\frac{de}{dt} = a_v \frac{d\sigma_v'}{dt} \qquad (6)$$

If the total vertical stress σ_v, and the reference pore-water pressure u_s remain unchanged during consolidation, then $d\sigma_v'/dt=-du'/dt$ and Eq. 4 becomes

$$\frac{k_v}{\gamma_w}\frac{\partial^2 u'}{\partial z^2} = \frac{a_v}{1+e}\frac{\partial u'}{\partial t} \qquad (7)$$

In terms of $m_v=a_v/(1+e)$, where $m_v=\Delta\varepsilon_v / \Delta\sigma_v'$ and ε_v is vertical strain, we have

$$\frac{1}{\gamma_w}\frac{k_v}{m_v}\frac{\partial^2 u'}{\partial z^2} = \frac{\partial u'}{\partial t} \qquad (8)$$

By introducing the coefficient of consolidation c_v defined as

$$c_v = \frac{1}{\gamma_w}\frac{k_v}{m_v} \qquad (9)$$

we obtain

$$c_v \frac{\partial^2 u'}{\partial z^2} = \frac{\partial u'}{\partial t} \qquad (10)$$

The dependent variable *u'* is a function of the independent variables *z* and *t*. In the partial differential Eq. 10, *u'* is differentiated twice with respect to *z* and once with respect to *t*. Consequently, the solution of Eq. 10 requires two boundary conditions in terms of *z* and an initial condition in terms of *t*.

The differential Eq. 10 can be solved subject to any set of initial and boundary conditions to obtain an expression for the excess pore-water pressure. A solution using the Fourier expansion method leads to

$$u'(z,t) = \Delta\sigma_v \sum_{m=0} \frac{2}{M}\sin\left(M\frac{z}{H}\right)\exp(-M^2 T_v) \qquad (11)$$

where $M=\pi(2m+1)/2$

$$T_v = \frac{c_v t}{H^2} \qquad (12)$$

is a pure number called the *time factor*, and *H* is the maximum drainage distance [5].

The degree of compression of a sublayer during consolidation is

$$U(z,t) = \frac{e_0 - e}{e_0 - e_p} \qquad (13)$$

where e_p is the void ratio when the excess pore-water pressure becomes zero. Because a linear time-independent relationship between void ratio and effective vertical stress is assumed in formulating the theory of consolidation represented by Eq. 10, the degree of

compression defined by Eq. 13 is identical with the degree of effective vertical stress increase. This in turn is equal to the degree of excess pore-water pressure dissipation

$$U(z,t) = \frac{u_i' - u'}{u_i'} \qquad (14)$$

The degree of consolidation of the layer of thickness H is

$$U = \frac{s}{s_p} \qquad (15)$$

where s_p is the settlement of the layer when the excess pore-water pressure becomes zero throughout the thickness H. The expression for U as a function of the time factor T_v, is obtained by integrating with respect to z the degree of excess pore-water pressure dissipation of the sublayers. For example, from Eq. 11 we obtain

$$U = 1 - \sum_{m=0} \frac{2}{M^2} \exp(-M^2 T_v) \qquad (16)$$

Several $U - T_v$ curves are shown in Fig. 1. For an open layer (thickness $2H$) the relationship between U and T_v, is determined by Eq. 16 and the curve C_1 for all cases in which the initial excess pore-water pressure varies linearly with z.
If the consolidation pressure increment for a half-closed layer decreases from some value $\Delta\sigma_{vt}$ at the top to zero at the bottom, the relation between U and T_v is given by the curve C_2. If it increases from zero at the top to $\Delta\sigma_{vb}$ at the bottom. Figure 1.b shows the curves C_1, to C_3 plotted to a semilogarithmic scale from which small values of U can be obtained more accurately. In the arithmetic plot, Fig. 1.a, the initial part of the curve C_1 has a parabolic shape. In fact, up to a degree of consolidation of 60% the relation between U and T_v, is accurately defined by $U = 2\sqrt{T_v / \pi}$.

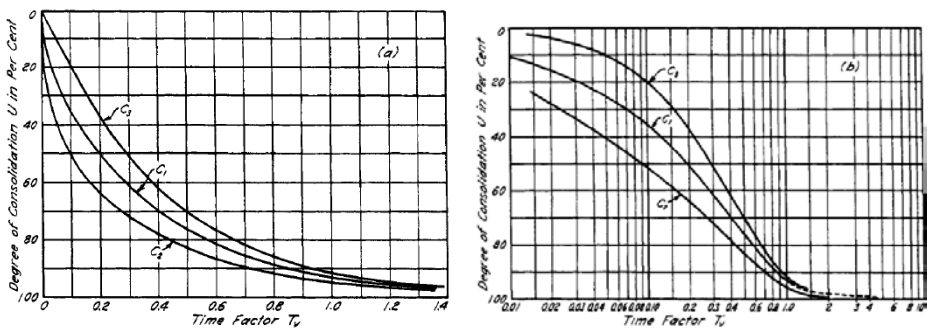

Figure 1. Relation between degree of consolidation and time factor. In (a) the time factor is plotted to an arithmetic and in (b) to a logarithmic scale [2]

3. VERTICAL DRAINS

In theory the final magnitude of consolidation settlement is the same, only the rate of settlement being affected [3,4].

In the case of an embankment constructed over a highly compressible clay layer, Fig. 2, vertical drains installed in the clay would enable the embankment to be brought into service much sooner and there would be a quicker increase in the shear strength of the clay. A degree of consolidation of the order of 80% would be desirable at the end of construction. Any advantages, of course, must be set against the additional cost of the installation.

The traditional method of installing vertical drains is by driving boreholes through the clay layer and backfilling with a suitably graded sand. Typical diameters are 200–400mm and drains have been installed to depths of over 30 m. The sand must be capable of allowing the efficient flow of water while preventing fine soil particles from being washed in. Careful backfilling is essential to avoid discontinuities which could give rise to 'necking' and render a drain ineffective. Necking could also be caused by lateral soil displacement during consolidation.

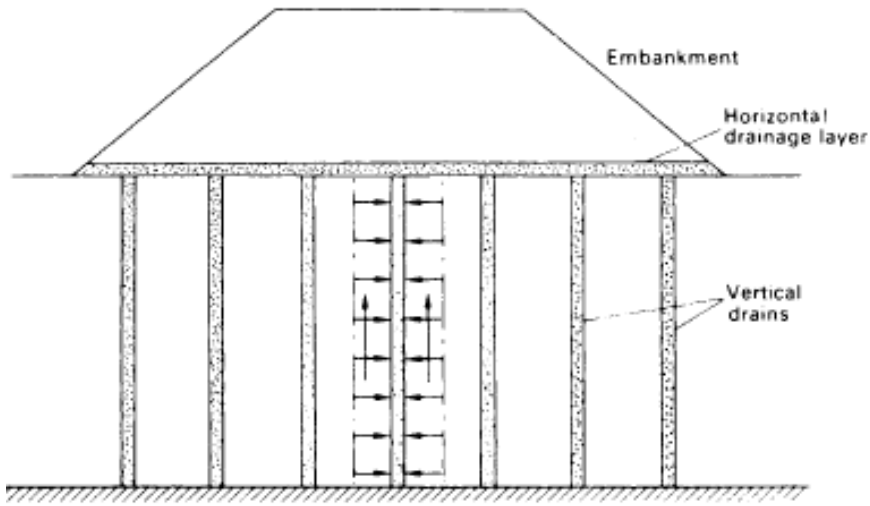

Figure 2. Vertical drain [3]

Vertical drains may not be effective in overconsolidated clays if the vertical stress after consolidation remains less than the preconsolidation pressure. Indeed, disturbance of overconsolidated clay during drain installation might even result in increased final consolidation settlement. It should be realized that the rate of secondary compression cannot be controlled by vertical drains.

In polar coordinates the three-dimensional form of the consolidation equation, with different soil properties in the horizontal and vertical directions, is

$$\frac{\partial u_c}{\partial t} = c_h\left(\frac{\partial^2 u_c}{\partial r^2} + \frac{1}{r}\frac{\partial u_c}{\partial r}\right) + c_v\frac{\partial^2 u_c}{\partial z^2} \qquad (17)$$

The vertical prismatic blocks of soil surrounding the drains are replaced by cylindrical blocks, of radius R, having the same cross-sectional area (Figure 3).

The solution to Equation 17 can be written in two parts: $U_v = f(T_v)$ and $U_r = f(T_r)$ where U_v = average degree of consolidation due to vertical drainage only; U_r = average degree of consolidation due to horizontal (radial) drainage only.

Time factor for consolidation due to radial drainage only defined Equation 12.

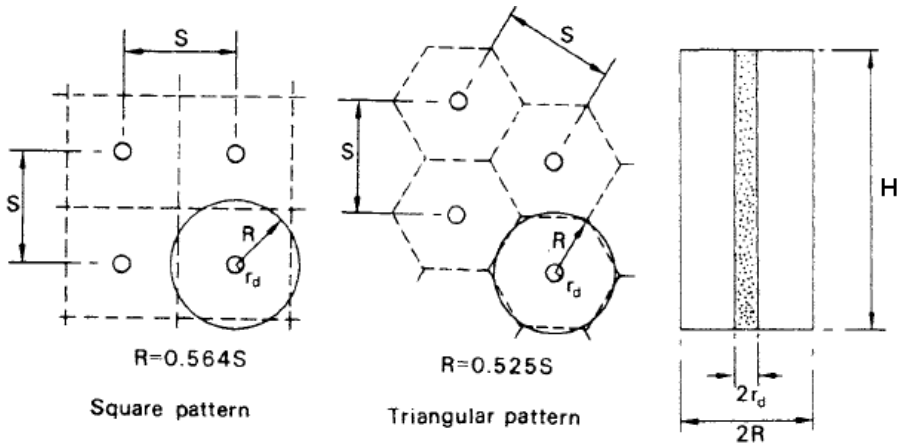

Figure 3. Cylindrical blocks [3]

The expression for T_r confirms the fact that the closer the spacing of the drains, the quicker the consolidation process due to radial drainage proceeds. The solution for radial drainage, due to Barron, is given in Figure 4, the U_r / T_r relationship depending on the ratio $n = R/r_d$, where R is the radius of the equivalent cylindrical block and r_d the radius of the drain. It can also be shown that

$$(1-U) = (1-U_v)(1-U_r) \qquad (18)$$

where U is the average degree of consolidation under combined vertical and radial drainage.

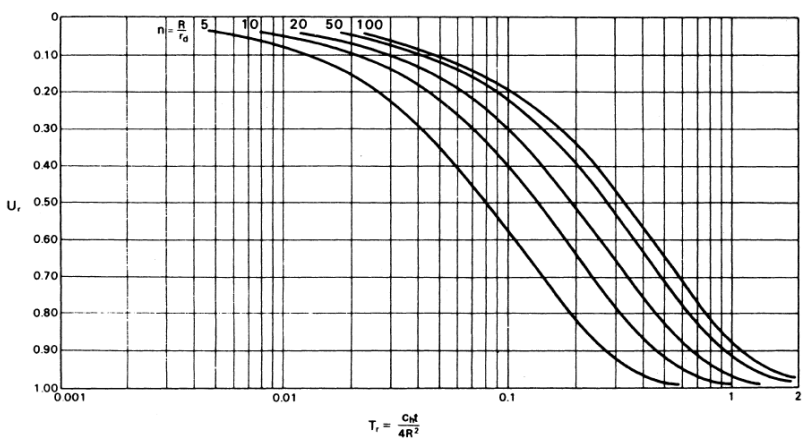

Figure 4.

Solution for radial consolidation [3]

In large-scale soil, consolidation shuffling is rapidly performed, immediately after loading, because resistance to water withdrawal from the breach is very small. In fine-grained soils, consolidation depends to a large extent on the speed of water evacuation from the pores. When the layer of clay or soil is low in high-water impermeability, the acceleration of consolidation by pre-loading alone will not be effective, as a large period of time is required to achieve significant shuffling. In this case, vertical drains are installed, which reduce the drainage path, and therefore the time of consolidation. Vertical drains have a direct impact on the acceleration of primary consolidation, but have no direct impact on secondary consolidation. The earlier completion of the primary consolidation results in the earlier beginning of the secondary consolidation. This is also the greatest importance of the drains. It should also be emphasized that the acceleration of consolidation would be successful, it would be necessary to allow the pressurized layer to extrude water from the layer.

4. NUMERICAL EXAMPLE

For the purposes of the construction of the plateau, geotechnical tests were carried out on the basis of which the budget was prepared, as stated in this paper. Numerical example is the real.

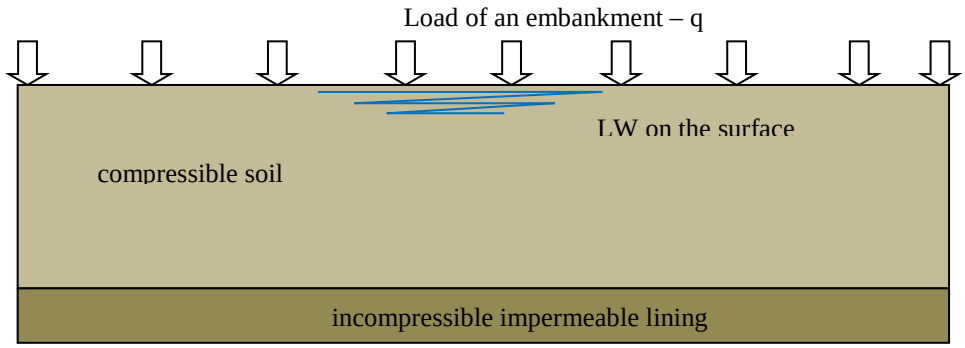

Figure 5. Cross-section of the terrain below the embankment

Characteristic compressible layer

- layer thickness H = 5.40 m
- saturated volume weight γ_z = 18.50 kN/m^3
- submerged volume weight γ' = 18.50-9.81 = 8.69 kN/m^3
- coefficient of vertical consolidation $c_v = 2.00*10^{-3}$cm^2/sec = $2.315*10^{-2}$ m^2/dan
- coefficient of horizontal consolidation $c_h = 3*c_v = 6.945*10^{-2}$ m^2/dan
- compressibility module M_v= 3000 kN/m^2

Load of an embankment – q

The average height of the embankment H_n = 4.00 m

q_n = 20.00 kN/m^3*4.00 m = 80.00 kN/m^2

Consolidation settlement

Budget through compression modulus

$S_c = H*q/M_v^{100-200}$= 540*80.00/3000 = 14.40 cm

70 cm above the middle of the placenta

Calculation of the consolidation time for vertical drainage in the natural state
Consolidation Time:
$t = (T_v*H^2)/c_v = (T_v*4.00^2)/ 2.315*10^{-2} = 690*T_v$
Diagram Figure 1a [2] - Characteristic curve for unilateral drainage - C1

Table 1.Calculation primary consolidation

U%	10	20	30	40	50	60	70	80	90
T_v	0.008	0.031	0.071	0.126	0.197	0.289	0.403	0.567	0.846
t(дани)	6	21	49	87	136	199	278	391	584

Time required for primary consolidation = 584 days = 19.50 months = 1.6 years.
Additional measures to accelerate consolidation - installation of wick drains.

Calculation of consolidation time for radial drainage with vertical drains (wick drains)
Characteristics of wick drains

- width lines b = 100 mm
- thickness lines d = 3 mm
- equivalent drain diameter $d_w = 2*(b+d)/pi= 2*(100+3)/3.14 = 65.6$ mm
- diameter of the disturbed zone $d_s = 4*d_w = 4*65.6 = 262.4$ mm => s = 4
- the drains are installed in a triangular raster with a distance of 1.00 m
- an equivalent diameter of action $D_e = 1.05*1.00$ m = 1050 mm
- n = 1050/65.6 = 16
- consolidation coefficient horizontal $c_h = 6.945*10^{-2}$ m^2/dan

Consolidation Time:
$t = T_r*D_e^2/c_h = 1.05^2*T_r / 6.945*10^{-2} = 15.9\ T_r$

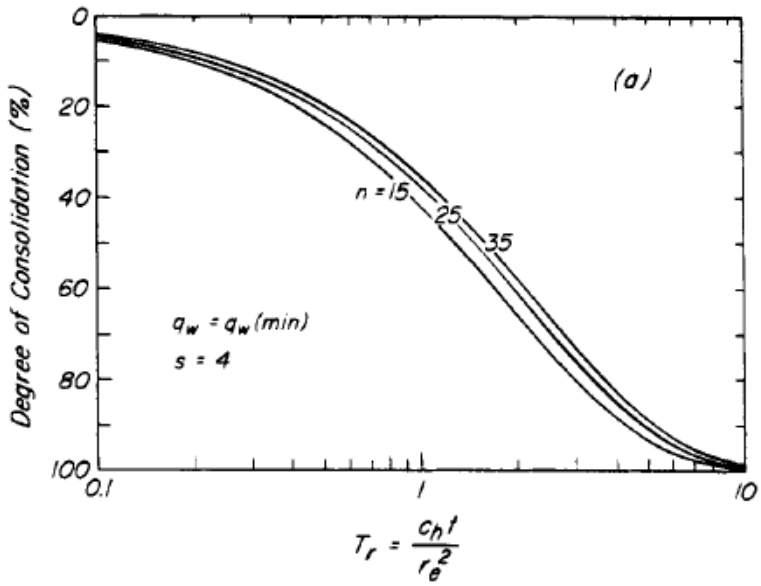

Figure 5. Diagram time- degree of consolidation [2]

Table 2. Calculation primary consolidation – wick drains

U_r%	10	20	30	40	50	60	70	80	90
T_r	0.205	0.428	0.664	0.955	1.282	1.702	2.242	3.005	4.306
t(дани)	3	7	11	15	20	27	37	48	69

The time required for primary consolidation t = 69 days is shorter than the estimated time of embankment construction. In the construction of plateau is significantly shortened the time of consolidation.

5. CONCLUSIONS

Modern design and construction of roads implies an ever-wider application of geotechnical measures in the construction of embankments. Investors, especially roads, require construction works to be carried out as soon as possible. The construction of embankments, especially from local materials, is in collision with this requirement. Therefore, the issue of acceleration of consolidation is getting more and more important. This condition makes geotechnical research as detailed as possible, and in mind also methods of accelerating consolidation, among other things, vertical drains.

The paper is presenting theoretical considerations of consolidation and one of the methods of accelerating consolidation, using vertical drains, is shown.

Acknowledgement: The paper is result of the investigation in the projects OI 174027 and TP 36043 financed by the Ministry of Science and Technological Research of Republic of Serbia

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47| Претходно саопштење
Preliminary report
doi 10.7251/STP1813642Z ISSN 2566-4484

VODOPROPUSNOST STIJENSKE MASE

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Sažetak:

Prisustvo vode u stijenskoj masi odosno procjeđivanje ima važnu ulogu pri izgradnji inženjerskih objekata (brane, tuneli, ...), kao i oblikovanju stijenskih kosina, uslovljenih realizacijom različitih projekata. Stijenska masa kakvu nalazimo u prirodi (in-situ) je heterogena, anizotropna, raspucala i nalazi se u prirodnom stanju naprezanja.U numeričkom modeliranju za potrebe planiranog geotehničkog projekta, pored ostalih ulaznih parametara, neophodno je, što tačnije, definisati i vodopropusnost stijenske mase. U radu se opisuju mehanizmi tečenja vode kroz stijenski masiv i metodologija definisanja parametra vodopropusnosti za takvu geološku sredinu.

Ključne riječi: Stijenska masa, vodopropusnost.

WATER PERMEABILITY OF ROCK MASS

Abstract:

The presence of water in the rock masses, or water filtering, has an important role in the construction of engineering facilities (dams, tunnels, ...), as well as in formation of rock slopes, caused by the implementation of various projects. The rock mass, that we find in nature (in-situ), is heterogeneous, anisotropic, jointed and is in the natural state of stress. On numerical modeling of planned geotechnical project, in addition to other input parameters, it is necessary, as more precisely, to define the water permeability of the rock mass. The paper describes the mechanisms of water flow through the rock mass and the methodology for defining the waterpermeability parameter of such a geological environment.

Keywords: rock mass, water permeability.

1. INTRODUCTION

Water in the rock mass appears in the voids (pores) of intact rock and in the discontinuities. Such as porosity of the intact of the rock is small, we can say that water flow in the rock mass to a large extant unfolds through discontinuities. Because of that we can say that caracteristic for the rock mass is crack porosity. Presence of water in the rock mass has important role in the construction of the engineering fascilities as well as design the rock slops, conditioned by realization different projects. Big challenge for the engineers (hydraulics and hydrogeologists) is to describe flow in the rock mass jointed porosity in solving engineering tasks.

An important factor in the construction of the tunnel is seepage flow wich has important role on the stability of the temporary face of the excavation. Hydrostatic and hydrodynamic pressure of the water in the rock mass results in difficulty such as sliding and dropping of rock wedges. At dam construction leakage around the sides of the dam and below the foundations has important role on the stability of the dam, and for this reason it is necessary to know very well the rock mass (permeability and capacity) in order to carry out appropriate analyzes and brought a quality solution of problems of leakage.

On the slopes in the rock mass the size of the seepage forces has significant impact on stability. The assumption is that through the jointed rock mass leaking takes place only through discontinuities. Water flow through the rock mass is therefore in the function of discontinuited, their connection and the size of the aperture of discontinuity. Classical hypothesis of groundwater flow in the analyzes rock mass includes two assumptions:

- The flow takes place only through discontinuities (the permeability of the intact rock is negligible)
- The flow is laminar.

2. THE IMPACT OF WATER ON THE PROPERTIES OF THE ROCK MASS

The presence of water in the rock mass it aggravates the conditions of stability, just by creating hydrostatic pressure and affects mechanical behavior rock mass, it reduces its strength. The most important water effects are the following:

- Pore pressure decreases the strength of the intact rock
- Filling discontinuities reduces the solidity of the total rock mass
- Causes physical and chemical changes and as a result of the weakening of the intact rock and the rock mass (process of weathering)
- Acts as an erosive medium (in clay and soft materials) by washing out fine particles
- Causes chemical reactions that change the composition of the rock
- In soft (clayey and clayey-sandy) rocks the pores of the pores of water work on reducing the strength parameters (cohesion and friction angle).

2.1. POROSITY OF INTACT ROCK

As we know each intact rock contains a part of the voids, in order to allow for a seepage flow, at least part of these voids must be interconnected to form passages through which water can permeate. Total porosity is defined as:

$$n = \frac{V_P}{V_P + V_S} = \frac{V_P}{V} \tag{1}$$

where:

V_P is pore volume,

V_S is volume of solids,

V is reference volume.

In the description of flow through the porous intact rock, the seepage velocity of v_s defined as a quotient water quantities in the unit of time Q, and is referred to is "discharge" or "flow-rate" through the total cross-sectional area A, normal in relation to the flow direction (Fig.1).

$$v_s = \frac{Q}{A} \tag{2}$$

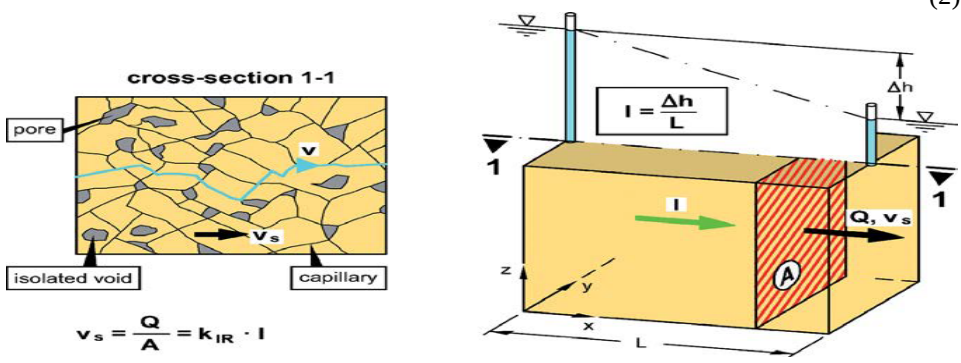


Figure 1. Seepage flow of intact rock- Darcy's Law [15]

It was found that the seepage velocity is proportional to the hydraulic gradient I (Darcy 1856). In the example of one-dimensional flow represented in Fig.1 this relationship, known as “Darcy’s law”, takes the following form:

$$v_s = k_{IR} \cdot I = -k_{IR} \cdot \frac{\partial h}{\partial x} = k_{IR} \cdot \frac{\Delta h}{L} \tag{3}$$

where:

k_{IR} is coefficient hydraulic permeability (intact rock),

I is hydraulic gradient.

Equation can be generalized to the three-dimensional case at:

$$\{v_S\} = k_{IR} \cdot \{I\} \tag{4}$$

where:

$\{v_S\}$ and $\{I\}$ are vectors of seepage velocity and hydraulic gradient.

$$\{v_S\} = (v_{SX}, v_{SY}, v_{SZ})^T \tag{5}$$

$$\{I\} = \left(I_{x,} I_y, I_z\right)^T = -\left(\frac{\partial_h}{\partial_X}, \frac{\partial_h}{\partial_Y}, \frac{\partial_h}{\partial_Z}\right)^T = -\{\nabla\} h \tag{6}$$

Equation is valid if the intact rock permeability is isotropic.

2.2. FLOW TROUGH DISCONTINUITIES

Due to the low water particle velocity, in most cases the flow of water in discontinuities can be considered laminar. As is already known from Darcy's law that the velocity of the proportional hydraulic gradient, the velocity of flow in discontinuity is counted as:

$$v_s = k_d \cdot I \tag{7}$$

$$k_d = \frac{g \cdot (2a_i)^2}{12\nu} \tag{8}$$

and is called "coefficient permeability" of the discontinuity,

$(2a_i)$ is aperture discontinuity,

ν is kinematic viscosity of water and it is usually $1.3 \cdot 10^{-6}\, m^2/s$ at water temperature of $10^0 C$.

Discontinuities encountered in nature usually are not smooth as it has been assumed so far. According to Lomize (1951) [5], the streamlines in laminar flow of water between two parallel glass plates remain parallel if $\frac{k}{D_h} \leq 0.032$. Such flow is referred to as “irrotational”. This implies that flow remains practically uninfluenced by the discontinuity walls if $\frac{k}{D_h} \leq 0.032.$. Such a discontinuity wall is denoted as “hydraulically smooth”.

If $\frac{k}{D_h}$ > 0,032 the streamlines diverge and sometimes whirl due to local rotation of water particles. Lomize (1951) [5] found the following relationship between flow rate per unit width (specific flow) Q_S and mean aperture $2\bar{a}_i$ of rough fissures:

$$Q_S = \bar{v} \cdot 2\bar{a}_i = k_d \cdot I \cdot 2\bar{a}_i = \frac{g \cdot (2\bar{a}_i)^3}{12\nu \cdot f} \cdot I \tag{9}$$

where:

k is maximum amplitude of the roughness wall discontinuity

D_h is hydraulic diameter

$2\bar{a}_i$ is averaged aperture of the discontinuity over the entire surface

f is friction factor.

$$k/D_h = k/2 \cdot 2\bar{a}_i \tag{10}$$

On the basis of flow experiments conducted by Louis (1967) [6], for laminar flow the following relationship has been found for k_d as a function of the relative roughness of the discontinuities' walls:

$$k_d = \frac{g \cdot \left(2\bar{a}_i\right)^2}{12\nu} \quad \text{if it's } k/D_h \leq 0.032 \tag{11}$$

$$k_d = \frac{g \cdot \left(2\bar{a}_i\right)^2}{12\nu \cdot \left[1 + 8.8 \cdot \left(k/D_h\right)^{1.5}\right]} \quad \text{if it's } k/D_h > 0.32 \tag{12}$$

$$f = 1 \quad \text{if it's } k/D_h \leq 0.032 \tag{13}$$

$$f = 1 + 8.8 \cdot \left(k/D_h\right)^{1.5} \quad \text{if it's } k/D_h > 0.32 \tag{14}$$

Thus, k_d can be expressed as:

$$k_d = \frac{g \cdot \left(2\bar{a}_i\right)^2}{12\nu \cdot f^{\frac{2}{3}}} = \frac{g \cdot \left(2\bar{a}_i\right)_h^2}{12\nu}, \quad \left(2\bar{a}_i\right)_h = \frac{2\bar{a}_i}{f^{\frac{1}{3}}}. \tag{15}$$

2.3. HOMOGENEOUS MODEL

The permeability of jointed rock can be described by means of a homogeneous model. For this purpose, a representative elementary volume (REV) must be defined in which the rock mass can be considered as statistically homogeneous in the sense that an increase of this volume does not change the mean permeability of the rock mass which is referred to as "equivalent permeability" (Baghbanan & Jing 2007) [1].

To evaluate the dimension of the REV discrete models can be helpful. For this purpose, seepage flow through networks of discontinuities so-called "discrete fracture networks" (DFN) has been simulated (Baghbanan & Jing 2007) [1].

In Baghbanan & Jing (2007) a crystalline rock in the Sellafield area (England) with four discontinuity sets was examined by simulating flow through a large number of two-dimensional DFNs using the distinct element model (DEM). In this study DFNs with constant and statistically distributed apertures and trace lengths of discontinuities were investigated. Accordingly, the size of the REV was found to be dependent not only on the mean values of apertures and trace lengths but also on their statistical distribution and degree of correlation. It was shown that homogeneous models are applicable if the statistical distributions of the discontinuity properties exhibit sufficiently low standard deviations. This requirement is normally fulfilled in regularly jointed rock.

3. PERMEABILITY

To describe the permeability of jointed rock with the aid of a homogeneous model we assume impermeable intact rock and laminar flow in the discontinuities. In the same way as for porous rocks, is introduced seepage flow v_S defined as the quotient of the discharge Q and the cross-sectional area A perpendicular to the direction of flow (Fig.2). The cross-sectional area A incorporates the cross-section of both the discontinuities and the intact rock. Fig.2 illustrates Darcy's law for a rock mass containing one discontinuity set D with persistent, open joints, which are assumed to be oriented parallel to the hydraulic gradient I. The aperture $2a_i$ and the spacing s of the discontinuities are assumed to be constant. According to Wittke (1990) [13], in this case seepage flow is:

$$v_s = \frac{Q}{A} = k_D \cdot I, \;\; k_D = k_d \cdot \frac{2a_i}{s} = \frac{g \cdot (2a_i)^3}{12\nu \cdot s} \tag{16}$$

k_D is the coefficient permeability of the discontinuities, which can also be described by means of a cubic law with regard to the aperture of the discontinuities.

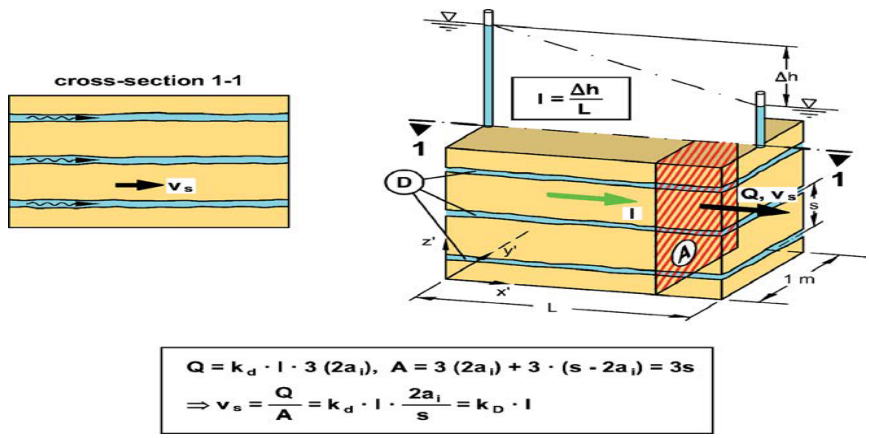


Figure 2. Darcy's law for a rock mass with one set of persistent, open discontinuities

If the aperture and spacing of the discontinuities are not constant, the corresponding values in the previous equation must be replaced by the hydraulic aperture ($2a_i$)^h and the mean spacing $\bar{s}$.

$$k_D = k_d \cdot \frac{(2a_i)_h}{\bar{s}} = \frac{g \cdot (2a_i)_h^{\,2}}{12\nu} \cdot \frac{(2a_i)_h}{\bar{s}} = \frac{g \cdot (2a_i)_h^{\,3}}{12\nu \cdot \bar{s}} \tag{17}$$

To obtain the hydraulic aperture, the mean apertures and friction factors of all discontinuities must be subjected to an averaging procedure. To illustrate the huge influence of aperture on the magnitude of the permeability of jointed rock, in Fig. 3 the

permeability coefficients k_D parallel to a discontinuity set with constant spacing of $s = 1m$ and with differing mean apertures $2a_i$ and relative roughnesses k/D_h are compared with the permeability coefficients of soil (Wittke 1990) [13].

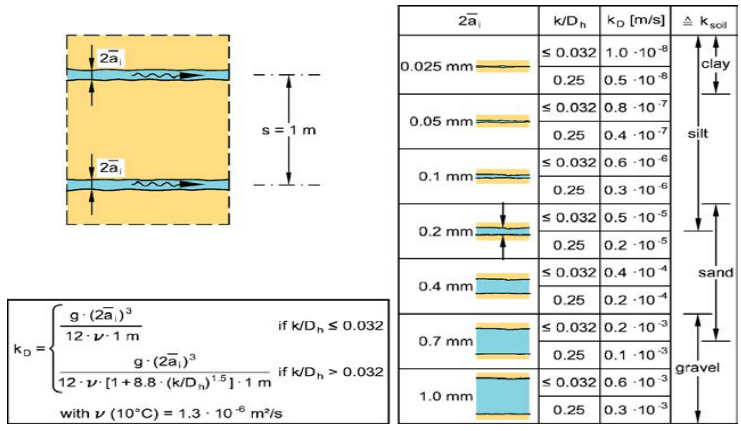


Figure 3. Comparison of coeffi cients of permeability of a rock mass containing one set of persistent, open discontinuities with those of a soil [15]

A typical example is a rock mass wich we encounter in nature is that we have set of bedding-parallel discontinuities related with a jointed set oriented perpendicular on them. If the traces of the bedding-parallel discontinuities and the joints are oriented parallel to the x axis and y axis, respectively, as illustrated in Fig. 4, the permeability of such a rock mass can be expressed by the following equivalent permeability tensor:

$$[K] = [K_B] + [K_j] = \begin{bmatrix} k_{Bxx} & 0 \\ 0 & 0 \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & k_{Jyy} \end{bmatrix} = \begin{bmatrix} k_{Bxx} & 0 \\ 0 & k_{Jyy} \end{bmatrix} = \begin{bmatrix} k_{xx} & 0 \\ 0 & k_{yy} \end{bmatrix} \quad (18)$$

where:

k_{xx} and k_{yy} are the permeability of the rock mass parallel and normal to the bedding.

Assuming steady-state, laminar flow through the discontinuities, Doolin & Mauldon (2001) [2] derived an approximation for the permeability coefficient k_{yy} normal to the bedding.

Accordingly, this is dependent on both aperture $(2a_i)_{hBj}$ and spacing s_{Bj}, of the bedding-parallel discontinuities as well as aperture and spacing of the joints $(2a_i)_{hJij}$ and s_{Jij} (Fig. 4).

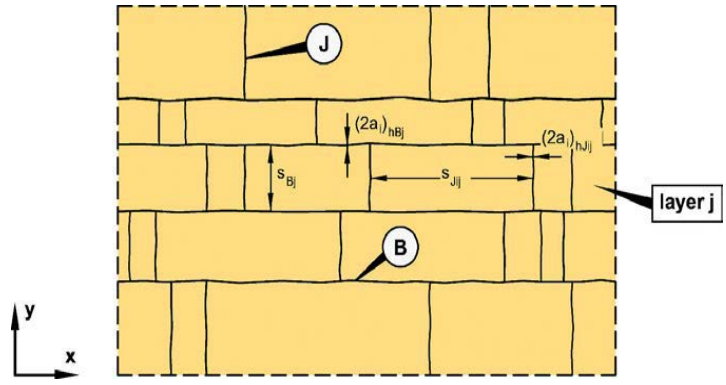


Figure 4. Rock mass with persistent horizontal bedding-parallel discontinuities and vertical jointsof negative exponential spacing ending at the bedding [2]

When the individual values of these quantities are replaced by the mean values, $\left(2\overline{a}_i\right)_{hJ}$ $\left(2\overline{a}_i\right)_{hJ}$, $\overline{s}_B$ i $\overline{s}_J$, k_{yy} can be calculated as:

$$k_{yy} = \frac{g \cdot c \cdot \overline{s}_B \cdot \left(2\overline{a}_i\right)_{hB} \cdot \left(2\overline{a}_i\right)_{hJ}^{3}}{12\nu \cdot \left[\ c \cdot \overline{s}_B \cdot \overline{s}_J \cdot \left(2\overline{a}_i\right)_{hB} + \overline{s}_J^{\,2} \cdot \left(2\overline{a}_i\right)_{hJ}\ \right]} \tag{19}$$

The permeability parallel to the bedding can be expressed by

$$k_{xx} = k_B = \frac{g \cdot \left(2\overline{a}_i\right)_{hB}^{3}}{12\nu \cdot \overline{s}_B} \tag{20}$$

Equations reflects connectivity of joints and bedding-parallel discontinuities. c - is a factor depending on the distribution of the joints' spacing (Doolin & Mauldon 2001) [2]. If the spacing constant then c = 2 is valid. If the spacing of the joints follows a negative exponential distribution which has been validated in a large number of discontinuity measurements in the field then is c = 4 (Priest & Hudson 1976, Beacher et al., 1977, Hudson & Priest 1979, Priest & Hudson 1981, Wittke 1990) [12] [13].

If $\left(2\overline{a}_i\right)_{hB} \gg \left(2\overline{a}_i\right)_{hJ}$ the permeability k_{yy} normal to the bedding is dominated by the permeability k_j of the joints and can be approximated by (Doolin & Mauldon 2001) [2].

$$k_{yy} = k_j = \frac{g}{12\nu} \cdot \frac{\left(2\overline{a}_i\right)_{hj}^{3}}{\overline{s}_j} \tag{21}$$

In this case the connectivity of joints and bedding-parallel discontinuities can be neglected.

If $\left(2\bar{a}_i\right)_{hB} \langle\langle \left(2\bar{a}_i\right)_{hJ}$, k_{yy} is controlled by the permeability k_B of the bedding-parallel discontinuities. k_{yy} can be approximated (Doolin & Mauldon 2001) [2].

$$k_{yy} = c \cdot \left(\frac{\bar{s}_B}{\bar{s}_J}\right)^2 \cdot k_B = c \cdot \left(\frac{\bar{s}_B}{\bar{s}_J}\right)^2 \cdot \frac{g}{12\nu} \cdot \frac{\left(2\bar{a}_i\right)_{hB}^3}{\bar{s}_B} \tag{22}$$

4. DETERMINATION OF WATER - PERMEABILITY IN ROCK MASS

Two methods for determining the water-permeability of the rock mass are described below:

- Lugeon test
- Tracer test.

4.1. LUGEON TEST

Lugeon test, sometimes referred to as the Packer test, is a on-site test method for estimating the average hydraulic conductivity of the rock mass. The test is named after Maurice Lugeon (1933), a Swiss geologist who first formulated the test. Lugeon test is performed in an isolated borehole. The results provide information on the hydraulic conductivity of rock mass including intact rock and discontinuity.

4.1.1. Description and procedure

The Lugeon test can be carried out in boreholes with arbitrary orientation. The borehole diameter should be at least 46 mm. The test section may be located below or above the groundwater table. The test is carried out in the borehole section which is isolated by pneumatic packer. The water is injected in isolated part of borehole. The packers can be inflated using a gas compressor on the surface, and so they can isolate and seal that portion of the borehole. A pressure transducer is also located in that portion to measure the pressure with a help of reading station on the surface. The sealing length should not fall below 0.5 m, usually of length from 1 m to 5 m. The testing device consists of a water supply system comprising a water reservoir, a pump, a flow meter, a regulating valve and a delivery line to carry water from the pump down to the borehole and into the test section (Fig.5). Prior to the beginning of the test a maximum test pressure (Pmax). Pmax is chosen such that it does not exceed the confinement stress (σ_3) expected at the depth (D) where the test is being conducted, thus avoiding the development of hydraulic fracturing or hydraulic jacking:

$$P\max = D \cdot 0.226 \, {}^{bar}\!/_{m} \tag{23}$$

The test is conducted in five stages, with a particular water pressure magnitude associated with each stage. A single stage consists of keeping a constant water pressure at the test interval for 10 minutes by pumping as much water as required. The first stage is held at a low water pressure, increasing the pressure in each subsequent stage until reaching Pmax. Once Pmax is reached, pressures are decreased following the same pressure stages used on the way up, thus describing a “pressure loop”. Table 1 shows the pressure magnitudes customarily used during the five test stages.

Table 1. The magnitude of pressure typically used for Lugeon test

Test stage	Pressure
1st	0.5 Pmax
2nd	0.75 Pmax
3rd	Pmax
4th	0.75 Pmax
5th	Pmax

During the execution of each stage, both water pressure (P) and flow rate (Q) values are recorded every minute. Subsequently, average values for P and Q are then used to compute the hydraulic conductivity for each stage. The hydraulic conductivity is expressed in terms of the Lugeon value, which is empirically defined as the hydraulic conductivity required to achieve a flow rate of 1 liter/minute per meter of test interval under a reference water pressure equal to 1 MPa (10 bar). Lugeon value is defined by next equation [6]:

$$Lugeon\ value = \left(Q/L \right) \times \left(P_0/P \right) \tag{24}$$

where:
Q is flow rate (lit/min),
L = Length of the borehole test interval,
P_0 isreference pressure of 1 MPa,
P is test pressure (MPa).
Lugeon's value is not only represeting the hydraulic conductivity of the rock mass but can also be a condition indicator on the joints of the rock, as can be seen in Table 2.

Table 2. Condition of rock mass discontinuities associated with different Lugeon values

Lugeon range	Classification permeability	Hydraulic conductivity range (cm/sec)	Condition of rock mass discontinuities
< 1	Very low	$<1\times10^{-5}$	Very tight
1-5	Low	$1\times10^{-5}-6\times10^{-5}$	Tight
5-15	Moderate	$6\times10^{-5}-2\times10^{-4}$	Few partly open
15-50	Medium	$2\times10^{-4}-6\times10^{-4}$	Some open
50-100	Higth	$6\times10^{-4}-1\times10^{-3}$	Many open
>100	Very hight	$>1\times10^{-3}$	Open closely spaced or voids

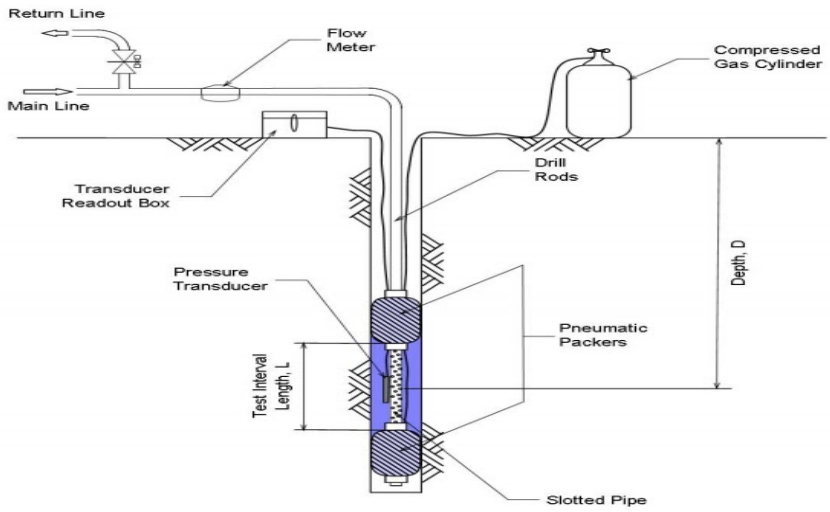
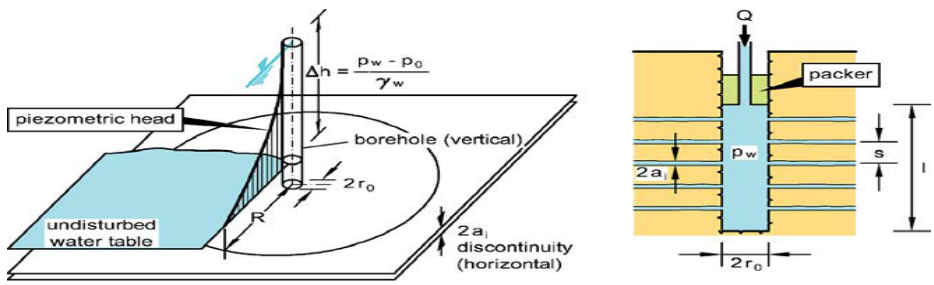


Figure 5. Lugeon test configuration

With Lugeon tests, as mentioned above, only the equivalent rock mass permeability in the direction normal to the borehole can be measured, so tests in boreholes of different orientation may provide an indication of rock mass anisotropy. In many cases and with the aid of additional information obtained from the evaluation of core drillings and the observation of borehole walls with respect to discontinuity data, it may be possible to measure the permeability of a discontinuity set. For this purpose, Lugeon tests are carried out in a borehole oriented perpendicular to the set. Figure 6 shows the determination of the local permeability of a horizontal discontinuity set D by means of a Lugeon test carried out in a vertical borehole assuming laminar and radial flow (Wittke 1990)[13]. The permeability coefficient k_D can be calculated according to replacing k_{RM} by k_D (Fig. 6, DGEG 1984c, Wittke 1990)[13].



$$k_D = \frac{Q \cdot \gamma_w}{2\pi \cdot l \cdot \Delta h} \cdot \ln\left(\frac{R}{r_0}\right) = \frac{g \cdot (2a_i)^3}{12\nu \cdot s}$$

Figure 6. Lugeon test, determination of the permeability of a horizontal discontinuity set in a vertical test hole [13]

4.2. TRACER TEST

Testing with tracer consists from that you insert tracer into borehole or well. Like tracer usually is using uses fluorescent dyes. Dilution rate of the tracer like the time appearing of the tracer in control well, can be used to calculate the permeability as it has been described (Lewis, 1966) [4] and (Maini, 1971) [8]. Monitoring or precision measurement of the concentration can be performed manually (by probing sampling) or by probes.

The test traser is based on the assumption that we have a steady-state seepage flow of ground water intersection through the vertical well, the tracer moves under the influence of the hydraulic gradient and the flow is conducted according to Darcy's law:

$$v = k \cdot I \tag{25}$$

where:

I is hydraulic gradient which can be determined by observing the water level in wells (injected and controlled) and the distance between the wells (borehole).

The flow velocity is obtained from the equation:

$$v = \frac{l}{t} \tag{26}$$

where:

l is distance between boreholes,

t is tracer travel between boreholes.

In analyzing a tracer dilution test, the flow velocity is related to the rate at which the tracer concentration diminishes within the test section of the injection well. For an assumed homogeneous isotropic porous medium (Lewis, 1966) [4] gives the following equation of velocity:

$$v = \frac{\pi \cdot w_d}{8 \cdot t_d} \cdot \ln\left(C_r\right) \tag{27}$$

where:

w_d is well diameter,

C_r is ratio of the final to the initial tracer concentration,

t_d is dilution time period.

(Maini, 1971) [8] was in analysis of tracer dilution test in a fissure system which he applied same criterion like analysis of flow between parallel plate. It is assumed that a set of equally spaced horizontal fissures, each with the same equivalent parallel plate aperture e, intersect the test section of the injection well. The flow velocity through the fissures is given by

$$v = \frac{\pi \cdot w_d \cdot \ell}{8 \cdot n \cdot e \cdot t_d} \cdot \ln\left(C_r\right) \tag{28}$$

where:

n is number of fissures intersecting the test section,

ℓ is test section length.
Coefficient jointed permeability is defined equation:

$$k_j = \frac{\gamma_w \cdot e^2}{12\mu_w} \tag{29}$$

where:

γ_w is unit weight of water,

μ_w is dynamic viscosity of water.

Test of tracking the travel time from tracer includes large portion of the rock mass, reflecting high or low permeability zones in order to determine the average coefficient of permeability. Test of dilution is convenient as such tests are rapid, conducted in one hole. These methods avoid unnatural conditions which can occur at testing under the pressure of water. The main disadvantage of tracer tests is their limitation to use below the groundwater table.

5. TRANSIENT SEEPAGE FLOW

The equation describing transient seepage flow is based on the application of the equation continuity condition and Darcy's law and has a shape (Wittke, 2000b) [14]:

$$\frac{\partial}{\partial x}\left(k_{xx}\cdot\frac{\partial h}{\partial x}+k_{xy}\cdot\frac{\partial h}{\partial y}+k_{xz}\cdot\frac{\partial h}{\partial z}\right)+\frac{\partial}{\partial y}\left(k_{yx}\cdot\frac{\partial h}{\partial x}+k_{yy}\cdot\frac{\partial h}{\partial y}+k_{yz}\cdot\frac{\partial h}{\partial z}\right)+\frac{\partial}{\partial z}\left(k_{zx}\cdot\frac{\partial h}{\partial x}+k_{zy}\cdot\frac{\partial h}{\partial y}+k_{zz}\cdot\frac{\partial h}{\partial z}\right)=S_0\cdot\frac{\partial h}{\partial t} \tag{30}$$

where:

S_0 is specific coefficient storage defined as:

$$S_0 = \frac{\partial n_{eff}}{\partial h}. \tag{31}$$

6. STEADY - STATE SEEPAGE FLOW

The equation of steady-state seepage flow in a rock mass is obtained by setting $\frac{\partial h}{\partial t} = 0$:

$$\{\nabla\}^T\left([K]\cdot\{\nabla\}h\right)=0 \tag{32}$$

The following applies if the permeability of the rock mass is homogeneous:

$$[K]\cdot\{\nabla\}^T\cdot\{\nabla\}h=0 \tag{33}$$

If the permeability of the rock mass is not only homogeneous but also isotropic, the distribution of piezometric heads is independent of permeability

$$\{\nabla\}^T\{\nabla\}h=0 \tag{34}$$

Therefore, the specific storage coefficient of homogeneous unconfined aquifers can be expressed as:

$$S_0 = \frac{n_{eff}}{H} \tag{35}$$

where:

H is thickness aquifer.

If H is the thickness of the water-bearing rock formation that is affected by seepage flow, for example, the thickness of an aquifer penetrated by a well, the effective porosity n_{eff} can be expressed as

$$n_{eff} = \int_{h=0}^{h=H} S_0 dh \tag{36}$$

The effective porosity of jointed rock corresponds to the volume of open interconnected discontinuities V_D related to the reference volume V referred to as the relative joint volume:

$$n_{eff} = n_D = \frac{V_D}{V} \tag{37}$$

For a rock mass with m - orthogonal discontinuity sets (n = 1, 2, 3) with mean aperture $2\bar{a}_i$ and mean spacing $\bar{s}$, n_D may be calculated by way of approximation as:

$$n_D \approx \frac{m \cdot \left(2\bar{a}_i\right)}{\bar{s}} \tag{38}$$

Thus, for this particular case the following relationship is obtained:

$$S_0 = \frac{\partial n_D}{\partial h} = \frac{n_D}{H} \approx \frac{m \cdot \left(2\bar{a}_i\right)}{\bar{s} \cdot H} \tag{39}$$

The specific storage coefficient of a joint aquifer is normally considerably smaller than that of a pore aquifer. As a consequence, the time required for a lowering of the water table in a joint aquifer is much smaller than that in a pore aquifer of the same permeability.

The drawdown of the water table $\Delta h(r,t)$, due to a pumping rate Q_p around a well as a function of distance r from the wells axis and time t in a homogeneous aquifer with isotropic permeability k can be calculated as follows (Theis 1935) [9]:

$$\Delta h(r,t) = \frac{Q_P}{4\pi \cdot k \cdot H} \cdot W(u) \tag{40}$$

$$W(u) = \int_u^{\infty} \frac{e^{-\nu}}{\nu} d\nu \tag{41}$$

$$u = \frac{S_0 \cdot r^2}{k \cdot 4t}$$ is the so-called well function. (42)

where:

S_0 - is the specific storage coefficient of the aquifer.

The upper equation is valid if the level of groundwater table is smaller compared to with the tickness H of the aquifer penetrated by the well. In this case, the vertical velocity component of the seepage velocity can be neglected. If u <0.01, it can be approximated as

$$\Delta h(r,t) \approx \frac{Q_P}{4\pi \cdot k \cdot H} \cdot \ln\left(\frac{2{,}25 \cdot k \cdot t}{r^2 \cdot S_0}\right). \tag{43}$$

If we take it $\Delta h(r,t) = 0$, will get $(r) = R$ radius of influence on well (borehole), in time t:

$$r(t) \approx \sqrt{\frac{2.25 \cdot k \cdot t}{S_0}} \Rightarrow t = t_0 = \frac{R^2 \cdot S_0}{2.25 \cdot k}. \tag{44}$$

To estimate the radius of influence $(r) = R$ on borehole (well) when requires drawdown Δh, using a formula for well gotten from (Dupuit,1863) [3], (Thieme, 1870.) [10], wich is valid at steady state of seepage flow

$$Q_p = \frac{\pi \cdot \left(H^2 - h_0^{\,2}\right) \cdot k}{\ln R - \ln r_0} \tag{45}$$

where is:

$$h_0 = H - \Delta h_0. \tag{46}$$

7. CONCLUSION

The presence of water in rock masses respectively permeability is a great influence on the realization of many engineering projects. In order to define the water permeability of the rock mass, it is necessary to have data on characteristics of the same, among which are the most important characteristics of discontinuity. The assumption is that through the jointed rock permeability the estimation takes place only through discontinuities. The flow of water through the rock mass is therefore a function of discontinuity, their connection and the size of discontinuity aperture. Due to the low water particle velocity, in most cases the flow of water in discontinuities can be considered laminar. What needs to be emphasized is that the discontinuities we encounter in nature are usually not as smooth as we suppose. Therefore, the conditions of turbulent flow occur only at relatively large discontinuity apertures or at high hydraulic gradients, and the assumption of laminar flow which is

reasonable for most practical problems in rock engineering. One way to establish a model of permeability and seepage flow currents in a jointed rock is to simulate any discontinuity in rock mass with aperture, roughness, filling. Permeability is then treated as a flow through a network of discontinuities. The description of the water permeability jointed rock by using a homogeneous model can be assumed to be the impermeability of the intact rock and the laminar flow through the discontinuities, respectively it was shown that homogeneous models are applicable if the statistical distributions of the discontinuity properties exhibit sufficiently low standard deviations. This requirement is normally fulfilled in regularly jointed rock.

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48| Претходно саопштење
Preliminary report
doi 10.7251/STP1813658N ISSN 2566-4484

MODELING THE RHEOLOGICAL PROPERTIES OF FRESH CONCRETE USING A 3D FINITE ELEMENT MODEL

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Abstract:

During the last thirty years, concrete has been industrially mutating from a soft granular medium to a proper non-Newtonian fluid. To benefit from the full potential of the modern fluid concretes such as Self-Compacting Concrete (SCC), prediction tools of the form filling taking into account the properties of the concrete, the shape and size of the structural element and the casting technique are needed. Development of a finite deformation elasto-plasticity model based on the multiplicative decomposition of the deformation gradient is presented. The presented model in this paper includes application of inelastic material properties are specified with the Drucker Prager hardening option.

Keywords: Fresh concrete, Flow modeling, Finite element model.

MODELOVANJE REOLOŠKIH SVOJSTVA SVEŽEG BETONA PRIMENOM 3D KONAČNIH ELEMENATA

Apstrakt:

Tokom poslednjih trideset godina, definicija betona prelazi put od mekog granularnog medija u odgovarajući ne-Njutnov fluid. Da bi korist od punog potencijala modernih betona tečne konzistencije kao što je samougrađujući beton (SCC), potrebni su alati za predviđanje oblika punjenja, uzimajući u obzir svojstva betona, oblik i veličinu konstruktivnog elementa i tehniku ugradnje ugradnje. Predstavljen je prikaz elasto-plastičnog modela konačnih deformacija zasnovanog na multiplikativnoj dekompoziciji gradijenta deformacije. Model predstavljen u ovom radu uključuje primenu nelinearnih svojstava prema Drucker-Prager-ovom kriterijumu tečenja.

Ključne reči: Svež beton, Modelovanje sleganja, Metod konačnih elemenata

1. INTRODUCTION

Fresh concrete properties, especially workability, significantly affect transporting, placing, and compacting concrete. These properties have significant effects on the quality and cost of concrete construction. They also potentially determine certain hardened concrete properties, such as uniformity, strength and durability. One particularly important fresh concrete property is workability. Workability is defined as "the property of freshly mixed concrete or mortar that determines the ease with which it can be mixed, placed, consolidated, and finished to a homogenous condition". Concrete must have proper flowability, or rheology, in order to obtain desirable workability [1].

These all depend on the rheology of the material and a list of specific factors for consideration in these processes would include flow and frictional resistance against surfaces, adhesion, resistance to segregation, resistance to settlement and the formation of bleeding water, low water content to obtain high strength and durability, resistance to sagging under self weight on a wall or inclined surface, and low pressure on the temporary formwork erected to support a wall or other component [1].

Research has shown that a suitable range of rheology is helpful to prevent segregation [2]. The rheology study can also determine the design in pumped concrete. The fluidity of the vibrated concrete, determined from the rate of efflux from the pipe, is controlled by the peak velocity of the vibration and influenced by the rheology of the unvibrated concrete [3].

The rheology of concrete can be affected by different factors: mix proportions, characteristics of the cement, aggregate properties, amount and type of admixtures, time, temperature, and mixing condition. Among all these factors, aggregate properties are the most important because the aggregate normally occupies up to 70-80 percent of the total concrete volume of concrete. The flowability of concrete can be significantly changed by using different aggregates. The aggregate directly affects the flowability of concrete through interparticle forces (such as interlocking and friction of solid particles) and the movement of solid and liquid phases inside fresh concrete mixtures.

Several factors, such as size, type, gradation and texture of aggregates, also affect the properties of fresh concrete. The study of the effect of aggregate on concrete rheology is still very limited, and no efficient concrete rheology model considering the effect of aggregate had been developed so far [3].

2. FUNDAMENTALS OF CONCRETE RHEOLOGY

Rheology is the science of the deformation and flow of matter, and the emphasis on flow means that it is concerned with the relationships between stress, strain, rate of strain, and time. Concrete in its fresh state can be considered as a fluid and therefore the basic principles of rheology can be applied to this material [4].

The simplest fluid is one that obeys Newton's law of viscous flow, which can be described as:

$$\tau = \eta \cdot \dot{\gamma} \qquad (1)$$

In this equation τ is the shear stress (Pa), η is the coefficient of viscosity (Pa·s), and $\dot{\gamma}$ is the rate of shear (shear rate) or the velocity gradient (s-1). The flow behavior of any

fluid requires the measurement of the relationship between shear stress and shear strain rate of the material, which is normally called the flow curve. As shown in Figure 1, the Newton liquid described in Equation 1 can be represented with a plot of the shear rate versus the shear stress that has a straight line passing through the origin, with a slope of η.

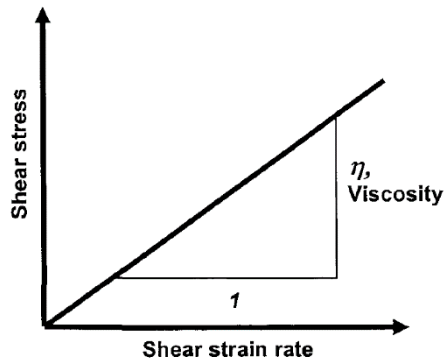

Figure 1. The Newton model

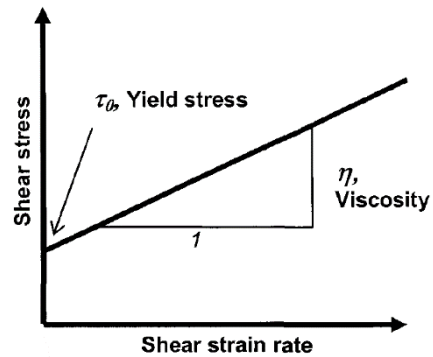

Figure 2. Bingham model

For a very diluted suspension of solids in a liquid, there is no interparticle force; and the effect of small increases in the amount of suspended solid is merely to increase the coefficient of viscosity. Nevertheless, concrete has to be considered as a very concentrated suspension, in which the volume ratio of solids-to-water would be as high as around 4.5:1.

For such concentrated materials, there are forces acting between the particles. This does not merely change the viscosity, but actually changes the type of flow. The Bingham model, as seen in Figure 2, concrete has a yield stress, which indicate the minimum stress to start a flow of a material. The material obeys Bingham model and can be written as:

$$\tau = \tau_0 + \eta \cdot \dot{\gamma} \qquad (1)$$

In this equation τ_0 is the yield stress (Pa) and η is the plastic viscosity (Pa·s).

Both parameters should be used in order to fully describe the rheology of the materials that obeys Bingham's model, because some materials may have the same viscosity but different yield stresses or the same yield stress but different viscosities.

Another important parameter of rheology is thixotrophy. A thixotropic fluid undergoes a decrease in viscosity with time, while it is subjected to constant shearing. The shear rate was first increased to a certain value, then immediately decreased to the starting point. This "hysteresis loop", the area between the up and down curves is caused by the decrease in the fluid's viscosity with increasing time of shearing resulting from the material's structural breakdown. Generally, the larger the "hysteresis loop" area, the higher degree that the material structure is broken down [1]. Some thixotropic fluids, if allowed to stand undisturbed for a while, can regain their initial viscosity, while others can not. This behavior is due to interparticle attraction and weak bonds.

Newtonian liquid has a constant viscosity. A Bingham material needs to overcome the yield stress to initial flow, and its plastic viscosity is also constant. In a shear thickening material, viscosity increases continuously with shear rate, while viscosity decreases continuously with shear rate. In the material having shear thinning with yield stress, viscosity decreases with shear rate once the yield stress has been exceeded.

3. A FINITE DEFORMATION ELASTO-PLASTIC DRUCKER-PRAGER MODEL

Example in this paper illustrates the use of the extended Drucker-Prager plasticity model for a problem involving finite deformation. Software Abaqus provides three different yield criteria of the Drucker-Prager class. In all three the yield function is dependent on both the confining pressure and the deviatoric stress in the material. The simplest is a straight line in the meridional (p–q) plane. The other yield criteria are a hyperbolic surface and a general exponential surface in the meridional plane.

In this example, material parameters of fresh concrete shown in the literature were applied for the linear Drucker-Prager model are examined by simulating a concrete slump test. The slump test is a standardized procedure performed on fresh, wet concrete to determine its consistency and ability to flow. The test consists of filling a conical mold with concrete to a specified height. The mold is then removed, and the concrete is allowed to deform under its own weight. The reduction in height of the concrete cone, referred to as the “slump,” is an indication of the consistency and strength of the concrete. This example is a simulation of such a test. A finite element analysis of this problem has been published by Famiglietti [5].

No specific system of units is used in this example for the dimensions, the material parameters, or the loads. The units are assumed to be consistent. A standard, conical mold is used when performing a slump test on concrete. The cone is 0.3 units high. The radius at the base of the cone is 0.2, and the radius at the top is 0.1.

The mesh used in the example is shown in Figure 3. First-order CPE4 elements are used. A Young's modulus of 2.25 and a Poisson's ratio of 0.125 define the elastic response of the concrete. A density of 0.1 is used as specified in [5].

It is assumed that the inelastic behavior is governed by the cohesion or shear strength and by the friction angle of the material. A cohesion of 0.0011547 and friction angle of 20° is used. Perfect plasticity is assumed. Since these parameters are provided for a Mohr-Coulomb plasticity model, they must be converted to linear Drucker-Prager parameters. Plane strain deformation and an associated plastic flow rule, where the dilation angle is equal to the material friction angle , are assumed for the purpose of this conversion.

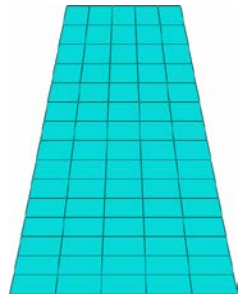

Figure 3. Undeformed mesh (CPE4 elements)

The inelastic material properties are specified with the *DRUCKER PRAGER option and the *DRUCKER PRAGER HARDENING option.

The loading is a gravity load, 0.981, applied to the entire model. The load is increased linearly from zero at the beginning of the step to its maximum value at the end of the step. The load is ramped up using the *AMPLITUDE, DEFINITION=SMOOTH STEP option. This amplitude definition provides a smooth loading rate, which is desirable in quasi-static or steady-state simulations.

The base of the concrete cone is held fixed in the vertical direction but is free to move in the radial direction. Friction between the concrete and the support is not considered. Since finite strains and large displacements must be accounted for, the NLGEOM parameter is specified on the *STEP option. The models with the hyperbolic and exponential yield criteria use the default values for the *CONTROLS option. However, for the linear Drucker Prager model the *CONTROLS, PARAMETER=FIELD option is used to override the automatic calculation of the average forces to decrease the computational time required for the analysis. The convergence criteria is set to 1%, and the average force is set to 5.0 × 10–5.

The maximum time increment is limited in the models such that no more than 2.0% of the total load is applied in any given increment. This is done so that the point of initial yield and the shape of the inelastic response are captured accurately during the analyses.

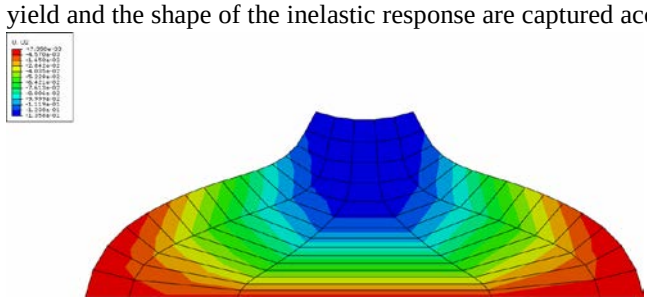

Figure 4. Deformed mesh (deformed "concrete slump")

4. CONCLUSION

Rheological model has been shown that it can predict the plastic viscosity and yield stress of fresh concrete and model were developed for predicting the mortar and concrete rheological properties as well as for evaluating the factors that influence mortar and concrete rheological behavior.

This paper has presented a finite-strain elasto-plastic Drucker-Prager model based upon the multiplicative decomposition of the deformation gradient. The equations have been developed within a framework using a spectral decomposition approach found in literature. Solution of an example problem (the concrete slump test), has been performed to illustrate implementation of finite deformation elasto-plastic Drucker-Prager model.

ACKNOWLEDGEMENTS

The paper is part of the project TR 36017, financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

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49| Претходно саопштење
Preliminary report
doi 10.7251/STP1813664L ISSN 2566-4484

СЕИЗМИЧКА ОТПОРНОСТ ПОСТОЈЕЋИХ ОБЈЕКАТА ПО ДОКУМЕНТУ FEMA310

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Резиме:

У овом раду, укратко је приказан принцип примјене документа ФЕМА310 за оцјену сеизмичке отпорности постојећих објеката, за ма који тип објекта, и дат је примјер оцјене на првом и другом нивоу, кроз два типа зиданих конструкција. Примјена овог документа у првом и другом нивоу оцјене је конзервативан, поједностављен начин за одређивање сеизмичке отпорности, који је заснован на многим искуственим подацима и обухвата најважније параметре објеката који могу да утичу на сеизмичку отпорност. Упутства су једноставна за примјену, али мјестимично су прилагођена америчким правилницима. Разматрана су два типа зиданих конструкција са крутом и флексибилном међуспратном таваницом, кроз која је дат примјер оцјене на првом и другом нивоу.

Кључне ријечи: Сеизмичка отпорност постојећих објеката, зидане конструкције, FEMA310

SEISMIC EVALUATION OF EXISTING BUILDINGS ACCORDING TO DOCUMENT FEMA 310

Abstract:

In this paper, the principle of application of the FEMA310 document for seismic evaluation of existing buildings is briefly illustrated, for any building type, and examples of evaluation are given for the first and second tier of evaluation process, for two types of masonry structures. The application of this document at tier one and tier two of the evaluation process is a conservative, simplified way of determining seismic resistance, based on many experiential data and including the most important parameters of buildings that can affect seismic resistance. Instructions given by FEMA310 are easy to apply, but are adapted to US standards. Two examples for evaluation of masonry buildings on first and second tier of evaluation are given, for masonry buildings with rigid and flexible diaphragmas.

Keywords: Seismic evaluation, existing buildings, masonry buildings, FEMA310

1. INTRODUCTION

Many buildings in use date from the time when seismic analysis in applicable guidelines was not defined, and for many existing buildings, the original capacity in terms of accepting seismic forces was temporarily reduced by damage in earthquakes from the past or by some other ways. Determining seismic resistance of existing buildings has to be done in order to protect people, users of such buildings, in case of future earthquakes.

The largest earthquake-related damages and victims are the result of damage and demolition of existing buildings, which are not designed according to aseismic rules. For that reason, many countries have adopted guidelines for establishing the reliability and vulnerability of existing buildings, and in that respect, The United States have made the biggest progress.

Federal Emergency Management Agency (FEMA) issued guidelines for seismic rehabilitation of buildings within the NEHRP project (National Earthquake Hazard Reduction Program). The aim of this program is to reduce negative consequences, physical injuries and earthquake-related losses. Within this program, FEMA acts as an agency whose activities are based on its implementation and maintenance.

FEMA273 deals with earthquake impacts on site locations and refers to maps with an evaluation of earthquake hazard probability and the degree of vulnerability. Also, there are documents related to processes of rehabilitation FEMA273-276, FEMA356. [3]

FEMA310 - Handbook for the Seismic Evaluation of Buildings from 1998, defines the exact steps for analyzing existing buildings of different types, made of concrete, steel, masonry or wood elements. The FEMA310 is based on the FEMA178 - Handbook for the Seismic Evaluation of Buildings.

An analysis of existing buildings is not a simple activity. In order to evaluate the building, the scope of the necessary investigative works is large. The basis of the analysis is the examination, study, and computational analysis, which are accessed after getting familiar with the building and obtaining the available information. It is necessary to perform a global analysis of the system as a whole, as well as a detailed analysis of the main elements of the system, which is in the case of analysis of seismic resistance, a system for accepting horizontal, lateral forces. The expert should define the program of necessary testing of structural elements and materials used, and due to the impossibility of performing sufficient volume of investigative works, the evaluation is often done quite conservatively.

According to our standards, design recommendations in seismic areas are simple and correct solutions of the building layout, even distribution of load-bearing walls in both directions, application of simple constructive systems, rigid diaphragms, use of suitable quality materials. [4] Also the evaluation according to the FEMA310 manual is based on the general characteristics of the building that is considered to be seismically favorable, and further evaluation demands more detailed analysis, when initial demands are not met, or in case of doubt in the regularity of some structural element or parameter of the construction material. Detaility of evaluation is graded in levels. The instructions for analysis are general, but each building is unique and may contain certain problems that are not defined in this Manual. Herein, a description of the evaluation process according to the FEMA310 manual, is given, and two examples of the evaluation at the first and second tier are shortly described, through two types of masonry structures. Examples were conducted in order to gain general insight into the evaluation principle according to the document. The evaluation is not detailed, with several assumptions.

2. SEISMIC RESISTANCE OF EXISTING OBJECTS ACCORDING TO THE DOCUMENT FEMA 310 – GENERAL NOTES

Evaluation according to the FEMA 310 document is performed in three levels (tiers), for any seismic area, and before evaluation certain evaluation requirements have to be met. Evaluation levels defined in the Manual are as follows:

- Tier 1 – screening phase;
- Tier 2 – evaluation phase;
- Tier 3 – detail evaluation phase.

Evaluation in first and second tier can be conservative, as many rough assumptions are used in the analysis. By a detailed analysis in third tier of evaluation, it is possible to prove that buildings with identified deficiencies in the first and second tier of the evaluation have adequate seismic resistance, according to the criteria of the third tier.

Prior to the evaluation, the expected level of performance of the building is determined, upon which depends the type and the scope of the evaluation. Buildings can be evaluated according to one of the two levels of performance listed below:

- Life safety performance level, LS;
- Immediate occupancy performance level, IO.

The criteria are more stringent for buildings that should satisfy the requirements for immediate occupancy performance level.

For both performance levels, the seismic demands are based on spectral response acceleration values for maximum considered earthquake.

Maximum considered earthquake is an earthquake with a probability of exceeding 2% for a return period of 50 years, with the maximum expected value based on known data for that area. For the purpose of comparison, when designing towards Eurocode 8, the buildings are designed to withstand an earthquake with a probability of exceeding 10% over a return period of 50 years, without collapsing.

2.1. Evaluation requirements

The evaluation at all tiers should be based on facts as much as possible, in relation to the assumptions, so before the evaluation, for each building, it is necessary to determine the following:

- The scope of previous investigations required;
- Perform a visual inspection of the building, site visit;
- The level of performance;
- The area of seismicity;
- The building type.

An expert should evaluate the level of additional works. Prior to evaluation, an expert should have an insight into the geomechanical characteristics and soil parameters, the constructive system, the details of the reinforcement, as well as data related to the behavior of the building in the event of any previous earthquakes. Certain data can be obtained from the available project documentation, and additional information is collected by performing physical testing, measurements and structural overview.

The site visit is done in order to check the compliance of collected data with the state on the site, as well as in order to collect additional data, determine the general condition of

the building and inspect the accessibility to the structure elements. The expected level of performance is defined before the start of the evaluation by the expert performing the evaluation and/or by the relevant competent institutions.

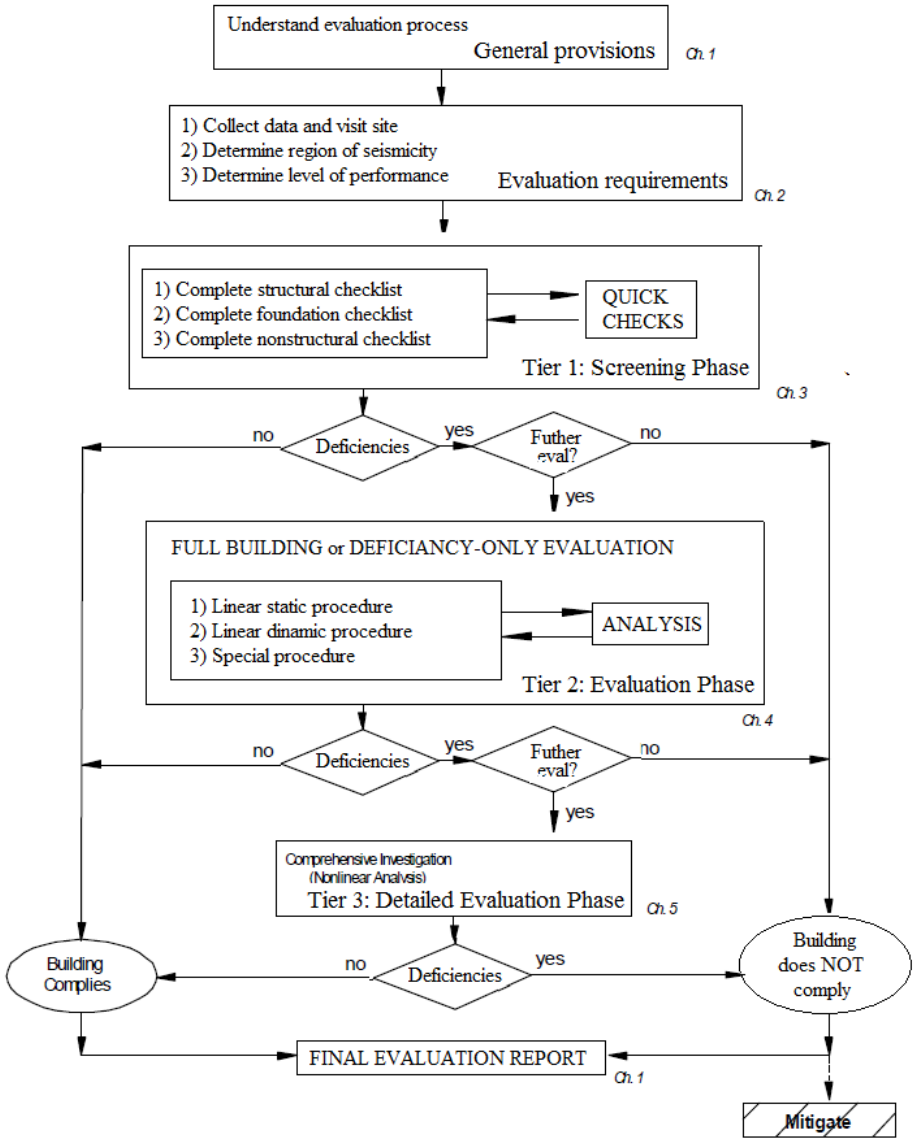

Figure 1. Schematic representation of the evaluation process [1]

Also, it is necessary to define the area of seismicity, which is defined as the area of low, medium or high seismicity, according to the values given in the Manual, and based on the design spectral response acceleration parameter at one second period - SD1 and design short period spectral response acceleration parameter SDS, which are determined on the basis of spectral response acceleration parameter at one second period S1 and short period spectral response acceleration parameter Ss. These parameters are read from seismic maps.

There are no such maps in area of Bosnia and Herzegovina. For the purpose of evaluation, the seismological map of the Banja Luka region was used [5], [6], and the maximum acceleration can be determined was determined according to the orientational formula proposed by Murphy and O'Brien [2]:

$$\log at = 0{,}25 \cdot I + 0{,}25 \quad (1)$$

where I is the degree of seismicity in Merkali.

If we have some other known data, soil and object parameters can be determined more precisely.[6]

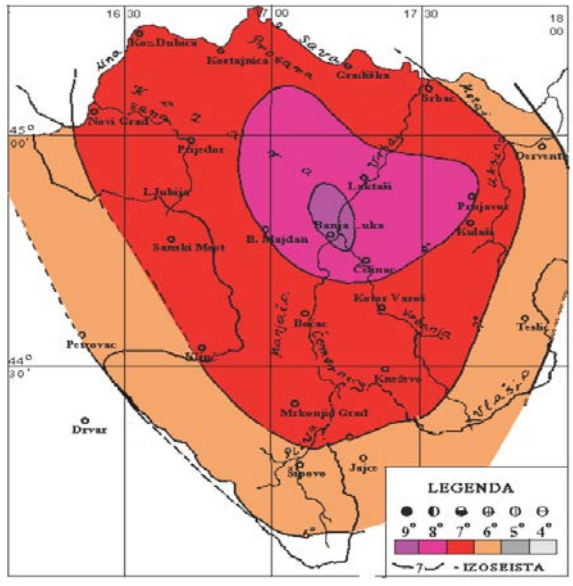

Figure 2. Figure 2. Seismological map of earthquake isotope for the territory of Banja Luka [3]

The type of building depends on static system, in terms of transmission the lateral forces and the type of diaphragm. According to the Manual, the buildings are classified into 12 types.

2.2. Tier 1 evaluation process

The objective of the first tier evaluation is to quickly identify buildings, through the corresponding checklists, which meet the basic constructive parameters defined in this Manual and to identify possible deficiencies. In the first tier, in case of doubt, quick checks are defined for certain checklists statements. The first tier evaluation is done for the whole building.

2.2.1. Selecting and using particular checklist

Different checklists are used for each building type in estimation. Also, there are general checklists for buildings that cannot be classified into the listed building types.

The checklists used for the evaluation at the first tier were formed on the basis of observing the behavior of various building types and their damage during numerous earthquakes. The only building type for which there is no tier one structural checklist, but a special analysis is defined, which is placed in the second tier of evaluation, are masonry buildings

with flexible diaphragms. Non constructive checklists are defined in first tier of evaluation for this building type.

Depending on the defined performance level and region of seismicity, for each building type, three checklists are defined:

- Structural checklist;
- Nonstructural checklist;
- Geological site hazard and foundation checklist.

Selection and type of the checklist is based on:

- Performance level (IO or LS);
- The level of seismicity of the area;
- Building type.

If a building cannot be classified in any type, a general checklist is provided, giving a general insight into possible disadvantages. For each building type there are basic and supplementary lists for constructive and non constructive parameters, and depending on the level of performance and area of seismicity, it is determined whether both checklists or only basic one is filled, Tab 1.

Table 1. Selection of the checklist based on seismicity and the defined level of safety

Region of seizmi-city	*Perfo-rmace level*	*Zahtjevane kontrolne liste*					
		Region of low seismicity	*Basic structur-al*	*Supleme-ntal structural*	*Geological site hazard and foundation checklist*	*Basic nonstructu-ral*	*Supleme-ntal nonstructu-ral*
Low	LS	√					
	IO		√		√	√	
Moderate	LS		√		√	√	
	IO		√	√	√	√	√
High	LS		√	√	√	√	
	IO		√	√	√	√	√

Checklists are filled out by recording whether their statements are accurate, inaccurate, or cannot be applied to the building being evaluated. Each statement in the checklist is followed by an indication of a particular chapter of the second tier of evaluation, for a better understanding and description of further analysis of the second tier.

2.2.2. Computational analysis for the first tier of evaluation

In some cases it is necessary to perform quick checks in order to determine the fulfillment of the statements regarding the strength and stiffness of certain structural elements, with the previous determination of the lateral seismic forces. Checklist statements guide us to use cetran quick checks.

The pseudo-lateral force is calculated for the purpose of quick check in the first tier of the evaluation, but also in some cases for the second tier of evaluation. This force is used in linear analysis and causes expected deformation of the building at designed earthquake.

Pseudo-lateral force in a given horizontal direction is determined by equation:

$$V=[C\ S]\_a\ W \tag{2}$$

where:

C – modification factor regarding building ductility, defined tabulary by the Manual, and depending on building type and floor number;

S_a – response spectral acceleration at the fundamental period of the building in the direction under consideration;

W – total dead load and expected live load.

The pseudo-lateral force on the floor j is determined by the expression:

$$V_j=((n+j)/(n+1))(W_j/W)V \quad (3)$$

where:

n – total number of floors above ground level;

j – the number of floor under consideration;

W_j – total dead load and expected live load above the level j;

W – total dead load and expected live load;

V – pseudo-lateral force, defined by the expression (2).

Response spectral acceleration Sa is calculated according to the expression:

$$S_a= S_{D1}/T \leq S_{DS}, \quad (4)$$

where:

$S_{D1} = 2/3\ F_v S_1$– design spectral response acceleration parameter at one second period;

(5)

$S_{DS} = 2/3\ F_a S_s$– design short period spectral response acceleration parameter;

(6)

F_v, F_a – the coefficients of the magnification given tabullary in the Manual, depending on the site class and the acceleration spectrum parameters S_1 i S_S;

S_1 – spectral response acceleration parameter at one second period, provided in FEMA Seismic Map Package;

S_S – short period spectral response acceleration parameter, provided in FEMA Seismic Map Package;

T – fundamental period of building vibration in seconds (defined by equation (7))

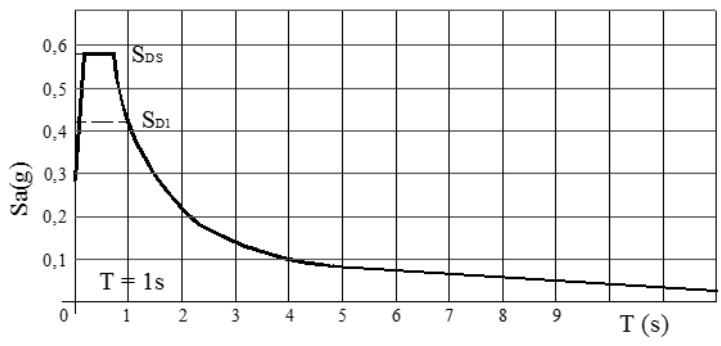

Figure 3. Meaning of design spectral response acceleration parameters

Fundamental period of building vibration T, is defined by the expression:

$$T=C_t h_n^{(3/4)} \quad (7)$$

where:

C_t – coefficient depending on the building type;

h_n – height in feet above the base to the roof level.

For evaluation at the first tier characteristics values of material parameters can be used.

2.3. Tier 2 evaluation process

If it is evaluated that certain elements of the building do not meet the criteria defined in the first tier checklists, the second tier evaluation may be performed for elements that did not meet the criteria defined in the particular checklist items or for the entire building.

Second tier evaluation does not require testing of materials, but characteristic values are not used as in the first tier. These characteristics are derived from certain guidelines depending on the year of construction of the building, construction diaries, and physical testing. Physical testing is not required.

2.3.1. Computational analysis for the second tier of evaluation

Based on the checklists in tier 1, the chapters of the second tier of evaluation are defined. Tier 2 analysis procedures, after first tier evaluation, and which only relate to the control of detected irregularities, are listed in parentheses after the checklist statement.

- At the second tier of evaluation, there are instructions for four types of analysis:
- Linear static analysis;
- Linear dynamic analysis;
- Special analysis (for unreinforced masonry structures with flexible diaphragms);
- An analysis by which non-constructive elements are controlled.

The analysis for all types of buildings, with respect to the control of the structural parameters, except for unreinforced masonry structures with flexible diaphragms, is performed according to a linear static or dynamic analysis. Herein the principle of analysis according to these two methods is briefly described. Analysis is carried out in order to check the capacity of the system for receiving lateral forces. Dynamic analysis must be carried out for buildings over 30 m, buildings with unequal distribution of mass or stiffness, or with geometric irregularities.

The first step in the analysis, static or dynamic, is to define a mathematical model. The basic guideline for the model is given by the Manual. The construction with rigid diaphragms can be analyzed in plane if the torsional effects are small and can be ignored or taken indirectly in the calculation. In other cases, the building is modeled three-dimensionally. Only the stiffness of the basic components of the building should be taken into the account, and if the secondary components are to be modeled, the total stiffness of the secondary components must not exceed 25% of the stiffness of the basic components taken into account for each floor.

When analisis is performed by a linear static method, the pseudo-lateral force is calculated according to the expression (2). The basic period of the model is calculated by equation (7) or alternatively, according to eigenvalue obtained after dynamic analysis.

The vertical arrangement of pseudo-lateral force is determined according to the expression:

$$F_x=C_{vx} V \tag{9}$$

$$C_{vx}= (w_x h_x^k)/(\sum_{(i=1)}^{n}[w_i h_i^k]), \tag{10}$$

where:

$k = 1.0$ for $T\leq 0.5$ s; $k=2.0$ for $T>2.5$ s (for the values in between linear interpolation is performed);

C_{vx} – vertical distribution factor;

V – pseudo-lateral force, calculated by the equation (2);

w_i – part of the total weight of the building that belongs to the level i;

w_x – part of the total weight of the building that belongs to level x, which is considered;

h_i – height from base to level i;

h_x – height from base to level x;

The total diaphragm force at the level x:

$$F_{px}=1/C\ F_i\ w_x/(\sum_{i=1}^{n} w), \quad (11)$$

where:

F_i – pseudo-lateral force at level i, defined by equation (9);

w_i – part of the total weight of the building that belongs to the level i;

w_x– part of the total weight of the building that belongs to level x, which is considered;

C – modification factor regarding building ductility, defined tabullary by the Manual, which depends on building type and floor number;

Structural deformation and displacements are calculated using the lateral force calculated by the equations (2), (9) i (11).

Prior to the dynamic analysis, it is necessary to define spectral acceleration, as by the analysis in the first tier of the evaluation, based on the equation (4) or according to the special conditions of the site, when a spectral analysis for the building is performed.

Diaphragms are analyzed for the effect of seismic force obtained by dynamic spectral analysis, and for the effects of horizontal forces that occur as a result of displacement or change in stiffness of vertical elements above and below the diaphragm.

The number of modes must be sufficient to cover more than 90% of the body mass involved in each of the horizontal axes.

Seismic forces determined by dynamic analysis must not be less than 85% of the force value determined by static analysis.

2.3.2. Acceptance criteria

Total loads are calculated from gravity loads (dead load, effective live load and snow load) and seismic loads. With these loads, component actions are calculated and compared to component strength.

All actions are classified as force-controlled actions or deformation-controlled actions.

Deformation controlled actions are those actions that cause deformation that are allowed to exceed the flow boundary, while force controlled actions are those that cause deformation which is not allowed to cross the flow limit. As an example, it can be said that the bending moment is deformation controlled action, while the shearing moment, or the axial force is force controlled action.

At the end of the analysis, the following conditions must be met:

$$Q_{CE} \geq Q_{UD}/m \geq Q_{UF} \quad (12)$$

where:

Q_{CE} – expected component strength;

Q_{UD} – deformation controlled actions;

Q_{UF} – force controlled action;

m – coefficient that takes into account component ductility, as defined in the Manual.

Tier 3 evaluation

The third tier of evaluation is taken into account, if there is a doubt that the criteria of the first and second tiers are too conservative for a realistic evaluation, and that a more detailed

analysis is needed. It can be done for the entire building or for elements that did not meet the criteria of the second tier.

Two evaluation procedures were defined on the third tier of evaluation of existing buildings, according to United States standards, a procedure for the rehabilitation of an existing buildings or procedure applicable to the design of new buildings. In evaluation by the criteria of the third tier, the characteristics of all embedded materials, destructive or non-destructive methods, are examined.

If the rehabilitation procedure is carried out, 75% of seismic forces are counted.

Third tier of evaluation is done according to nonlinear methods, defined by US standards.

3. EXAMPLES OF MASONRY BUILDING ANALYSIS

The evaluation according to the Manual was applied on masonry buildings of type 15: Unreinforced masonry bearing wall buildings - URM, which has two subtypes URM and URMA.

URM-type buildings have external and internal bearing unreinforced brick walls. In older buildings, the framings on the floors and on the roof consist of straight or diagonal wooden beams. The diaphragms are flexible in relation to the walls. When they exist, the connections between the walls and the diaphragms consist of bent steel plates or anchors embedded in the couplings and attached to the framings. The foundations are made of brick or concrete.

URMA-type buildings are similar to URM type. They are distinguished by the fact that the diaphragms are stiff in relation to the unreinforced brick walls. In older constructions or large multipurpose structures, the diaphragms are cast in concrete on site

3.1. First tier of evaluation of building of type URMA

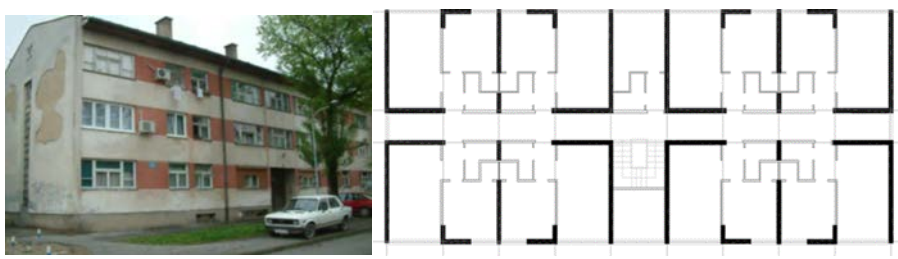

Figure 4. Example, building of type URMA - perspective and floor plan

In this example, the URMA-type building with three floors and the regular basis was analyzed. As the building was built in the 1950s, before the application of the rulebook on construction of buildings in seismic areas, it has no vertical or horizontal concrete elements. Vertical load-bearing elements are longitudinal and transverzal brick walls. The walls are 25 cm wide, made of full bricks. The diaphragms are of reinforced concrete, 12 cm thick, rigid in its plane. The mortar and lime mortar were used for masonry purposes.

The safety level on the basis of which the evaluation is performed is life safety level.

Basic characteristics of the soil are approximately determined using geological map of Republika Srpska. The seismic parameters are also determined approximately based on the available maps of the region.

In the basic constructive checklist, the controlled items for this building type are:

- Building system;

- System for absorbing lateral forces;
- Connections.

In each statement of the list, there is noted number of chapter from the second tier that clarifies the statement and gives directions for further analysis, in case of not meeting the statement requirements or doubt. Some of the statements cannot be applied to the subject building.

According to the checklist, this construction has some irregularities that have to be further analyzed in tier 2 of evaluation.

3.1.1. Control of the building system

Within the control of a building system, the following items are controlled:

- Load transfer path

It is demanded that the construction contains a single continuous trajectory for seismic load transfer for buildings rated as LS and IO for any horizontal direction of action, which should transfer the inertial forces from mass to foundations. Rigid diaphragms should accept the seismic forces, and transfer them through the brick walls to concrete foundations. There must be no discontinuity in this system. All the walls should extend to the foundation, and the diaphragm should transfer the lateral forces to the supporting walls. There is no computational analysis for this item.

- Mezzanines

If existing, the construction of the inner mezzanines must be a separate construction, independent of the main structure in aspect of receiving the lateral force, or must be anchored on the supporting system elements which receive the lateral forces of the main structure.

- The existence of weak and flexible floors

The strength of a constructive system for receiving lateral forces on each floor must be greater than 80% of the adjacent floor strength, below or above, for facilities rated as LS or IO, and the rigidity of a constructive system for receiving lateral forces on each floor must be greater than 70% of the adjacent floor stiffness, below or above, or greater than 80% of the average stiffness of three floors below or above for buildings rated as LS or IO. For the weak and flexible floor, analysis is conducted according to the second tier of evaluation. For the weak floor, the strength of the elements is calculated and the ability of the floor to accept half of the total pseudo-lateral force is controlled.

- Regularity of geometry

There must not be difference in the horizontal dimensions of the constructive system for receiving the lateral forces for particular floor by more than 30% relative to adjacent floors, for buildings rated as LS or IO, with the exception of one-story structures on the roof of the building. In the case of irregular geometry, a linear dynamic analysis is performed according to the second tier and the ability of the elements to accept the pseudo-lateral force is controlled.

- The existence of vertical discontinuities

All the vertical elements of the constructive system for receiving lateral forces must be continuus to the ground. In the case of vertical discontinuities there must be control of the elements ability to receive the load, as well as the ability of the diaphragms and the connections to transfer the load from the discontinuous location to adjacent elements.

- Regularity of weight distribution

There should be no difference in the effective weight of more than 50% between floors, for buildings rated as LS or IO. In the case of a variable mass, a linear dynamic analysis is performed, according to the second tier instructions and the ability of the elements to accept the pseudo-lateral force is controlled.

- Torsion [7]

The distance between the center of mass and the center of the stiffness should be less than 20% the width of the building in each direction, for buildings rated as LS or IO. In the case of a distance between the center of mass and the center of stiffness of the floor greater than 20% of the width of the building in any direction, the analysis are performed according to the second tier instructions. The maximum movement of the floor is calculated including torsional effects, and the control of vertical elements after calculated displacements is performed.

- Deterioration of concrete and wall elements

There must not be visible concrete or reinforcement steel damage in any component of the constructive system for the reception of lateral forces, and also the deterioration of the wall elements must not be visible. It is necessary to identify the extent of the damaged elements and to determine the impact on the system for receiving lateral forces. For each damaged element based on the degree of damage, the actual bearing capacity has to be determined.

- Coupling control

The mortar in joints should not be easily scraped with a metal tool, and there must not be area with eroded mortar in the couplings. It is necessary to identify the depth and extent of the joint damage. The walls with unstable mortar in the couplings should be omitted from the analysis and the adequacy of the transmission system for the lateral forces has to be checked without them. Alternatively, actual shear strength can be determined by testing.

- The existence of cracks in unreinforced masonry walls

Diagonal cracks in wall elements may not be larger than 3.2 mm, for buildings rated as LS or 1.6 mm for buildings rated as IO, and horizontal offsets in horizontal couplings shall not be greater than 3.2 mm, for buildings rated as LS and 1.6 mm for buildings rated as IO. Taking into account the extent of damage and their impact on the bearing capacity of the elements, it is necessary to check the adequacy of the lateral force resisting system. The extent of damage, location, number, and the direction of the cracks must be considered.

3.1.2. Control of lateral force resisting system

Regarding lateral force resisting system, the following items are controlled:

- Renundancy

In each main direction, the number of axes with shear walls must be larger than two, for buildings rated as LS or IO. An analysis of the system for transferring lateral forces, according to the second tier of evaluation procedures, has to be performed. All elements

and connections have to be checked. In the case of incorrect elements in one axis, these elements are excluded, and the analysis is performed for the remaining axes.

- Shear stress check

Shear stress in unreinforced masonry walls, calculated using quick checks according to the first tier analysis procedure, must be less than 0,10 MPa for brick wall elements and 0,20 MPa for concrete wall elements for buildings rated as LS or IO. A quick check is carried out according to the first tier of evaluation, according to the procedure described.

3.1.3. Connection control

Within the connection control of the building, the following items are checked:

- Walls anchorage

The exterior concrete or masonry walls must be anchored with steel anchors or strips which are left out from diaphragm to accept the forces acting out of their plane, at each level of the diaphragms.

- Transfer to the shear walls

Diaphragms must be reinforced and connected to transfer the load on the shear walls for buildings rated as LS, and the connections should transfer the shear stresses from the walls for buildings rated as IO. An analysis of the system for transferring lateral forces to the second tier is performed. Requirements for diaphragms and connections are checked.

- Grinder-column connection

The connection between the beam and the pillar should be positive.

After performing structural checklist in tier one of evaluation, and after control of lateral force resisting system, by quick checks, it is indicated that walls do not have capacity for accepting lateral forces.

3.2. Second tier of evaluation of building of type URM

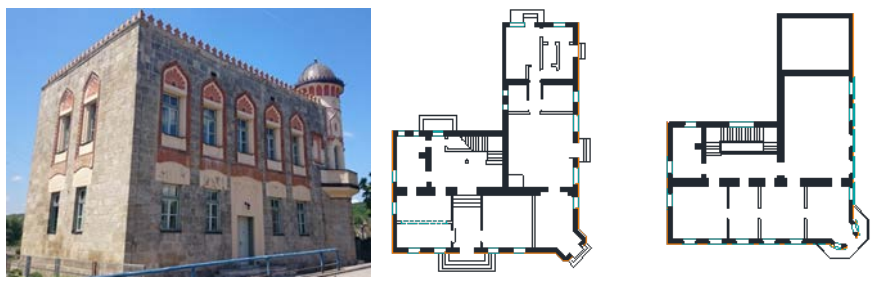

Figure 5. Example, building of type URM - perspective and floor plan

The second considered example of a masonry building is a building with a flexible diaphragm, with two levels. Floor plan is in shape of letter "L". The overall dimensions are 17,05x20,40 m. The diaphragms are wooden, made of wooden beams; over whom plasterboard is placed.

All the walls are made of brick, tall, and without horizontal and vertical beams. The load-bearing walls can be divided into two groups: internal load-bearing walls made of full brick, with 30, 45 and 60 cm thickness, and facade double walls, with stone on the outside. The thickness of the brick part is 30 cm, and the stone facade 15 cm. Lime mortar was used as a bonding agent for all walls.

Data on the geomechanical characteristics of the site are taken from the available geomechanical maps.

The seismic parameters are determined approximately based on the data for the Banja Luka region.
For this building type in order to control the lateral force resisting system, the checklists are not used, but special procedure defined in second tier, which regards separate analysis for different elements of building.
The special procedure applies to unreinforced masonry structures, with flexible diaphragms at all levels, and for constructions that have a minimum two axes with bearing walls in the main directions. The analysis is defined separately for partition walls, diaphragms and load-bearing shear walls. In the example, the analysis was performed only to control the stress in the shear walls.
For the evaluation at this level, certain tests on the construction material were required.
With regard to the criteria for the shear capacity, after a calculation, it was concluded that the building has sufficient surface area for the reception of lateral forces.
Construction details, such as anchoring of walls and details of non-structural elements are not known in this case, so analysis was not carried out.

4. CONCLUSION

In this paper, the principle of application of the FEMA310 document to evaluate the seismic resistance of existing buildings, for each building type, is briefly described. In the examples, first and second tier analysis were performed for two types of masonry structures, with rigid and flexible diaphragms.
The application of this document at the first and second tier of evaluation is a conservative, simplified way to determine seismic resistance based on many experiential data and encompasses the most important building parameters that can affect seismic resistance. The instructions are easy to apply, but are mostly adapted to United States standards, concerning mostly usage of seismic maps and load definition.
The third level of evaluation is not analyzed, as the analysis is recommended by the linear or nonlinear dynamic method following the United States valid rulebooks.
In the first example, which is discussed herein, the building with rigid diaphragms, being analyzed, was constructed prior to the adoption of the rulebook on construction in seismic areas and does not meet the requirements for the aseismic design according to the technical regulations for construction on seismic sites. Such objects in the area of Banja Luka are mostly upgraded and reconstructed. According to a rough evaluation by document FEMA310, at the first tier, after performing a quick check control defined by the Manual, the evaluated building did not meet the requirements for lateral bearing capacity of the sharing walls.
In the second example, the masonry building with flexible diaphragms is analyzed. An analysis of share walls was performed in terms of accepting the seismic load. Although this is an old building, as the thickness of the walls is large, the requirements are met, according to the special procedure of the second tier of evaluation.

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50| Претходно саопштење
Preliminary report
doi 10.7251/STP1813679N ISSN 2566-4484

МОГУЋНОСТ ОТКРИВАЊА ПРОМЕНЕ ГЕОМЕТРИЈЕ НА ВЕЛИКИМ БРАНАМА ПРИМЕНОМ ГЕОДЕТСКИХ МЕТОДА

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Резиме:

Велике бране изложене су утицају различитих сила које током времена изазивају промену њиховог положаја и геометрије. Познавање промене положаја и геометрије великих брана је од критичног значаја за одређивање њихове стабилности и сигурности. Бране се у процесу деформационе анализе апроксимирају скупом дискретних тачака а затим се на основу промене положаја ових тачака у простору и времену доносе закључци о промени положаја и геометрије брана. За сигурност великих брана је од изузетног зачаја да се одреде промене положаја и геометрије док су оне малих величина како би се открили негативни трендови и благовремено предузеле мере за спречавање последица од угрожене сигурности бране. У овом раду се истражују могућност откривања промене геометрије великих брана на основу резултата добијених геодеским методама.

Кључне речи:Деформациона анализа, тестирање статистичких хипотеза.

ON THE POSSIBILITY OF GEOMETRIC CHANGES OF LARGE DAMS DETERMINATION BY GEODETIC METHODS

Abstract:

Large dams are exposed to the influence of various forces which in time cause changes in their position and geometry. Knowledge about changes in position and geometry of large dams is of crucial importance for their stability and security determination. Dams, in process of deformation analysis, are approximated by set of discrete points and on the base of the changes in position and through time of those points the conclusions of changes of dam position and geometry are made. For large dams' security of highest importance is to detect changes of position and geometry where they are small in order to discover the negative trends and to take measures for prevent consequences of jeopardized dams' security in time. This paper investigates the possibilities of dams' geometry changes detection on the base of geodetic measurements.

Keywords: Deformation analysis, statistical hypotheses testing.

1. INTRODUCTION

Large dams are objects of high value and they are being built with the purpose create a new values i.e. to satisfy elementary human needs mainly for water providing and needs for electric power. The other utilization of water accumulations such as providing irrigation systems in agricultural production are not of smaller importance as this increases the food safety of the population. In that sense large dams are significant component of social wealth and the base for civilizational development. Bearing in mind previous facts large dams need necessary attention in order to keep their functionality in as long period as possible and to extend the period of their exploitation.

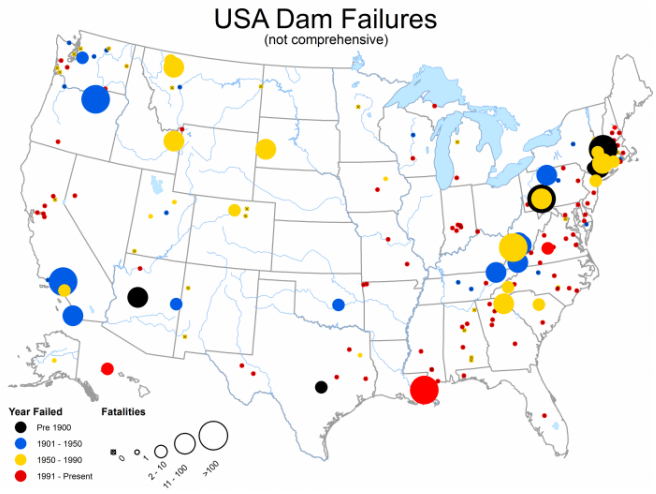
Large dams along with accumulation are also a risk for downstream area. In case of their failure different damages could occur including possibilities of human lives loss and big material damages.

Material losses are multiple:

- Damage of large dam itself,
- Material loss which ocurs in downstream area and
- Losses which occur because of termination or decrease of functionality of large dam at the level of value which could be sreated if large dam was not damaged.

Large dams are complex systems. Their complexity originates from their complexity itself, influence of accumulation, influence of external conditions as well as from complex interactions between large dam and the soil on which it was being built. If those influences are represented by forces it could be said that the large dam will keep its shape (geometry) and position until the forces are in balance. The change of balance between forces inevitably leads to the changes of geometry or the position of large dam or both. Determination changes of geometry and position of large dam (when those changes are monitored in enough large period of time) could point out the trends which lead to its vulnerability. In order to decompose the problem on the elementary factors the concepts of risk and hazard were developed which are the base for large dams risk management [1]. Development of risk and hazard concept as well as risk management is the utility for unwanted events prevention but they cannot eliminate all of them. The map of dam failure in USA [2] is shown on figure 1.

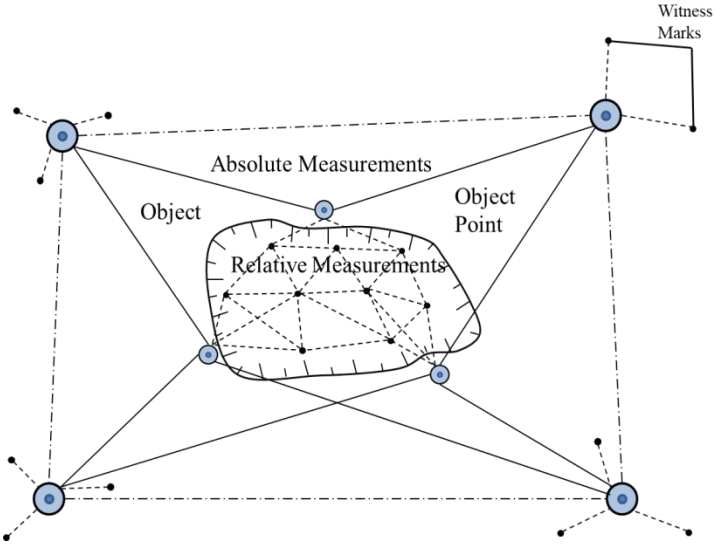
Determination of geometrical changes of large dams is of crucial importance for making conclusion about their state as well as for decision making about timely undertaking measures and activities for prevention failures. The change of geometry of large dams in geodetic sense means changes of certain or all dimension of large dam parts related to other parts of it or change of shape of their parts (or complete large dam). In order to determine or monitor those changes large dam is approximated (or discretized) with finite set of points and after that, by measuring in certain time intervals, the coordinates and heights changes of these points could be determined in space. Mutual changes of these points position are defined as relative movements while the changes related to stable reference (control) points which are defined as absolute movements. In this paper research will be limited to the relative movements of points.



Слика 1. Мапа оштећења брана у САД

Figure 1. Map of dam failures in the USA

Concept of absolute and relative movements is shown on figure 2 [3].



Слика 2. Концепт апсолутних и релативних померања

Figure 2. Concept of relative and absolute meaurements

Specificity of geodetic networks for large dam monitoring are before all related to the high level of accuracy and determination of small movements of points and limited possibilities for their design with maximal level of quality parameters. The limitations for geodetic network design are mainly related by position for control point's stabilization as well as for obstacles for visibility between control points and marks situated on large dam. The optimization of geodetic networks for large dam monitoring

design could mitigate the problem but it could not completely eliminate it [4]. The pillar (reference points) stabilization is limited to the positions which are not influenced by large dam and/or accumulation and provide long term stability in geological sense. Another limitation factor is the position of the river and impossibility to choose the optimal position for control points. As a result of research efforts for determination of absolute and relative movements of points the numerous methods for deformation analysis of geodetic networks were developed [5]. In literature and in practice dominates the opinion that this problem is not solved yet.

2. METHODOLOGY

For dimension changes between points which approximate large dam it is necessary:

- To choose dimension which will be analysed,
- To formulate null and alternative statistical hypothesis,
- To adopt the level of significance for decision making about adoption or rejection null hypothesis,
- To form test staistics based on adjustment of measurements,
- To compare value of test statistics and determine if it follows the theoretical distribution and
- If test statsistcs follows the theoretical distribution on the adopted level of significance conclusion is that results are harmonized with null hypothesis and the reasons for its' rejection do not exists while, in opposite case the reasons for its adoption do not exists.

Because of importance of data about the changes of large dams dimensions the authors suggests local tests of each dimension.

The test statistics is [6]:

$$t = \frac{d}{m_d} = \frac{|X_n - X_0|}{\sqrt{m_{X_n}^2 + m_{X_0}^2}} \sim t_{1-\alpha}(f) \qquad (1)$$

where:

- t – Students' statistics,
- d – the difference of certain dimension in two series of measurements (for example: null and n),
- m_d – mean root square error of researched dimension,
- X_0, X_n – dimension in two different series of measurements null and n respectively,
- $m_{X_0}^2$, $m_{X_n}^2$ – mean square error of dimension X in null and n respectively and
- $t_{1-\alpha}(f)$ – quantile of Students' distribution for significancy level α and number of freedom f.

The difference of researched dimension is obtained on the base of coordinates in two series of measurements while the mean square errors are obtained as a function of adjusted values by following formula:

$$m_X = m_0\sqrt{g^T Q_x g} \tag{2}$$

where:

- m_X – root mean square error of researched dimension as a function of adjusted values,
- m_0 - root mean square error of unit wight obtained from adjustment,
- g^T - linearized function of researched dimension and
- Q_x - cofactor matrix from adjustment.

Statistical hypotheses could be formulated in this case in the following way:

- H_0: dimension X is equal in two series of measurements and
- H_a: dimension X is not equal in two series of measurements.

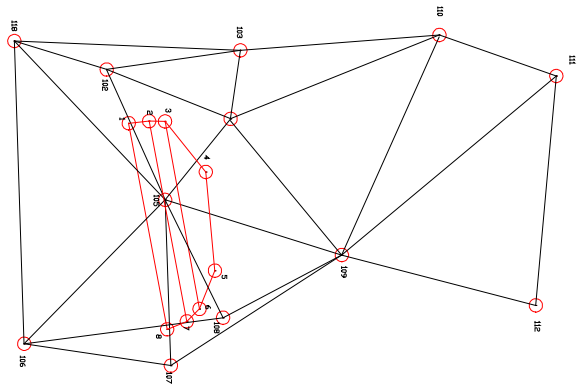
If dimension X is tested related to designed value then test statsistics (1) reads:

$$t = \frac{d}{m_d} = \frac{|X_n - X_P|}{m_{X_n}} \sim t_{1-\alpha}(f) \tag{3}$$

where X_P – is designed value while the rest symbols have the same meaning as in formula (1). Along with mentioned individual tests the tests of equality of sets of points as well as the tests of equality of positions [7].

3. RESULTS AND DISCUSSIONS

In order to illustrate possibility for change in geometry determination which represents the state and of geometry of large dam in time and space the analysis is realized on the one real example. The shape of geodetic network and position of points which represents earth filled large dam is given on figure 3.



Слика 3. Пример геодетске положајне мреже за осматрање велике бране

Figure 3. the example of geodetic network for earth filled large dam monitoring

The change of directions and distances between null and actual series were analyzed and results are shown as follows. Table 1 contains data about changes of directions while the data about changes of distances are given in table 2.

Табела 1. Промене дирекционих углова

Table 1. Change of directions

Pravci ["]							
Станица	Визура	Дирекциони текући	Дирекциони нулти	Δ ["]	m_p	t	Ho
8	1	258.45589	258.45573	1.6	1.5	0.7676	Да
7	2	258.39583	258.39568	1.5	2.2	0.4761	Да
6	3	258.53574	258.53545	2.9	3.0	0.6830	Да
5	4	84.03314	84.03344	-3.0	3.7	0.5705	Да
1	2	353.39202	353.40195	-59.3	19.5	2.1554	Не
2	3	0.10200	0.09504	29.6	13.8	1.5150	Да
3	4	70.49466	70.49473	-0.7	1.9	0.2596	Да
8	7	337.19310	337.20328	-61.8	33.1	1.3201	Да
7	6	315.07374	315.09343	-116.9	24.9	3.3245	Не
6	5	264.03314	264.03344	3.0	3.7	0.5705	Да

Табела 2. Промене дужина

Table 2. Changes of distances

Duzine [mm]							
Станица	Визура	Дужина текућа [m]	Дужина нулта [m]	Δ [m]	m_d	t	Ho
8	1	220.9451	220.9482	-3.1	3.5	0.6089	Да
7	2	214.6740	214.6789	-4.8	3.2	1.0650	Да
6	3	200.9266	200.9446	-18.0	2.7	4.6608	Не
5	4	104.4496	104.4536	-4.0	3.0	0.9451	Да
1	2	21.5965	21.5930	3.5	1.8	1.3957	Да
2	3	16.8323	16.8333	-1.0	1.7	0.4167	Да
3	4	165.8576	165.8583	-0.7	1.9	0.2620	Да
8	7	22.3370	22.3314	5.6	2.6	1.5135	Да
7	6	18.8081	18.8042	3.9	4.3	0.6304	Да
6	5	144.4735	144.5012	-27.7	3.0	6.5975	Не

Criteria for adoption of null hypotheses is as follows:

$$t = \frac{d}{m_d} < t_{1-\alpha}(f) = t_{0.95}(161) \cong \mathcal{N}(0,1) = 1.9600$$

where $\mathcal{N}(0,1)$ is normal distribution for significance level $\alpha = 0.05$.

A criterion for normal distribution is more stringent than criteria for Students' distribution and for the case of large number of freedom it is possible to use it. When the analysis of geometry of large dams is provided it is needed to use more stringent criteria for changes determination because of immanent risk and hazard.

According to obtained results it is possible do conclude that there is consent with majority of null hypothesis about equality of directions and distances between points which represents the behaviour of the dam and that only in two cases the alternative hypotheses for directions (ϑ_1^2, ϑ_6^5) as well as for two distances (d_6^3, d_6^5) were adopted.

The value of changes which could be determined by utilization of formula (1) for significance level $\alpha = 0.05$ and for criterion for normal distribution is:

$$\frac{d}{m_d} < 1.9600 \tag{4}$$

For all changes of geometric elements of large dam for which the difference is bigger than $1.9600 m_d$ the alternative hypothesis could be adopted i.e. it is possible to conclude that analyzed element of geometry has changed its value between two series of measurements.

On the base of obtained results there are no reasons to conclude that geometry of large dam is not changed but only that obtained results do not prove the changes for analyzed elements of geometry between two series of measurements. The elements of geometry of large dam which have been changed between two series of measurements need additional and careful analysis in order to determinate causes.

4. CONCLUSION

The determination of geometry changes of large dams is of crucial importance for reliable conclusions about their state and behaviour. Limitations in the process of geodetic networks for large dams monitoring design are caused by topography and conditions for mutual visibility of reference points as well as the visibility of points which represents the dam. Those limitations could decrease the accuracy and reliability of coordinates of points which represent large dam as well as the dimension which is analyzed.

Shown example shows that changes of geometry of points which represents large dam (changes of directions and distances between points) could be detected while they are relatively small and that it is possible to monitor their development in time.

Detection of trends in geometry of large dams change makes possible to undertaking activities for prevention or elimination unwanted events, as dam failures, timely.

For the sake of caution it is needed to use more stringent criterion for null hypotheses adoption about geometry of large dam equality between two series of measurements. Also it is needed to check equality between measured and designed values for some dimension of the dam. Utilization of more stringent criteria is justified especially when the number of freedom is big and in that case it is posible to use normal distribution instead of Students' distribution.

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51| Претходно саопштење
Preliminary report
doi 10.7251/STP1813687A ISSN 2566-4484

GEOPORTAL FOR SEARCHING AND VISUALIZATION OF CADASTRAL DATA

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Abstract:

Geoportal is an indispensable part of the national spatial data infrastructure and a central point of access to spatial data. The paper presents the development of a geoportal based on the principles of service-oriented architecture. Open source frameworks and libraries were used to create geoportal. The aim of the paper is to present a partially different approach to the development of geoportals, based on the modern principles of web application development. The case study was conducted for the cadastral municipality of Brod, the municipality of Brod, Republika Srpska, Bosnia and Herzegovina.

Keywords: land administration, cadastral data, geoportal

ГЕОПОРТАЛ ЗА ПРЕТРАЖИВАЊЕ И ВИЗУЕЛИЗАЦИЈУ КАТАСТАРСКИХ ПОДАТАКА

Резиме:

Геопортал представља незаобилазан дио националне инфраструктуре геопросторних података и централну тачку приступа геопоросторним подацима. У раду је приказана израда геопортала за приказ катастарских података заснована на принципима сервисно-оријентисане архитектуре. За израду геопортала коришћена су развојна окружења и библиотеке отвореног кода. Циљ рада је приказ дјелимично другачијег приступа развоју геопортала, заснованог на савременим принципима развоја веб апликација. Студија случаја рађена је за катастарску општину Брод, општина Брод, Република Српска, Босна и Херцеговина..

Кључне ријечи: земљишна администрација, катастарски подаци, геопортал

1. INTRODUCTION

In order to integrate the land administration system in the Republic of Srpska and Bosnia and Herzegovina into European frameworks, it is necessary to implement the European recommendations and directives, primarily INSPIRE [1]. This Directive provides general rules for the establishment of national infrastructures for spatial information in Europe and obligates the institutions which are owners or who have the competence over spatial information defined in the 34 themes of INSPIRE Directive to make them publicly available. Accessibility is provided through geoportals, which represent the core of the geospatial data infrastructure and a central point for accessing and using data from the jurisdiction of different institutions. The paper presents a model of geoportal for the search and visualization of cadastral data, and a case study was conducted for the cadastral municipality of Brod, the municipality of Brod, Republika Srpska, Bosnia and Herzegovina. The displayed data were used exclusively for the purpose of research.

2. MATERIALS AND METHODS

As part of the research, the analysis and valorization of available literature in the field of research was carried out, and a special emphasis was placed on research carried out in the Balkans region. Methods of analysis, synthesis, comparisons were used, and through the case study by the method of modeling, a geoportal based on the principles of service-oriented architecture was realized.

2.1. RESEARCH AREA

In addition to the conducted case study, the paper gives an overview of the situation in the field that is the subject of research in the countries of the Western Balkans. Bearing in mind the European perspective of the countries of the region and the importance of adopting and implementing the INSPIRE Directive, all countries have made certain steps in order to make the geospatial data defined by this directive accessible (Figure 1). The solutions applied differ in the quantity and sources of available geospatial data, as well as the applied technological solutions. Different approaches have been used in the legal regulation of the field of national spatial data infrastructure. In some parts of the region, special laws have been adopted (Albania, Croatia, Macedonia), while in other countries this area has been regulated within the laws regulating the field of state survey and cadastre.

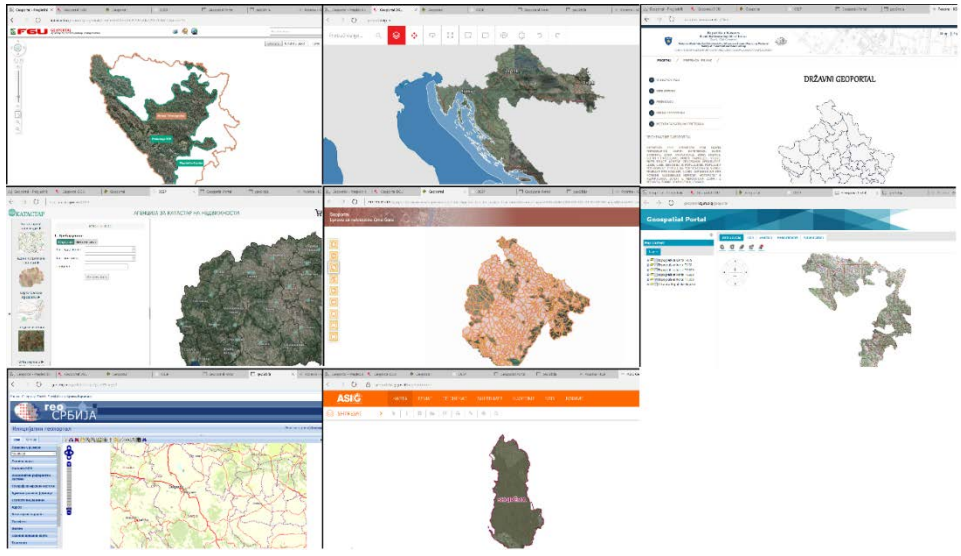

Figure 1.Geoportals of the countries of the Western Balkans

2.2. RECENT RESEARCH

In the countries of the European Union, as well as in the countries of the region, a considerable number of research have been carried out in the area of establishing spatial data infrastructure. A part of the research indicates the importance and role of the cadastre in the national spatial data infrastructure [2] [3]. There are also examples of web real estate cadastre application based on service-oriented architecture and GIS technology [4]. A part of the research carried out in the countries of the region is also relevant to the review of the establishment of spatial data infrastructure from the point of the strategy and the definition of the institutional framework [5], and an overview of the state and results of the implementation of the INSPIRE Directive [6].

3. TECHNICAL SOLUTION

The aim of presented technical solution for geoportal is to ensure modern aproach to web app development and simplicity of use. For the development of geoportal for the display of cadastral data, JavaScript programming language and MERN stack was used (Figure 2). MERN (MongoDB, Express.js, ReactJS, Node.js) is an acronym that is named after the solutions used to implement applications, from the database level (MongoDB), through the service level (Node.js and Express.js) to the user interface (ReactJS). This approach is particularly suitable for creating web applications with a high level of interaction. GeoServer was used to store, style and enable the availability of georeferenced graphic data. To get data from GeoServer, the JavaScript OpenLayers library was used.

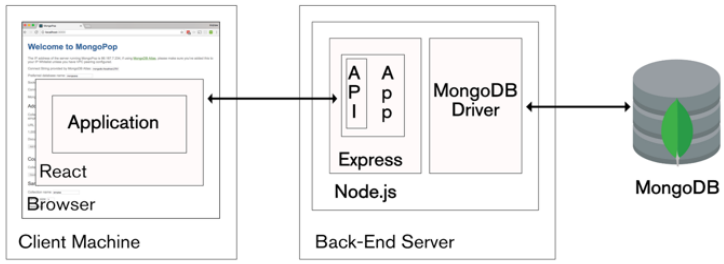

Figure 2. MERN architecture [7]

In the context of software design, components represent modular units with a defined interface [9]. The component diagram shows the organization and relationships between components. A diagram of components for a concrete case study is given in Figure 3.

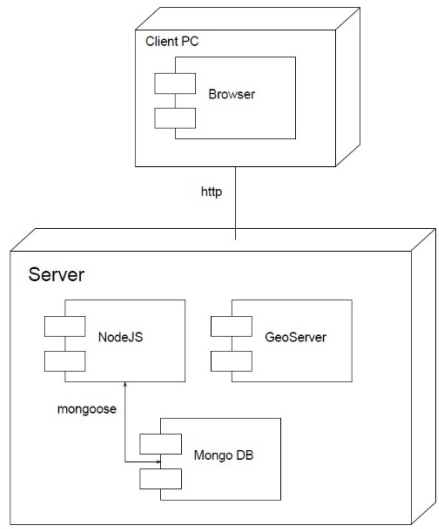

Figure 3. Diagram of components

The Use Case Diagram provides an overview of usage cases, actors, packages and so on. The UML (Unified Model Language) specification often describes the use case diagrams as a class diagram specialization, which are structural diagrams [8]. A diagram of use cases for this case study is given in Figure 4.

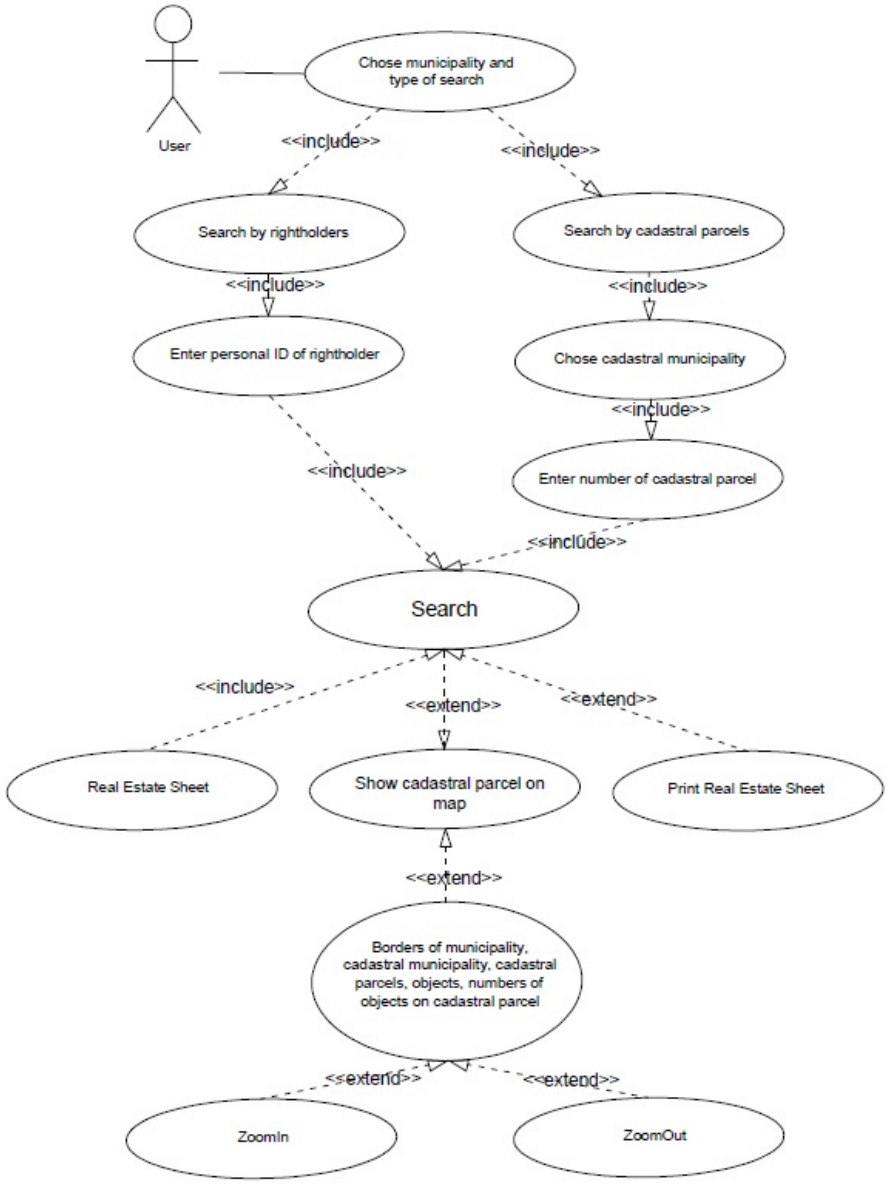

Figure 4. Use case diagram

3.1. DATABASE

For the purposes of the case study, the MongoDB database (NoSQL) was used. The basic characteristics of the MongoDB database are the lack of relationships and documentation based. In the example shown, each database instance represents a single sheet of real estate cadastre stored in a JSON (JavaScript Object Notation) format, or a binary variation of this format known as BSON (where B is a Binary tag) (Figure 5).

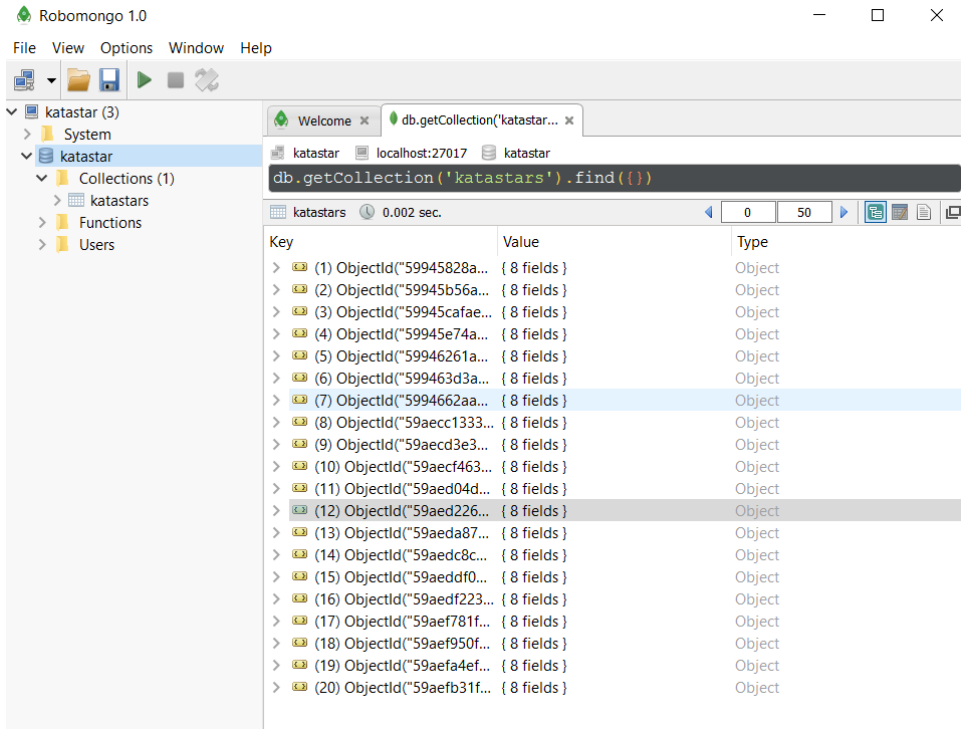

Figure 5. Instances of database

For each document, a unique identifier, ObjectId, is automatically generated, similar to the primary key in SQL databases, and there is the possibility of defining its own unique identifiers. The documents are made up of field-and-value pairs [10], and the structure of the document is given in Figure 6.

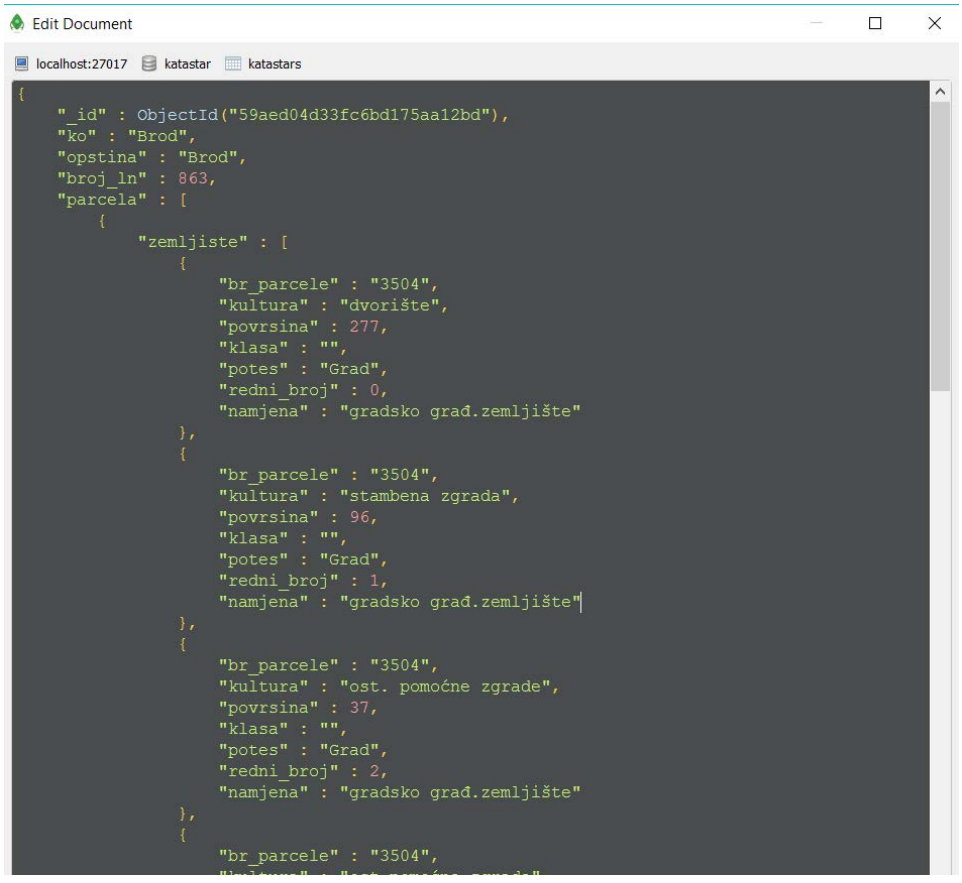

Figure 6. Structure of the real estate sheet No 863 CM Brod in database

3.2. SERVICES

The presented solution is based on the REST (Representational State Transfer) architecture model.

In this case study, two services were used:

- Service for serving alphanumeric data from the database (Express.js service that uses the data contained in the MongoDB database katastar, in the collection of objects katastars) and
- Graphic Data Service (GeoServer to which the graphic data in the .shp format is stored and where the data is styled).

Sending request to the server for displaying the data from the real estate database based on the number of cadastral parcel and identification number of the right holder on immovable property is shown in Figure 7 and retrieving data from database and sending response to client side is shown in Figure 8. Retrieving graphic data in form of feature from GeoServer by using OpenLayers library is shown in Figure 9.

```
// PRETRAGA PO PARCELAMA
pretraziParcele(e) {
   e.preventDefault();
   var br_parcele = this.refs.parcela.value;

   fetch('/api/katastar-parcela?br_parcele='+ br_parcele).then(function(data) {
     return data.json();
   }).then(json => {
     this.setState({br_parcele: json})
   })
   }



 // PRETRAGA PO KORISNICIMA
 handleSubmit(e) {
   e.preventDefault();
   var jmbg = this.refs.posjednik.value;

   fetch('/api/katastar-posjednik?jmbg=' + jmbg).then(function(data) {
     return data.json();
   }).then(json => {
     this.setState({posjednik: json})

   })
   }
```

Figure 7. Request to the server for displaying the data from the real estate list based on the number of cadastral parcel and identification number of the right holder on immovable property

```
//Vracanje posjednika prema jmbg
router.get('/katastar-posjednik', function(req, res, next){
     Kat.find({
        posjednik: {$elemMatch: { jmbg: req.query.jmbg}}

     }).then(function(kat) {
        res.send(kat);

    })
})


//Vracanje parcela
router.get('/katastar-parcela', function(req, res, next){
     Kat.find({
     parcela: {$elemMatch: { zemljiste: {$elemMatch: { br_parcele: req.query.br_parcele}}}}
     }).then(function(kat) {
        res.send(kat);
    })

})
```

Figure 8. Retrieving data from the database and replying to the client side

```
var Opstine_RS = new Vector({
    source: new SourceVector({
        url: 'http://localhost:8080/geoserver/wfs?service=WFS&' +
        'version=2.11.1&request=GetFeature&typenames=brod:Opstine_RS&' +
        'outputFormat=application/json&srsname=EPSG:3857&' + 'Access-Control-Allow-Origin:*',
        format: new GeoJSON()
    }),
    style: new STYLE({
      stroke: new Stroke({
        color: 'rgba(0, 0, 255, 1.0)',
        width: 2,
       label: "${Opstina_RS}",

      }),
    }),
    visible : true,
});


var koRS = new Vector({
    source: new SourceVector({
        url: 'http://localhost:8080/geoserver/wfs?service=WFS&' +
        'version=2.11.1&request=GetFeature&typenames=brod:NM_RS&' +
        'outputFormat=application/json&srsname=EPSG:3857&' + 'Access-Control-Allow-Origin:*',
        format: new GeoJSON()
    }),
    style: new STYLE({
      stroke: new Stroke({
        color: ' #eeeeee',

        width: 2

      }),
    }),
    visible : true,
});
```

Figure 9. Retrieving vector data from GeoServer via WFS service

4. RESULTS AND DISCUSSION

The user interface is created to allow easy searching and display of alphanumeric and graphic data, and also offers the possibility of printing real estate cadastre sheets (Figure 10, Figure 11). The Javascript library of ReactJS was used for creation.

The display of the contents of the real estate sheet is divided into four groups:

- Rights holders,
- Parcels,
- Objects and rights holders on objects and lots and
- Restrictions and rules.

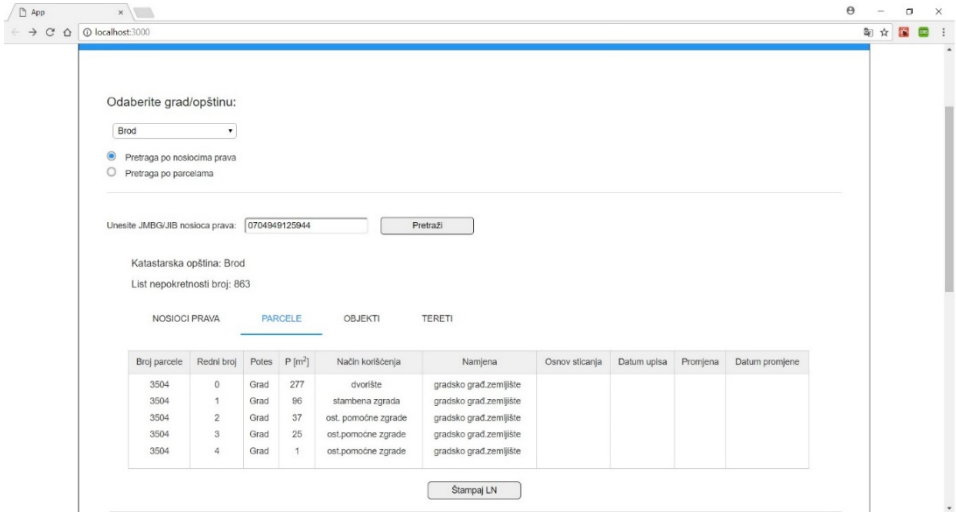

Figure 10. Search result based on identification number of real estate right holder

For each of the above data groups, the values of the following fields from the database, analogue B, A, A1, B1 and V sheet of the real estate sheet are shown:

Table 1. Content of real estate cadastre sheet splitted in categories

Right holders	Parcels	Buildings	Right holders on objects and lots	Restrictions and Rules
Name/Title	Parcel number	Parcel number	Name/Title	Parcel number
Scope of right	Number	Building	Scope of right	Number of restriction
Type of right	Division	Sub-sheet	Type of right	Registration number
Type of property	Area	Use	Sub-sheet	Restriction/rule description
Type of scope	Use	Area	Type of property	Registration date
	Allocation	Address	Type of scope	
	Legal ground for aquisition	Legal ground for aquisition		
	Registration date	Floor		
	Number of amendment	Number of floors		
	Date of amendment	Registration date		
		Number of amendment		

		Date of amendment		

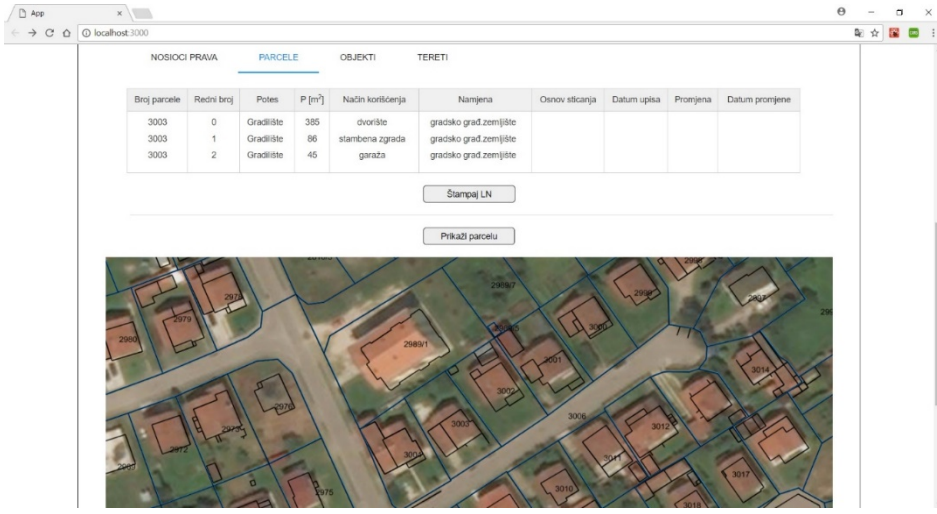

Figure 11. Display of cadastral parcel in the real estate sheet and on the digital cadastral plan

Based on rendered data from GeoServer, there is possibility of displaying the boundaries of political and cadastral municipalities, settlements, cadastral plots and facilities.

5. CONCLUSION

Bearing in mind the rapid development of information and communication technologies and their impact on the field of land administration, it can be concluded that investing in the development of modern services that enable the availability of data from public records through the Internet has complete justification. In the field of geospatial data, special and even primary importance is given to data on real estate, which are under the jurisdiction of state institutions for geodetic and property-legal affairs. Benefits from the implementation of such technologies are multiple, both for users of geospatial data, as well as for different entities within the jurisdiction of a particular type of geospatial data. The solution applied is characterized by a modern approach in terms of used development environments and libraries (Express.js, ReactJS) and ease of user interface.

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52| Претходно саопштење
Preliminary report
doi 10.7251/STP1813699T ISSN 2566-4484

SPACE, CONSTRUCTION AND PLANNING. AN OVERVIEW OF THE CURRENT URBAN CONDITION OF SURROUNDINGS IN POST-SOCIALIST CITIES IN THE SEE REGION

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Abstract:

Urban residents worldwide express a desire for contact with nature and each other, attractive environments, places in which to recreate and play, privacy, a more active role in the design of their community, and a sense of place identity. However, the spatial and urban planning system does not provide conditions for a such way of urban development. It is often completely opposite, so cities are going developing without meeting the needs of their citizens and neglecting so much needed relation between spatial resources, system of planning and process of construction. The roots of this problem arise in the period after World War II, so the work represents a theoretical critique of modernist city and physical planning. Since 25 years after the fall of socialism and the transition period, there has not yet been estabished a system of planning that would correspond to the needs of the contemporary context of a new urban age, this analysis calls for re-thinking of spatial and urban planning, considering the relationship between the context, the planning and construction process. The focus of consideration are space as the basic potential and resource, and the role of planner as of the main actor of process.

Keywords: spatial and urban planning, urban conditions, SEE region

Građani širom svijeta izražavaju želju za kontaktom sa prirodom, jedni sa drugima, atraktivnim okruženjima, mjestima za igru i rekreaciju, za privatnost, aktivniju ulogu u oblikovanju njihove zajednice i osjećaj identiteta zajednice. Međutim, sistem prostornog i urbanističkog planiranja ne pruža uslove za takav način urbanog razvoja. Često je sasvim suprotno, tako da se gradovi razvijaju bez zadovoljavanja osnovnih potreba svojih građana i zanemaruju toliko potreban odnos između prostornih resursa, planiranja i izgradnje. Korijeni ovog problema sežu u period poslije drugog svjetskog rata, tako da rad predstavlja teoretsku kritiku modernističkom gradu i fizičkom načinu planiranja. S obzirom da ni tokom 25 godina perioda tranzicije, još nije uspostavljen sistem planiranja koji bi odgovarao ptrebama savremenog konteksta novog urbanog doba, ovaj rad poziva na ponovno promišljanje prostornog i urbanističkog planiranja, preispitujući odnos između konteksta, procesa planiranja i procesa izgradnje. U fokusu razmatranja su prostor kao osnovni potencijal i resurs, te uloga planera kao glavnog aktera procesa.

Ključne riječi: prostorno i urbanističko planiranje, kontekstualni uslovi, Region Jugoistočne Evrope

1. INTRODUCTION

Post-socialist cities in the SEE region are facing the problems of the decline of traditional industries, unemployment, the spreading of marginal urban zones, the decline of downtowns, social exclusion, a high level of contamination and an overall destruction of the environment. Rural areas, although often in advantage due to the better quality of the environment, are facing economic pressure, often associated with the loss of basic services and access to them as well as shrinking hinterlands. These trends in cities and rural areas are additionally threatened by globalization [1] and an even increasing cultural homogenization [2]. This leads to further development pressure and the loss of a local identity [3], [4].

On the other hand, the spatial and urban planning system does not provide conditions for an urban development which meets the needs of citizens and pointing so much needed relation between spatial resources, system of planning and process of construction. Plans, often distant form people's needs, do not cope with all aspects of reality; and in most cases, never reach to be completely implemented into the real urban space. They are often much more close to abstraction in the conditions of contemporary world [5].

Thus we may say that our cities are facing serious challenges, the resolving of which requires a better integration of the activities of the authorities and communities and of business interests. Nevertheles, to face this, firstly the system of spatial and urban planning should be re-considered in order to improve relationship between the context, the planning and construction process.

2. METHODOLOGY

The analysis is based on theoretical framework [6] a long-life professional experience as well as on the method of a long-term observation, which permits studying city life in the native environment in order to understand "things" experientially and from the real-life perspective.

The paper examines the current condition for spatial setting (surroundings). The issue is seen through the lense of three main spatial properties: (1) space as the basis of urbanization including demographic and functional component, (2) space as a requirment in contruction and (3) space as an object of councious human activities. The aim is to understand problems of contemporary urban and spatial planning process as the constant process of change in cities [7] as well as to propose future main tasks and strategic principles of planning. It should demonstrate the importance of professional expert-oriented approach supported by researches, experimental projects, innovative methods and techniques that are subject of constant reviewes and rethinking cities in relation to the entire territory.

3. SPATIAL AND URBAN PLANNING IN LOCAL CONTEXT

The system of spatial and urban planning was for a long time suffering from the uncontrolled embracing of "models" imported from outside, which were not compatible

with either the needs or the capacities of the country in which they were being "implanted". The shortcomings of this system lied in the approach, i.e. in reliance on the old Athens Charter [8], which was characterized by rigid functionalism, instead of the promotion of a vision founded on integrated and connected towns and regions, i.e. territories [9], which are easily accessible for all who live and work there or who visit them.

Of all the mistakes made by city planners in the postwar era, the passion for highway construction has to be one of the most foolhardy. After the early success of systems like the freeways, cities everywhere were carved up to make way for giant roads, crashing through neighbourhoods and creating opportunities for “comprehensive redevelopment”. This was considered progress, a necessary part of entering the modern world [10]. But some strange things happened – As time went on, communities began rejecting the plans and fighting back against the bulldozers, halting development in its tracks and kickstarting the modern conservation movement [11]. The main problem in the approach to planning was limited connectivity, not only in the physical sense, but also in the sense of the temporal connection between the multicultural roots that have formed our identity and the local features.

On the other hand, 25 years after the fall of socialism there has not yet been estabished a system of planning that would correspond to the needs of a new urban age. Since planning was undeveloped, it had no influence as professionally oriented in the period of socialism. During the turbulent and dynamic transition period, the system of urban planning functioned without the appropriate legal framework, retaining the socialist model of physical planning, which did not correspond to changes, so changes in urban area were often faster than planed ones [7].

One can see from the aforesaid that is necessary to change the approach to spatial and urban planning by relying on the vision of the New Athens Chapter [12] according to which contemporary construction has its basis in integrated space [13]. In that context, one should bear in mind that, within the various activities forming the term of production of space, there are different approaches that a spatial planner needs to envisage in critical and analytical terms. Thus, the following types of approaches stand out in the explanation of the role of spatial settings.

The spatial settings of development can be envisaged in such a way that the form of a setting can be predetermined, which can be controlled by means of "codes" and regulations [14]. The opposite line of this thought claims that the path along which, for instance, a population forms groups, has been determined through a free choice of power and multiple interests and choices — so they can never be effectively conducted by means of any predetermined order. As a contrast to this, there is a free choice, or some kind of informality, but spatial planning supporters claim that such a thing is not easy to define, i.e. that the choice of space for constructors and freedom in that context are not so obvious. On the other hand, some scholars stress the importance of “the autonomous potential of self-organizing system” that is a “critical alternative” to the progressive globalization of neo liberal states [15].

Anyway, it is certain that space, as a kind of phenomenon, unites various activities within itself: those of constructors, architects, urban planners, spatial planners, landscape architects, local authorities, different stakeholders, etc, but also inhabitants, which are everyday more allowed to take public participation or to take other kind of responsibility of acting in urban space. In that context, we will focus on the three main properties of space which are, (1) space as the basis of urbanization including demographic and functional component, (2) space as a requirement and (3) space as an object of councious human activities [16].

3.1. SPACE AS THE BASIS OF URBANIZATION

3.1.1. THE INFLUENCE OF THE DEMOGRAPHIC COMPONENT ON THE FORMATION OF THE CHARACTER OF A SPATIAL SETTING

In general, an increase of a population leaves its mark on the urban growth, the structure and form of cities, and also, through trends of migration dynamics, on other elements forming part of space: redistribution of workforce, shortage of flats, etc. Thus, demographic trends can willingly or unwillingly cause changes, disturb previously established rhythms or establish new systems of physical relations within an area.

3.1.2. THE INFLUENCE OF A FUNCTIONAL COMPONENT OF URBANIZATION

Functional component of urbanization is a concrete social reality which has its own meanings, marks and events, and thus needs to be approached as such. Unfortunately, many countries, wishing to be more developed, attempt to imitate the programmes of rich postindustrial countries on the basis of Walt Rostow's thesis which reads as follows: "Development— historical imitation = westernization" [17].

Certainly, there are steps aimed at reaching means between affluence and a well-organized industrial and post-industrial system, but that connection is by no means a simple one. It is certain that, due to the existence of non-industrialized countries, many of those industries were able to commence their development in the first place. In addition to general factors, which point the importance of economic influence, there are also some elements which exert a direct influence on space, such as traffic, dwelling or commerce as basic urban facilities [18], [19].

Traffic stems from the human need for communication due to spatial separation between various activities. Thus, trends in traffic or transport of an activity from one location to another is important for an urban area also because of the creation of an impression that such trends are indispensable, or maybe undesirable. Dwelling does not result only from the influence of a demographic and spatial component — it also represents a phenomenon itself — through an expression of the satisfaction of needs. On the basis of its inherited fund, dwelling acts as a determining factor of the spatial organization of a city. Industry and commercial facilities which later replaced it, in its own way, exerts an influence on the urban structure through its location-related requirements.

3.2. SPACE AS A REQUIREMENT IN CONSTRUCTION

Viewed in these terms, space affects life, the way of living and production of power with all its elements. Thus, the land, as a collection of all the forms of the using of space, has drawn the attention of scholars, above all from the aspect of its value, which contributes to the establishment of a balance between the available areas and the effective population size [20]. However, the land acts at the same time as a limiting factor for population density. When viewed, however, through the prism of urban needs, the suitability of land in terms of tehnical requirements has a certain value and role, whereas, on the other hand, it is expected to meet the needs of housing and recreation zones as well. It is also the basis for the accommodation and distribution of various activities and, as such, it plays a significanrt role in the "harmonization" of the natural and created environment.

Wherever insufficient importance is attached to such harmonization, it is the soil that influences, with its price, the choice of a location for construction. It is climate as well that has to be taken into account in the conceptualization of a project as a whole and in each of its elements: the base and orientation of buildings, the formation and character of a structure, the spatial scope and the areas between buildings. Space is also a setting for maintaning links for traffic and the establishment of contacts.

3.3. SPACE AS AN OBJECT OF A CONSCIOUS HUMAN ACTION

The development of human consciousness has led, throughout history, to new ideas according to which one may influence the formation of a setting. This is an expressive or artistic space. From the aspect of spatial development, in order that an idea should become a concept, all the aspects of overall orientation need to be understood: its production conditions and relations, its social context, its area with its meanings — all united through a person — constructor / house builder. However, in order to be understood, all these aspects of overall orientation, which manage human relations, need to be experienced through the specific elements of spatial situations, which, on the same conceptual principles, is to produce various models of urban settings.

Thus, before anything else, the differences in the conditions and way of living, in relations between the "common" and the "personal" and in the types of their concretization are to provide information about an environment. That confirms that it is the human act transforming the environment on the basis of the given conditions that is in the focus of "events" in any case. Thus construction does not imply built areas only, but also a system of life, i.e. a broader term signifying the creation of a wide range of space producers

4. FUTURE MAIN TASKS AND STRATEGIC PRINCIPLES OF PLANNING

Spatial and urban planning is a practical expression of the concepts that offer an equal opportunity to citizens and other urbn actors alike for using their respective potentials in the best possible manner, no matter where they are situated. Due to its integrative nature, spatial planning has a potential to coordinate strategic actions by taking into account the needs of local communities. It is founded on numerous principles of harmonious, balanced, efficacious and sustainable territorial development. Spatial planning promotes economic and social cohesion as it translates the principles of balanced and sustainable development into practical activities for individual towns and regions.

During the assessment of tasks and establishment of policies, spatial integration demands an integrative, proactive and participative approach to design, communication and monitoring. The aforesaid principles apply whether spatial planning refers to the spreading of a town, urban development, new expansions, new infrastructure, urban regeneration, restoration, local initiatives or individual projects. Activities and interventions refer to all the types of areas: residential areas, historic centres, downtowns, business centres, industrial areas, ports, tourist locations, green zones, rural areas, suburbs, etc.

The role of a planner is to react and respond to events in society and to the laws and policies in the field of planning. Whether that will be the role of a visionary, a technocrat manager, an advisor, supervisor or instructor, depends on the various political and social frameworks of a context in which they act. However, an urban and spatial planner in new conditions have to find new, innovative ways and to experiment with more flexible environmental standards and regulations. In comparison to other disciplines, spatial planning stands out due to its basic focus on the interests of society, settlements and regions as a whole and long-term future. In that context, spatial planners are committed to serving the general interest. Spatial planners analyze, compose, implement and monitor development strategies, policies, programmes and key projects. They also contribute to professional advancement and research in order that education should continuously follow the demands of present and future times.

In this context the planning practice, culture and paradigm should change towards critical thinkng of the city, innovations, transdisciplinarity, reinventing planning as a part of good urban governance, as well as to flexible planning strategies etc. Integrated urban planning and design should be seen as a mechanism for creating and achieving sustainable and resilient settlements having finally in mind that continuous plan development process itself should be seen as a methodology for contemporary urban planning.

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53| Стручни рад
Professional paper
doi 10.7251/STP1813706J ISSN 2566-4484

PARTICIPACIJA U PROJEKTOVANJU: OD RETORIKE DO PRAKSE (I NAZAD?)

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Rezime:

Participacija u urbanom planiranju je inkluzivni, demokratski, javni proces urbanog planiranja i odlučivanja, naročito važan za prostore kod kojih se složene društvene i ekonomske okolnosti mogu pogrešno interpretirati primenom standarne top-down metode. Rad preispituje stvarne doprinose ovog modela implementiranog na izgradnju javnih prostora i kulturne infrastrukture u okviru projekta Novi Sad evropska prestonica kulture 2021 (EPK 2021), koji je zasnovan na demokratiji, decentralizaciji, inkluziji i participaciji građana u kreiranju urbanih prostora. Strategija je pokrenuta sa nekoliko projekata koji se bliže realizaciji. Iz ovog procesa izvedeni su zaključci o mogućnostima realizacije, kao i prednostima i slabostima strategije u odnosu na konkretne projekte, ali i istaknuta potreba o daljem unapređenju urbane prakse i neophodnim izmenama sporih i nepripremljenih mehanizama gradske administracije.

Ključne riječi: urbano planiranje, urbana participacija, bottom -up planiranje, Novi Sad

DESIGN PARTICIPATION: FROM RHETORIC TO PRACTICE (AND BACK?)

Abstract:

Design participation is considered an inclusive, democratic and transparent process of urban planning and decision-making, particularly important for environments where complex social and economic realms could easily be misinterpreted in a common top-down design approach. This paper examines actual contributions of this methodology, implemented in ongoing strategies for designing and building public spaces and cultural infrastructure as part of the project Novi Sad European Capital of Culture 2021, which is based on democracy, decentralisation, inclusion and citizens' participation. Now, these strategies were put into action, with several projects prepared, launched and brought closer to actual realisation. This process revealed conclusions inrespect to implementation possibilities, as well as its strengths and weaknesses in actual projects, and ephasized the need to further improve urban practice and undertake change of the slow and unprepared procedures of the City administration.

Keywords: urban design, participative design, bottom-up design methodology, Novi Sad

1. SOCIAL SUSTAINABILITY AND PARTICIPATION

For the purpose of discussion of urban sustainability and urban life, if we take a standpoint that social sustainability (the meaning of which is a cause of much debate), is a process and not a final state of society, participation in urban planning may be considered one of the tools in creating urban, i.e. social sustainability of the urban environment.[1] In that sense, social sustainability can be considered as a series of procedures implemented with the aim to raise awareness of the space we as urban inhabitants occupy.

From a sustainability viewpoint, public spaces that have potential to gather a number of social groups are paramount for functioning of a city. Sociologists interpret public space as a spatial prerequisite for spontaneous sociability and social cohesion [2]. According to Bassand, urban function is based on a number of urban processes, but also on actors that participate or influence these processes in any way. Amiability of these actors builds important elements of social cohesion. „Urban functioning represents the agglomeration of very complex interdependent activities which lead to confrontation, which needs to be managed by urban sociology.“[3] The need to identify and understand these interdependences, and avoid confrontation, on the level of public space, leads to the need for public participation in identifying and designing spaces of importance to the community.

Public participation has many facets; this paper considers participation as citizen participation in designing identity of public spaces. Participation is of tremendous importance in urban planning of public spaces and is considered an approach to planning and shaping cities with social sustainability in mind. It’s an organized process that initiates interaction between designers of space and its end users, with the aim to produce a final decision as a result of that interaction.

Participation may be implemented on various levels of urban planning: from participating in choice of space, in specifying requirements for the space in question, choosing between different design options… up to taking part in project realization. Participation cannot be merely a series of discussions whose results will be disregarded, because that would stultify the entire process, causing scepticism and, ultimately, resulting in individuals boycotting any public participation efforts to contribute to communities. All engagement requires certain satisfaction in the sense that final conclusions, as the result of a series of compromises between participants, should, to a certain extent, be incorporated in the realized space.

The basic role of participation is to give back the citizens trust in the decision-making system; as such, participation should not be merely a way to meet formal requirements when approaching spatial planning. In addition, the role of participation is informing the decision-makers about the space and the actual needs of those who use it or consider it their own. It should be noted that the public is rarely unanimous in their demands; that requirements are often mutually exclusive; that different social, generational, cultural and other user groups have disparate needs and perspectives on public space. It is the role of public space to consolidate all these different user groups, and it is the role of participation to aid in creating such a public space.

Also, the importance of participation is in education of citizens, primarily in respect to understanding the complexity of interests surrounding an urban space, in respect to

possible means of reaching consent on controversial topics, and in respect to issues and obstacles in planning and realization of urban spaces in question.

In addition, one of the challenges is choice of the topic that would get an appropriate response (size and importance of a specific public space for the community we wish to include in a participative process, relation of citizens to a given space, whether they experience the space in question as a public one). What also proves a challenge is establishing the level of participation for the public in the process of planning and reaching a final decision, identifying adequate stakeholders, raising public awareness about the space at hand and planning issues as well as establishing focus on the goals.

Lorenz Aggens developed a framework according to which representatives of the public interested in participation in the process may be determined using orbits of activity. Each participation level may be observed as an orbit of activity, whereby the level closest to the decision-making process expends most energy and work on behalf of participants. Aggens identifies the public in six levels, orbits: (1) unsurprised apathetics, (2) observers, (3) commenters, (4) technical reviewers, (5) active participants in the process who invest their work and energy and, finally, (6) co-decision makers. [4] Managing participants' enthusiasm levels is yet another challenge, when the process from planning to realizing a space is a lengthy one. [5]

There is a rich experience base for applying various participations models; however, observed in the context of urban sustainability processes, participation should aim towards raising awareness of the social accountability of individuals towards urban spaces.

2. NEW PLACES: NOVI SAD URBAN POCKETS

The initial assumption is that micro urban units are spaces of enormous potential that offer numerous possibilities for multiplication of importance and meaning of urban space, and that successful urban renewal may be accomplished only through complex, multidisciplinary interventions that combine architectural, economic, social, psychological, historical... aspects of space, whereby the role of social participation in these processes must not be disregarded.

We assume that the biggest contribution of social participation is in recognizing and interpreting functions of micro-urban units, that belong to public urban areas but that remain unrecognized by planners as areas of particular interest. Existence of such urban spaces contributes to developing a feeling of community in urban integration of social groups that accept that space as theirs, and social participation promotes urban education and raising awareness of the significance of public urban spaces. It also contributes to sustainability of those newly-formed spaces.

Novi Sad urban planning anticipates public participation mostly only as part of formal public insight sessions and discussions raised when a plan is being adopted. It is on rare occasions that these procedures cause any attention of the public and result in any form of active participation of stakeholder groups.

This is why the strategy for building public spaces and cultural infrastructure, as part of the project Novi Sad European Capital of Culture 2021 (ECC 2021), is based primarily on implementing such a model of public participation in creating and realizing urban policies and practice; the project highlights the exceptional value of participative processes in disseminating democratic, inclusive and citizen participation in creating

urban environments. [6] In particular, this method is featured in development strategies of small public spaces – spaces identified by the citizens as focal points of their local communities and in which they show particular interest.

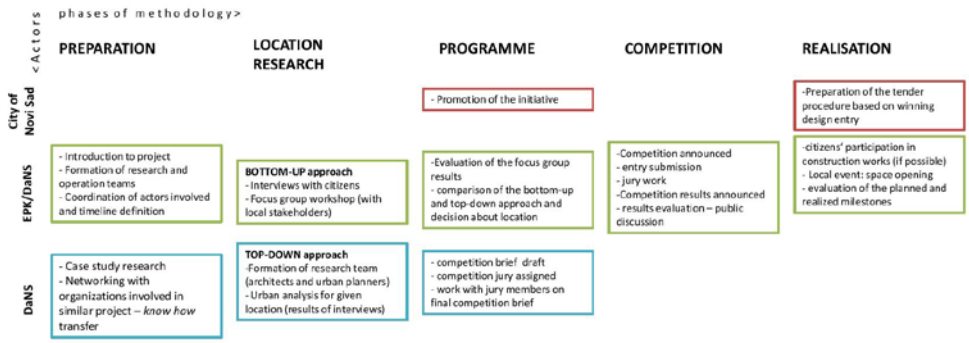
First implementations of these strategies followed immediately after winning the title ECC 2021. Further project development, as presented in the application, encompassed implementation of proposed strategies in physical space. The decision to develop and refurbish urban spaces of all urban and suburban local communities, 46 in total, was immensely stimulating for decentralization processes and citizen education on the topic of value of urban culture. Processes that would lead to realization of these spaces were initially tested during the first half of 2017. They defined the road for a very challenging methodology that was adopted and put to test.

Project New Places (Nova mesta) started its development through two sets of diametrically placed ideas on what participation is, the phase in the process in which its use is justified and in what manner its requirements should be considered and interpreted. The primary standpoint of the ECC Foundation, in charge for project's realization, was in good part formed under the influence of Christian Potiron, an international advisor for citizen participation, whose professional experience in the field of cultural policies, civic initiatives etc. sees participation as the base in all phases of the process of realizing public spaces. Contrary to this, the Association of Novi Sad Architects, in charge for project's realization, places participation as a pre-project methodology that examines the needs that then become the core program proposition of an architectural design competition as the most lively and most public form of professional debate on urban space. Finally, it was concluded that the initial standpoint be realized in an simple and more logical manner in different project, a micro-granting scheme, which completely resides on civic initiative throughout – beginning with the nomination of space, organization of planning and design, with professional assistance, up until project realization; New Places – urban pockets entered realization as a bottom-up approach, beginning with participation in various forms, to then incorporate the conclusions of this phase in a public architecture competition, as well as profiled through careful choice of jury members and citizen participation in further considerations of competition proposals. This seemed justified for several reasons: first, participation of professionals in the process of designing small public spaces is important for establishing best practice in shaping public space, which has been under heavy fire of financially motivated interests, illegal privatization and shady procurement procedures for years; also, citizen participation is highly debatable when there is no awareness, previous experience, or, often, motivation to engage in the process; it could, in certain cases, render the procedure unpredictable and vulnerable; finally, similar work methods implemented in the region imply positive experience and outcomes in respect of establishing this practice, which might lead to other work models in the future.

2.1. Model Testing: Four Urban Pockets of Novi Sad

The first set of spaces that were considered encompassed urban (South Telep, Detelinara) as well as suburban (Kovilj, Sremska Kamenica) local communities in Novi Sad. Image 1 illustrates the established process methodology. It is closely modelled on the one tested in Zagreb, as part of the City Acupuncture Project (2012-2014), whose initiator was the Youth Section of the Zagreb Architects Society; the model resides on micro interventions in urban environment, through interdisciplinary action, participation

of end users and support of authorities [7]. Since this initiative was long-term, they were able to test a top-down method as well – urban research of Zagreb through planning and design methods, which identified spaces and anticipated interventions. Comparison of simulations and actual results that were realized pointed to interesting commonalities and dissimilarities in regard to professionals' standpoint and actual needs of local communities, on the field.



Slika 1. *Diagram of the established work process*

On the other hand, the Novi Sad model was established in a short period of time. Therefore, it could only partly enable result comparison between the top-down and bottom-up approaches in location selection. It could not, however make new conclusions that would enhance design practices and urban policies. Choice of location relied on surveys of inhabitants of the affected local communities, which established their interests and a general frame of local needs. At the same time, an expert research of subject areas was conducted - identification of locations, their urban, ambient and social values, as well as potential for interventions. Specific locations, usually three, that were the subject of focus groups, were determined by superposing these two analyses. Focus groups were guided conversations with representatives of stakeholder groups, local government, as well as citizens deemed in surveys as active contributors in areas in question, or those trusted by the local inhabitants. Introductory format of focus groups was comprised of a short expert talk on urban pockets and a wide variety of urban spaces that fall under this category, means to articulate them and the range of possible approaches to this problem. The goal of this talk was to familiarize workshop participants with the wide range of potential interventions, prior to actually starting work. Following this, the participants were introduced to the "nominated" spaces and the participants commenced a guided discussion on the topic at hand. In certain cases, spaces identified in surveys were not equally rated by citizen participants of focus groups. Also, spaces identified as potentially valuable during research, were sometimes deemed not a priority in their local community. Focus groups were moderated by an urban sociologist, and they were most productive when they were established as a system of participants equal in significance, who were ready to engage and listen to each other. Dialog was extremely constructive and it often led to election of one space that stood out for its significance and which was then, as such, carefully programmed to meet the needs of different citizen stakeholder groups.

If we analyze the undertaken participation process in project "Nova mesta" using Aggens's definition of orbits of activities, we can distinguish all levels of public involvement. There is certain number of citizens unwilling to participate, or those uninterested for process itself, which are described in orbits 1 and 2. However, since the project is based on small scale intervention affecting local communities, living and working close to those spaces, the number of "unsurprised apathetics" was insignificant, what additionally justified application of participative methodology for this case. The second orbit, the observers, were group of those citizens interested only in taking the information about the project during public survey phase, but not wanting to give any feedback. This orbit also included people who were informed about the programme through media, or other means, what makes their number difficult to define. The next participation orbit - commenter - included people interested in project but not motivated to be actively involved. They were ready to share information, take part in interview and point out the actual problems of the community. Their inclusion was essential for two reasons: firstly, their involvement led towards actual nomination of space to be considered for design intervention, which are reflection of the local community needs; secondly, this was first step in introducing participation practice of this kind to wider community and promotion of its potential to actually change the perception of public space. This orbit is considered for potential resource for further expansion of the modalities citizens' involvement into urban politics and practice.

The most important aspect of the participation process in actual creation of the local public space is at the level of the active participants' orbit. Although our local communities has only vague comprehension of the participation practice, and what might be the benefits, the number of those interested to actively contribute to the process, in all phases, was above the expected. The enthusiasm of the involved citizens was boosted by the fact that spaces at hand were actual choice of the local community, so they could easily recognize their interest and problems, as well as potential of the programmes they proposed to enhance quality of life on local scale. Also, the new format of the guided talk in focus groups, the relatively short period of time in which all the phases of the process were executed was essential for high level of enthusiasm between participants, along with strong promises made about actual realization of the space, in near future.

Slika 2. *Citizen survey and focus group work*

2.2. Participation and competition practice

The most sensitive part of the entire process was transfer/generalization of results to form an actual project specification. This was the step that differentiated the two approaches to the project from the very beginning. This is why competition participants were presented with some basic space selection parameters as part of preparation activities through emphasizing potential; final functional interpretation was to be left to proposal authors as a unique creative contribution to understanding the focus group dialog, which was made available to applicants in the form of workshop proceedings. This approach created an 'interpretative' field and reduced the risk of hinting applicants to a specific 'desired' design solution. This was later visible in the proposals themselves, which significantly ranged in approach. Also, the four spaces that the competition was announced for, offered urban environment proposals of radically different qualities – ranging from natural embankments, to hi-frequency urban residential areas.

Another valuable asset in this process, defined by Aggens as "technical reviewer", was in this case active partner during the participation process (Architectural Association of Novi Sad), and included even competition jury, who were engaged in preparation of the Call, establishing evaluation criteria, and avoiding potential obstacles of the rather new competition practice based on this methodology. The competition jury was a response to its regional character; it did, also, gather relevant experts from a range of architectural practice domains – initiators of such processes in the region that offered the know-how, representatives of competition backers, local government responsible for realization, urban sociologists and architects prolific in similar design practices.

Competition proposals and winning projects illustrated a distinct diversity in approach and proposed solution, which enabled establishing a practice that fosters a contemporary approaches and essentially establishes modern values in local communities, from the very beginning of the project. Public debate surrounding winning competition proposals gave positive feedback on selected projects and a clear confirmation that architectural solutions are outside of the range that could have been anticipated by inhabitants of the affected communities. This in turn gave validation to the notion of active expert involvement, and the education benefits that these realizations will have on the inhabitants.

3. CONCLUSION REMARKS: CHALLENGES OF PARTICIPATION PRACTICE IMPLEMENTATION

Space is not merely a physical dimension. It is comprised of a series of intangible values, content and events that facilitate a range of relationships between its users. [8] Public spaces are symbolic and integrative in character, and it is there that inhabitants of a community build their collective identity. They must be determined: spatially, structurally and programmatically – functionally organized in such a manner so as to guide, attract and retain potential users. Translated into a spatial framework of the micro units in question, such organization would mean meeting the needs of existing users and appending content that could attract users from other social groups. Herein lies the basis for user participation when identifying and designing public space.

Slika 3. *Winning proposals: upper left -"Linear bench + eaves" for the Zmaj Jova Square plateau in Sremska Kamenica, upper right - Drive-through marketplace (park and marketplace space in Kovilj), bottom-Pavillion/pontoon (south Dunavac riverbank)*

Finding a solution throughout all aspects of the process of designing a space (from functional to visual): within financial and physical constraints, designer aspirations and requirements of numerous stakeholder groups is the main challenge of urban planning. Participative processes initiated by the Novi Sad ECC 2021 project anticipate new practices in urban planning, which are, sadly, used rather selectively. In contrast to the New Places project, other projects focusing on infrastructural projects do not meet even the basic requirements of sound architectural practice – finding the best solution through open architectural competition call. The participation process itself is, in some cases, formally conducted before, and in other, after the design procurement procedures have already been concluded, with the basis of project specification not reflecting the actual needs of the locality affected.

The initial set of spaces that have followed this entire methodology are currently, according to city officials, on the "brink of realization" (which is also to be procured and built at lowest price), but actually even left out from the new planning and regulation documents, which are being developed and ratified in the meantime. The high intensity of the process, in preparation phase, high level of citizens' awareness and activism, is

coming close to become yet another argument for the ignorant, but sadly common, attitude towards citizens' initiatives. The main reason for this situation lays in slow and unprepared mechanism of city administration, and strict and rigorous follow of the same by city officials. So far, we have situation where almost surprising level of citizens' motivation to get involved, in spite of having modest or no knowledge about its possibilities, almost certainly no practice or experience with same, is taken for granted, and not stimulating for making structural changes in already established procedures. The fact that no actual space is still under construction stands as a reminder of numerous discrepancies existing within the system. Even when the first of the local public spaces starts its makeover, it will be just the beginning of a very uncertain process, which does not define: the role of a designer in the process of realization, production of project execution plans and their contractor, restrictions that public procurement procedures impose on choice of material and urban equipment. All this points to the need for further work on adjusting specific procedures, administrative mechanisms, as well as education of all participants in the process about the need for such changes.

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54| Стручни рад
Professional paper
doi 10.7251/STP1813715T ISSN 2566-4484

OCJENA IZLOŽENOSTI LJUDI VIBRACIJAMA I BUCI U ZGRADAMA ZA STANOVANJE

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Abstract:

Zgrade namijenjene za rad i stanovanje mogu biti pobuđene na vibracije djelovanjem različitih pobudnih izvora koji se mogu nalaziti unutar ili izvan samog objekta. Strukturne vibracije u zgradama mogu izazvati osjećaj neugode i umanjiti komfor kod stanara, kao i efikasnost osoba koje koriste radne prostorije u zgradi. Neki izvori vibracija mogu djelovati na način da proizvode i dodatne efekte, npr. strukturni zvuk ili zvuk koji se prenosi vazduhom, zveckanje prozora i drugih predmeta u objektu. Standard ISO 2631-2 definiše metodologiju ocjene izloženosti ljudi vibracijama u zgradama, ali ne propisuje granične vrijednosti vibracija kojima mogu biti izloženi stanari ili korisnici zgrada, kao što je slučaj i sa većinom nacionalnih propisa u ovoj oblasti. Za razliku od vibracija u zgradama, nacionalni propisi ograničavaju nivo zvuka koji se emituje u životnoj sredini. U ovom radu prikazan je postupak ocjene izloženosti ljudi negativnom djelovanju buke i vibracija u zgradama, kao i detaljna analiza slučaja u vezi s tim.

Keywords: vibracije u zgradama, buka, izloženost ljudi, metode ocjene.

ASSESSMENT OF HUMAN EXPOSURE TO VIBRATION AND NOISE IN RESIDENTIAL BUILDINGS

Abstract:

Vibration in buildings may occur from different external or internal sources. Where occupants can detect vibration in buildings, it may potentially impact their comfort or working efficiency. Some vibration sources give rise to audible effects such as structure-borne noise and airborne noise, and secondary rattling of building elements or contents. The international standard ISO 2631-2 concerns human exposure to whole-body vibration in buildings, but like most national standards, it doesn't prescribe the permissible vibration amplitudes with respect to the comfort and annoyance of the occupants. Contrary to vibration standards, the national regulations concerning environmental noise prescribe the limits of allowed sound intensity in residential and office premises. This paper gives an overview of the process used to assess the influence of vibration and noise on humans in buildings. Also, a detailed case study regarding adverse comment due to noise and vibration in building is shown.

Keywords: building vibration, noise, human exposure, assessment methods.

1. INTRODUCTION

Occupants can detect structural vibration in buildings and can be affected by them in many ways. Their comfort and quality of life can be reduced as well as their working efficiency [1]. In contrast, it is well known that people tolerate much higher vibration magnitudes in vehicles than in buildings, because vibrations have different frequency range in these two cases. Vibration in building that can be perceived by humans remain in the low- frequency range, close to the frequencies of human body internal organs [2]. Human response to vibration in buildings is very complex. The basic human response to vibration in buildings is adverse comment, which depends on specific circumstances. In most cases, the degree of annoyance and complaint cannot be explained purely by the magnitude of monitored vibration. An analysis of these complaints shows that other parameters related to vibration source (for example work time) or produced by vibration in exposure area (noise) may also give an explanation of the complaints [3, 4]. Vibration sources inside and outside buildings may generate human whole-body vibration, together with the parallel effects, such as structure-borne and airborne noise, induced rattling, movement of furniture and other object, as well as visual effects [5, 6]. The most well-known standards for measurement and evaluation of human exposure to whole-body vibration are ISO 2631–1 (1997) and BS 6841 (1987). Although BS 6841 (1987) was developed as a British standard, it has been used extensively (often in preference to ISO 2631–1, 1997) outside Britain [2]. Some researchers made comparison between standards related to human perception of whole-body vibration in building [7] only quoting the provisions in the standards. Some authors made comparative analyzes between different standards, regarding particular parameters for assessing the influence of vibration on humans, the range of considered frequencies, duration of vibration, signal processing and general approach to the problem [8, 9].

2. HUMAN RESPONSES TO BUILDING VIBRATION

In residential buildings, adverse comment regarding building vibration is probably when the vibration levels are slightly above the threshold of perception. In general, acceptable levels are likely to be related to general expectations of the occupants and are not determined by any other factor such as health hazard in short term or working efficiency.

Thresholds of perception for continuous whole-body vibration vary widely among individuals. Approximately half of the people in a typical population, no matter standing or seated, can perceive a vertical weighted peak acceleration of 0.015 (m/s^2). A quarter of the people would perceive a vibration of 0.01 (m/s^2), but the least sensitive people would only be able to sense a vibration magnitude of 0.02 (m/s^2) or more. Threshold of perception is slightly higher for vibration duration of less than about one second [3, 5].

2.1. CHARACTERISTIC OF BUILDING VIBRATION

Parameters to be considered in vibration analysis are as follows: characteristic of vibration sources, nature of the vibration time history, exposure time to vibration, associated phenomena, i.e. parallel effects. When it vibrates, a building may move as an entity on its foundations (at very low frequencies, up to a few Hz), or individual buildings components, such as floors, may perform their own vibration movement (at higher frequencies, ranging from a few to tens of Hz). The magnitude and direction of vibration will depend on the location in the building.

2.1.1. Sources of building vibration

Vibration in buildings can be caused by different external or internal sources [6].
External vibration sources include:

- traffic (road and underground traffic),
- industrial sources (e.g. presswork),
- construction or demolition works.

This vibration is transferred to a building through the ground, and vibration passing into the building depends on the transfer function between the ground and the building. The dynamic characteristics of a building (eigenvalues) can cause higher vibration levels at some specific frequencies due to resonance. The wind and external airborne acoustic excitation can also generate building vibration.
Internal sources of vibration can be divided into:

- mechanical excitation (e.g. lifts, air-conditioning or ventilation plants, heavier office machinery, washing machines, vacuum cleaners, etc.),
- human induced excitation (walking, jumping, dancing, etc.).

Mixed-use buildings can undergo specific problems, where vibrations caused by human activities in one part of the building are transmitted to more sensitive areas in another part of the building.

2.1.2. Nature of vibration time history

The time history of vibration can be [4, 6]:

- continuous - uninterrupted vibration for the assessment period, daytime or night-time,
- intermittent - perceived in separately identifiable repeated periods,
- occasional - occurring less frequently than intermittent and it is less predictable,
- impulsive - it is a rapid built-up to a peak followed by a damped decay, that might or might not involve several cycles of vibration.

Each of these types of time history can have a constant or variable amplitude.

2.2. FREQUENCY WEIGHTING

The way in which humans perceive vibration depends on different factors, including the vibration frequency content and direction. People are most sensitive to whole-body vibration within the frequency range of 1 to 20 Hz, but there are different human sensitivities to vibration in different directions of excitation. Because of that, different frequency weightings of measured acceleration magnitude are required for the different axes of vibration. The directions of vibration are related to the structure rather than to the human body. The orientation of the structure-related coordinate system shall be as for a standing person, as shown in Fig. 1.

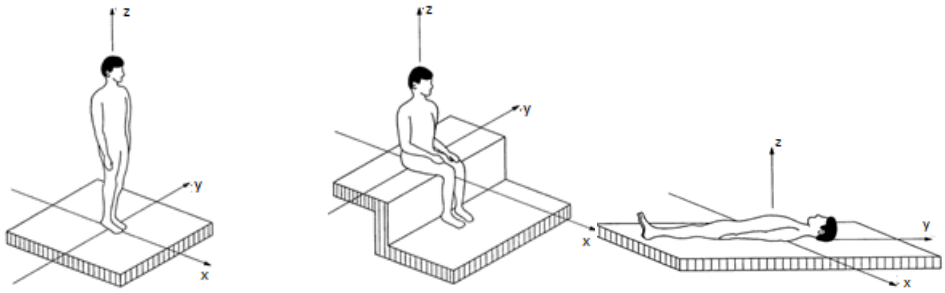

Figure 1. Direction of coordinate system for mechanical vibration influencing humans in buildings [5]

Regarding this issue, different countries have different regulations specified in standards. For example, the international standard ISO 2631-2 [4] specifies the use of the frequency weighting W_m, Fig. 2, which is applicable in the frequency range 1 Hz to 80 Hz, where the posture of an occupant does not need to be defined. This frequency weighting is irrespective of the measurement direction.

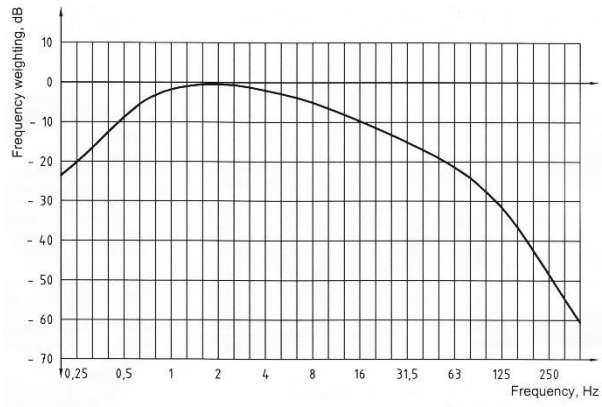

Figure 2. Frequency weighting W_m , with acceleration as the input quantity [4]

On the other hand, British standard BS 6472-1 [6] specifies that different frequency weightings of measured acceleration magnitude are required for the different axes of motion. The frequency range concerned is 0.5 Hz to 80 Hz for the three translational axes: fore-and-aft, lateral and vertical, Fig. 1. The weighting curve modulus W_b for vertical acceleration is shown in Fig. 3a, and weighting curve modulus W_d for horizontal acceleration is shown in Fig. 3b. The weightings demonstrate maximum sensitivity to vertical acceleration in the frequency range 4 Hz to 12.5 Hz and to horizontal acceleration in the range 1 Hz to 2 Hz. The weighting W_b is the most appropriate frequency weighting for use with vertical vibration when the levels of vibration are clearly above the threshold of perception.

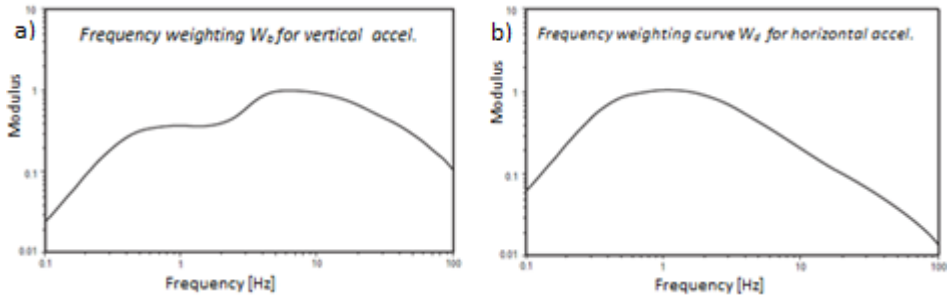

Figure 3. Frequency weighting curves according to BS 6472-1 [6]

2.3. MEASUREMENT OF BUILDING VIBRATION

The ability of a person in a building to sense vibration depends on what he/she is doing, where he/she is positioned in the building, how he/she is coupled to the building, as well as on the dominant direction of the vibration. A person who is moving is less sensitive to vibration than a person who is seated. The coupling is the most direct when the person is standing on the floor. If the person is seated, the coupling is less direct and the seat structure may dampen vibration. In some situations, a bed structure can amplify the vibrations received from the building.

2.3.1. Direction of measurement

The vibration should be measured in all three orthogonal directions simultaneously using triaxial transducer. If the direction of the dominant vibration is known, the motion may be measured uniaxially along the axis in which the weighted acceleration amplitude is the greatest. Transducer should be mounted so as to truly reflect the motion of the object or surface being measured [3].

2.3.2. Location of measurement

The main goal in the selection of the measurement location should be to establish the vibration level at the point of entry to the body. However, that particular location is slightly possible to be identified. So, the vibration should be measured on the floor of the room where the highest magnitude of the frequency weight vibration occurs, or on a suitable surface of the building structure. The way in which a floor responds depends on two factors: whether the excitation is external or internal and whether the floor is “low frequency” or “high frequency” [6]. If the excitation of building is external (ground-born vibration), the rigid body motion or the lowest mode of vibration (so called “dish-shaped” mode) will dominate in the floor response. One or two measurement points in the central part within one-third and two-thirds of the width or length are sufficient to determine the vibration response in this case of excitation. If the excitation is internal (e.g. pedestrian footfalls), floor response will vary according to the modal parameters (natural frequencies, mode shapes and damping) of the floor. Assessment should be made at or near the places where the most adverse comment has been generated, with the typical walking path and pacing rate as excitation.

2.3.3. Duration of measurement

The duration of measurement should be sufficient to ensure statistical precision and to ensure that the measured vibration is typical of the assessed exposure.

2.3.4. Assessment methods

For the evaluation of vibration in buildings with respect to comfort and annoyance, overall weighted values of vibration should be measured. It is preferable to measure vibration in acceleration terms assessed using the frequency weight value r.m.s. (the root mean square value) or the vibration dose value VDV, [4].

The international standard ISO 2631-1 defines the r.m.s. method as a basic method of assessment, but notes that sometimes additional methods are required, such as the vibration dose value method, VDV, or the maximum transient vibration value method, $MTVV$. The r.m.s. method averages acceleration amplitudes in duration time:

$$a_w = \left[\frac{1}{T} \int_0^T a_w^2(t)\, dt \right]^{\frac{1}{2}} \tag{1}$$

where:

$a_w(t)$ is the frequency weighted acceleration as a function of time in (m/s^2), using W_m weightings,

T is the duration of measurement in (s).

The British standard BS 6472-1 [6] describes how to determine the vibration dose value, VDV, from frequency weight vibration measurement. The VDV is used to estimate the probability of adverse comment which might be expected from humans regarding building vibration. The VDV is defined by the relation:

$$VDV_{b/d,day/night} = \left[\int_0^T a_w^4(t)\, dt \right]^{\frac{1}{4}} \tag{2}$$

where:

$V_{b,d\ day/night}$ is the vibration dose value in $(m/s^{1.75})$,

$a_w(t)$ is the frequency weighted acceleration in (m/s^2), using W_d or W_b weightings as appropriate,

T is the duration of measurement in [s].

Where possible, the VDV should be determined from a measurement obtained over the full exposure to vibration, that is 16h for daytime or 8h for night-time period. The VDV method is more sensitive to vibration peaks than the basic method of assessment, using fourth power instead of the second power of the acceleration time history. A doubling or halving of the vibration magnitude is equivalent to an increase or decrease of exposure duration by a factor of sixteen.

After the frequency weight measurement of r.m.s. acceleration or VDV values is completed at the relevant measurement places, their significance in terms of the probability that the determined vibration level might result in "adverse comment" by those who experience it, can be derived from Table 1. and Table 2. These values represent the best judgment currently available and may be used for both vertical and horizontal vibration.

There is no exact definition of the term "adverse comment" in standards dealing with building vibration. It can be realized as a technical rather than legal term. Adverse comment is just the way by which occupants express negative responses to vibration.

Table 1. *The frequency weighted r.m.s. acceleration (m/s^2) corresponding to a low probability of adverse comment [6]*

Place	Exposure periods				
	16 h	1 h	225 s	14 s	0.9 s
Residential buildings 16 h daytime	0.01 to 0.02	0.02 to 0.04	0.04 to 0.08	0.08 to 0.16	0.16 to 0.32

Table 2. *The VDV values ($m/s^{1.75}$) which may result in various probabilities of adverse comment within residential buildings [6]*

Place and time	Low probability of adverse comment VDV ($m/s^{1.75}$)	Adverse comment possible VDV ($m/s^{1.75}$)	Adverse comment probable VDV($m/s^{1.75}$)
Residential buildings 16 h daytime	0.2 to 0.4	0.4 to 0.8	0.8 to 1.6
Residential buildings 8 h night-time	0.1 to 0.2	0.2 to 0.4	0.4 to 0.8

2.4. PARALLEL EFFECT TO BUILDING VIBRATION

Human reaction to building vibration may also depend on related effects which occur at the same time with vibration. Thus, it is necessary to consider all parallel effects such as structure-borne or air-borne noise, induced rattling and visual effects [4, 6].

2.4.1. Structure-borne noise

Vibrations of building structures generate noise which can be heard within the building, whether they are caused by ground-borne vibrations, acoustic excitation from external sources or from some internal sources. The typical characteristic of structure-borne noise is the low-frequency noise in the frequency bandwidth below 100 Hz (for example noise from underground trains, or same internal sources in building).

Structure-borne noise should be measured at the location in the room where its effect is considered to be most disturbing. Very often, it is covered by ambient noise from other sources which creates difficulties in its definite determination.

2.4.2. Airborne noise

Airborne noise heard in building at the same time as vibration is felt might be related to the vibration source. The presence of noise at the same time with the vibration might affect a person's response. In this situation airborne noise could be measured.

Also, the low-frequency airborne noise can be an issue in vibration-related complaints. Typical source of low-frequency airborne noise is the air-conditioning and ventilation system in building. Care should be taken to distinguish between vibration and low-frequency noise.

2.4.3. Induced rattling

The building vibration might cause a parallel effect such as rattle of windows, furniture or ornaments. Their occurrence might emphasize the presence of vibration.

2.4.4. Visual effect

In the case of low-frequency vibration (less than 5 Hz) visual effects may be observed, such as the swinging of suspended features. These factors may emphasize the disturbance and annoyance caused by vibration.

3. ASSESSMENT OF NOISE IN BUILDING

The national standard regarding building acoustics JUS U.J6.201 [11], as well as the Rulebook on permissible limits for the intensity of environmental sound and noise [12] in our country, specify the permissible noise levels in rooms in residential buildings, which should not be exceeded, as shown in Table 3.

Table 3. *Permissible equivalent sound pressure level [11]*

Permissible noise level in rooms in residential buildings 15 min L_{AeqT}(dB)		
Noise source criterion	Daytime (6:00 – 22:00)	Night-time (22:00 – 6:00)
Noise originating from service rooms in building (heating plant substation, transformers, elevators, etc.), home installations (water supply, sewage, etc.) and devices in adjacent flats (various machines and home appliances), as well as noise emitted by stationary sources outside building	40	30
Noise originating from non-stationary sources outside building (e.g. traffic)	45	35

According to ISO 1996-1 [14], the parameter for noise assessment is the A-weighted equivalent continuous sound pressure level measured over time interval of T=15 minutes, L_{AeqT}, defined by the equation:

$$L_{AeqT} = 10\log\left[\frac{1}{T}\int_T \frac{p_A^2(t)}{p_0^2}dt\right] \tag{3}$$

where:

$p_A(t)$ is the A-weighted instantaneous sound pressure at running time t,

p_0 is the reference sound pressure (=20 μPa),

T is the duration of measurement.

Generally, noise generated by building services is a significant problem. Building services can generate noise via airborne or structure-borne paths or both. The amount of structure-borne noise can be reduced by increasing the vibration isolation in a system. That can be done by different sound protection measures [13]:

- Reduction of the structure-borne noise transmission from the tube material to building construction - this is achieved by mounting the tube using elastic elements. By the soft plastic insert, the direct contact between the tube material

generating the sound energy and building construction are eliminated, minimizing the radiation of noise from installations through the building construction to the airspace of the room where the noise could be heard.

- Attenuation of the sound energy extending along the tube - this is achieved by inserting the elastic couplings made of rubber into the tubing. This separates the part of the installation which contains some dominant noise source from the rest of the installation which passes near the places to be protected from noise.
- Attenuation of the sound energy extending through fluids - this is achieved by installing a dampener in the ventilation and air conditioning tubes, which can weaken the noise extending along the tube.

4. CASE STUDY

4.1. PROBLEM DESCRIPTION

The case of occupant's adverse comment to noise and vibration problem in a one-room apartment (studio) located in a mixed-use building (residential/business) in the center of Banja Luka has been analyzed, [10]. According to the national regulations [12, 15], there are six acoustic zones that are distinguished regarding their purpose and permissible levels of outside noise: I) hospital, medical; II) tourist, recreational; III) purely residential, educational, health institutions, public green and recreational areas; IV) commercial, commercial-residential, warehouse without heavy transport; V) business, administrative, commercial, crafts, service; VI) industrial, warehouse, service and traffic area without housing. The analyzed building is located in the acoustic zone IV, in the vicinity of a very busy city street, figure 4a. The apartment is positioned on the first floor, above office rooms which are located in one part of the ground floor and the basement of the building.

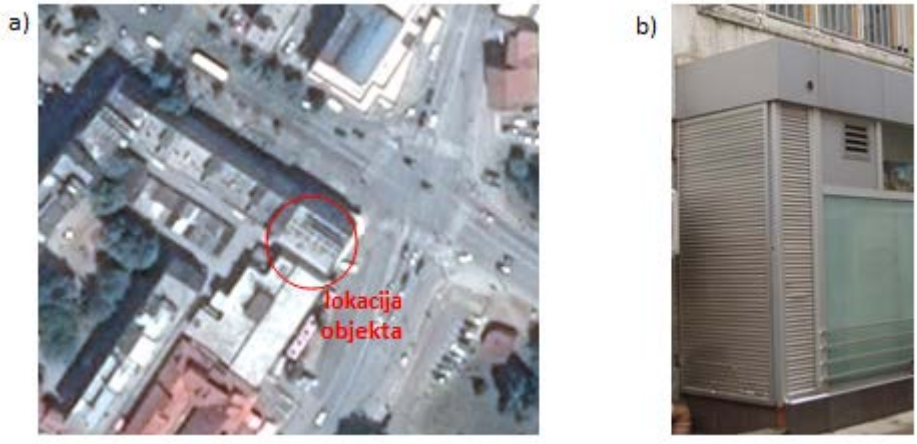

Figure 4. a) location of building, b) chamber enclosing the exterior units of the air-conditioning system

The occupants complained about discomfort caused by a continuous sound heard after the reconstruction of the ceiling in the office rooms below the apartment. The aim of that reconstruction was the installation of the air conditioning system and the ventilation (airing) in the office rooms. The three exterior units of the cooling system, so called

“split” air-conditioner system, are located on the outside wall of the building (under the windows of the apartment being considered) and enclosed in a special chamber made of sheet metal panels, Figure 4b. This space also enclosed the ventilation exhaust ducting from the toilet located in the basement of the office, with built-in ventilator for forced circulation. Also, there is the exhaust of the ventilation ducting from the office ground floor. Apart from the assumption that unpleasant sound comes from the air-conditioning and ventilation system, it has been taken into account that there is a heating plant substation in the other part of the building’s basement and that no noise had been heard before the reconstruction of the ceiling which can be related to that substation.

The assumption is that annoying and unpleasant sound represents the combination of the structural-borne and airborne sound generated from these installations.

4.2. MEASUREMENT METHODOLOGY

4.2.1. The measurement of noise

In order to determine the sound level, the 15-minute A-weighted equivalent continuous sound pressure level, L_{AeqT}, was measured during daytime (6:00-22:00) and night-time (22:00-6:00), as specified in [12, 16] .

The following measurement equipment was used for this investigation, Figure 5:

- Portable Pulse type 3560 C, by Bruel&Kjaer,
- Free field microphone, type 4191, and pre-amplifier, type 2669, by Bruel&Kjaer,
- Overall level analyzer for the Portable Pulse, that meets the requirements of class I instruments according to IEC 651, 1979, for noise meters,
- Noise calibrator, type 4231, by Bruel&Kjaer (calibrator’s sound level 94 dB at frequency of 1 kHz).

Figure 5. Multi-analyzer Portable Pulse type 3560 C and free field microphone with pre-amplifier

Although the names of the parameters measured by the Portable Pulse differ from the names of the parameters measured by standard sound level meters (e.g. sound level meter 2260 Investigator, by Bruel&Kjaer), essentially they are the same parameters. A comparative overview of these parameters is given in Table 4.

Potential noise sources were classified as follows:

- noise sources inside the building are machine installations in the office area (heating, ventilation and air conditioning installations),

- stationary noise sources outside the building are the air conditioners installed under the apartment window,
- source of non-stationary sound outside the building is traffic.

Table 4. *Comparative overview of parameters for Portable Pulse and Investigator*

	Portable Pulse 3560 C	2260 Investigator
Peak sound pressure value	Peak Time History (using 1s peak interval)	Peak (1s)
Equivalent continuous sound pressure value	Linear	LEQ
Equivalent sound pressure value with impulse	Linear + Impulse	LIm
Instantaneous sound pressure value	Exponential	INST
Maximum instantaneous sound pressure value	Exponential + Max.	Max. L.

Measurement conditions are defined in such a way that measurement was performed in the apartment with closed windows and closed entrance door of the apartment. The only room of this apartment has the function of the living room and the bedroom, thus it falls under the noise sensitive room category. The room is furnished with ordinary furniture pieces (dresser, sofa bed, table and chairs, refrigerator and freezer, TV set), the floor is wood parquet covered with a carpet. During measurement, a constant non-stationary traffic noise was heard from the adjacent street.

The measurement location was chosen in the center of the room, where the microphone was away from the walls for more than 1 m, at a height of about 1.2 m from the floor.

4.2.2. The measurement of vibration

In order to evaluate vibration in the building with respect to comfort, the overall W_m-frequency weighted values of r.m.s. accelerations and VDV were measured, as prescribed in [4]. The following equipment, shown in Fig. 6, was used for the measurement of vibration signals:

- Human Vibration Analyzer, type 4447, and
- triaxial accelerometer, type 4506, by Bruel&Kjaer.

The Human Vibration Analyzer Type 4447 complies with the technical requirements of ISO 8041:2005, Human response to vibration - Measuring instrumentation, and can perform measurement compliant with the standards pertaining to human vibration. The instrument is designed primarily for use in Health and Safety at Work applications. Along with the pre-set frequency weightings for hand-arm (W_h) and whole-body (W_d and W_k) vibrations, it possesses the pre-set frequency weighting (W_m) for the measurement of building vibrations too. Triaxial accelerometer is the classical vibration sensor which delivers the measured signal to the analyzer for further processing.

The measurement of the r.m.s and VDV values of the frequency weighted acceleration was done over period of 1 h, for the cases when machine installations were on and off. The accelerometer was mounted on the floor using double adhesive tape, and measurement was done for several variation of the accelerometer position.

Figure 6. Human Vibration Analyzer type 4447 by Bruel&Kjaer and triaxial accelerometer

4.3. RESULTS AND DISCUSSION

The measurement results of the r.m.s. and the VDV values of acceleration are given in Table 5. Referring to the values as shown in Table 1 and 2, one can conclude:

- for the case when the machine installation in the office was off, the r.m.s. values are just slightly above the threshold of perception (0.015 m/s^2), while the VDV value for the time interval of 8 h points to "low probability of adverse comment".
- for the case when the machine installation in the office was on, the r.m.s. values point to "low probability of adverse comment" for the exposure period of 8 h, while the VDV value for the time interval of 8 h points to "adverse comment possible".

Table 5. *Measured r.m.s. (m/s^2) and VDV ($m/s^{1.75}$) values of acceleration*

Conditions	r.m.s. (m/s^2) 8h	VDV ($m/s^{1.75}$) 8h
the machine installation in the office was off	0.0174	0.273
the machine installation in the office was on	0.039	0.730

The measurement of the equivalent noise level was performed during daytime and night-time, and measurement results are given in Table 6. The graphic representation of the measured sound levels for daytime and night-time are presented in Figures 7 and 8.

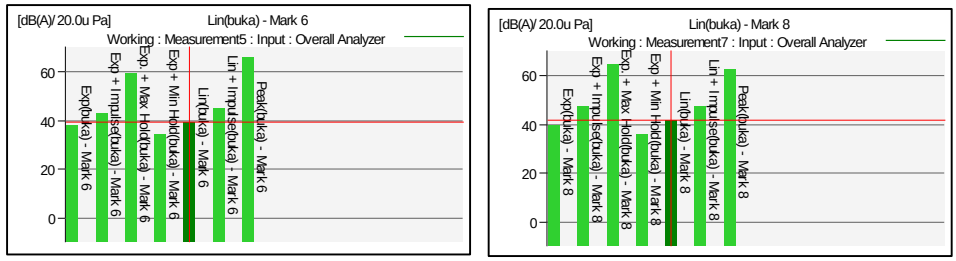

Figure 7. Sound levels for daytime: a) L_{Aeq} = 38.7 dB (the machine installation in the office was on), b) L_{Aeq} = 41.2 dB (the machine installation in the office was off)

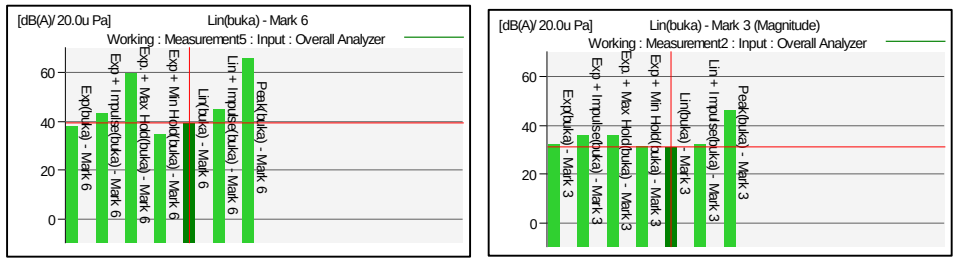

Figure 8. Sound levels for night-time: a) L_{Aeq} = 35.7 dB (the machine installation in the office was off, household appliances – the refrigerator was on), b) L_{Aeq} = 30.8 dB (the machine installations in the office was off; household appliances – the refrigerator was off)

Table 6. *Measured A-weighted equivalent continuous sound pressure level*

	Time and day	Sound level L_{Aeq} (dB)	Note
Daytime period	9:15 - 9:30 Saturday	36.9	not known whether the machine installation in the office was on or off
	14:45 - 15:00 Tuesday	38.7	the machine installation in the office was on
	15:30 - 16:00 Tuesday	41.2	the machine installation in the office was off
Night-time period	21:45 – 22:00 Friday	35.7	household appliances /refrigerator/ was on; the machine installation in the office was off
	22:00 -22:15 Friday	30.8	household appliances /refrigerator/ was off; the machine installations in the office was off

In accordance with the prescribed permissible noise levels as shown in Table 3, the measured noise is estimated as follows:

- The equivalent noise level L_{Aeq} = 36.9 dB measured at the time interval 9:15 - 9:30 hrs doesn't exceed the permissible level of L_{Aeq} = 40 dB for daytime.

- The equivalent noise level L_{Aeq} = 38.7 dB measured at the time interval 14:45 - 15:00 hrs, when the machine installation was on, doesn't exceed the permissible level. The equivalent noise level L_{Aeq} = 41.2 dB, measured at the time interval 15:30 - 16:00 hrs when the machine installation was off, exceeds the permissible level of L_{Aeq} = 40 dB, if the assessment criterion is the permissible level of noise emitted from the source inside the building (criterion A in Table 3). However, this measurement was performed during busy hours, and it was concluded that higher traffic volume raised the noise level for 2.5 dB, although the machine installation was off. Since the traffic is a non-stationary source outside the building, the assessment criterion should be the permissible level of noise emitted from the source outside the building (criterion B in Table 3), and according to this criterion, the permissible level of L_{Aeq}= 45 dB for daytime is not exceeded.
- The equivalent noise level L_{Aeq}= 35.7 dB measured at the time interval 22:00 - 22:15 hrs exceeds the permissible level of L_{Aeq}= 30 dB for nigh-time. The refrigerator placed in the room was on during noise measurement. After the refrigerator was turned off, the equivalent noise level of L_{Aeq}= 30.8 dB was measured. Taking into account the traffic noise which was heard during measurement, the permissible level of noise emitted from the source outside the building (criterion B in Table 3) was chosen as the assessment criterion, and according to this criterion there is no exceedance of the permissible level of L_{Aeq}= 35 dB for night-time

Although the results of the objective noise measurement showed no exceedance of the permissible noise levels, it was found that the requirements of architectural acoustics were not fully met during reconstruction of the ceiling in the office rooms below the apartment. Specifically, the mechanical installations of the ventilation and air conditioning systems in the office were placed within the area of the lowered ceilings that border the apartment. Thus, an acoustic standard has not been met, according to which it is desirable to avoid direct contact of noisy rooms and noise-sensitive rooms. This is especially significant for the analyzed case, because the analyzed apartment is a one-room studio, so it falls under the category of rooms particularly sensitive to noise.

It was found that the ventilator was installed inside the ventilation duct in the lowered ceiling of the ground floor. The ventilator was mounted laterally to the structural AB beam, but no elastic support elements for the ventilator and pipe were used. The pipe outlet is located in the wall under the windows of the apartment. Installation of ventilation system is primarily the problem of airborne noise in buildings that are radiated into the rooms through the ventilation outlets or the airborne noise emitted by ducts made of tin-plated walls into their environment. Ventilation duct might in some cases create structural-borne noise in the building structure through hanging or support points.

5. CONCLUSIONS

Human response to vibration in buildings is very complex. The analyzed case shows that other parameters related to vibration sources inside and outside buildings, or produced by vibration in exposure area such as structure-borne and airborne noise, may also give an explanation of the complaints. In the analyzed case of adverse comment to noise and vibration in residential building, it was shown that the requirements of architectural

acoustics were not fully met. During reconstruction in the office rooms below the apartment, the mechanical installations of the ventilation and air-conditioning systems were set improperly into the lowered ceiling, producing annoying noise and vibration. Although the results of the objective noise measurement didn't show any exceedance of the permissible noise levels, it is recommended that the duct be mounted by using elastic elements.

In the acoustic practice, there are different ways to reduce the impact of noise emitted by the mechanical installations in buildings. The most important measure is to carefully make the plan of the internal organization of the installation facility at the very beginning, i.e. in the development phase of the project. It is particularly important to minimize the setting of installation next to rooms that are critical from the aspect of sound protection (e.g. bedrooms), as this measure is cheaper than any subsequent solution offered by acoustics.

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55| Стручни рад
Professional paper
doi 10.7251/STP1813730A ISSN 2566-4484

УТИЦАЈ ВИСКОЗНИХ ДЕФОРМАЦИЈА БЕТОНА ПРИ ПРОРАЧУНУ ПОНАШАЊА ВИСОКИХ ЗГРАДА ТОКОМ ВРЕМЕНА

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Резиме:

На примјеру прорачуна понашања високе зграде указано је да временске деформације бетона имају значајан допринос на промјену понашања вертикалних носећих елемената - стубова и зидова. Указано је на феномен различитог скраћења бетонских/челичних стубова и бетонског језгра усљед скупљања и течења бетона током времена. Ова скраћења могу имати негативне посљедице по употребљивост конструкције, елемената испуне, инсталација у згради и сл. Прорачуни су урађени коришћењем прорачунског модела развијеног од стране аутора у оквиру ширег рада на анализи утицаја реолошких својстава код сложених спрегнутих конструкција слојевитим коначним елементима.

Кључне ријечи: високе зграде, течење и скупљање бетона, коначни елементи.

THE INFLUENCE OF CONCRETE VISCOUS DEFORMATIONS IN THE CALCULATION OF THE HIGH-RISE BUILDINGS BEHAVIOR OVER TIME

Abstract:

An example of a high-rise building behavior calculation shows that weather deformations of concrete have a significant contribution to changing the behavior of vertical load-bearing elements - columns and walls. The phenomenon of different shrinkage of concrete/steel pillars and concrete core due to the shrinkage and creep of concrete over time is pointed out. These shrinkages may have negative consequences on the usability of the structure, the filling elements, the installation in the building, etc. The calculations are made using a budget model developed by the author as a part of the more detailed paper on the analysis of the rheological properties impact in complex composite structures with layered finite elements.

Keywords: high-rise buildings, creep and shrinkage of concrete, finite elements..

1. УВОДНЕ НАПОМЕНЕ

На примјеру прорачуна понашања високе зграде, изложеном у овом раду, указано је, често у пракси занемариван, допринос деформисања вертикалних носећих елемената (стубова и зидова) током времена, што првенствено изазива различита скраћења бетонских и/или челичних стубова у односу на крута бетонска језгра. Ова различита скраћења вертикалних елемената, током времена, доприносе прерасподјели напрезања, нагињању таваница и зграде у цјелини, угрожавању секундарних елемената, инсталација, опреме у згради и сл. Овакве временске вискозне промјене у елементима могу утицати на стабилност, поузданост, функционалност и употребљивост објекта у цјелини или појединих његових дијелова.

2. ПРИМЈЕР ПРОРАЧУНА ВИСОКЕ ЗГРАДЕ

Узет је једноставан примјер једне вишеспратне зграде, димензија у основи 21x21 m (слика 1.) и висине 30 m (слика 2.), са симетричном вертикалном конструкцијом која се састоји од централног бетонског језгра и ободних стубова. Међуспратне конструкције су пуне бетонске плоче у систему са гредама (подвлакама). Разматрана су два случаја, гдје су за вертикалне елементе зграде узети бетонско језгро и:

- бетонски стубови
- челични стубови

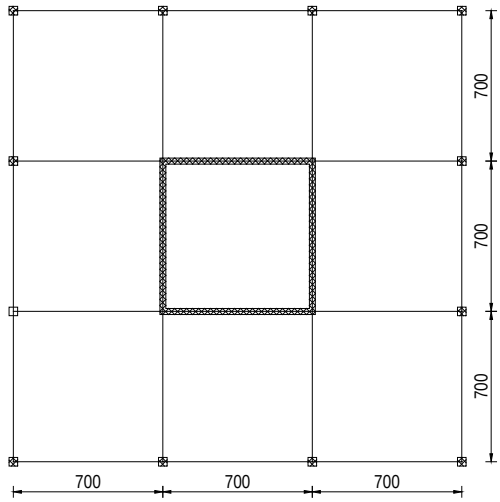
Технологија изградње конструкције зграде је по систему спрат по спрат, са узастопним оптерећивањем стубова и централног бетонског језгра. Усвојено је да се једна етажа гради 28 дана и да се тада међуспратна конструкција ослобађа оплате и скеле. Његовање бетона се одвија у току 28 дана од бетонирања у складу са уобичајеним поступцима у пракси. У складу са технологијом градње усвојени су статички системи и оптерећења за прорачун конструкције зграде по овде развијеном моделу са уведеним вискоеластичним коначним елементима (слика 3.).

Циљ овог примјера је да се укаже на феномен скраћење вертикалне конструкције високе зграде, односно на различито скраћење стубова и бетонског језгра усљед скупљања и течења бетона током времена. Ова различита скраћења могу имати негативне утицаје по сигурност и употребљивост конструкције, елемената испуне, инсталација у згради и сл.

Прорачуни су изведени у складу са развијеним прорачунским моделом и програмом ВАСКЕЛ од стране аутора овог рада [1,2,3]. Реолошки параметри за бетон су узети у складу са EC2, а у прорачуну је за поступак и функцију бетона узета суксцесивна примјена AAEM-методе.

У раду [4] приказан је прорачун дуготрајног диференцијалног скраћења зграде висине 300 m у Чилеу. Указано је на значајан допринос дуготрајних деформација и на потребу предвиђања ових утицаја још у прелиминарним фазама пројектовања.

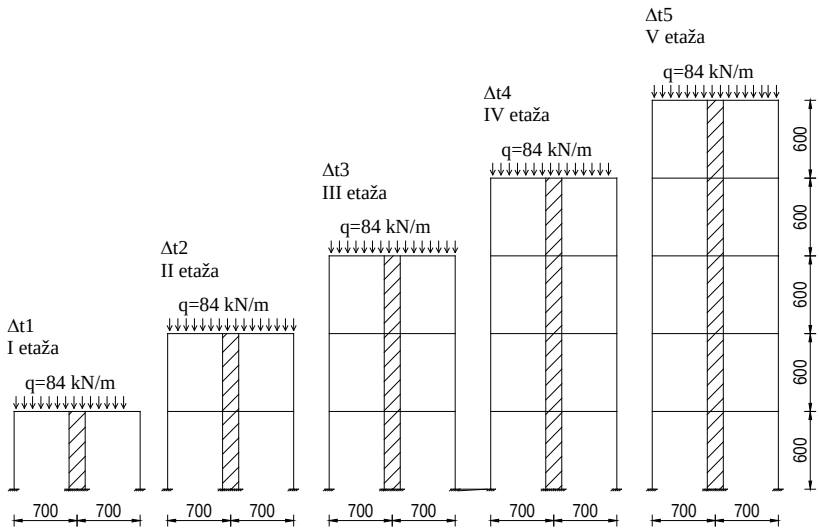
Сличан примјер је анализиран у раду [5] где је указано на значајан допринос реологије бетона на промјену стања напрезања и деформација у конструкцији зграде високе 30 m, а алгоритам прорачуна је реализован у програмском окружењу Matlab 7 у сарадњи са комерцијалним програмом TNO Diana 9.4.



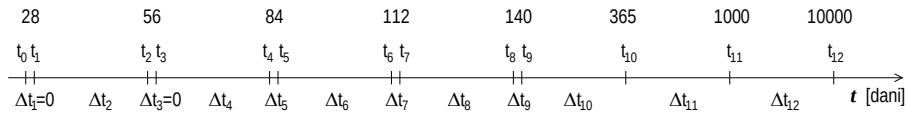
Etaža	Betonski stubovi	Èelicni stubovi
I	45/45	HEA 400
II	40/40	HEA 400
III	35/35	HEA 400
IV	30/30	HEA 400
V	25/25	HEA 400
Grede: b/d=30/60 cm		
Ploèa: d=18 cm		
Zidovi: d=30 cm		

Eb=32 GPa
Ea=210 GPa

Слика 1. Основа конструкције зграде



Слика 2. Статички системи и оптерећења у току градње зграде



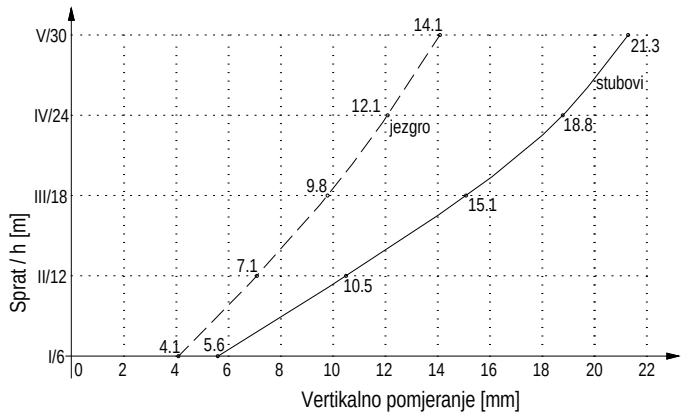
Слика 3. Дискретизација времена у складу са градњом зграде

Дискретизација времена спроведена је у складу са сликом 3. Укупно посматрано вријеме подијељено је на 12 интервала у складу са технологијом градње зграде, укључујући све основне промјене на конструкцији и оптерећењу. Тако је кроз првих 9 интервала обухваћена изградња објекта по етажама (градња спрат по спрат), што

је трајало укупно 140 дана. Кроз 10., 11. и 12. интервал издвојени су дискретни тренуци од 365, 1000 и 10000 дана респективно. У прорачуну нису занемарене различите старости бетона доњих дијелова зграде у вријеме новог оптерећивања, односно градња наредне етаже укључује оптерећење саме те етаже али и допринос реологије бетона раније изграђених доњих етажа.

2.1. ПРОРАЧУН ВИСОКЕ ЗГРАДА СА БЕТОНСКИМ СТУБОВИМА

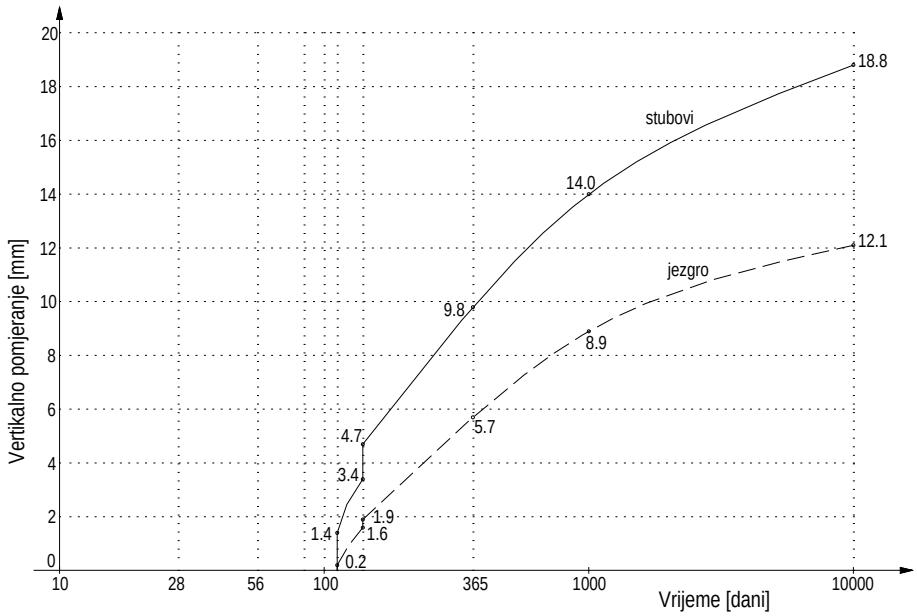
Вискозно понашање бетона, код зграде са крутим бетонским језгром и ободним бетонским стубовима, током времена изазива скраћење вертикалне конструкције. То скраћење за посматрани дискретни/крајњи тренутак расте по висини зграде (слика 4.). Максимално скраћење бетонских стубова петог спрата (h=30 m) је 21.3 mm. Бетонски стубови се скраћују нешто више од бетонског језгра за све етаже, а највећа разлика износи 7.2 mm на петом спрату. Ободни бетонски стубови су под већим напонима притиска, него што је то случај код централног бетонског језгра, па је и за очекивати њихово веће еластично, али и вискозно скраћење током времена (слика 4.).



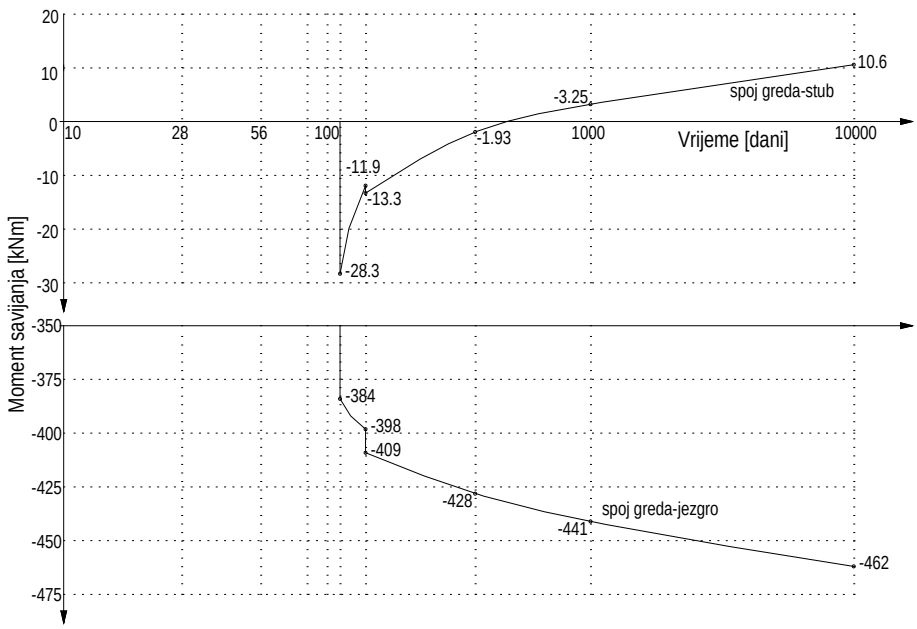
Слика 4. Вертикално померање спратова за t∞

На слици 5. дати су дијаграми скраћења вертикалне конструкције објекта за IV спрат (h=24 m) током времана. Ободни бетонски стубови су се скратили одмах након скидања подупирача IV-ог спрата (еластично скраћење) за 1.4 mm, а од изградње V спрата за додатних 1.3 mm. Вискозне деформације су знатно израженије од еластичних, и оне износе 16.1 mm, чиме је укупно скраћење стубова за крајњи тренутак достигло вриједност од 18.8 mm. Сличан облик дијаграма вертикалног помјерања је и за централно бетонско језгро али са мањим вриједностима, како еластичних, тако и вискозних деформација (слика 5.). Еластично скраћење овог језгра износи 0.2 mm и 0.3 mm од изградње IV-ог и V-ог спрата респективно (укупно 0.5 mm), док је вискозно скраћење знатно веће од еластичног и износи 11.6 mm.

На слици 6. дати су дијаграми промјене момената савијања на крајевима греде IV спрата током времена. Интензитет момента савијања греде на споју са стубом временом опада (апсолутна вриједност) услед већег вертикалног помјерања („спуштања“) стубова у односу на круће језгро, док из истог разлога интензитет момента савијања греде на споју са језгром расте (апсолутна вриједност). Значајно је истаћи да је негативна вриједност момента савијања греде на споју са стубом временом прешла у позитивну вриједност.



Слика 5. Вертикално померање IV спрата

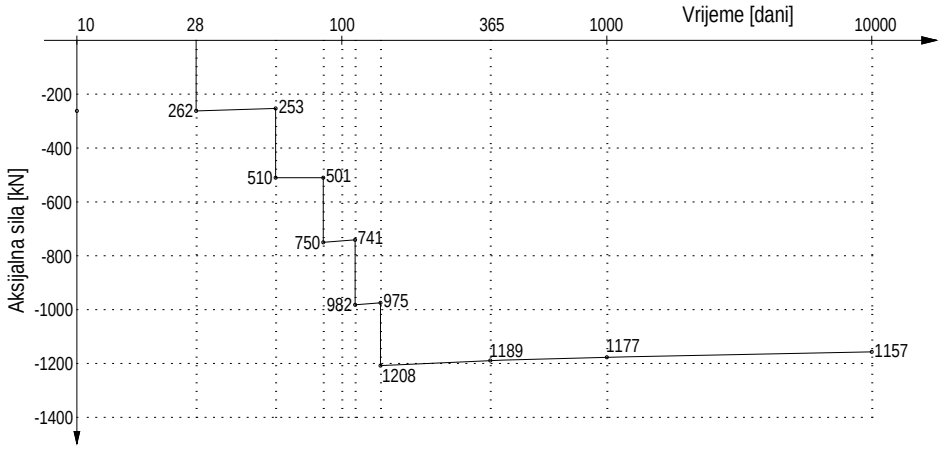


Слика 6. Момент савијања на крајевима греде IV спрата

Еластични дио момента савијања на споју греде са стубом износи укупно 29.7 kNm (негативан моменат), а вискозни дио је 40.3 kNm али супротног знака (позитиван моменат). Код споја греде и језгра еластични дио момента савијања износи укупно

395 kNm (негативан моменат), а вискозни дио је 67 kNm (негативан моменат), што укупно износи 462 kNm и представља увећање негативног момента савијања за 17%.

На слици 7. дат је дијаграм промјене аксијалне силе за бетонски стуб приземља током времена. Прираст ове силе притиска прати поступак градње објекта спрат по спрат, а усљед различитих вискозних деформација стубова и језгра аксијална сила у коначним интервалима времена има благу тенденцију опадања.



Слика 7. Аксијална сила у стубу приземља

Еластични дио аксијалне силе притиска у стубу приземља од утицаја свих етажа износи 1242 kN, а вискозни дио за који се умањује сила износи 85 kN, што укупно износи 1157 kN и што представља пад силе притиска у стубу приземља за више од 7%. Овај пад силе у бетону био би више изражен да је у прорачуну укључена арматура стубова, јер би се тада извршила прерасподјела дијела напона са бетона на арматуру током времена (релаксација бетона).

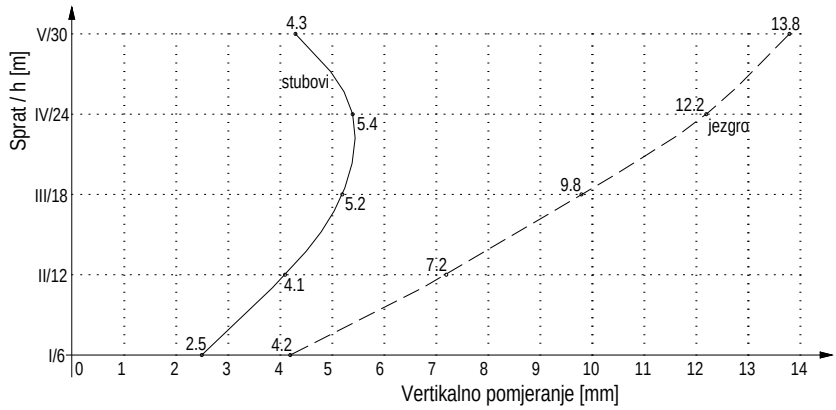
2.2. ПРОТРАЧУН ВИСОКЕ ЗГРАДА СА ЧЕЛИЧНИМ СТУБОВИМА

Максимално скраћење вертикалне конструкције објекта за крајњи тренутак је 13.8 mm, када се посматра бетонско језгро и највиша тачка (V-и спрат, h=30 m), док је по етажама то скраћење у складу са дијаграмом датим на слици 8. Ободни челични стубови се скраћују знатно мање од централног бетонског језгра и та разлика се по висини објекта мијења. За пети спрат разлика вертикалних помјерања између челичних стубова и бетонског језгра износи 9.5 mm, док је за први спрат та разлика свега 1.7 mm.

Усљед скупљања и течења бетона централно бетонско језгро се током времена под напонима притиска додатно скраћује, док челични стубови због одсуства течења немају директне временске деформације. Пораст деформација челичних стубова током времена је посљедица реологије бетона централног језгра. Ова реологија доводи до прерасподјеле напрезања па тиме и додатних деформација челичних стубова.

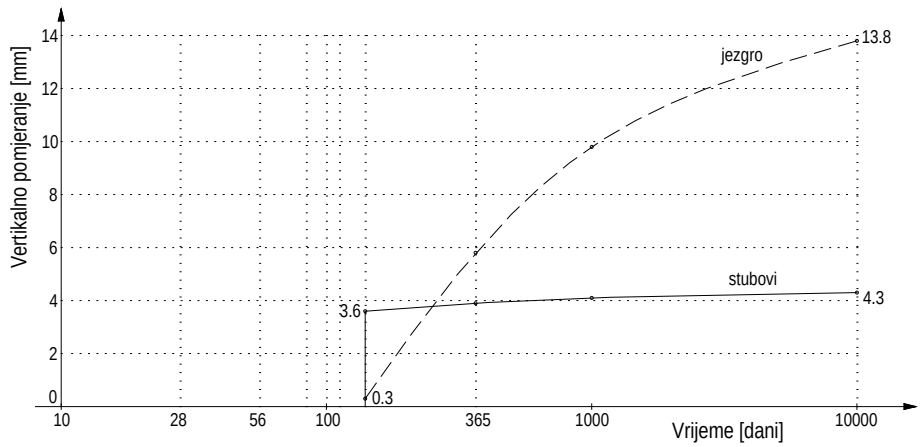
На слици 9. дати су дијаграми скраћења вертикалне конструкције објекта за пети спрат (h=30 m) током времана. Може се констатовати да је промјена вертикалних помјерања знатно израженија код централног бетонског језгра (еластичне и вискозне деформације) него код ободних челичних стубова (еластичне

деформације) због одсуства течења челика. У односу на еластично скраћење (0.3 mm), код централног бетонског језгра, вискозно скраћење је знатно више изражено (13.5 mm).



Слика 8. Вертикално померање спратова за t∞

Код челичних стубова пораст скраћења са еластичних 3.6 mm на укупних 4.3 mm је посљедица прерасподеле напрезања са бетонског језгра на челичне стубове усљед релаксације бетона током времена.

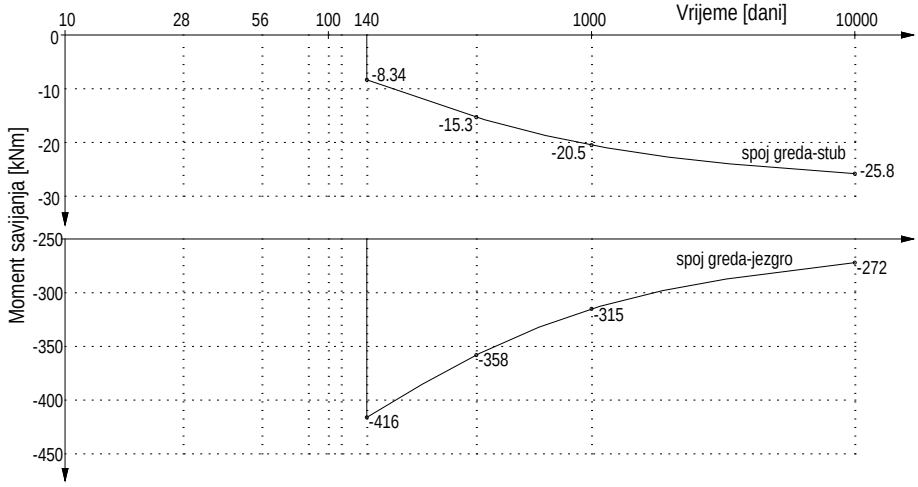


Слика 9. Вертикално померање V спрата

На слици 10. дат је дијаграм промјене момента савијања током времена за греду посљедњег спрата на спојевима са челичним стубом и бетонским језгром. Пораст негативног момента савијања на мјесту споја греде и челичног стуба прати смањење негативног момента на споју греде са бетонским језгром. Ово је посљедица прерасподјеле напрезања усљед скупљања и течења бетона централног језгра и његовог интензивнијег скраћења у односу на еластичне стубове („омекшавање“ средњег ослонца за греде).

На споју греде са челичним стубом негативни момент савијања је порастао три пута (са 8.34 kNm на 25.8 kNm), док је на другој страни греде, на споју са бетонским

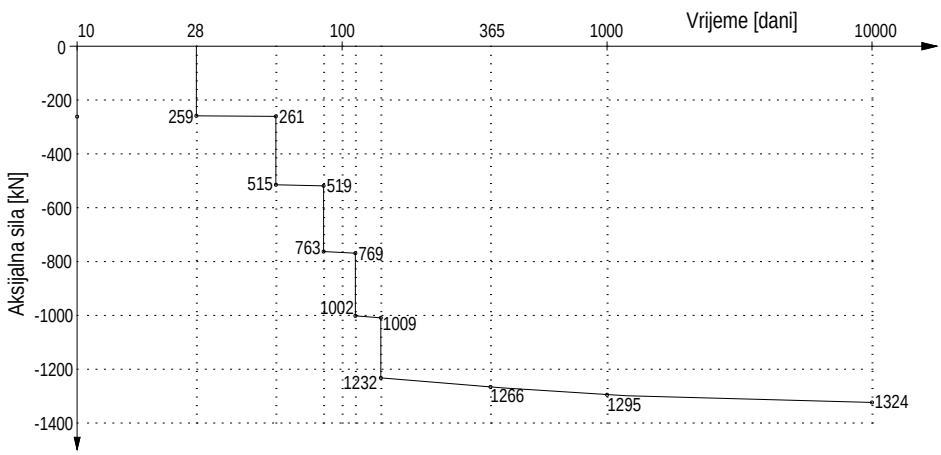
језгром, негативни момент савијања опао за један и по пута (са 416 kNm на 272 kNm).



Слика 10. Моменти савијања на крају греде V спрата

Може се констатовати да различито скраћење бетонског језгра и челичних стубова током времена може довести до прекорачења момента савијања ригли на спојевима са челичним стубовима. О овоме је нужно водити рачуна још у прелиминарним фазама пројектовања хибридних високих зграда.

На слици 11. дат је дијаграм промјене аксијане силе притиска у челичном стубу приземља током времена. Пораст ове силе прати поступак градње објекта (еластични дио силе), док временом сила додатно расте и без додавања оптерећења. Ово је посљедица прерасподјеле напона усљед скупљања и течења бетона централног језгра и његовог интензивнијег скраћења у односу на еластичне ободне челичне стубове.



Слика 11. Зграда са челичним стубовома. Аксијална сила у стубу приземља

Еластични дио аксијалне силе у челичном стубу приземља од утицаја свих етажа износи 1212 kN, а вискозни дио усљед прерасподјеле силе са бетонског језгра на челичне стубове износи 112 kN, што је пораст за скоро 10%.

Може се констатовати да различито скраћење бетонског језгра и челичних стубова током времена, те пораст напона притиска у челичним стубовима, може довести до прекорачења дозвољених вриједности за челик, као и врло неповољних ефеката извијања челичних стубова. Овакви случајеви захтијевају посебну пажњу још у прелиминарним фазама пројектовања вишеспратних зграда.

3. ЗАВРШНЕ НАПОМЕНЕ

Високе зграде са бетонском или мјешовитим (челик-бетон) конструкцијом захтијевају посебне анализе временских деформација. Различите деформације вертикалних елемената могу бити посљедица разлике напона, различите изложености, односа површине и запремине, скупљања и течења бетона и одсуства течења код челика. Поред тога, у случају недостатка симетрије у конструкцији зграде могу се развити бочна помјерања и врло неповољни ефекти другог реда за витке челичне стубове [4,5].

Уколико се ови утицаји у прорачунима изоставе могу се временом јавити негативне посљедице по објекат. Поред угрожавања носивости конструкције и безбједности објекта могу се јавити нагињања подова, пуцање греда и плоча, прскање материјала ентеријера, извијање лифтовских вођица и цјевовода, оштећења зидова испуне и сл. Хибридне конструкције челик-бетон су осјетљивије на ове ефекте чак и код објеката ниже спратности, док су симетричне бетонске конструкције знатно сигурније чак и за висине 50-100 m [5].

Поменути негативни ефекти код вишеспратница не пружају неку могућност корективних мјера након изградње, те је веома важно ове ефекте сагледати у фази пројектовања и градње објекта, те на вријеме предуприједити њихов негативни утицај.

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56| Стручни рад
Professional paper
doi 10.7251/STP1813739P ISSN 2566-4484

TEHNO-EKONOMSKA ANALIZA SAĆASTIH I PUNIH "I" ČELIČNIH GREDNIH NOSAČA U POGLEDU NOSIVOSTI I FUNKCIONALNOSTI

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Rezime:

Prednosti saćastih u odnosu na pune I gredne nosače mogu biti značajne. Oni mogu imati i do 50% veću visinu poprečnog presjeka u odnosu na "izvorne" nosače od koga su oni nastali a samim tim i veću nosivost na moment savijanja. Cilj rada je pokazati ekonomsku opravdanost saćastih nosača u odnosu na pune u pogledu nosivosti i funkcionalnosti. Varirani su rasponi i opterećenja na statičkom sistemu proste grede te je se za uredjeni par (raspon, opterećenje) dodijeljen jedan puni i jedan saćasti nosač čija nosivost i funkcionalnost (ugibi) zadovoljavaju a potom se porede njihove cijene. Saćasti nosač je ekonomičniji u pogledu ukupne težine čelika ali on zahtjeva dodatne troškove izrade. U radu su prikazani specifičnosti proračuna saćastih nosača, budući da oni trenutno nisu "obrađeni" u aktuelnim evropskim standardima (Eurocode 3).

Ključne riječi: saćasti nosači, proračun saćastih nosača, tehno-ekonmska analiza

TECHNO-ECONOMIC ANALYSIS OF CASTELLATED AND SOLID "I"- PROFILED STEEL BEAMS IN TERMS OF LOAD CAPACITY AND SERVICEABILITY

Abstract:

Advantages of castellated beams compared to solid steel beams can be significant. They can have up to 50% increase of cross section height compared to its original beam from which they were made of, i.e. greater bending capacity. Aim of this paper is to show the economic justification of castellated beams compared to solid beams in terms of load capacity and serviceability. The spans and loads on simple beam are varied and for a regulated pair (span, load), one solid and one castellated beam are determined, whose load capacity and serviceability are satisfied, and then their price was compared. Castellated beams are more economical in terms of total weight, but their production demands additional costs. Also in this paper, particularities of castellated beams design will be presented, since current European regulations (Eurocode 3) do not cover mentioned design methods.

Keywords: castellated beams, design of castellated beams, techno-economic analysis

1. INTRODUCTION

Increase in load-bearing capacity of solid I-profiled beams can be achieved in several ways. One of the ways is welding additional steel plates on flanges of I profile (Figure 1. a) and so increasing part of area of cross section that is mainly intended for bending resistance (Flanges). Consequence of adding additional material is, logically, additional weight, which is, in economical way, downside of this type of load-bearing optimization. Other way of increasing bending resistance is increasing height of cross section by cutting web in two equal parts, placing plate in-between and then weld them together, like shown on Figure 1. b. Moment of inertia then has higher value but additional weight cause more cost.

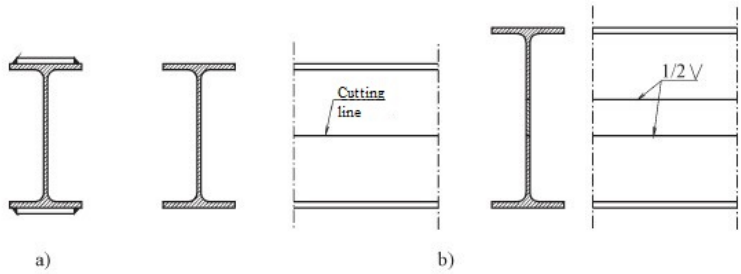

Figure 1. Types of increasing load-bearing capacity: a) By adding plates on flanges; b) By web cutting and putting plate inbetween

Most popular way of increasing load-bearing capacity of solid beams without additional weight is way of producing castellated beams (name of castellated beams comes from specific look of cut parts that looks like top of castle). Web is cut in specific zig-zag line then those parts are displaced and welded at specific places so that final height can be increased up to 50% like shown of Figure 2.. That way, additional cost will be only caused by cutting and welding and significant increase in moment of inertia will be achieved.

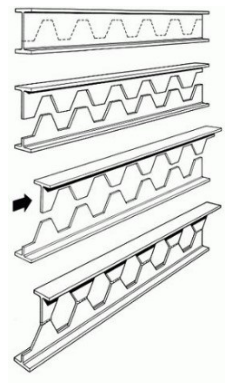

Figure 2. Zig-zag cutting, displacement and welding of solid beams - Castellated beam

Idea of paper is to compare costs of one solid I profiled beam and one castellated beam that both have same load-bearing capacity at ultimate limit state and both fulfill serviceability requests. Castellated beams, compared to their correspond solid-profiled-

beam pair, with same load-bearing characteristics, have less weight because they were made of solid profile with smaller height, but similar capabilities because of similar value of moment of inertia. Generally, costs in steel constructions are calculated relative to steel weight, so castellated beams will surely cost less, but additional cost are required due to procedure of cutting and welding. This paper shows in which range of production costs castellated beams will be cost-effective version of load carry-optimized solid beams.

Unrelated to previously mentioned possible cost-effectiveness of castellated beams, they have numerous advantages, such as possibility of setting installation ducts through the web, increase in floor height, increase in illumination of space and unique aesthetic appeal.

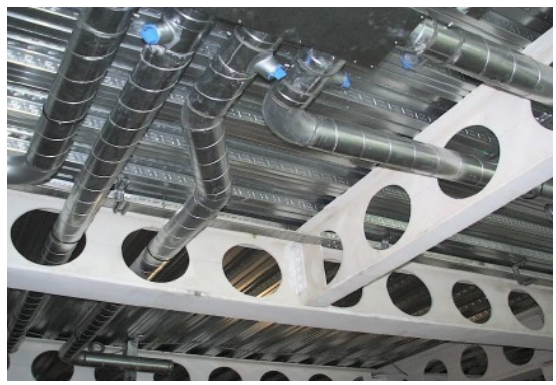

Figure 3. Advantage of web openings

2. LOAD-BEARING MECHANISM AND DESIGN OF CASTELLATED BEAM

Presence of web openings have significant influence on castellated beams so they behave different in comparison to ordinary solid I profiled beams. Because of those openings, application of classic procedures for designing and determining internal forces for linear beams should be questioned. Not only typical types of failures are present but some new types of failure are possible, that are especially characteristic for castellated beams.

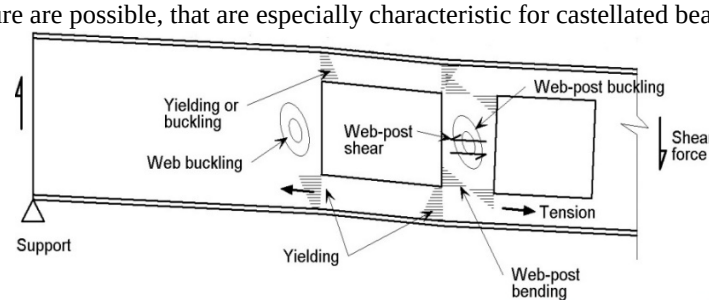

Figure 4. Type of failures

When bending and shear resistance of castellated beams are considered separately, calculation methods are same as for solid beams, therefore, statics should be determined on simple beam, and couple of design checks on characterical cross-sections (cross section on place with opening and without opening) with extreme values should be made

(Figure 5. a) and b)). Bending resistance are typically determined by area of flanges, so that, presence of web opening doesn't have much influence on it and generally all area of web can be neglected. Shear resistance are, mostly, determined by area of web, so web opening presence does have significant influence. It is interesting fact that, although web opening reduce shear resistance of the web, generally when static system of simple beam is consider, "usage" of shear resistance of solid I profiled steel beams does not exceed 30%, hence, that reducement of the area of web represent optimization of cross section in terms of shear resistance.

Ordinal number of calculation	Corresponding I solid profile	Bending resistance efficiency of cross section	Shear resistance efficiency of cross section
1	IPE 200	86%	19%
2	IPE 270	78%	24%
3	IPE 300	90%	31%
4	IPE 360	74%	15%
5	IPE 450	89%	21%
6	IPE 550	82%	22%
7	IPE 500	78%	13%
8	IPE 600	97%	19%
9	HEB 550	92%	24%
10	HEB 500	63%	12%
11	HEB 650	83%	17%
12	HEB 650	65%	11%
13	HEB 900	75%	14%

Table 1. Efficiency of load capacity of I solid profile cross-sections due to applied load

Cross section of castellated beam on place with web opening is generally divided into two "T" sections (upper and lower) and all the resistance are consider as isolated T section. Design bending moment (M_{Ed}) is decomposed on two equal normal forces ($N_{M,Ed}$) with oposit direction so that one of each acts on each T section and then it is compared with normal force resistance of T section ($N_{T,Rd}$). The half of design shear force (V_{Ed}) is assigned to each T section and so it compared to shear resistance of each T part ($V_{T,Rd}$).

It is rare that "global" moment or shear force will cause failure of castellated beams. Very specific failure mechanism, especially for castellated beams, that is more often, is "Vierendeel" mechanism which occurs when there's certain interaction of bending moment and shear force. It is shown that shear force cause additional "secondary" bending moment that can, in extreme case, cause occurrence of four plastic hinges at the corner of openings. This means that T sections are not only loaded on normal and shear force but additional bending moment so T section has interaction of normal and shear force and bending moment. (Figure 5. c))

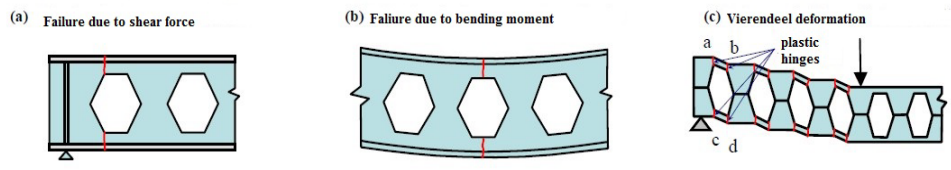

Figure 5.

For beams that are not axially compressed, only global mode of buckling is lateral-torsional buckling. If the beam isn't laterally braced, failure of lateral-buckling will be dominant over other failure mode. Newer experiments [1] shows that there is no

difference in behaviour of solid and castellated beams in terms of lateral-torsional buckling. All the calculation for solid beams can be used for castellated beams using reduced cross section (at web opening).

One the other most common type of failure of castellated beams is web post buckling, which is actually type of local buckling mode. Generally, this kind of failure is caused by normal stress distribution in parts of web between openings where one diagonal is compressed, like shown on Figure 6. There is no actual theoretically based formula that describes and calculate this phenomenon but all the solution for securing the beam from faliure is by empirial formulas. Popular theoretical model is strut model (Figure 6.) but more practical one is connecting the bending moment in 3-3 intersection on Figure 7. with web-post buckling using empirial coefficients. Also, design checks on horizontal shear force in intersection 4-4 should be made, where beam is welded.

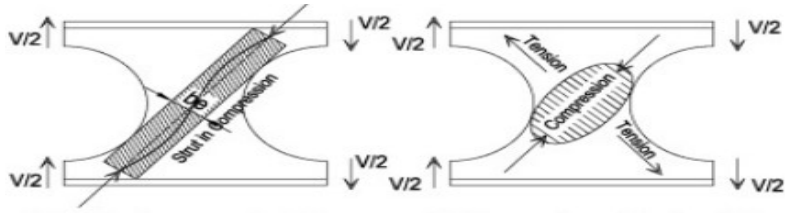

Figure 6. Strut model and actual stress distribution in web between openings

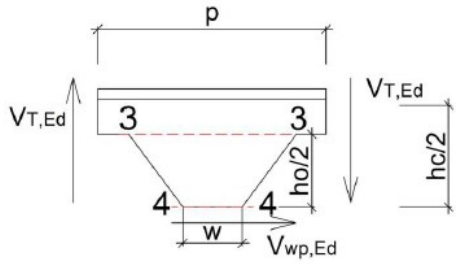

Figure 7. Characteristic intersections of web-post

All types of failures suggest that the best choice of static system for calculating internal forces is not simple beam but Vierendeel truss with rigid nodes (Figure 8.). In the past, engineers used simplifications, due to static indeterminacy, in terms of adding joints in middle of "struts" where bending moment has zero value in "real" rigid Vierendeel truss. Nowadays, problem with static indeterminate systems is overcame with usage of various software for static analysis and there is no real need for such simplification.

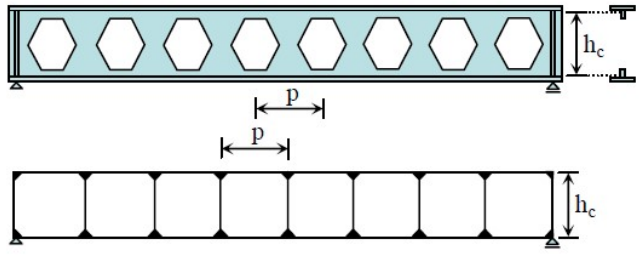

Figure 8. Vierendeel truss

Mistake in selection of static system is often made when castellated beam is considered as a simple beam with characteristic of reduced cross section (on a web opening place). With such consideration many types of important failures are neglected and level of uncertainty is extremely high. Also, the deflection calculation is most accurate when Vierendeel truss is chosen as model. Many softwares use the principal of virtual forces and it is more practical and accurate enough than using finite element method especially in every day engineering practice. Also, it is very important to mention that using static system of simple beam, with reduced cross section characterics, in deflection calculation gives 10-70% [2] smaller values of deflection which shows that model isn't appropriate.

All the detailed calculation, formulas and geometry recommendation based on principles of Eurocode 3 is given in [3] and are used for purpose of analysis of this paper.

3. CURRENT STANDARDS, DESIGN GUIDEBOOKS AND SOFTWARE FOR DESIGN OF CASTELLATED BEAMS

Taking in consideration various types of failures and complex behavior of castellated beams under the load, it is understandable that is extremely hard to simplify design for engineering practice. Practice demands simple models, which describes, as close as possible, realistic behavior of beam, like classic linear models. Although, castellated beam, on first, look like linear models with constant cross section height, but they can't be modeled as one, because of specifics described in previous chapter. This fact also makes problem to software intended for static analysis and design of steel construction, because they don’t take in consideration all the specifics of castellated beams and consider them as a beam with reduced cross section, so the results aren't reliable.

Current and actual standard in Europe (in Bosnia and Herzegovina, Eurocode is still in procces of adoption) for steel constructions is Eurocode 3. It mainly covers design of almost all the steel elements that are used in construction industry but that is not the case with castellated beams, currently. Actually, Eurocode society published 1992. an Annex N in prestandard of Eurocode 3 [4] especially intended for designing and geometry recommendation of the castellated beam but withdraw it with offical version of Eurocode 3 [6] published in 2005. so that design of castellated beam isn't cover by Eurocode until today (January, 2018.). In 2016. European committee for standardization has initiated procedure of creating new part of Eurocode 3 that would be intented for castellated beam design („EN 1993-1-13: Rules for beams with large web openings“) but for now, it is in early stage.

Although design method is not "covered" with actual standards and regulations, it doesn’t mean that castellated beams cannot be designed using the principles of Eurocode. For this very reason, design guidebooks that describes design procedures based on Eurocode 3 are popular. One of the most popular guidebook is one published by The Steel Construction Institute (SCI) named "Design of composite beams with large web openings" (populary called "P355") and it is free to download. Even though it's about composite beam it is stated that all the calculation are adjustable to non-composite beams just with neglecting the influence of concrete slab in formulas. Other popular guidebook is published by ArcelorMittal named "ACB-Cellular Beams" which are popular mostly because of ther diagrams for fast choosing appropriate beam for specific load and span. Since the ArcelorMittal is one the worlds biggest producers and sellers of steel elements, this guide book is just valid for their elements, but it can be used for rough estimation of profile size.

Most of the commercial softwares for static analysis and designing of construction elements does not give possibility to calculate and do design check of castellated beams with all of their specifics mentioned in previous chapter. It is clear that software for finite element method give best accuracy but that modeling is time-consumption and inefficent for everday practice. Because of that reason, worlds manufacturers and sellers of castellated beams and other steel elements produced their own software which is specially made for castellated beam design. These software ("ACB+" by ArcelorMittal, "Cellbeam" by Westok and "FBEAM" by Fabsec) offer the most complete design of castellated beam, taking into consideration all possible type of failures. The only flaw of this softwares is that the shape of opening is restricted to circular shape.

4. CALCULATION SET UP AND RESULTS ANALYSIS (TECHNO-ECONOMIC ANALYSIS)

It is obvious that load-bearing capacity of castellated beam is greater than its original beam from which it were made of, and such knowledge, that for certain span and certain load castellated beam has more load-bearing capacity form its original solid I profile which also satisfy mentioned requests, is not of practical benefit. Therefore, it is more convenient to choose castellated beam made from "smaller" profile that meets requirements for mentioned load and span and then compare it to previously mentioned solid beam. Castellated beam has less weight and consequently are more economic in terms of total steel weight but they demand additional cost production. Presence of web openings contribute to better space utilization and that is one of the major advantages which is why engineers decide for their usage. In this paper, economic justification of castellated beams compared to solid I profiled steel beams, in terms of load capacity and serviceability, is analyzed.

Next cases are considered:

- Static system: Simple beam (with lateral bracing)
- Spans: 5 m, 10 m, 15 m, 20 m and 25 m (Allowable deflection: L/200)
- Steel profiles: IPE and HEB
- Steel quality: S235
- Loads:
    - Dead: 5 $\frac{kN}{m}$, 10 $\frac{kN}{m}$ and 15 $\frac{kN}{m}$
    - Live: 5 $\frac{kN}{m}$, 10 $\frac{kN}{m}$ and 15 $\frac{kN}{m}$

	Dead load g [kN/m]	Live load q [kN/m]	Total load for ULS (1.35g+1.5q) [kN/m]	Total load for SLS (1.00g+1.00q) [kN/m]
I Load Case	5	5	14.25	10
II Load Case	10	10	28.5	20
III Load Case	15	15	42.75	30

Table 2. Load cases

Regulated pair of spans and load cases are given below. Each of pair has its own ordinal number.

Ordinal number of calculation	Span [m]	Load case
1	5	I
2	5	II
3	5	III
4	10	I
5	10	II
6	10	III
7	15	I
8	15	II
9	15	III
10	20	I
11	20	II
12	25	I
13	25	II

Table 3. Regulated pairs of span and load cases

Ordinal number of calculation	Span [m]	Load case	Corresponding solid I profile beam	Corresponding castellated beam	Weight of solid profile [kg]	Weight of castellated beam [kg]	Material savings [kg]
1	5	I	IPE 200	IPE 180 (244)	112.00	94.00	18.00
2	5	II	IPE 270	IPE 240 (340)	180.50	153.50	27.00
3	5	III	IPE 300	IPE 270 (379)	211.00	180.50	30.50
4	10	I	IPE 360	IPE 300 (438)	571.00	422.00	149.00
5	10	II	IPE 450	IPE 400 (593)	776.00	663.00	113.00
6	10	III	IPE 550	IPE 500 (768)	1060.00	907.00	153.00
7	15	I	IPE 500	IPE 450 (670)	1360.50	1164.00	196.50
8	15	II	IPE 600	IPE 550 (845)	1830.00	1590.00	240.00
9	15	III	HEB 550	HEB 450 (652)	2985.00	2565.00	420.00
10	20	I	HEB 500	HEB 400 (575)	3740.00	3100.00	640.00
11	20	II	HEB 650	HEB 550 (804)	4500.00	3980.00	520.00
12	25	I	HEB 650	HEB 500 (728)	5625.00	4675.00	950.00
13	25	II	HEB 900	HEB 700(1038)	7275.00	6025.00	1250.00

Table 4. Comparison of solid and castellated beams

Ordinal number of calculation	Weight of solid profile [kg]	Weight of castellated beam [kg]	Material savings [kg]	Percentage [%]
1	112.00	94.00	18.00	16.07
2	180.50	153.50	27.00	14.96
3	211.00	180.50	30.50	14.45
4	571.00	422.00	149.00	26.09
5	776.00	663.00	113.00	14.56
6	1060.00	907.00	153.00	14.43
7	1360.50	1164.00	196.50	14.44
8	1830.00	1590.00	240.00	13.11
9	2985.00	2565.00	420.00	14.07
10	3740.00	3100.00	640.00	17.11
11	4500.00	3980.00	520.00	11.56
12	5625.00	4675.00	950.00	16.89
13	7275.00	6025.00	1250.00	17.18

Table 5. Material savings in percentages

When castellated beams are used instead of solid profiles for same span and load material savings, are, in average, around 15%. Therefore, economic justification, in terms of load capacity and serviceability, will exist only if cost of production of castellated beams (cutting and welding) are in range of costs of material savings. Price of

steel elements are billing by weight. Price of production costs are also (because it's more practical) bill by weight of material from which is castellated beam made from. So, as long as production cost (unit price) is less than 15% of unit price of steel, castellated beam will be more economic in terms of load capacity and serviceability.

5. CONCLUSION

Economic justification, in terms of load capacity and serviceability, of castellated beam is only dependent of costs of their production (cost of cutting and welding). If the unit price of production (billed by unit weight of original material) is below 15% of general unit price of steel, castellated beams will be more economic than solid beams that fulfill same load requests.

Such low production cost is very hard to achieve, so economic justification of castellated beam, surely, should be questioned. It is maybe possible for large manufacturers of steel elements to achieve those price but it is sure that is not possible for regular workshops.

Castellated beams have numerous advantages which don't relate to their economic side, such as possibility of ducting the installation through web openings, increase in floor height, aesthetic appeal and many others and so should be used for these advantages.

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57| Стручни рад
Professional paper
doi 10.7251/STP1813748R ISSN 2566-4484

SISTEM ZA NAVODNJAVANJE MALINA NA TERITORIJI OPŠTINE BRATUNAC

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Rezime:

U Republici Srpskoj je aktuelna izgradnja sistema za navodnjavanje u poljoprivredi, u svrhu povećanja prinosa. Jedan od projekata, koji se realizuje, je izgradnja sistema za navodnjavanje malina na teritoriji opštine Bratunac. Na području 20 mjesnih zajednica, gradi se 27 sistema za navodnjavanje. Ukupne površine za navodnjavanje iznose oko 490 hektara. Parcele su u privatnom vlasništvu, prosječne površine oko 0,2 hektara. Sistemi se sastoje od vodozahvata (bunari pored rijeke Drine ili direktno zahvatanje iz brdskih lokalnih vodotoka), potisnih cjevovoda, rezervoara, distributivnih cjevovoda, hidranata za uzimanje vode za pojedinačne parcele. Projekat se finansira kreditom Svjetske banke. Očekuje se povećanje prinosa sa navodnjavanih površina za minimum 30%.

Ključne riječi: potrebne količine vode, vodozahvati

SYSTEM IRIGATION OF RASPBERRY ON THE TERRITORY OF BRATUNAC MUNICIPALITY

Abstract:

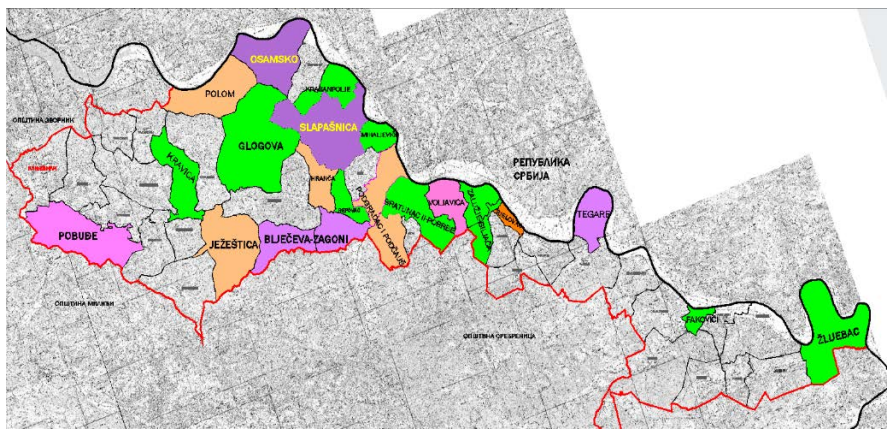
In the Republic of Srpska, the construction of an irrigation system in agriculture is ongoing, in order to increase the yield. One of the projects that is being implemented is the construction of a system for irrigation of raspberries in the territory of the municipality of Bratunac. In the area of 20 local communities, 27 irrigation systems are being built. The total area for irrigation is about 490 hectares. Plots are privately owned, with an average area of 0.2 hectares. The systems consist of water intakes (wells along the Drina river or direct catch from smaller streams), pressure pipelines, reservoirs, distribution pipelines, hydrants for taking water for individual land plots. The project is funded by the World Bank loan. It is expected to increase yields from irrigated areas by at least 30%.

Keywords:water demand, water intakes

1. UVOD

Narodna skupština Republike Srpske je na 21. sjednici održanoj 1. novembra 2012. godine donijela Odluku da prihvati zaduženje prema Svjetskoj banci – Međunarodnoj organizaciji za realizaciju Projekata razvoja sistema za navodnjavanje. Projekte će realizovati Ministarstvo poljoprivrede, šumarstva i vodoprivrede – Jedinica za koordinaciju projekata u poljoprivredi u saradnji sa Ministarstvom finansija. Cilj projekata je rehabilitacija i modernizacija postojećih sistema za navodnjavanje, izgradnja novih sistema i jačanje institucionalnih kapaciteta u javnom i privatnom sektoru za osiguranje održivosti i efektivnog korišćenja izgrađenih sistema [1].

Opština Bratunac je prepoznala ovaj projekat kao vrlo unosan za lokalno stanovništvo, koje se sve više odlučuje za gajenje malina na vlastitim parcelama. Očekuje se povećanje prinosa za minimum 30% sa parcela koje se redovno navodnjavaju. Stoga se ušlo u realizaciju sistema za navodnjavanje malina na području 20 mjesnih zajednica opštine Bratunac, na površini oko 490 ha.



Sl.1. Planirane površine za navodnjavanje na području opštine Bratunac [4]

2. POTREBNE KOLIČINE VODE

U poslednje vrijeme su evidentne pojave dugotrajnih i intenzivnih suša, koje zbog nestašice vode prouzrokuju znatne štete u poljoprivrednoj proizvodnji. Nedostatak vode tokom vegetacionog perioda sve više ograničava poljoprivrednu proizvodnju i umanjuje prinose.

Pri projektovanju sistema za navodnjavanje, potrebno je poznavati potrebe uzgajanih kultura za vodom na određenom području. Na osnovu proračuna potreba poljoprivrednih kultura za vodom i proračuna raspoloživih količina vode, utvrđuje se manjak vode u tlu za svaku kulturu, odnosno potreba za navodnjavanjem. Na osnovu veličine površine na kojoj će se uzgajati pojedina kultura, izračunava se ukupni nedostatak vode za datu površinu.

Za izračunavanje potrebnih količina vode za navodnjavanje poljoprivrednih kultura, korišteni su klimatski podaci sa meteorološke stanice Ljubovija za period od 1990. do 2009. godine. Potrebno je uzeti u obzir sledeće prosječne mjesečne klimatske parametre: temperaturu vazduha, relativnu vlagu, srednju brzinu vjetra i insolaciju.

Mjesečne vrijednosti padavina se koriste za izračunavanje prosječne vrijednosti padavina i vjerovatnosti prekoračenja godišnjih padavina od 80%. Za izračunavanje efektivnih padavina, koristila se metoda USDA Soil Conservation Service Method.

Evapotranspiracija kulture je određena na temelju referentne evapotranspiracije i pripadajućeg koeficijenta potrošnje vode ili koeficijenta kulture u određenom stadiju razvoja.

Referentna evapotranspiracija je voda koja se gubi procesima transpiracije i evaporacije sa određene površine u određenom vremenu. Vrijednosti referentne evapotranspiracije zavise od podneblja, odnosno klimatskih elemenata koji se koriste za izračunavanje evapotranspiracije.

Referentna evapotranspiracija se računa prema Penman-Monteith metodi, pomoću kompjuterskog programa Crop Wat 8.0.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

gdje su:

ET_o - referentna evapotranspiracija [mm day^{-1}],
R_n - neto radijacija na površini usjeva [MJ m^{-2} day^{-1}],
G - toplotna indukcija tla [MJ m^{-2} day^{-1}],
T - dnevna temperatura vazduha na 2 m visine [°C],
u_2 - brzina vjetra na 2 m visine [m s^{-1}],
e_s - zasićenje pritiska pare [kPa],
e_a - stvarni pritisak pare [kPa],
e_s - e_a deficit zasićenja pritiska pare [kPa],
Δ - nagib krive pritiska pare [kPa $°C^{-1}$],
γ - psihometrijska konstanta [kPa $°C^{-1}$].

Nazivi planiranih sistema za navodnjavanje malina, površine sistema i sračunate potrebne količine vode za navodnjavanje se daju u narednoj tabeli.

Redni broj	Mjesna zajednica	Naziv planiranoga sistema	Površina za navodnjavanje (ha)	Potrebna količina vode (l/s)
1	Slapašnica	Slapašnica	26,13	14,16
2	Krasanpolje	Krasanpolje	28,44	15,15
3	Kravica	Kravica-Mandići	18,90	10,56
		Kravica-Šiljkovići	21,60	12,50
4	Osamsko	Osamsko	22,50	12,22
5	Polom	Polom	8,01	15,75
6	Ježeštica	Ježeštica	29,07	15,75
7	Repovac	Repovac	13,92	7,56
8	Bratunac II i Pobuđe	Bratunac II i Pobuđe	10,82	5,95
9	Blječava-Zagoni	Blječava-Zagoni	24,79	13,44
10	Mihaljevići	Mihaljevići	5,06	2,74
		Hranča	29,46	15,97

11	Hranča	Hranča-Smoljeva	12,00	6,50
12	Fakovići	Fakovići	21,60	12,12
		Fakovići-Grabovička rijeka	8,20	4,44
13	Konjević polje	Pobuđe	17,58	9,69
14	Zalužje-Biljača	Zalužje-Biljača	14,34	7,77
15	Žlijebac	Žlijebac	2,94	1,61
		Žlijebac (tirolski vodozahvat)	4,70	2,63
		Žlijebac-Vatljevići	8,35	4,85
		Žlijebac-Vranjkovina	4,72	2,74
16	Bjelovac	Bjelovac	35,60	19,35
17	Glogova	Glogova	19,86	10,76
		Glogova-Magašići	25,63	14,92
18	Voljavica	Voljavica	10,00	5,97
19	Podgradac i Podčauš	Podgradac i Podčauš	13,06	7,13
20	Tegare	Tegare	27,11	14,69

Tabela 1. Potrebne količine vode po pojedinim sistemima [4]

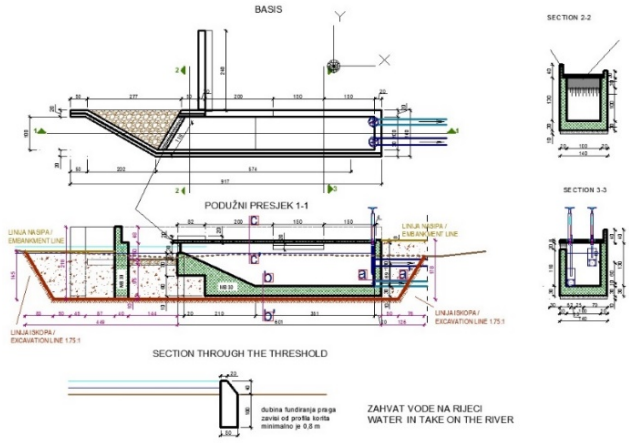
3. GRAĐEVINSKI OBJEKTI

Sistem za navodnjavanje se sastoji od sledećih građevinskih objektata i opreme: zahvati vode, cjevovodi, rezervoari, hidromehanička oprema, odgovarajuća elektro oprema za pogon sistema, nadzor i upravljanje.

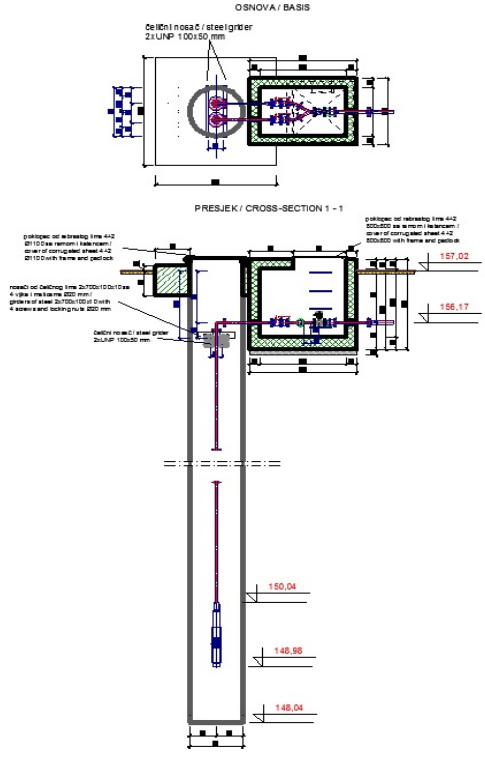
Zahvati vode: Zahvatanje vode se vrši kopanim i bušenim bunarima pored rijeke Drine, kao i vodozahvatima sa odgovarajućim sabirnim komorama na lokalnim brdskim vodotocima.

Bunari pored rijeke Drine su dubine od 7 do 16,5 m. Rade se bušeni bunari sa čelinom konstrukcijom profila 800 mm i kopani bunari sa poliesterskom konstrukcijom prečnika 1000 mm i 1200 mm. U svaki bunar se montiraju po dvije uronjene bunarske pumpe. Pored bunara se radi odgovarajući armirano-betonski šaht za opremu (ventili, vodomjer, fazonski komadi). Voda iz bunara se potiskuje u armirano-betonske rezervoare. Na sistemu je projektovano ukupno 16 bunara.

Vodozahvatima se voda zahvata direkto iz lokalinih brdskih vodotoka koji imaju dovoljne količine vode u ljetnjem periodu kada su potrebe za navodnjavanjem najveće. Na sabirnim komorama vodozahvata se ugrađuje odgovarajuća hidromehanička oprema za regulisanje toka vode (usine korpe, zasuni, tablasti zatvarači). Na sistemu je projektovano 6 vodozahvata na brdskim vodotocima.



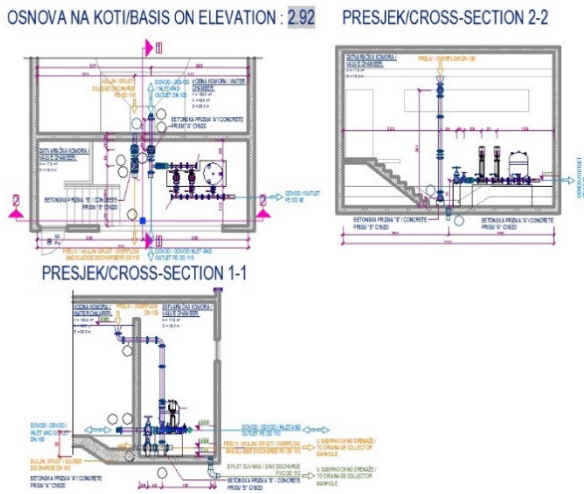
Sl. 2. Zahvat vode iz manjeg vodotoka [5]



Sl.3. Bunarski zahvat vode [5]

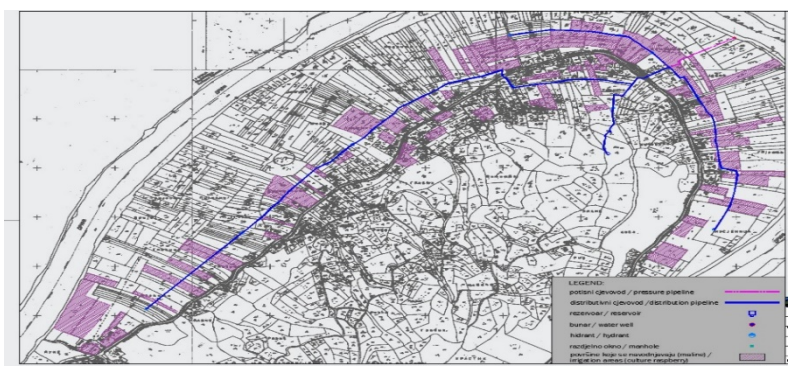
Rezervoari: Rade se armirano-betonski jednokomorni poluukopani rezervoari, opremljeni odgovarajućom hidromehaničkom opremom, kao i elektro opremom za regulisanje nivoa vode u rezvoarima (sonde za regulisanje režima rada bunarskih pumpi,

kada se voda u rezervoar transportuje pumpanjem ili ventili sa plovkom, kada se voda u rezervoar transportuje gravitaciono sa vodozahvata na vodotocima). Planirana su 24 rezervoara, ukupna zapremina rezervoarskog prostora je 2875 m^3.

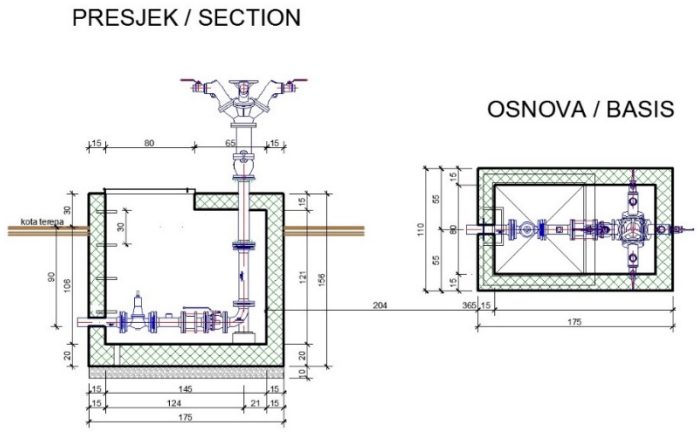


Sl. 4. Rezervoar sa zatvaračkom komorom i pumpom [5]

Cjevovodi: Transport vode na sistemima se vrši odgovarajućim potisnim i distributivnim (gravitacionim) cjevovodima. Cjevovodi su od polietilena PEHD PE 100, prema EN 12201. Profili cijevi su od 32 do 180 mm, radni pritisci su od 6 do 25 bara, ukupna dužina cjevovoda je oko 90 km. Cjevovodi su opremljeni odgovarajućom opremom za normalno funkcionisanje i uzimanje vode iz cjevovoda (čvorišta, usisno-odzračni ventili, muljni ispusti, hidranti).



Sl. 5. Situacioni prikaz jednog sistema za navodnjavanje [5]



Sl. 6. Hidrant za uzimanje vode iz cjevovoda [5]

4. UPRAVLJANJE SISTEMOM

Za upravljanje radom sistema, osnovaće će se posebna firma na nivou opštine Bratunac. Pored redovne kontrole i održavanja montirane opreme, potrebno je voditi detaljnu evidenciju o zahvaćenim količinama vode za navodnjavanje pojedinačnih korisnika, kako bi se vršila pravična raspodjela troškova koji će se javiti tokom eksploatacije sistema. Također je potrebno vršiti kontrolu vlažnosti tla, na osnovu koje će se određivati potrebe malina za dodatnim količinama vode iz sistema za navodnjavanje.

5. TROŠKOVI IZGRADNJE SISTEMA

Troškovi izgradnje sistema za navodnjavanje iznose 8.129.156,41 KM (sa uračunatim PDV-om):

- Bunari sa opremom 657.721,35 KM
- Rezervoari, cjevovodi, šahtovi sa hidromehaničkom opremom 7.419.352,51 KM
- Kontrolno komandni centar i daljinsko upravljanje 52.082,55 KM

Finansiranje izgradnje sistema je putem kredita Svjetske banke (85%) i lokalne zajednice (15%).

6. ZAKLJUČCI

Izgradnja i puštanje u funkciju sistema za navodnjavanje malina na području opštine Bratunac, ima veliki značaj za dalji razvoj lokalne zajednice. Uzgajanje malina je postalo unosno zanimane lokalnog stanovništva. Korišćenjem sistema za navodnjavanje, očekuju se povećani prinosi za minimum 30%.

Puštanjem sistema u rad (početkom vegetacione sezone 2018. godine), realizovaće se jedan od projekata navodnjavanja poljoprivrednih površina u Republici Srpskoj [1]. Do sada su u Republici Srpskoj pušteni u funkciju sledeći obnovljeni, rehabilitovani i modernizovani sistemi navodnjavanja poljoprivrednih površina: Sistem za navodnjavanje na području Novog sela u opštini Bijeljina (622,25 ha), Sistem za navodnjavanje Gojkova i Stakića polja u opštini Pelagićevo (202,3 ha). U toku je realizacija projekta za navodnjavanje poljoprivrednih površina u Ljubinjskom polju u opštini Ljubinje (250 ha), kao i realizacija sistema za navodnjavanje dijela Trebinjskog polja u opštini Trebinje (1070 ha).

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58| Стручни рад
Professional paper
doi 10.7251/STP1813756J ISSN 2566-4484

UPOTREBA OTVORENIH PODATAKA I APLIKACIJA U PROCESU EDUKACIJE

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Abstract:

Ovaj rad ima za cilj da prikaže iskustva u obrazovanju u upotrebi pre svega satelitskih snimaka ali i drugih podataka sa otvorenim pristupom. Prikazane su različite satelitske platforme sa različitim prostornim i spektralnim rezolucijama. Takođe razmatramo primenljivost ovih podataka u obrazovnom procesu, posebno sa studentima sa studijskog programa Geodezija i geomatika na Fakultetu tehničkih nauka Univerziteta u Novom Sadu. Prikazani su i neki praktični primeri. Na kraju, ovaj rad takođe opisuje probleme iz praktičnog pogleda na nastavu i daje preporuku o tome kako rešiti te probleme koristeći pristup učenja zasnovanog na problemu.

Keywords: satelitski snimci, obrazovanje, geoinformatika, daljinska detekcija

USE OF OPEN DATA AND APPLICATIONS IN THE EDUCATION PROCESS

Abstract:

This paper aims to show experience in education using open access data, especially sattelite images. We describe different satellite platforms with different spatial and spectral resolution. We also discuss applicability of these data in education process especially with students on study program Geodesy and Geomatics on Faculty of technical sciences, University of Novi Sad. Some practical examples are also shown. At the end, the paper also describes problems from practical view of teaching and recommendation how to solve those problems using Problem based learning approach.

Keywords: open data, education, geoinformatics, remote sensing, satellite images

1. INTRODUCTION

The Sustainable Development Goals (SDGs) were born at the United Nations Conference on Sustainable Development in Rio de Janeiro in 2012 [1]. The objective was to produce a set of universal goals that meet the urgent environmental, political and economic challenges facing our world. There are 17 goals which are interconnected, so often the key to success in one will involve tackling issues more commonly associated with another. The most powerful and proven tool for sustainable development, education, is also one of the 17 goals. According to this goal, the desire is to provide the same opportunities in terms of accessible vocational education, as well as to eliminate disparity in terms of gender and wealth, with the aim of achieving universal access to quality higher education.

The data are probably the most valuable and least-used resource for the entire region of southeastern Europe, especially in the countries of the former Yugoslavia. Local and national authorities in those countries don't understand that intelligent data management helps them to create new opportunities for the development of the economy and employment. If they increase the availability of data of each type, they will increase efficiency in service delivery, and improve the outcome of the education.

The EU Commission has been investing significant resources over the years to overcome the challenges it entails by supplying large amounts of data for public use. The opening of data is recognized globally as a process that will significantly contribute to the achievement of the Sustainable Development Goals after 2015 [2].

The Global Open Data Index, The Global Open Data Initiative (GODI), The Open Data Foundation (ODaF), The Open Data Handbook, Open Gov Partnership (OGP), are just some of the organizations which define what open data are and how should they be treated by governmental and non-governmental institutions. "Open data and content can be freely used, modified, and shared by anyone for any purpose" [3] is the most common and the most frequently used definition of open data.

The importance of spatial data in the 21 century is increasing exponentially, mainly because of growing availability and usability in everyday life, and because of the vast data quantity which are being collected, processed and analyzed in different ways and by different profit or non-profit institutions. The objective of this paper is to introduce open access spatial data and open source GIS applications in education process, especially with students from study programs, where "geo" and "spatial" is normal way of thinking and viewing the world. These data and application and their open availability can have a significant influence on the mindset of future generations that are now being educated.

This paper is organized as follows: the next section presents what is most use open access spatial data and application. Section three gives an explanation about data applicability, and how open access data can be used in higher education. Also, this section describes the importance and opportunities of remotely sensed data for different kind of applications. Paper concludes with an outlook on problem-based learning (PBL) approach using open access data and open source GIS.

2. OPEN DATA AND APPLICATIONS

Open spatial data from different sources provides geospatial engineering solutions for managing spatial data from survey through design, construction and data distribution, utilising open standards and engineering best practices. If we need information about land cover monitoring, land cover change detection, weather disasters, floods, fires, and other

occurrences, there are a lot of agencies that are monitoring and collecting data from the whole planet or just some part of it on a daily basis. These information's are collected with satellite platforms with different spatial, spectral, temporal and radiometric resolutions. Property and access to this information's present an important step towards understanding the environment in which we live in and how do we influence on our environment.

On the other side, beside data that are coming from different ways of monitoring, there are lot of type of spatial data which arise from different kind of community. One of the best examples is Open Street Map (OSM) [4]. OSM has created a cartograph community that adds and maintains information about roads, paths, bars, railroad stations and many other facilities around the world. The OSM community is diverse, and include enthusiasts, GIS professionals, engineers running OSM servers, humanitarians mapping areas affected by disasters, and many others. OSM gives open data, which means that you can freely use it for any purpose as long as you give credit to OpenStreetMap and contributors.

An open source application by definition is software that you can freely download, use and also modify for your own needs. Open source projects are typically created from a community of volunteer programmers. There is very large number of open source GIS programs, and globally they can be divided into several groups. Usually, they can be divided on desktop and web open source GIS, or they can be divided in terms of programming languages that they are based on (for example Java, and .NET). In addition to the benefit of cost reduction, there are many advantage of using GIS open source applications. Open source GIS software will give you the opportunity to learn all aspects of GIS through the free use of available courses and resources. Having access to the source code, allows users to customize application in any way that they can think of.

In addition to all the benefits of open source tools there are some disadvantages. Some open source software doesn’t have user-friendly interface and for new users it’s hard to conduct even simple tasks. Commercial solutions often have better and more complete documentation and better user support. Also, commercial software typically offers a robust suite of features right out of the box

2.1. SATELLITE DATA

2.1.1. European Space Agency - ESA

European Space Agency (ESA) is an international agency, founded in 1975., which deals with space exploration and coordinates European civil space activities. ESA is an international organization with 22 Member States. By coordinating the financial and intellectual resources of its members, it can undertake programs and activities far beyond the scope of any single European country. [10]

Copernicus is the most ambitious Earth observation program to date. It will provide accurate, timely and easily accessible information to improve the management of the environment, understand and mitigate the effects of climate change and ensure civil security. This initiative is headed by the European Commission (EC) in partnership with the European Space Agency (ESA).

European Space Agency (ESA) within the Copernicus program is constantly developing and planning new Sentinel satellite platforms. The Sentinels will provide a unique set of observations, starting with the all-weather, day and night radar images from Sentinel-1A and -1B, launched respectively in April 2014 and April 2016.

The Sentinel-1 mission comprises a constellation of two polar-orbiting satellites, operating day and night performing C-band synthetic aperture radar imaging, enabling them to

acquire imagery regardless of the weather. Sentinel-1 satellites produce radar images with the repeat cycle of 6 days. [11]

Sentinel-2 mission provides multispectral high-resolution images of the Earth's surface. The mission consists of two satellites that are in the same orbit at a height of 786 km and are positioned 180° from each other. Sentinel-2A was launched on June 23, 2015, and Sentinel-2B on March 7, 2017.

Each of the Sentinel-2 mission satellites has a Multispectral Instrument (MSI) capable of recording in 13 spectral bands: 4 bands at 10 m, 6 bands at 20 m and 3 bands at 60 m spatial resolution. The Multispectral Instrument (MSI) works passively by collecting the Sun's rays that are reflected from the Earth's surface. It uses push-broom concept by collecting rows of image data across the orbital swath and uses the forward motion of the spacecraft along the path of the orbit to provide new rows for acquisition. Temporal resolution of one Sentinel-2 satellite is 10 days, which means that the combined temporal resolution of the whole system is 5 days. [11]

Sentinel-3 is an European Earth Observation satellite mission developed to support GMES ocean, land, atmospheric, emergency, security and atmospheric applications. The main objective of the Sentinel-3 mission is to measure sea surface topography, sea and land surface temperature, and ocean and land surface color with high accuracy and reliability to support ocean forecasting systems, environmental monitoring and climate monitoring. The mission definition is driven by the need for continuity in provision of ERS, ENVISAT and SPOT vegetation data, with improvements in instrument performance and coverage. [11]

Images from these 3 missions are open access data and users only need to register at the Copernicus Data Hub in order to download it. Hub offers different filters for the image data acquisition, amount of cloud coverage, area of interest. Beside raw images users can download preprocessed data with different level of corrections. For Sentinel-2 there are processing levels 1C (radiometric and geometric corrected data) and 2A (scene classification and an atmospheric correction applied to Top-Of-Atmosphere (TOA) Level-1C orthoimage product).

It should be noted that Sentinel data can be downloaded from other sources such as USGS or PEPS hubs or through some software such as QGIS with its Semi-Automatic Classification Plugin.

Beside the listed missions above ESA is planning to launch 3 more satellite systems: Sentinel-4, Sentinel-5 and Sentinel-6 which will be equipped with different types of sensors and whose data will be used for various research.

2.1.2. United States Geological Survey - USGS

The United States Geological Survey is a scientific agency of the United States government whose subjects of research are natural hazards, water, energy, minerals and the impacts of climate and land-use change. To achieve that they collect a large amount of data about Earth, atmosphere and even space. They provide real-time or near real-time data and information on current conditions and Earth observations to users under open data license. In the real-time data section users can find information about earthquakes (auto update KML file), water (graphs and reports), floods (real-time map), geomagnetism, remote land sensing (Landsat) and so on. They also offer large number of thematic maps, GIS data and geological maps. It should be noted that the most of these data are only for the area of U.S. Their Landsat satellite program offers satellite images of the whole world and it was the first program of its kind.

Landsat program for Earth observation lasts from 1972 when the first Landsat was launched. Since 1982 Landsat 4 satellite platform began to deliver satellite images with 30 meters spatial resolution in visible, near-infrared and short-wave-infrared wavelengths, which enabled the first severe Earth land cover monitoring [5]. A big step forward in information access occurred in 2008 when the US Geological Survey issued a decision that enabled all of the Landsat images to become free and open access to anyone [6].

Today Landsat 7 and Landsat 8 satellites are still active from which Landsat 8 images are more used today. Landsat 8 carries two push-broom instruments: Operation Land Imager (OLI) and Thermal Infrared Sensor (TIRS). The Operational Land Imager (OLI) measures in the visible, near-infrared, and short-wave infrared portions of the spectrum. Its images have 15 m panchromatic and 30 multi-spectral spatial resolutions. Thermal Infrared Sensor (TIRS) measures temperature of Earth surface in two spectral bands with spatial resolution of 100 m. Temporal resolution of Landsat 8 satellite is 16 days.

Figure 1 shows some of the results that can be obtained from the open access satellite data for the area of Republic of Serbia. Landsat satellite images can be used for generation of land cover maps, or maps of different vegetation indices that can be used in the area of agriculture (quality of agricultural cultivated plants or condition of other types of crops and fruit fields) or in environmental applications. Also, Landsat satellite images can be used for mapping flooded areas and flood simulations. Figure 1 also illustrates forest map for the area of Fruška gora National Park, obtained from radar PALSAR images, while Aster images, among other applications, can be also useful for Digital Elevation Model (DEM) generation [7].

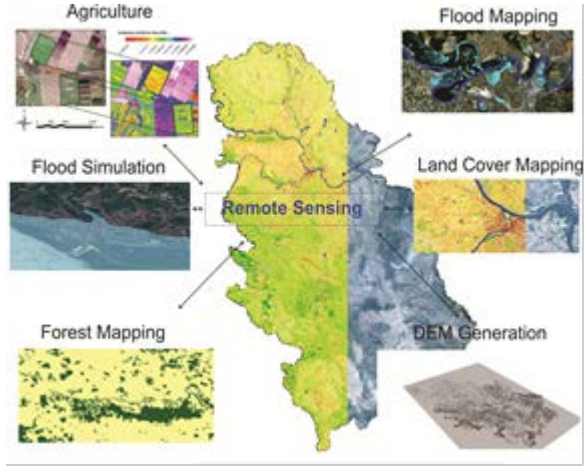


Figure 1. Examples of products obtained from the processing of open access satellite data for the area of Republic of Serbia

2.2. VOLUNTEERED GEOGRAPHIC INFORMATION - VGI

2.2.1. Open Street Map - OSM

Sites such as Wikimapia and OpenStreetMap are empowering citizens to create a global patchwork of geographic information, while Google Earth and other virtual globes are encouraging volunteers to develop interesting applications using their own data [7].

OpenStreetMap was created in 2004 by Steve Coast in UK inspired by the success of the Wikipedia. It was created as an answer to the European restrictions on use or availability of map information. A key motivation for this project is to enable free access to current geographical information where, in European countries, accurate digital geographical information is considered to be expensive and out of the reach for individuals, small businesses, and community organizations [9]. The idea soon spread to the rest of the world. Number of OSM users grown exponentially and OSM database was filled with more and more data. All registered users can enter new data that they've collected using manual survey, GPS devices, aerial photography, and other free sources. Entered data is then validated by other users, so everyone is contributing as much as they can. Crowdsourced data collected by the users are then distributed under the open data license. Today OSM is one of the biggest map providers and source of different spatial information. Rather than the map itself, the data generated by the OpenStreetMap project is considered its primary output.

OSM uses topological data structures for storing data. Elements that have been used are: nodes (stored as coordinate), ways (ordered lists of nodes), relations (ordered lists of nodes, ways and relations) and tags (metadata). All OSM data are stored in a PostgreSQL database with PostGIS extension. Database has 4 different tables for each of the primitives in which objects are stored. Data download can be done through the OSM export page. Data for the given area are created as a database dump that exist in two formats: XML and PBF. Downloaded data can be then opened in some GIS tool such as QGIS.

QGIS treats OSM files as a regular vector files, grouping together points, lines and polygons into separate layers. Once loaded into QGIS data can be used for different spatial analysis and can be exported as a different data format.

2.3. QGIS

QGIS is a user friendly open source Geographic Information System (GIS) application licensed under the GNU General Public License. QGIS was released in July 2002 as official project of the Open Source Geospatial Foundation (OSGeo). Its core functions provide powerful desktop tool for spatial data manipulation, spatial file browser, a server application that provides OGC compatible WMS and WFC services and a QGIS web client. QGIS supports both raster and vector layers; vector data is stored as either point, line, or polygon features. Multiple formats of raster images are supported, and the software can georeference images. QGIS provides a continuously growing number of capabilities provided by core functions and plugins. QGIS supports shapefiles, coverages, personal geodatabases, dxf, MapInfo, PostGIS, and other formats. Web services, including Web Map Service and Web Feature Service, are also supported to allow use of data from external sources.

The main advantage of QGIS over other tools is its big community. QGIS is a volunteer driven open source project, which means that anyone can see the source code of the program and modify the existing functions or create new ones. There are more than 500 plugins developed by users which extend the basic functionality of the program. Plugins are written in C++ or Python.

Developed by Luca Congedo, the Semi-Automatic Classification Plugin (SCP) is a free open source plugin for QGIS that allows for the semi-automatic classification (also known as supervised classification) of remote sensing images. It provides several tools for the download of free images, the preprocessing, the postprocessing, and the raster calculation.

The overall objective of SCP is to provide a set of intertwined tools for raster processing in order to make an automatic workflow and ease the land cover classification, which could be performed also by people whose main field is not remote sensing.

SCP includes the tool for searching and downloading Landsat images (from Landsat 1 MSS to Landsat 8 OLI), Sentinel-2, Sentinel-3, ASTER and MODIS satellite images. In the process of image download automatic conversion to reflectance of downloaded bands is available. Atmospheric correction can also be conducted later with the use of the image metadata file. SCP uses dark object subtraction algorithm for image preprocessing.

One of the main functionalities of SCP is supervised image classification which is done through SCP dock. The SCP dock allows creation of ROIs (Regions Of Interest) and spectral signatures, and the classification of a band set image. The training input, created with SCP, stores the ROI polygons and spectral signatures used for the land cover classification. [12]

In SCP, land cover classes (and ROIs) are defined with a system of classes (Class ID) and macroclasses (Macroclass ID) that are used for the classification process. Each macroclass ID is related to a macroclass name and each class ID is related to a class name, but only macroclass ID and class ID are used for the classification process and SCP recognises classes based on ID. Once training sets are collected, SCP dock allows signature analysis by reviewing signature plot and scattering. Three classification algorithms can be used: Minimum Distance; Maximum Likelihood and Spectral Angle Mapping. Accuracy assessment can also be done through SCP. Plugin allows a random ROI generation and class photointerpretation that are later used for classification assessment. [12]

Beside listed, SCP offers a lot of image manipulation tools. Images can be subset to a shape of a ROI or shapefile, band sets can be created by merging different bands into different levels of the image, image RBG preview can be set to a specific set of bands. SCP is a powerful plugin for remote sensing based analysis and it's been constantly upgraded through many of its iterations. Current version is 6.0.1.1

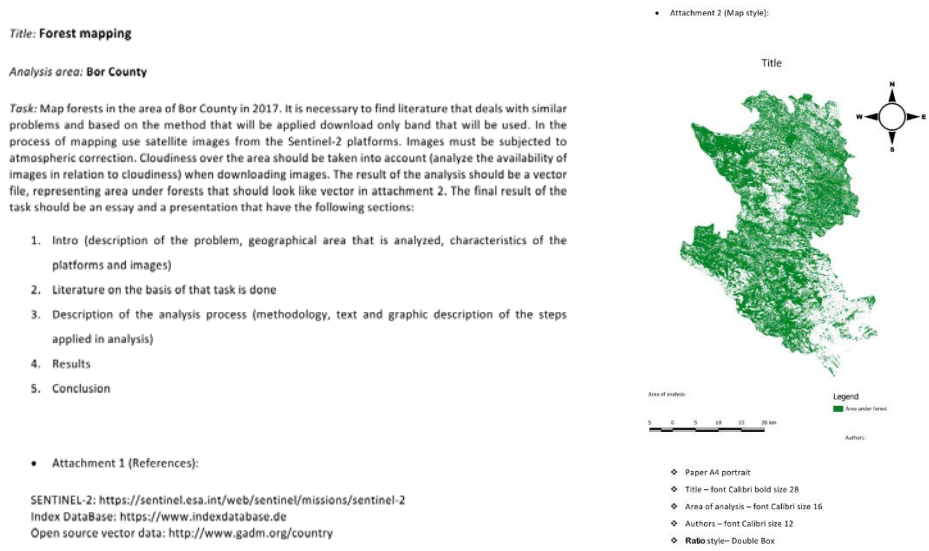
3. EXPERIENCE IN DATA APPLICABILITY IN EDUCATION PROCESS

In the framework of this paper, an overview of the use of open data and open source application on the study program Geodesy and Geomatics, Faculty of Technical Sciences in Novi Sad is given. Within this study program, students are familiarized with various subjects that are basically based on spatial data. The trend of collecting spatial data is increasingly relied on knowledge in the area of remote sensing. Courses Photogrammetry and remote sensing in the fourth and Remote sensing and computer image processing in the seventh semester are substantially interconnected, and fully enable students to learn about the method of collecting spatial data from different types of platforms. Students are primarily learned on how to collect and process data from satellite platforms, as well as how to do the post-processing of such data and raises the value of the input spatial information to an entirely new level.

Teaching and exercises from these subjects are designed so that students fully master the basic techniques of collecting and processing spatial data, as well as mastering the use of different software in the field of remote sensing.

In the seventh semester of 2017/18, one part of the course Remote sensing and computer image processing has been changed, in the way to introduce problem-based learning

approach. This practical mean that 15% of exercises from those subject is changed. All students who attended the course were divided into 12 groups of 5 students. Each group was formed so it contained students with different level of knowledge. Members of every group had to choose one student for the group leader. The leader of the group shared tasks among other members, organized a work plan, and if necessary arranged consultations with the professor. The students assignments were: Red edge band impact analysis; Flood monitoring; Urban area growth detection; Temperature trends in urban areas; Forest fire detection; Tree species classification, Forest area identification; Water bodies mapping; Correlation between vegetation indexes; Vegetation stress analysis; Analysis of vineyard health and Chlorophyll content detection. Assignments were given in a form of template, which is shown in the Figure 2



Title: **Forest mapping**

Analysis area: **Bor County**

Task: Map forests in the area of Bor County in 2017. It is necessary to find literature that deals with similar problems and based on the method that will be applied download only band that will be used. In the process of mapping use satellite images from the Sentinel-2 platforms. Images must be subjected to atmospheric correction. Cloudiness over the area should be taken into account (analyze the availability of images in relation to cloudiness) when downloading images. The result of the analysis should be a vector file, representing area under forests that should look like vector in attachment 2. The final result of the task should be an essay and a presentation that have the following sections:

1. Intro (description of the problem, geographical area that is analyzed, characteristics of the platforms and images)
2. Literature on the basis of that task is done
3. Description of the analysis process (methodology, text and graphic description of the steps applied in analysis)
4. Results
5. Conclusion

- Attachment 1 (References):

SENTINEL-2: https://sentinel.esa.int/web/sentinel/missions/sentinel-2
Index DataBase: https://www.indexdatabase.de
Open source vector data: http://www.gadm.org/country

- Attachment 2 (Map style):

- Paper A4 portrait
- Title – font Calibri bold size 28
- Area of analysis – font Calibri size 16
- Authors – font Calibri size 12
- **Ratio** style– Double Box

Figure 2. Example of PBL task

Each group had the title of their assignments, followed by a geographical area that they were analyzing. The most given areas were from wider area of Serbia. Next part contained a detailed description of the problem and the time period for which the analysis was to be performed. All satellite images had to be open access and cut to the shape of the area of interest (AOI). Those AOI's were most often administrative units of Serbia, Montenegro or Republic of Srpska in a form of shapefile that are open access from websites such as Global Administrative Areas (http://www.gadm.org/country). Then the groups task was to analyze existing literature dealing with that problem and to find the best solution for their assignments. In the last part we gave them useful references as a starting point for their analysis. As a result, group had to produce some raster or vector file that contained the resulting data, write down all what they have done in a form of essay, prepare adequate map or maps of the results and to prepare power point presentation to present their results to the entire class. Next two chapters present two student assignments, methods that they used and obtained results.

3.1. FOREST FIRE DETECTION

Title of this assignment was Forest fire detection, and area of interest for this assignment was area of Montenegro. In this assignment students must detect area of forest fire using Landsat8 satellite images. Students must find literature that deals with similar problems and based on the method that they find in literature, download only bands that they will be used. The analysis should be based on the temporal comparison of images before and after the fire. Images must be subjected to atmospheric correction. Cloudiness over the area should be taken into account (analyze the availability of images in relation to cloudiness) when downloading images. For the realization of this assignment we propose QGIS software. The result of the analysis must be raster that should look like raster given in description of assignment and the final result of the task should be an essay and a presentation.

Based on their analysis students concluded that they will use Normalized Burn Ratio (NBR) and difference Normalized Burn Ratio (dNBR) indices, to highlight areas that have been burned and to index the severity of a burn area using Landsat imagery. Students first downloaded images from USGS website for the area of Montenegro, one image with the date of acquisition 10.07.2017. and other 30.10.2017. For the entire assignment they used an open-source software QGIS. In QGIS they used Semi-Automatic Classification Plugin for atmospheric correction (Dark object subtraction method), NBR and dNBR calculation and Print composer for generating final result in a form of map. Because dNDR results vary from case to case and can be interpreted in different ways, they used USGS dNBR classification suggestion shown in the Table 1.

Table 1. Levels of vegetation burn, proposed by the USGS

SEVERITY LEVEL	NBR RANGE
Enhanced Regrowth, High	-0.500 to -0.251
Enhanced Regrowth, Low	-0.250 to -0.101
Unburned	-0.100 to 0.099
Low Severity	0.100 to 0.269
Moderate-low Severity	0.270 to 0.439
Moderate-high Severity	0.440 to 0.659
High Severity	0.660 to 1.300

The results of the dNBR and scaled dNBR are shown in the Figure 3 and Figure 4 below.

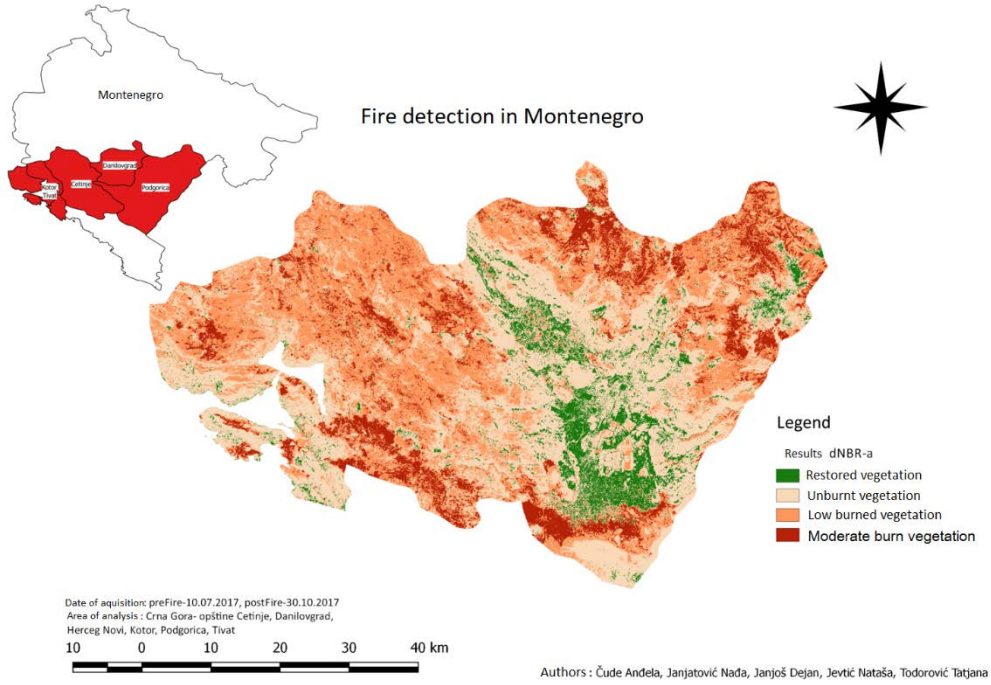


Figure 3. Results of dNBR classification

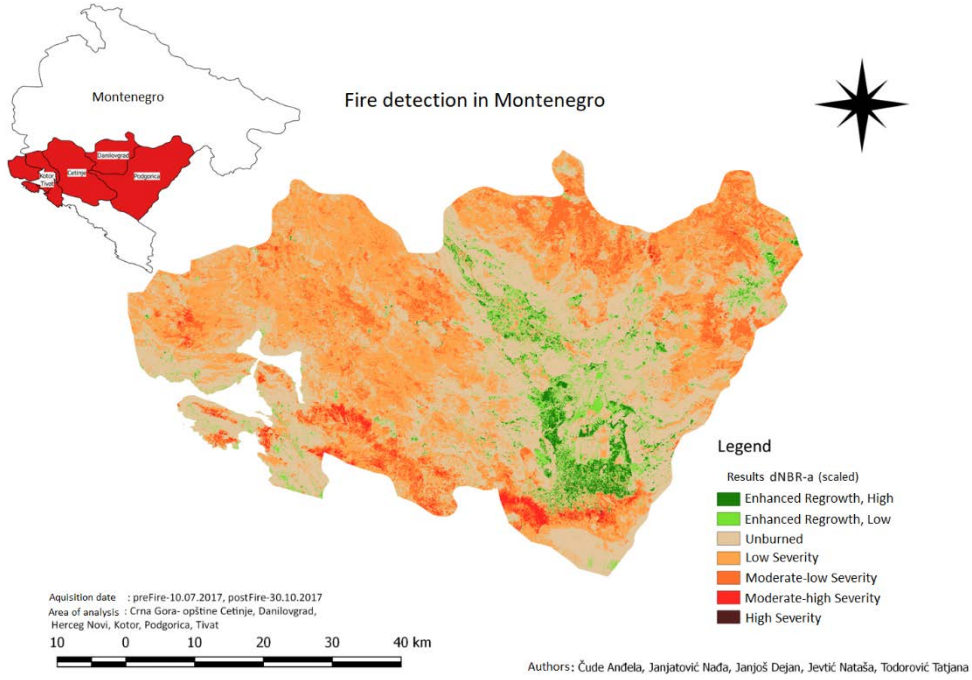


Figure 4. Results of scaled dNBR classification

3.2. FLOOD MONITORING

Title of this assignment was Flood monitoring, and area of analysis for this assignment was area of river Sava. In this assignment students must detect flooded area around river Sava in 2014. using Landsat8 satellite images. They have to find literature that deals with similar problems and based on found methods, to download only bands that will be used. The analysis should be based on the temporal comparison of images before and after the flood. Images must be subjected to atmospheric correction and cloudiness over the area should be taken into account when downloading images. For the realization of this assignment we propose QGIS software. The result of the analysis should be map of flooded area with OSM data as background, an essay and a presentation.

Based on their analysis students concluded that the best solution is to use supervised classification on two images, extract only pixels containing water and then use the change detection algorithm from QGIS. They conducted the same steps for image preprocessing as the group described above (atmospheric correction, band stack and image subset) in Semi-Automatic Classification plugin (QGIS). They collected training sites (areas in the map that are known to be representative of a particular land cover type) for water from downloaded images. Based on the training sites QGIS calculates spectral signature for water combining spectral information's from each band. Based on spectral signatures classification algorithm decides which pixel belongs in which class. Classification results are shown in Figure 5 and Figure 6.

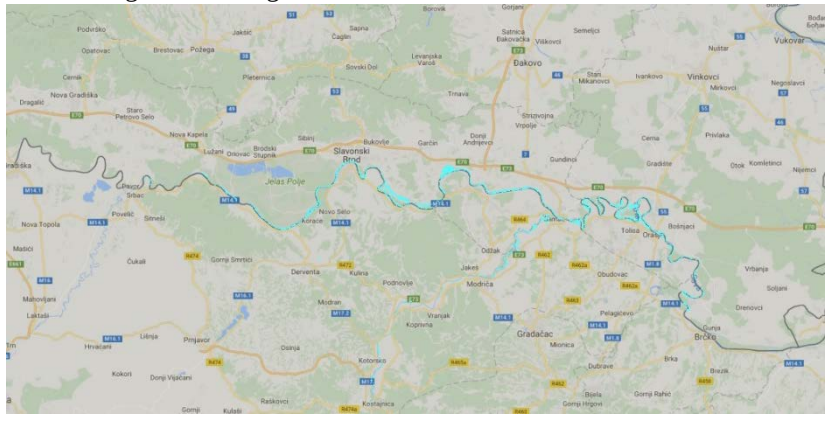


Figure 5. Classification before flood

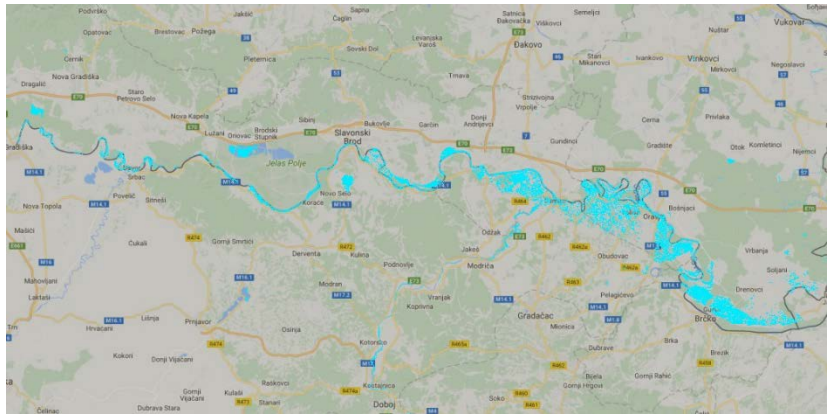


Figure 6. Classification after flood

In order to isolate areas that have been flooded, they used Land cover change option from SCP, which compares two images and produces third raster on which are shown areas where land cover changed. Figure 7 show the results, where red color represents flooded areas.

Figure 7. Flooded areas around river Sava in 2014.

4. CONCLUISION

There are 1 738 active satellites in the Earth's orbit from which 596 are used for Earth observation. Europe decided to send significant number of remote sensing satellites in space, and the data will be delivered free of charge. In combination with other platforms such are USGS platforms and volunteered geographic information such as OSM this will create new opportunities for the development in all fields.

In this paper we have introduced possibility of using open access data in Higher Education, in a way of promoting not just how to download and present such data, but also to promote simple way of how to process data, and how to do that with open source application. Also, we want to promote PBL as a way of standard way of learning in Higher education, especially with "geomatics" or let's say students that have touching points with geoinformatics area.

ACKNOWLEDGMENT
Results presented in this paper are part of the research conducted within the Grant No. 37017, Ministry of Education and Science of the Republic of Serbia.

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59| Стручни рад
Professional paper
doi 10.7251/STP1813769R ISSN 2566-4484

ОБРАЧУН КОЛИЧИНЕ ИСКОПАНИХ МАСА РУДЕ НА ОСНОВУ ФОТОГРАМЕТРИЈСКИХ СНИМАКА

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Резиме:

У оквиру рудника „Угљевик“ ради и геодетска служба. Поред свих задатака (експропријације, контроле геометрије постојећих инжењерских објеката, праћење рада клизишта итд.) примарни задатак геодетске службе је обрачунавање запремине ископаних маса, на површинском копу у току одређеног временског периода. У раном периоду експлоатације примјењивале су се класичне геодетске методе премјера, а протеклих двадесетак година за рачунање количина ископаних масе користили су се подаци добијени ГПС премјером. У раду је приказан обрачун количине ископаних маса у програмском пакету Global Mapper на основу обрађених фотограметријских снимака добијених беспилотном летјелицом.

Кључне ријечи: беспилотна летјелица, снимак, Global Mapper, ископане масе

PHOTOGRAMMETRIC SURVEY OF OPEN PIT MINE

Abstract:

There is a geodetic department in Ugljevik Coal Mine. In addition to all tasks (expropriation, geometry control of existing engineering objects, monitoring of landslides, etc.), the primary task of the geodetic service is to calculate the volume of the excavated masses on a surface mine during a certain period of time. In the early period of exploitation, classical geodetic methods of survey were applied, and for the past twenty years, the data obtained by the GPS survey were used to calculate the amount of excavated mass. The paper presents the calculation of the amount of mass in the Global Mapper software package based on the processed photogrammetric images made by the unmaned aerial vehicle.

Keywords: unmaned aerial vehicle, image, Global Mapper, excavated mass

1. УВОД

Фотограметрија и даљинска детекција су научне области чији принципи и поступци омогућавају добијање поузданих информација о Земљи, њеним карактеристикама и физичким процесима, као и свим промјенама које се дешавају на њеној површини и унутрашњости. Овакве информације добијају се на основу снимака који настају уз помоћ различитих врста сензора, снимањем без непосредног контакта са објектом и даљим мјерењима, анализама и прорачунима.

Термин UAV фотограметрија (UAV - Unmanned aerial vehicle) описује фотограметријску мјерну платформу којом се управља даљински, полуаутомаски или аутоматски без присуства пилота у летјелици. Платформа садржи фотограметријске мјерне системе, укључујући видео, термалне или ифрацрвене камере, ваздушни LiDAR систем или неку од комбинација ових мјерних система. Овакви UAV системи омогућавају регистровање и праћење положаја и оријентацију коришћених сензора у неком од локалних или глобалних координатних сиситема. Стога, UAV фотограметрија се може дефинисати као нови метод прикупљања података у фотограметрији. Ова област отвара нове могућности за прикупљање података, комбинујући ваздушну и терестричку фотограметрију, омогућава праћење података у реалном времену и јефтине алтернативе класичним фотограметријским методама.

2. СНИМАЊЕ РУДНИЧКОГ ПОВРШИНСКОГ КОПА „БОГУТОВО СЕЛО“

На подручју Угљевика руда угља се експлоатише још од осамнаестог вијека. Први организовани вид експлоатације угља почео је 1899. године са доласком Аустроугарске на власт у Босни и Херцеговини. У двадесетом вијеку рудна експлоатација наставља да се развија под управом различитих власти које су се смјењивале након и у току ратова. Након Другог свјетског рата долази до убрзаног развоја и модернизације пословања рудника.

Најважнији послови геодетске службе, у оквиру рудника „Угљевик“, су експропријација земљишта, контрола геометрије постојећих инжењерских објеката, праћење рада клизишта, као и обрачунавање количине ископаних маса на површинском копу у току одређеног временског периода. Количина ископаних маса се израчунава на основу обрађених фотограметријских снимака, добијених снимањем из беспилотних летјелица, за разлику од досадашњих начина, класичне геодетске методе премјера и рачунање количина ископаних масе, користили су се подаци добијени ГПС премјером.

Од 2016. године геодетска служба рудника „Угљевик“, за снимање површинског копа „Богутово Село“, користи беспилотни аерофотограметријски систем (БАС) eBee.

Беспилотни аерофотограметријски систем eBee је класичан вишенамјенски систем. Одликује га једноставност, ефикасност и задовољавајућа тачност крајњих података. Једноставност овог система се манифестује у више сегмената: једноставна употреба, прилагодљив софтвер и једноставност и компактност саме летјелице.

Систем eBee се састоји из више компонената, које заједно чине овај систем високо функционалним:

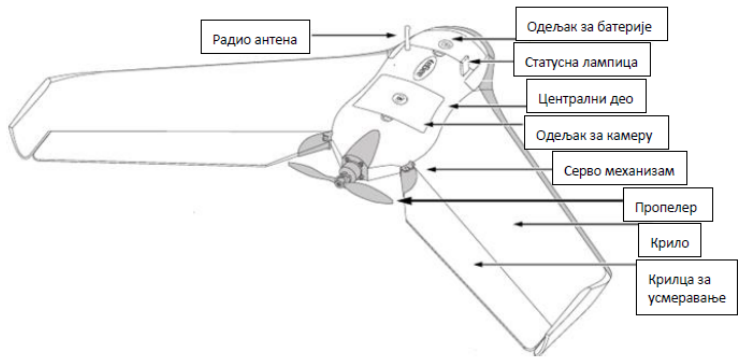
- Беспилотна летјелица eBee,
- Радио веза за надзор и управљање,
- Софтвер за планирање лета eMotion,
- Софтвер за накнадну обраду података PostFlight Terra 3D,
- Остали прибор.

Слика 1. Летјелица eEbee система у налету изнад насељеног мјеста [8]

Слика 2. Транспортни кофер беспилотне летјелице [8]

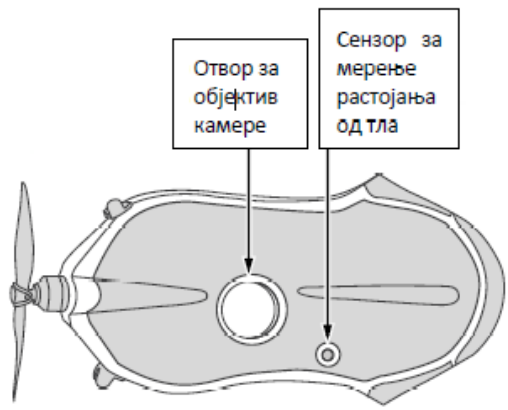
Беспилотна летјелица овог система је израђена од веома лаких материјала. Основа структура тијела летјелице је изграђена од карбонских влакана, док је само тијело израђено од полипропиленске пјене. Одликује је аеродинамичан облик који омогућава веома добре карактеристике при летењу. Ова летјелица припада групи MAV/Mini UAV система. Као и све беспилотне летјелице из овог система и ову одликују мале димензије. Дужина крила је 96 cm, док је њихова површина 0,25m². Маса ове беспилотне летјелице се креће од 0,42 kg до 0,71 kg у зависности од масе камере коју носи и капацитета батерије. Вријеме које ова летјелица може да проведе у ваздуху је у директној вези са капацитетом и карактеристикама батерије

која се налази унутар летјелице. Номинална издржљивост је између 45 и 50 минута активног летења при максималној брзини вјетра од 12 m/s.
Да би испунила свој примарни задатак летјелица мора да посједује низ инструмената помоћу којих се контролишу одређени параметри и врши прикупљање података током лета. На Слици 3. су приказани дијелови летјелице eBee система.



Слика 3. Дијелови летјелице eBee система [8]

Са доње стране летјелице уграђен је сензор који током цијелог периода летења мјери висину лета, која се затим приказује на рачунару у контролној станици. Такође, у том дијелу се налази отвор за објектив камере.



Слика 4. Позиција сензора за мјерење висине и отвора објектива камере [8]

3. ПРЕТХОДНО ПЛАНИРАЊЕ ЛЕТА

Системе попут овог одликује једноставност у раду, која се обезбјеђује примјеном намјенских софтвера и темељном припремом. Цијели ток прикупљања података састоји се из три цјелине којима се заокружује процес припреме, прикупљања података и њихове накнадне обраде. Општи поступак рада подразумијева сљедеће активности:

- припрема за рад у канцеларији,

- прикупљање података на терену и
- накнадна канцеларијска обрада података.

Под припремом за рад подразумијева се софтверско планирање радова које треба реализовати на терену. Конкретно, за овај задатак потребно је детаљно израдити сљедеће планове:

- план лета и
- план распореда оријентационих тачака.

Планирање је поступак који је неопходан прије изласка на терен. Обавља се у специјализованом намјенском софтверу под именом eMotion. Овај софтверски пакет има вишеструку намјену и неопходно га је инсталирати на преносиви рачунар. Користи се за:

- планирање лета,
- праћење параметара лета у реалном времену и
- контролу и исправку плана лета.

Планирање лета је процес који подразумијева претходно одређивање области изнад које требају да се начине снимци, дефинисање параметара лета (резолуција, подужни и попречни преклоп између сусједних снимака, процјењена јачина вјетра, максимална дужина лета, итд.), избор мјеста полијетања и слијетања летјелице, преглед изведених параметара лета (висина лета, трајање лета, број летова) (Слика 5).

Слика 5. Изглед основног прозора програмског пакета eMotion

3.1. Дефинисање параметара лета

Код дефинисања параметара лета неопходно је задати вриједност за резолуцију снимања и величину подужног и попречног преклопа снимака. За реализацију снимања површинког копа задата вриједност за резолуцију снимања је 4 cm/px, док је задата величина подужног преклопа снимака 75%, а величина попречног преклопа снимака је 60%.

Због специфичности окружења површинског копа, приликом дефинисања параметара лета, неопходно је узети у обзир и одређене карактеристике терена, као и атмосферске услове који владају у оваквом окружењу. Уопштено, треба водити рачуна о конфигурацији терена, типу земљишта, врсти терена (шумски појасеви, области под водом, урбана подручја, пољопривредна земљишта, површински копови), метеоролошким условима (облачност, јачина вјетра, температура), као и захтјеваној тачности излазних података.

Када се врши снимање терена са осјетним промјенама висинске разлике, као што је површински коп „Богутово Село“, неопходно је укључити опцију Use elevation data to set absolute waypoint altitudes (коришћење дигиталног модела терена) која је саставни дио планирања лета.

За добијање што бољих резултата авио снимања препоручује се да снимање буде у дану са повољним метеоролошким условима (сунчано вријеме, без јаког вјетра). Метеоролошки услови се не могу тачно предвидјети прије самог изласка на терен, али се могу узети у обзир неке приближне или очекиване вриједности за правац и јачину вјетра.

4. ПРИКУПЉАЊЕ ПОДАТАКА НА ТЕРЕНУ

Након детаљног планирања сваког сегмента теренског снимања у програмским пакетима неопходно је на терену извршити низ радњи, а које укључују:

- стабилизацију и сигнализацију оријентационих тачака,
- одређивање координата оријентационих тачака,
- избор мјеста полијетања и слијетања директно на терену,
- монтажу опреме и преглед плана лета,
- лансирање летјелице,
- контролу и праћење лета,
- слијетање летјелице и
- пренос података.

За потребе сталне контроле над летјелицом у току налета на рачунару (који је саставни дио теренске опреме), мора бити инсталиран програлмски пакет eMotion.

На површинском копу „Богутово Село“ геодетска служба рудника „Угљевик“ већ посједује развијену мрежу геодетских тачака, коју употребљава као мрежу оријентационих тачака и за евентуалне потребе премјера дијела рудничког копа.

Пошто није планирано снимање цијелог површинског копа, него само дијела површинског копа на којем је у том периоду вршен ископ, одабрано је пет оријентационих тачака равномјерно распоређених на подручју снимања и њихове координате су одређене употребом ГПС пријемника.

Слика 6. Одређивање координата оријентационих тачака ГПС методом

Након лансирања уз помоћ радио везе у програмском пакету eMotion могу се пратити сви параметри током лета. Статусни екран летјелице приказује важне информације о тренутном стању (тренутна висина лета, стање батерије, тренутна операција летјелице, упозорења). Подаци о висини лета изражени су на сљедећи начин:

- m/ATO – висина изнад мјеста полијетања.
- m/AMSL – висина изнад средњег нивоа мора.

Картица за надгледање лета симулира поглед из кокпита са бројним подацима о тренутној мисији, као што је то приказано на слици 7.

Слика 7. Приказ статусног екрана током лета

Опис функција командног менија:

- WARNING – ако се у току лета појави неко упозорење назив ове функције мијења се у „ACK WARNING” (упозорење се прихвата),
- START MISSION – летјелица стартује мисију од почетка,
- RESUME MISSION – летјелица наставља мисију од мјеста прекида,
- GO TO START WPT – летјелица одлази на полазно мјесто, кружи и чека сљедећу команду,

- GO TO HOME WPT – летјелица одлази на мјесто повратка, кружи и чека сљедећу команду,
- GO LAND – летјелица одлази на мјесто повратка и започиње процедуру слијетања,
- HOLD POSITION – летјелица започиње кружно летење око тренутне позиције и чека сљедећу команду,
- LAND NOW Click 3x – летјелица истог тренутка на тренутној позицији започиње циркуларно слијетање,
- ABORT LANDING – летјелица обуставља слијетање, пење се на безбједну висину и кружи док не добије сљедећу команду,
- ROLL – летјелица извршава лупинг и затим наставља мисију,
- FAST CLIMB – летјелица се оштро пење 40 m, а затим се спушта на претходну висину и
- FAST DECENT – летјелица нагло понире негде око 15-30 m, за затим се враћа на претходну висину.
- По завршеној мисији беспилотна летјелица одлази у рејон слијетања, кружи око мјеста слијетања, одлази на руту за слијетање и спушта се на дефинисано мјесто.

4.1. Пренос података

Посљедњи корак теренских активности је пренос података са беспилотне летјелице на персонални рачунар. Од података снимања преносе се снимци и путања лета. Снимци се биљеже на меморијској картици камере, а путање лета се записују у интерној меморији беспилотне летјелице. Када лет садржи велики број снимака или се снимање обавља из више летова, препоручује се ослобађање меморије са картице камере након преноса података. Након овог корака прелази се на процес завршне обраде података и рачунање потребних параметара.

Слика 8. Необрађен снимак, добијен из беспилотне летјелице

4.2. Процес накнадне обраде података

Методологија рада у току накнадне обраде података подразумијева неколико корака који се реализују према сљедећем редослиједу:

- припрема података за унос,

- унос података,
- унос координата оријентационих тачака (опционо),
- иницијална обрада,
- преглед извјештаја иницијалне обраде,
- георeференцирање пројекта (опционо),
- подешавање параметара обраде,
- избор изведених резултата обраде (опционо),
- генерисање директних резултата обраде и
- преглед и анализа резултата обраде.

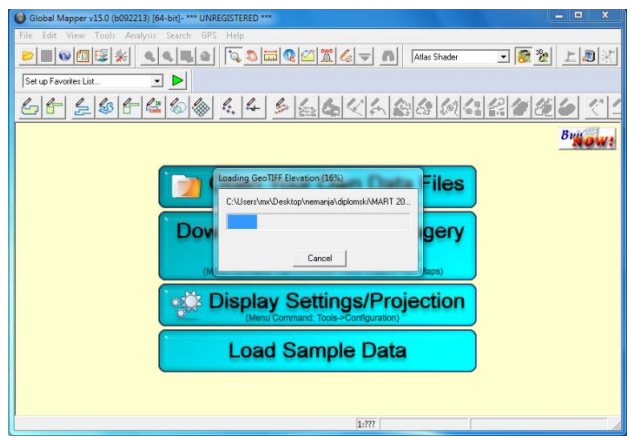
5. ОБРАЧУН ИСКОПАНИХ МАСА У GLOBAL MAPPER

Global Mapper је софтверски пакет географског информационог система чијим развојем тренутно управља компанија Blue Marble Geographics. Global Mapper је оперативан на рачунарима са Microsoft Windows оперативним системом. Он подржава векторске и растерске врсте податка и пружа преглед, конверзију и друге опште ГИС функције.

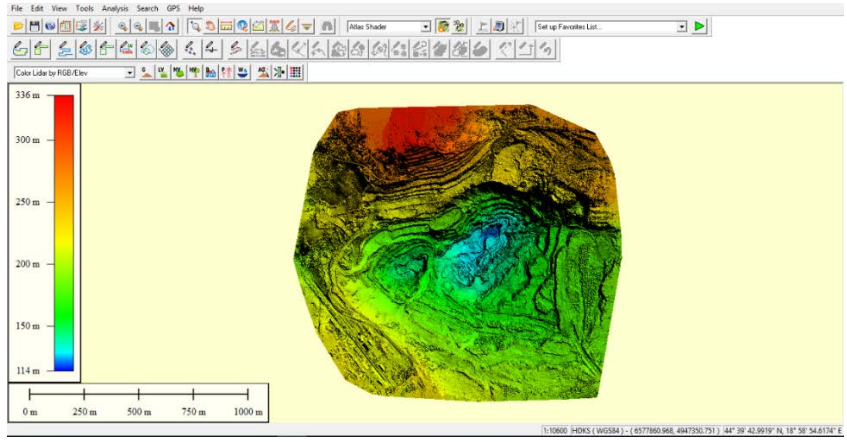
Поред многих програмских пакета који омогућавају обрачунавање ископаних маса, на површинском копу „Богутово Село“ Global Mapper се показао као задовољавајуће рјешење.

За обрачун маса ископаних у фебруару неопходно је процесирати податке прикупљене на почетку фебруара и на почетку мјесеца марта. Односно, било је неопходно извршити снимање површинског копа у том периоду, извршити обраду података, израдити дигиталне моделе терена и извршити рачунање количине ископаних маса у програмском пакету Global Mapper.

За рачунање количине ископаних маса неопходно је учитати поменуте снимке у Global Mapper (Open Your Own Data Files), слике 9. и 10.

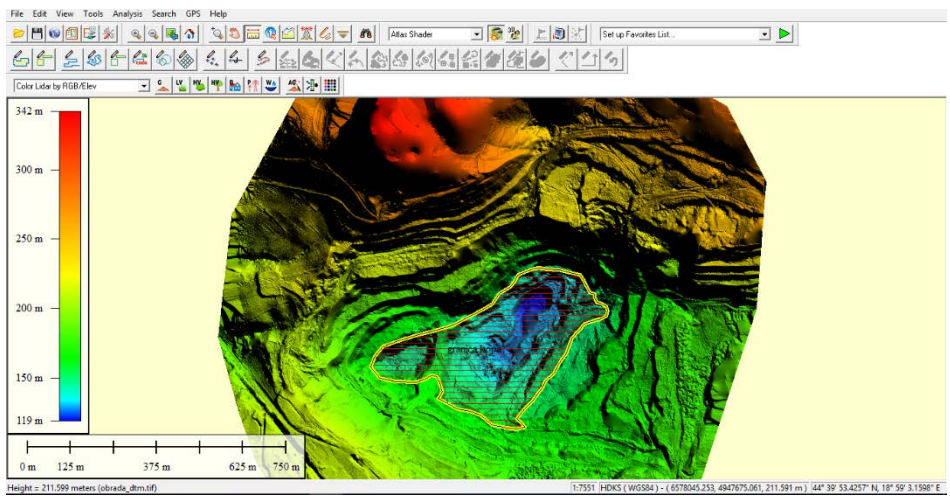


Слика 9. Учитавање снимка у програмски пакет Global Mapper



Слика 10. Учитани ДМТ површинског копа

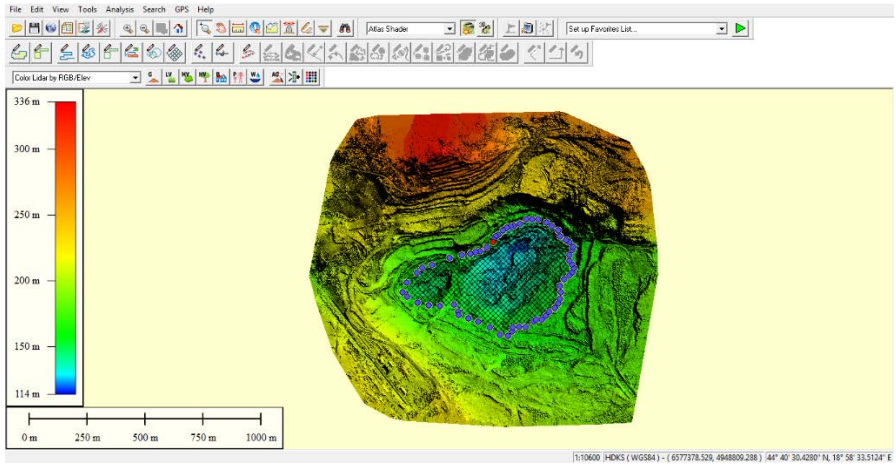
Након учитавања ДМТ потребно је исцртати границе подручја за који се врши рачунање количине ископаних маса, јер се никада не врше ископавања на цијелом подручју површинског копа. На одабраном подручју, помоћу опције Measure Tool, исцртава се граница полигона од интереса. Формирање полигона се завршава избором опције Close Polygon And Stop Measuring, слика 11.



Слика 11. Изглед одабраног полигона на дијелу површинског копа

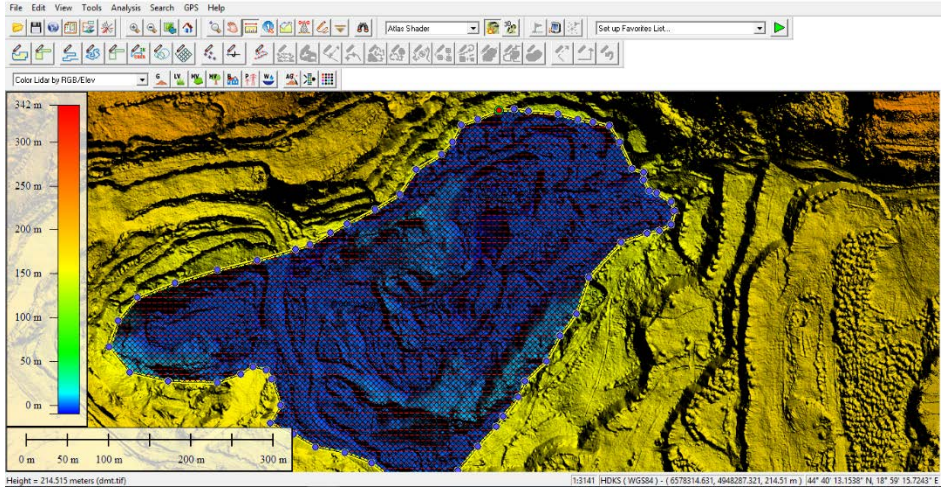
Меморисање обиљеженог полигона се врши избором опције Save Measurement. Приликом одабира те опције бира се и облик за чување обиљеженог полигона, који може бити типа линије или полигона. Одабрани полигон се чува као полигон, уз додјељивање одговарајућег имена.

За упоређивање ова два означена полигона непходан је прелазак на други ДМТ, избором опције Select у менију Edit, слика 12.



Слика 12. Приказ селектованог полигона површинског копа

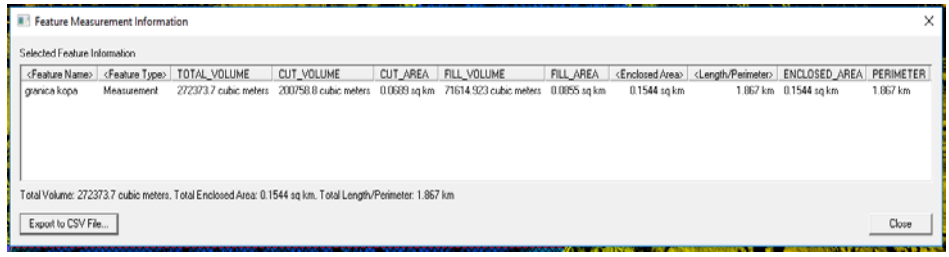
Тиме је полигон селектован и неопходно је копирати га у истом менију. Након тога се прелази на други ДМТ фајл у Global Mapper и врши поклапање са селектованим полигоном првог ДМТ, чиме су преклопљена два ДМТ. Након меморисања модела врши се избор мјеста за чување оба модела. Преклапање модела се врши у дијелу програма - Load Workspace. Затим се врши избор другог снимка, као и преклапање са првим. Преласком у дио програма – Analysis потребно је изабрати функцију Combine Terrain Layers, након чога се врши подешавање резолуције и одређивање распореда снимака. У картици Export Bounds бира се функција Crop Selected Area Features, у оквиру које се завршава поступак преклапања два ДМТ површинског копа. Када се одабрани полигон прикаже у тамно плавој боји, као на слици 13, поступак преклапања два ДМТ је завршен исправно.



Слика 13. Полигон спреман за вршење прорачуна

Реализацијом ових функција завршава се преклапање снимака, што омогућава рачунање потребне запремине, која се спроводи у оквиру оперције

Analysis/Measure Volume Between Surfaces. Резултат спроведеног поступка дат је у извјештају о израчунатој количини ископаних маса на означеном полигону, слика 14.


Feature Measurement Information

Selected Feature Information

<Feature Name>	<Feature Type>	TOTAL_VOLUME	CUT_VOLUME	CUT_AREA	FILL_VOLUME	FILL_AREA	<Enclosed Area>	<Length/Perimeter>	ENCLOSED_AREA	PERIMETER
granica kopa	Measurement	272373.7 cubic meters	200758.8 cubic meters	0.0689 sq km	71614.923 cubic meters	0.0855 sq km	0.1544 sq km	1.867 km	0.1544 sq km	1.867 km

Total Volume: 272373.7 cubic meters, Total Enclosed Area: 0.1544 sq km, Total Length/Perimeter: 1.867 km

Export to CSV File... Close

Слика 14. Извјештај о количини откопаних маса на означеном полигону

На основу извјештаја може се закључити да је у фебруару 2017. године на подручју површинског копа „Богутово Село“ ископано 200 758,800 m³ површинског слоја на 0,069 km² површине копа. Такође, у истом периоду насуто је 71 614,923 m³ земље на подручје од 0,086 km² већ затворених дијелова површинског копа.

6. ЗАКЉУЧАК

Примјена беспилотних летјелица у геодезији још увијек је релативно нова. У последњих десет година дошло је до напретка у области фотограметријских снимања. Поред тога, постоје велике могућности примјене у геодезији, као и у осталим областима науке, привреде и свакодневног живота.

Основна предност примјене ове технологије је добијање крајњих резултата у врло кратком временском периоду. Самим тим, до изражаја долази и економичност употребе ове технологије. Уз бројне предности, беспилотне летјелице имају и мане, које су техничке природе и које се могу превазићи развојем електротехнике и рачунарства, као и развојем нових материјала и конструкције летјелица.

Примјена беспилотних летјелица у рударству, огледа се у ефикасности овог система при снимању површинских копова. С обзиром да рачунање количине ископаних маса не захтијева превелику тачност, овај систем у потпуности испуњава све задате критеријуме. Примјена ГНСС премјера за потребе истих рачунања, прије набавке овог система, изискивала је много времена, напоран теренски и канцеларијски рад. Употреба беспилотне летјелице омогућава лакшу, ефикаснију и чешћу контролу стања површинског копа и његове околине.

Поред основне намјене, надгледања површинског копа, беспилотна летјелица је нашла примјену у ревитализацији простора на којима су затворени површински копови. Тај задатак обухвата надгледање засађених шумских појасева, ревитализације водених токова и контрола развоја биљног и животињског свијета.

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60| Стручни рад
Professional paper
doi 10.7251/STP1813782R ISSN 2566-4484

GEODETSKO PRAĆENJE STABILNOSTI ZAŠTITNE KONSTRUKCIJE TEMELJNE JAME OBJEKTA

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Rezime:

Visokogradnju, danas, karakteriše izgradnja objekata koji su po svojoj geometriji sve viši i kompleksniji, te su često smješteni u uža gradska jezgra gdje su na malom prostoru izgrađeni brojni objekti koji dodatno otežavaju i komplikuju izvođenje građevinskih i geodetskih radova. Da bi se dobile informacije o stabilnosti tla i da bi se obezbjedilo sigurno građenje podzemnih etaža, neophodno je geodetsko praćenje zaštitne konstrukcije temeljne jame. U radu je opisan postupak geodetskog praćenja u horizontalnoj ravni, sa mogućnošću otkrivanja pomjeranja većih od 5 mm.

Ključne riječi: visokogradnja, dijafragma, geodetsko praćenje.

GEODETIC MONITORING OF STABILITY OF THE CONSTRUCTION PIT DIAPHRAGM OF THE OBJECT

Abstract:

High-rise building, today, is characterized by the construction of facilities that are higher and more complex in their geometry, and are often located in the narrow city core where numerous facilities have been built in a small area that additionally complicate the execution of construction and geodetic works. In order to obtain information on the stability of the soil and to ensure the safe construction of underground floors, it is necessary to survey the protective structure of the foundation pit. This paper describes the method of geodetic tracking in the horizontal plane, with the possibility of detecting displacements larger then 5 mm.

Keywords: high-rise building, diaphragm, geodetic monitoring.

1. UVOD

Osmatranje i geodetsko praćenje objekata vrši se u cilju otkrivanja deformacija kao i njihovog uklanjanja radi bezbjedne izgradnje i eksploatacije objekta. Poslednjih godina nije tako rijetka pojava deformacija i oštećenja na stambenim objektima uz velika gradilišta a posebno u gusto izgrađenim sredinama. Najčešći uzroci deformacija objekata su neadekvatno stabilizovani duboki iskopi temeljne jame, geološki sastav tla, fizičko – mehanička svojstva tla i nivo podzemnih voda. Iz tog razloga duboki iskopi jame predstavljaju neposrednu opasnost za okolne objekte. Moguće posljedice se mogu spriječiti detaljnim geotehničkim i geodetskim istraživanjima prije i za vrijeme građevinskih radova i stabilizacijom iskopa temeljnih jama.

Na području užeg centra grada predviđena je izgradnja poslovnog objekta „CITY MALL" u Banjoj Luci. Kako se objekat gradi u pretežno izgrađenom dijelu grada, što zbog svoje infrastrukture onemogućava široki iskop za izgradnju podzemnih etaža neophodno je geodetsko praćenje dijafragme temeljne jame koja obezbjeđuje stabilnost kosina iskopa.

Objekat je lociran u samom centru grada Banja Luka, na parceli br. 3636/1 K.O. BANJA LUKA 7. Prostor građevinske parcele zauzima 8.185,26 m^2. Nalazi se unutar bloka između ulica Srpske, Vase Pelagića i Bana Dr. Teodora Lazarevića i graniči na zapadnoj strani sa budućim poslovnim prostorima i šetalištem između njih koje vodi do gradskog trga na kojem se nalazi hram Hrista Spasitelja.

Osnovni zahtjev investitora je da se nivoom rizika od 5% otkriju sva pomjeranja mjernih tačaka na dijafragmi temeljne jame veća od 5 mm.

Cilj ovog rada jeste da se provjeri stabilnost mjernih tačaka i utvrdi veličina pomjeranja nestabilnih tačaka.

2. DEFORMACIONA ANALIZA

Oblast geodezije koja se bavi ispitivanjem stabilnosti i deformacija tla i objekata na njemu u određenim vremenskim intervalima naziva se deformaciona analiza.

U zavisnosti od načina utvrđivanja stabilnih tačaka na terenu, postoje četiri osnovna pristupa koji se koriste u deformacionoj analizi [1]:

- model koji se zasniva na transformaciji koordinata tačaka tekuće u prethodnu epohu,
- model koji se zasniva na istovremenom izravnanju rezultata mjerenja dviju epoha,
- model koji se zasniva na stabilnosti koordinatnog sistema,
- model koji se zasniva na rotaciji koordinatnog sistema.

Primjena deformacione analize obuhvata definisanje donje granice pomjeranja nestabilnih tačaka, izbor metode koja će sa najvećom sigurnošću odrediti vektore pomjeranja nestabilnih tačaka, ocjena rezultata mjerenja, sa primjenom testiranja u cilju otkrivanja grubih grešaka, testiranje hipoteza za utvrđivanje stabilnih i nestabilnih tačaka, određivanje vektora pomjeranja nestabilnih tačaka sa odgovarajućom vjerovatnoćom, ocjena tačnosti dobijenih rezultata sa odgovarajućom prezentacijom. Nepomjerenost se određuje na bazi analize rezultata mjerenja i izravnatih veličina u nultoj i kontrolnoj epohi mjerenja u deformacionom modelu.

Pod geodetskim deformacionim mjerenjima podrazumjevaju se sva geodetska mjerenja koja imaju za cilj utvrđivanje promjena oblika i stabilnosti objekata ili dijelova Zemljine površine pod djelovanjem vanjskih ili unutrašnjih sila. Razvoj u ovoj oblasti vrši se u dva pravca: 1) ispitivanje stabilnosti i deformacija u mikrolokacijama i 2) ispitivanje pomaka i deformacija u makrolokacijama, tj. ispitivanje pomaka i deformacija dijelova Zemljine kore. U oba slučaja objekat se diskretizuje odgovarajućim brojem karakterističnih tačaka. Za ispitivanje pomaka i deformacija objekata, geodetska mreža se sastoji od referentne (osnovne) mreže tačaka – mreže tačaka izvan objekta, i mreže tačaka na samom objektu. Neophodno je da dio tačaka osnovne mreže bude postavljen izvan zone mogućih deformacija, kako bi se pravilno i sa sigurnošću utvrdili eventualni pomaci objekta i terena.

Kod određivanja pomaka i deformacija objekta geodetska mreža se najćešće izravnava kao slobodna. Pri izravnanju slobodnih geodetskih mreža postoji singularitet sistema normalnih jednačina, što se riješava pseudoinverzijom. Izravnanje pojedinih serija mjerenja daje najvjerovatnije vrijednosti mjerenih i nepoznatih veličina sa ocjenom tačnosti.

Prije bilo kakve analize rezultata mjerenja, nasuprot pažljivom i savjesnom izvođenju mjerenja, neophodno je testirati adekvatnost matematičkog modela izravnanja i provjeriti prisustvo grubih grešaka. Metoda koja se najčešće primjenjuje za izravnanje rezultata mjerenja i ocjenu tačnosti je Metoda najmanjih kvadrata. Za otkrivanje prisustva eventualnih grubih grešaka u rezultatima mjerenja najčešće se primjenjuje data snooping test. Na osnovu test veličine (1) dobićemo informaciju o potencijalnim mjerenjima sa grubom greškom [1] [2] [3]:

$$t_i = \frac{|\hat{v}_i|}{S_0 \cdot \sqrt{Q_{\hat{v}_{ii}}}} \approx z_p \qquad (1)$$

gdje su:

$\hat{v}_i$ vektor izravnatih popravaka mjerenih veličina,

S_0^2 aposteriori standardno odstupanje,

$Q_{\hat{v}_{ii}}$ i-ti dijagonalni element kofaktorske matrice izravnatih popravaka mjerenih veličina,

z_p kvantil Normalne raspodjele za usvojenu vjerovatnoću p.

Ovaj test radi se iterativno, odbacuje se samo jedno mjerenje sa najvećom vrijednošću test veličine (1) iz izravnanja. Broj vrsta u matrici koeficijenata sistema jednačina popravaka smanjuje se za jedan, odnosno u narednoj iteraciji ne postoji jednačina popravke za mjerenje opterećeno grubom greškom. Isto se dešava i sa vektorom slobodnih članova sistema jednačina popravaka. U matrici težina mjerenih veličina smanjuje se broj vrsta i kolona za jedan.

Da bismo testirali podudarnost tačaka između epoha neophodno je provjeriti homogenost mjerenja između epoha. Testiranje homogenosti mjerenja podrazumjeva poređenje varijansi iz izravnanja za nultu i tekuću epohu: $Ho: E\left(S_i^2\right) = E\left(S_0^2\right)$. Jednakost varijansi verifikuje se pomoću F testa. Ako je test veličina pod (2) (3) manja od kvantila Fišerove raspodjele ($T < F_{1-\alpha, f_0, f_i}$, f_0 i f_1 predstavljaju broj stepeni slobode u nultoj i tekućoj epohi) prihvatamo hipotezu o jednakosti varijansi u obe epohe, odnosno mjerenja su homogena.

$$F = \frac{S_0^2}{S_i^2}, \quad \text{pri} \quad S_0^2 > S_i^2 \tag{2}$$

$$F = \frac{S_i^2}{S_0^2}, \quad \text{pri} \quad S_i^2 > S_0^2 \ . \tag{3}$$

Zatim, računamo objedinjenu varijansu za epohe:

$$S^2 = \frac{f_0 \cdot S_0^2 + f_i \cdot S_i^2}{f_0 + f_i} = \frac{\left(\mathbf{v}^{\mathrm{T}}\mathbf{P}\mathbf{v}\right)_0 + \left(\mathbf{v}^{\mathrm{T}}\mathbf{P}\mathbf{v}\right)_i}{f}. \tag{4}$$

2.1. Testiranje podudarnosti tačaka kontrolne mreže statističkim testovima:

Najčešće korišćena metoda provjere podudarnosti tačaka između epoha je sukcesivna dekompozicija kvadratne forme. Definišemo hipotezu o podudarnosti tačaka između epoha $H_0 : E\left(\mathbf{\Delta}\right) = 0$, pri čemu $\mathbf{\Delta}$ predstavlja vektor pomjeranja tačaka između epoha. Obrazujemo kvadratnu formu:

$$q_\Delta = \mathbf{\Delta}^{\mathrm{T}}\mathbf{P}_\Delta\mathbf{\Delta}, \tag{5}$$

gdje je: $\mathbf{P}_\Delta = \mathbf{Q}_\Delta^- = \left(\mathbf{Q}_{x0} + \mathbf{Q}_{xi}\right)^-$. Ukoliko u modelu postoje tačke koje nisu zajedničke ili dopunski parametri, prije obrazovanja kvadratne forme (5) isti se eliminišu se iz matrice $\mathbf{Q}_x$ brisanjem odgovarujićih vrsta i kolona. Računamo test veličinu:

$$F = \frac{q_\Delta / h}{S^2} \quad \text{pri} \quad \frac{q_\Delta}{h} > S^2, \tag{6}$$

pri čemu h $\left(\mathrm{h} = 2 \cdot \mathrm{m} - \mathrm{d}\right)$ predstavlja broj nezavisnih komponenti vektora pomjeranja (m – broj tačaka kontrolne mreže; d – defekt mreže). Ako je test veličina (6) manja od kvantila Fišerove raspodjele $\left(F_{0.95,h,f}\right)$ prihvatamo hipotezu o podudarnosti koordinata tačaka u nultoj i i-toj epohi mjerenja. U suprotnom, bar jedna tačka je značajno pomjerena. U tom slučaju, vektor pomjeranja dijelimo na dva subvektora: 1) subvektor pomjeranja tačaka izvan objekta i 2) subvektor pomjeranja tačaka na objektu:

$$\mathbf{\Delta} = \begin{bmatrix} \mathbf{\Delta_r} \\ \mathbf{\Delta_o} \end{bmatrix}.$$

Takođe, matricu $\mathbf{P}_\Delta$ dijelimo na odgovarajuće submatrice:

$$\mathbf{P}_\Delta = \begin{bmatrix} \mathbf{P_{rr}} & \mathbf{P_{ro}} \\ \mathbf{P_{or}} & \mathbf{P_{oo}} \end{bmatrix}.$$

2.2. Testiranje stabilnosti referentnih tačaka (tačaka osnovne mreže)

Definišemo hipotezu o stabilnosti referentnih tačaka: $H_0 : E\left(\mathbf{\Delta}_r\right) = 0$. Računamo kvadratnu formu za referentne tačke:

$$q_{\Delta r} = \mathbf{\Delta}_{\mathrm{r}}^{\mathrm{T}} \cdot \overline{\mathbf{P}}_{\mathrm{rr}} \cdot \mathbf{\Delta}_{\mathrm{r}}, \tag{7}$$

gdje je $\overline{\mathbf{P}}_{\mathrm{rr}} = \mathbf{P}_{\mathrm{rr}} - \mathbf{P}_{\mathrm{ro}} \cdot \mathbf{P}_{\mathrm{oo}}^{-1} \cdot \mathbf{P}_{\mathrm{or}}$. Stabilnosti tačaka se provjerava F testom. Test veličina ima sljedeći oblik:

$$F = \frac{q_{\Delta r} / h_r}{S^2} \quad \text{pri} \quad \frac{q_{\Delta r}}{h_r} > S^2, \tag{8}$$

pri čemu $\mathrm{h_r}$ $\left(\mathrm{h_r} = 2 \cdot \mathrm{m_r} - \mathrm{d}\right)$ predstavlja broj nezavisnih komponenti vektora pomjeranja referentnih tačaka; $\mathrm{m_r}$ - broj tačaka osnovne mreže; d - defekt mreže. Ako je test veličina (8) manja od kvantila Fišerove raspodjele $\left(F_{0.95, f, h_r}\right)$ prihvatamo hipotezu o stabilnosti referentnih tačaka između epoha. U suprotnom, neophodno je lokalizovati nestabilne referentne tačke.

2.3. Testiranje stabilnosti tačaka na objektu

Definišemo hipotezu o stabilnosti tačaka na objektu: $H_0 : E\left(\mathbf{\Delta}_o\right) = 0$. Obrazujemo kvadratnu formu za tačke na objektu:

$$q_{\Delta o} = \overline{\mathbf{\Delta}}_o^{\mathrm{T}} \cdot \mathbf{P}_{\mathrm{oo}} \cdot \mathbf{\Delta}_o, \tag{9}$$

gdje je $\overline{\mathbf{\Delta}}_{\mathrm{o}} = \mathbf{\Delta}_o + \mathbf{P}_{\mathrm{oo}}^{-1} \cdot \mathbf{P}_{\mathrm{or}} \cdot \mathbf{\Delta}_{\mathrm{r}}$. Stabilnost tačaka se provjerava F testom. Test veličina ima sljedeći oblik:

$$F = \frac{q_{\Delta o} / h_o}{S^2} \quad \text{pri} \quad \frac{q_{\Delta o}}{h_o} > S^2, \tag{10}$$

pri čemu $\mathrm{h_o}$ $\left(\mathrm{h_o} = 2\mathrm{m_o} - \mathrm{d}\right)$ predstavlja broj nezavisnih kolona vektora pomjeranja tačaka na objektu. Ako je test veličina (10) manja od kvantila Fišerove raspodjele $\left(F_{0.95, h_o, f}\right)$ prihvatamo hipotezu o podudarnosti koordinata tačaka na objektu između epoha. U suprotnom, neophodno je izvršiti lokalizaciju nestabilnih tačaka.

2.4. Lokalizacija nestabilnih tačaka

Vektor pomjeranja dijelimo na dva subvektora: 1) subvektor koji sadrži dve komponente koje se odnose na tačku za koju pretpostavljamo da je pomjerena (nestabilna) i 2) subvektor čiji se elementi odnose na preostale tačke na objektu za koje pretpostavljamo da su nepomjerene (stabilne):

$$\mathbf{\Delta} = \begin{bmatrix} \mathbf{\Delta}_{\mathrm{p}} \\ \mathbf{\Delta}_{\mathrm{n}} \end{bmatrix}.$$

Takođe, matricu $\mathbf{P}_{\Delta}$ dijelimo na odgovarajuće submatrice:

$$\mathbf{P}_{\Delta} = \begin{bmatrix} \mathbf{P}_{\mathrm{pp}} & \mathbf{P}_{\mathrm{pn}} \\ \mathbf{P}_{\mathrm{np}} & \mathbf{P}_{\mathrm{nn}} \end{bmatrix}.$$

Za svaku tačku na objektu računamo kvadratnu formu:

$$q_{\Delta}^{\mathrm{p}} = \overline{\mathbf{\Delta}}_{\mathrm{p}}^{\mathbf{T}} \cdot \mathbf{P}_{\mathrm{pp}} \cdot \overline{\mathbf{\Delta}}_{\mathrm{p}}, \tag{11}$$

gdje je $\overline{\mathbf{\Delta}}_{\mathrm{p}} = \mathbf{\Delta}_{\mathrm{p}} + \mathbf{P}_{\mathrm{pp}}^{-1} \cdot \mathbf{P}_{\mathrm{pn}} \cdot \mathbf{\Delta}_{\mathrm{n}}$. Tačka sa najvećom vrijednošću kvadratne forme proglašava se nestabilnom. Za preostale tačke računamo kvadratnu formu:

$$q_{\Delta}^{\mathrm{rest}} = \mathbf{\Delta}_{\mathrm{n}}^{\mathrm{T}} \overline{\mathbf{P}}_{\mathrm{nn}} \mathbf{\Delta}_n, \tag{14}$$

gdje je $\overline{\mathbf{P}}_{nn} = \mathbf{P}_{nn} - \mathbf{P}_{np}\mathbf{P}_{pp}^{-1}\mathbf{P}_{pn}$. Ispitivanje stabilnosti preostalih tačaka u mreži vrši se F testom:

$$F = \frac{q_{\Delta}^{rest} / (h-2)}{S^2} \quad \text{pri} \quad \frac{q_{\Delta}^{rest}}{h-2} > S^2 , \tag{13}$$

Ako je test veličina (13) manja od kvantila Fišerove raspodjele $\left(F_{0.95,h-2,f}\right)$ tačke su stabilne. U suprotnom, na preostale tačke u mreži primjenjuje se prethodno opisan postupak lokalizacije nestabilne tačke.

3. PLAN GEODETSKOG OSMATRANJA

Prema zahtjevanoj tačnosti praćenja objekta, potrebno je odabrati odgovarajuću metodu i instrumente kojim se mogu ostvariti ovako postavljeni kriterijumi. Takođe, za potrebe praćenja pomjeranja i deformacija određuje se neophodan broj ravnomjerno raspoređenih tačaka koje karakterišu i definišu objekat. Mjerenje karakterističnih tačaka na objektu u izgradnji i objektu u neposrednoj blizini obavlja se periodično u strogo određenim vremenskim intervalima. Mjerenja se izvode u više epoha kako bi se mogli odrediti vrijednosti pomjeranja i slijeganja kao i deformacije i sama stabilnost objekta. Vjerodostojnu procjenu stabilnosti objekta moguće je dati pomoću statističkih testova na temelju upoređivanja tekuće i nulte epohe.

Prije početka osmatranja i ispitivanja stabilnosti terena tokom izvođenja građevinskih radova na iskopu temeljne jame, bilo je neophodno izvršiti pozicioniranje svih geodetskih mjernih tačaka u lokalnom koordinatnom sistemu (koordinatni sistem objekta), odnosno izvršiti nultu epohu mjerenja.

Nulta epoha mjerenja obuhvatila je sljedeće radove:

- postavljanje fiktivnih tačaka unutar gradilišta,
- mjerenje uglova i dužina totalnom stanicom na fiktivnim tačkama i njihovo izravnanje u koordinatnom sistemu objekta,
- određivanje koordinata mjernih tačaka na objektima koji su u neposrednoj blizini gradilišta, na osnovu vrijednosti dužina i uglova mjerenih sa fiktivnih tačaka u koordinatnom sistemu objekta,
- očitavanje dužina i uglova sa slobodne mjerne stanice na sve mjerne tačke na objektima i na obodu iskopa,
- izravnanje rezultata mjerenja i određivanje koordinata svih mjernih tačaka,
- izrada izvještaja.

Svaka naredna epoha mjerenja podrazumjevala je radove definisane u petom, šestom i sedmom koraku.

Opažanja su izvedena totalnom stanicom uglovne tačnosti od 5" i tačnosti mjerenja dužina od 2mm+2ppm.

4. GEODETSKA MREŽA ZA PRAĆENJE STABILNOSTI DIJAFRAGME TEMELJNE JAME

Geodetska mreža je neophodna osnova u mnogim geodetskim zadacima, pa tako i u zadacima inženjerske geodezije kao što je izrada geodetskih podloga za projektovanje objekata, obilježavanje geometrije objekata, praćenje građenja, kontrola geometrije

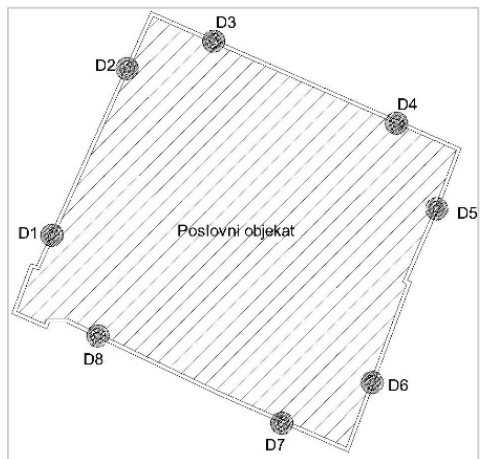
objekata, praćenje pomjeranja objekata i tla itd. Iako na terenu postoje uspostavljene državne geodetske mreže, one u većini slučajeva svojom lokacijom, načinom stabilizacije tačaka i tačnošću položaja tačaka mreže ne zadovoljavaju potrebe geodetskih radova u inženjerstvu. Zbog toga se projektuju i uspostavljaju geodetske mreže posebne namjene, koje su namjenjene posebnim potrebama tokom izgradnje i eksploatacije objekata.

Takva geodetska osnova u konkretnom slučaju će poslužiti za iskolčenje objekta, praćenje stabilnosti zaštitne konstrukcije temeljne jame objekta, iskolčenje osovina u toku izgradnje objekta i premjer izvedenog stanja nakon izgradnje objekta.

Da bi se pristupilo osmatranju dijafragme temeljne jame bilo je neophodno uspostaviti geodetsku mrežu objekta. Oblik i veličina geodetske mreže objekta, te način stabilizacije tačaka bili su uslovljeni karakteristikama budućeg objekta i terena u neposrednoj blizini. Stabilizacija tačaka izvedena je geodetskim mjernim prizmama na objektima koji se nalaze u zoni pomjeranja i na obodu iskopa za izgradnju objekta.

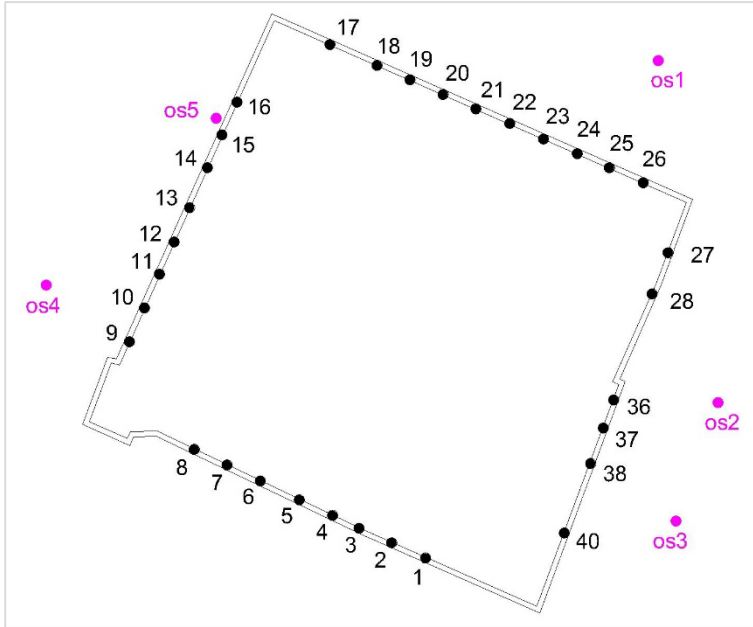
Mjerne prizme su postavljene na najvišim etažama okolnih objekata, na visini do 20 m iznad tla, i to po jedna prizma na zgradi Uprave za indirektnog oporezivanje i zgradi hotela Talija, dvije prizme na zgradi autoputeva i jedna prizma u blizini gradilišta na betonskoj banderi.

Ove tačke čine tzv. osnovnu (referentu) mrežu. Mreža je izravnata kao slobodna (sa minimalnim tragom matrice kofaktora za sve tačke). Mjerene su dužine. Uspostavljena geodetska osnova obezbjediće tačnost snimanja i obilježavanja detalja do 5 mm, uz upotrebu totalne stanice uglovne tačnosti 5" i tačnosti mjerenja dužina od 2mm+2ppm.



Slika 1. Segmenti dijafragme temeljne jame na kojima su raspoređene kontrolne tačke

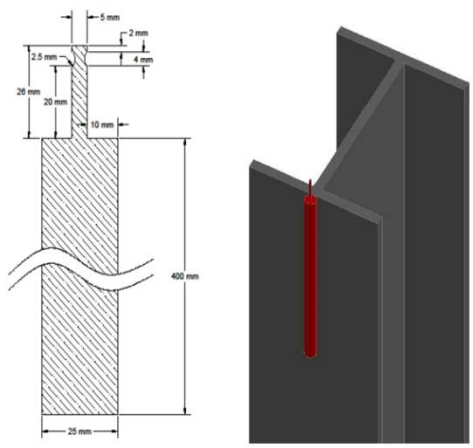
Na zaštitnoj konstrukciji temeljne jame raspoređe su 32 tačke, i one čine tzv. mrežu tačaka na objektu. Mjerne tačke su raspoređene na segmentima D1-D2, D3-D4. D5-D6, D7-D8, na međusobnom rastojanju od 7m. (Slika 1)



Slika 2. Prikaz rasporeda mjernih tačaka na dijafragmi

Obzirom da je temeljna jama osigurana betonskom dijafragmom, bilo je neophodno na betonskim zidovima ugraditi odgovarajuće nosače za mjerne prizme. Nosači su ugrađeni sa svake strane temeljne jame, i to po 8-10 komada. Na uglovima temeljne jame nije bilo neophodno ugrađivati nosače. (Slika 2)

Nosači mjernih prizmi su stabilizovani zavarivanjem na metalnim I profilima koji su graničnici segmenata dijafragme. Obzirom da je uvodni kanal širi od dijafragme, bilo je neophodno prije samog zavarivanja očistiti manji sloj betona koji se nalaze uz I profil. Pozicija postavljanja nosača prizme prikazana je na slici 3.

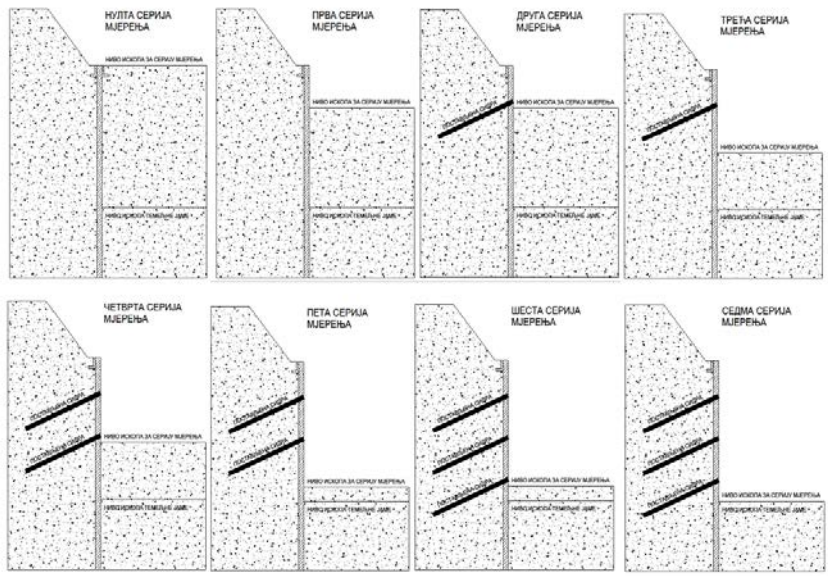


Slika 3. Grafički prikaz nosača prizme

5. OPIS EPOHA MJERENJA

Epohe mjerenja bile su uslovljene dinamikom iskopa i postavljanjem zatega u toku iskopa temeljne jame. (Slika 4) U svakoj epohi izvršeno je očitavanje dužina i uglova sa slobodne mjerne stanice ka referentnim tačakama i mjernim tačkama na obodu iskopa.
Geodetsko osmatranje izvedeno je kroz osam epoha (serija) mjerenja:

- Nulta epoha mjerenja izvedena je nakon rušenja uvodnog kanala i stabilizacije referentnih mjernih tačaka. U tom periodu nivo iskopa bio je u nivou uvodnih kanala.
- Prva epoha mjerenja izvedena je nakon iskopa do nivoa za postavljanje prvog sloja zatega.
- Druga epoha mjerenja izvedena je nakon postavljanja prvog sloja zatega.
- Treća epoha mjerenja izvedena je nakon iskopa do nivoa za postavljanje drugog sloja zatega.
- Četvrta epoha mjerenja izvedena je nakon postavljanja drugog sloja zatega.
- Peta epoha mjerenja izvedena je nakon iskopa do nivoa za postavljanje trećeg sloja zatega.
- Šesta epoha mjerenja izvedena je nakon postavljanja trećeg sloja zatega.
- Sedma epoha mjerenja izvedena je nakon iskopa do projektom definisanog nivoa temeljne jame.



Slika 4. Grafički prikaz epoha mjerenja u zavisnosti od faze građevinskih radova na iskopu temeljne jame

6. ANALIZA REZULTATA GEODETSKOG OSMATRANJA

Analiza stabilnosti zaštitne konstrukcije, odnosno ispitivanje stabilnosti karakterističih mjernih tačaka na dijafragmi temeljne jame izvršeno je u horizontalnoj ravni. U okviru

nulte epohe izvedena su geodetska mjerenja za pozicioniranje tačaka osnovne mreže i mreže tačaka na dijafragmi temeljne jame. Dobijene koordinate predstavljaju referentne vrijednosti.

S obzirom da su geodetski radovi izvođeni uporedo sa građevinskim radovima, nije bilo moguće opažati sve mjerne tačke na dijafragmi tokom jedne epohe mjerenja. Na primjer, u sedmoj epohi opažano je 26 tačaka. (Slika 5)

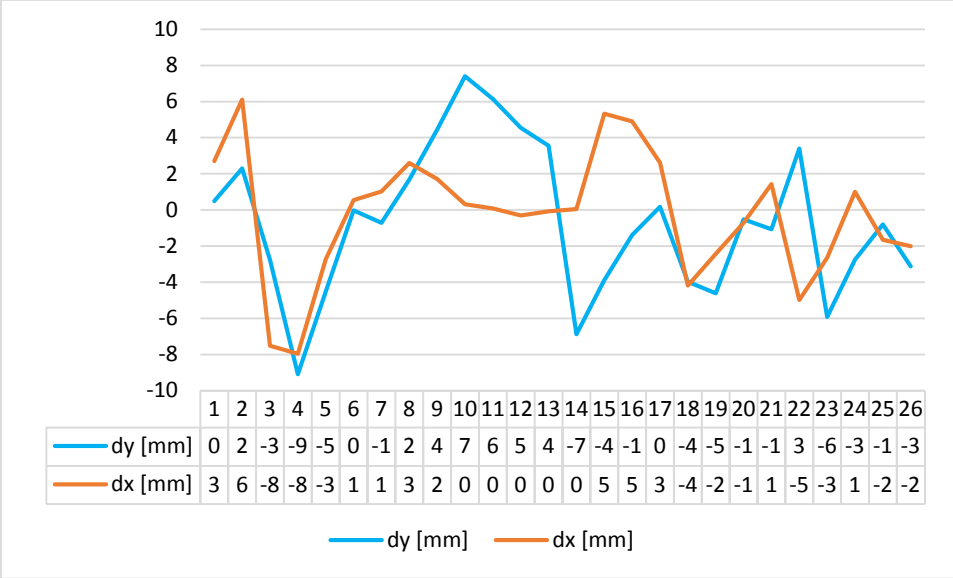
10.11.2016.	13.11.2016.	14.11.2016.	15.11.2016.	17.11.2016.	25.11.2016.	28.11.2016.	06.12.2016.
epoha 0	epoha 1	epoha 2	epoha 3	epoha 4	epoha 5	epoha 6	epoha 7
1	-	-	-	-	1	-	1
2	-	-	-	-	2	-	2
3	-	-	-	-	3	-	3
4	-	-	-	-	4	-	4
5	-	-	-	-	5	-	5
6	-	-	-	-	6	-	6
7	-	-	-	-	7	-	7
8	-	-	-	-	8	-	8
9	9	-	-	-	-	9	9
10	10	-	-	-	-	10	10
11	11	-	-	-	-	11	11
12	12	-	-	-	-	12	12
13	13	-	-	-	-	13	13
14	14	-	-	-	-	14	14
15	15	-	-	-	-	15	15
16	16	-	-	-	-	16	16
17	17	17	-	-	-	-	17
18	18	18	-	-	-	-	18
19	-	19	-	-	-	-	19
20	-	20	-	-	-	-	20
21	-	21	-	-	-	-	21
22	-	22	-	-	-	-	22
23	-	23	-	-	-	-	23
24	-	24	24	-	-	-	24
25	-	25	25	-	-	-	25
26	-	26	26	-	-	-	26
27	-	-	27	-	-	-	-
28	-	-	28	-	-	-	-
36	-	-	-	36	36	-	-
37	-	-	-	37	37	-	-
38	-	-	-	38	38	-	-
40	-	-	-	40	40	-	-

Slika 5. Opažane mjerne tačke na dijafragmi temljne jame po epohama

Za svaku epohu mjerenja sračunat je vektor pomjeranja mjernih tačaka kombinovanim izravnanjem nulte i tekuće epohe [1].

Za sve mjerne tačke na dijafragmi, tokom sedam kontrolnih epoha mjerenja, veličina pomjeranja iznosila je maksimalno do ±1 cm. Najveća pomjeranja su zabilježena u sedmoj epohi. Statističkim testovima sa nivoom rizika od 1% referentne tačke su proglašene stabilnim. Vrijednosti elemenata vektora pomjeranja mjernih tačaka na dijafragmi temeljne jame prikazane su za sedmu epohu mjerenja jer je ona obuhvatila opažanje najvećeg broj tačaka. (Slika 6)

Kritična vrijednost ukupnog pomjeranja tačaka za izvođenje građevinskih radova iznosi 10 cm. Pomjeranja veća od kritične vrijednosti mogu dovesti do pucanja i drugih oštećenja na dijafragmi temeljne jame.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
dy [mm]	0	2	-3	-9	-5	0	-1	2	4	7	6	5	4	-7	-4	-1	0	-4	-5	-1	-1	3	-6	-3	-1	-3
dx [mm]	3	6	-8	-8	-3	1	1	3	2	0	0	0	0	0	5	5	3	-4	-2	-1	1	-5	-3	1	-2	-2

Slika 6. Vektor pomjeranja mjernih tačaka u sedmoj epohi

7. ZAKLJUČAK

Da bi se izbjegla urušavanja i pucanja objekata neophodno je pratiti pomjeranja na gradilištu i u njegovoj neposrednoj blizini od samog početka gradnje objekta, posebno kada je riječ o gusto izgrađenim sredinama. U ovom radu prikazano je geodetsko praćenje stabilnosti zaštitne konstrukcije temeljne jame tokom iskopa, u horizontalnoj ravni, sa ciljem sigurne i uspješne izgradnje podzemnih etaža poslovnog objekta „CITY MALL" u Banjoj Luci.

Nakon izvedenog geodetskog osmatranja utvrđeno je da su pomjeranja mjernih tačaka na dijafragmi po epohama maksimalno do 1 cm. Najveće vrijednosti pomjeranja su se javile u poslednjoj epohi mjerenja, nakon završnih radova na iskopu temeljne jame. U svim epohama, statističkim testovima sa nivoom rizika od 1%, utvrđeno je da su tačke osnovne mreže stabilne.

Predviđeno je da se u toku izgradnje podzemnih etaža nastavi sa izvođenjem kontrolnih epoha mjerenja, periodično na svakih sedam dana. Ako se utvrdi da su pomjeranja zanemarivog intenziteta, interval kontrolnog mjerenja će se produžiti na 14 dana. U slučaju vanredih okolnosti, kao što su pojave pukotina, obilne padavine, zemljotresi i dr., izvodiće se dodatne epohe mjerenja.

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61| Стручни рад
Professional paper
doi 10.7251/STP1813794M ISSN 2566-4484

TEHNOLOGIJE 3D LASERSKOG SKENIRANJA I IMAGING LASERSKOG SKENIRANJA U PROCESU METROLOŠKE KONTROLE SKLADIŠNIH REZERVOARA

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Rezime:

U cilju prihvatanja rezervoara sa aspekta zakonske metrologije u procesu platnih transakcija, isti moraju biti izgrađeni i kontrolisani u skladu sa priznatom metrološkom praksom. Osnovni cilj pri konstruisanju i izgradnji rezervoara jeste ostvariti model koji će osigurati očuvanje skladištenog fluida. Najveći uticaj na rezervoare u eksloataciji ostvaruju geometrijski oblik, hidro-statički pritisak i temperatura, te stoga ova tri parametra treba precizno pratiti i kontrolisati. Oslanjajući se na međunarodne standarde i preporuke u vezi sa metodama za kalibraciju merila zapremine kao i kompetencijama i kvalifikacijama akreditovanih metroloških laboratorija za oblast zapremine, u ovom radu će se prikazati analiza dve metode u svrhu metrološke kontrole rezervoara. Daće se praktičan primer ocene usaglašenosti rezervoara na osnovu rezultata dobijenih sistemom Leica MS60 i Leica BLK360.

Ključne riječi: skeniranje, imaging, skladišni rezervoari, metrološka kontrola

3D LASER SCANNING AND IMAGING LASER SCANNING IN STORAGE TANKS METROLOGY CONTROL PROCESS

Abstract:

In order to secure that tanks are confirmed with the requirements of legal metrology, tanks shall be built in accordance with sound engineering practice. The main target during the process of construction and building of tanks is the ability of tanks to protect the storage fluid. Geometrical shape, hydro-static preassure and temperature are the main influencers to the capability of the fluid, so this three parameter must be permanently controld. In accordance with international standards and methods in the scope of legal metrology and calibrated laboratories, ths paper will present an analysis of two methods for tank control. It will be shown excample of conformity assessment of the thank you results collected by Leica MS60 and Leica BLK360 scanner stations.

Keywords: scanning, imaging, storage tanks, metrological cotrol

1. UVOD

Predmet ovog rada je uporedna analiza usaglašenosti relevantnih rezultata dobijenih imaging metodom laserskog skeniranja i 3D metodom laserskog skeniranja, horizontalnog cilindričnog merila za smeštaj fluida, odnosno rezervoara.

Pod rezervoarima se podrazumevaju nepokretni sudovi za smeštaj tečnosti. U praksi postoji više preporučenih metoda koje su u zakonskoj metrologiji priznate za potrebe metrološke kontrole, pa su samim tim metode kategorizovane kao volumetrijske i geometrijske. Volumetrijske metode koriste precizne etalonske cisterne kojima premeravaju nivo fluida utočenog u rezervoar, dok se geometrijske oslanjaju na ručne metode opasavanjem rezervoara mernim trakama, metode realizovane merenjem nivoa tečnosti mernom letvom (ili skalom sa nivokaznom cevi), nivokaznim staklom sa mernim lenjirom (ili uređajem sa automatskim nivoom merenja tečnosti), kao i trilangulacione i elektro-optičke metode spoljašnjeg i unutrašnjeg merenja rastojanja.

Rapidan i napredan razvoj tehnologije geometrijskog modelovanja trodimenzionalnih objekata doveo je do revolucionarne primene laserskog skeniranja. Tehnološki razvoj elekto-optičke laserske merne opreme poboljšao je i unapredio pristupe prikupljanja geoprostornih podataka, što je svakako unapredilo i performanse izvođenja merenja koja se mogu koristiti za potrebe ocene usaglašenosti rezervoara. Meri se veliki broj tačaka velike gustine – oblak tačaka (stotine hiljada ili nekoliko miliona tačaka) koji prikazuje realnije stanje rezervoara. Oprema omogućava merenje rastojanja i horizontalnih i vertikalnih uglova ka tačakama sa rezolucijom od 1 mm. Dakle u 3D oblaku izmerenih tačaka mogu se uzeti u razmatranje tačke na objektima koje su međusobno udaljene gotovo po 1 mm, što dosta dobro može modelovati geometriju i deformacije objekata. Ujedno mogu se izdvojiti svi unutrašnji objekti koji utiču na zapreminu kao i prikazati sve karakteristične i značajne deformacije.

Sama tehnologija laserskog skeniranja dobila je alternativu u vidu imaging skeniranja, prikupljanjem podatkaka o prostoru koristeći panoramske fotografije nalepljene preko oblaka tačaka visoke rezolucije. Ovakva tehnologija još uvek nije dovoljno testirana u praksi zakonske metrologije i merološke kontrole rezervoara, te ovaj rad ima za cilj da približi aspekte, sličnosti i razlike u primeni trodimenzionalnog i imaging laserskog skeniranja.

2. METROLOŠKA KONTROLA MERILA NAFTNIH FLUIDA

Fiksni skladišni rezervoari smešteni pod atmosferskim ili povišenim pritiskom sagrađeni su za skladištenje tečnosti i mogu biti korišćeni kao merila zapremine iste. Kada se koriste za takva merenja, moraju kompletno biti usaglašeni sa metrološkim i tehničkim zahtevima koji su zakonski propisani, uključujući i njihovo održavanje, postupak ocenjivanja usaglašenosti, postupak overavanja kao i period overavanja. U cilju potvrđivanja da su skladišni rezervoari kao merila naftnih fluida usaglašeni sa kriterijumima zakonske metrologije, neophodno je potvrditi da su oni u svemu izgrađeni i ekspolatisani prema usvojenim pravilima.

U skladu sa preporukama Međunarodne organizacije za zakonsku metrologiju OIML, dokument R71 opisuje dva koraka metrološke kontrole rezervoara kao merila zapremine nafte i naftnih fluida:

- Početna verifikacija (sastoji se od ocene usaglašenosti na licu mesta i kalibracije),
- Naknadna verifikacija ili kalibracija u ekspolataciji;

Početna verifikacija se izvodi iz dve faze. Tokom ispitivanja na terenu izgrađenu konstrukciju rezervoara treba ispitati da li odgovara zahtevima proizvodnih crteža. Mora biti usaglašena i dokumentovana sa svim zahtevima. Mora se uzeti u razmatranje: nesigurnost konsrtukcije, bilo koja stalna deformacija, krutost konstrukcije, stabilnost, položaj otvora, šahtova, pristupi otvorima za merenje, mogućnost realizacije etaloniranja, status plutajućeg krova ili poklopca, kao i mogućnost postavljanja identifikacione pločice. Rezervoari moraju biti ispitani na pritisak, propustljivost i čišćenje, i rezultati moraju biti dokumentovani pre početka kalibracije.

Kalibracija rezervoara je niz postupaka pomoću kojih se pri odgovarajućim uslovima utvrđuje odnos između nivoa tečnosti i zapremine tečnosti u rezervoaru , i trebalo da bude izvedena u skladu sa priznatim međunarodnim ISO normama ili ISO normama usvojenim od strane relevantnih nacionalnih institucija kao nacinalni dokumenti.

2.1. TEHNIČKI ZAHTEVI REZERVOARA

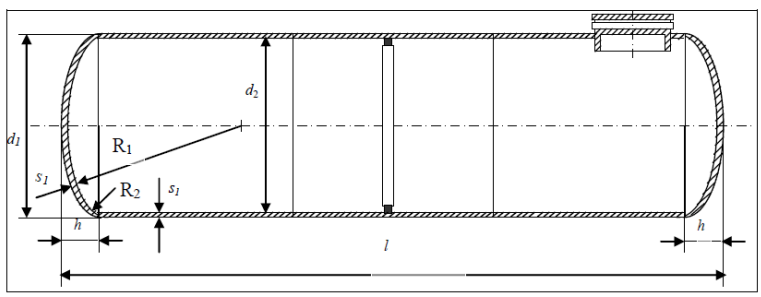
Oblik, materijal, armatura, konstrukcija i postavka rezervoara moraju biti takve da je rezervoar dovoljno rezistentan (otporan) na atmosferske i uticaje skladišne tečnosti, tako pod normalnim uslovima korišćenja ne trpi ozbiljne deformacije koje mogu negativno uticati na zapreminu rezervoara.

Donja referentna tačka, (koja predstavlja početak merenja nivoa tečnosti ili nultu tačku) i gornja referentna tačka (koja predstavlja tačku na mernoj vertikali u odnosu na koju se meri veličina praznog prostora), moraju biti postavljene tako da njihove pozicije ostaju u najvećoj mogućoj meri stabilne, smanjujući uticaj pomerenja prilikom punjenja i pražnjenja rezervoara, usled promena nivoa tečnosti u ekspolataciji, kao i pod uticajem spoljašnjih uslova.

Čelične cevi se frekventno upotreljavaju kao podrška referentnim pločama, pa njihova instalacija treba da bude takva da je donji vrh postavljen bliže dnu, a gornji kraj je usmeren ka vrhu rezervoara. Perforacije moraju biti dizajnirane za slobodan protok tečnosti omogućavajući merenja nivoa i temperature (skladno ISO 4266-1). Oblik rezervoara mora biti takav da bude predupređeno formiranje vazdušnih džepova tokom punjenja i tečnih džepova prilikom pražnjenja rezervoara. Takođe, posebna pažnja se posvećuje utvrđivanju stabilnosti rezervoara.

Ovi navedeni kriterijumi se proveravaju u procesu verifikacije i inspekcije fizičkog izgleda rezervoara, a nakon potvrđivanja da su navedeni uslovi ispunjeni, prelazi se na kalibraciju odnosno određivanje tabele zapremine rezervoara.

Na Slici 1 prikazan je izgled rezervoara sa zahtevanim elementima, saglasno zahtevima standarda SRPS M.Z3.010.



Slika 1. Horizontalni cilindrični rezervoar - konstrukcija

Na slici 1 označene su sledeće veličine koje se prilikom verifikacije rezervoara uzimaju u obzir:

l – ukupna dužina rezervoara,

h – visina bočnog dna

d1 – spoljnji prečnik cilindričnog dela rezervoara

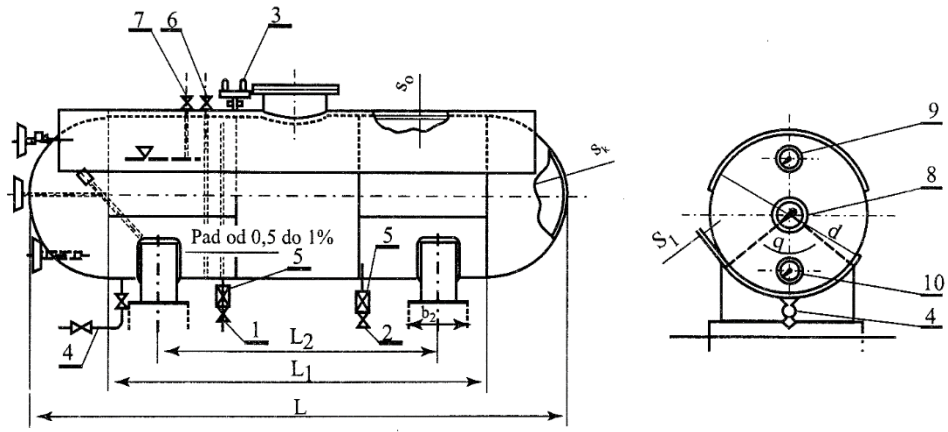
d2 –unutrašnji prečnik cilindričnog dela rezervoara

s1 – debljina zida

R1 – veći poluprečnik bočnog dna

R2 – manji poluprečnik bočnog dna.

Pored matematičkih veličina, položeni cilindrični rezervoari, u zavisnosti od namene, obezbeđeni su pripadajućim elementima koji se takođe ne smeju zanemariti prilikom njihove verifikacije. Primer konstrukcije jednog horizontalnog cilindričnog rezervoara sa pripadajućim elementima dat je na Slici 2 ovog rada, a predviđen je standardom SRPS M-Z.2. 600 (1991).



Slika 2. Konstrukcija rezervoara sa pripadajućim elementima

Na slici 2. Izdvojeni su sledeći priključci: 1-ventil za gasnu fazu, 2-ventil za tečnu fazu, 3-ventil sigurnosti odušni, 4-ventil za ispuštanje nečistoće, 5-ventil za ograničenje prekomernog protoka/protiv-lomni ventil, 6-mehanički pokazivač nivoa tečne faze, 7-ventil za kontrolu maksimalnog nivoa punjenja, 8- magnetni pokazivač nivoa tečne faze, 9-manometar sa manometarskom slavinom, 10-termometar.

2.2. METROLOŠKI ZAHTEVI REZERVOARA

Metrološke aktivnosti u kontroli rezervoara podrazumevaju izvođenje neophodnih koraka u cilju određivanja tačne zapremine fluida. Tabela zapremine se iskazuje u formi tabele ili matematičke funkcije (Vh) koja predstavlja odnos između visine nivoa tečnosti (h) kao nezavisno promenljive i zapremine tečnosti u rezervoaru (V) kao zavisno promenljive. Donja granica tačnosti zapremine predstavlja zapremina ispod koje je prekoračena najveća dozvoljena greška, uzimajući u obzir oblik rezervoara i metodu etaloniranja rezervoara, u opsegu merenja koji obuhvata vrednosti merenja zapremine rezervoara od nule (visina 0) do nazivne zapremine rezervoara odnosno najviše visine punjenja.

Proširena merna nesigurnost rezultata merenja zapremine očitane na tabeli zapremine rezervoara ne sme biti veća: ± 0,2 % zapremine, za vertikalne cilindrične rezervoare, odnosno ± 0,3 % zapremine, za horizontalne ili nagnute cilindrične rezervoare, saglasno preporuci OIML R71. Proširena merna nesigurnost, rezultata merenja zapremine odnosi se na zapremine prikazane u tabeli zapremine u opsegu od donje granice tačnosti zapremine do nazivne zapremine, a određuje se u skladu sa dokumentom "Uputstvo za izražavanje merne nesigurnosti" (JCGM 100:2008) i data je kao standardna merna nesigurnost, pomnožena faktorom prekrivanja/obuhvata k = 2, koji za normalnu raspodelu odgovara verovatnoći prekrivanja/obuhvata približno 95 %.

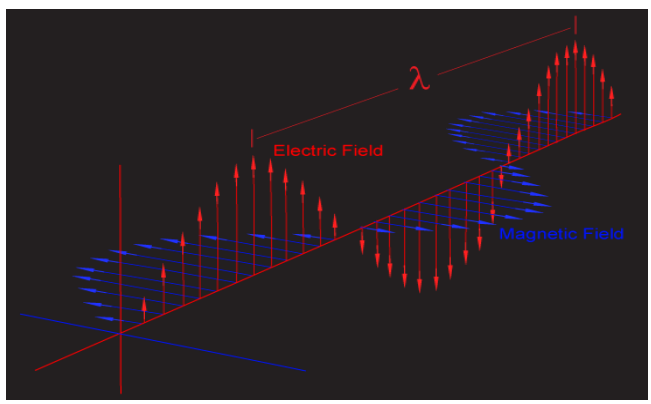
Uzimajući u obzr tehničke i metrološke zahteve koji se odnose na zakonsku kontrolu rezervoara, u nastavku rada predstaviće se mogućnosti novih tehnologija za prikupljanje podataka u procesu njihove metrološke kontrole.

2.3. 3D LASERSKO SKENIRANJE I IMAGING LASERSKO SKENIRANJE

Terestrički laserski skener (TLS) predstavlja instrument koji kao rezultat skeniranja daje skup 3D tačaka, koji se naziva oblak tačaka. Za svaku tačku vezuje se podatak u vidu tri prostorne koordinate i dodatna informacija o intenzitetu povratnog zračenja koja predstavlja četvrtu dimenziju podatka.

TLS je visokotehnološki uređaj koji u sebi sadrži veliki broj komponenti, a najvažniji su sistem za određivanje rastojanja i reflektivnosti površi i sistem za skretanje laserskog snopa i merenje pravaca.

Osnovni parametar koji utiče na tačnost i domet skeniranja je metod određivanja rastojanja zasnovano na elektromagnetnom zračenju. Elektromagnetno zračenje se može shvatiti kao energija koja se širi kroz prostor ili materiju u obliku brzih izmena električnog i magnetskog polja koji obrazuju jedan elektromagnetni (EM) talas, što je prikazano na slici 3. EM energija je sadržana u harmonijskim izmenama električnog i magnetnog polja talasa koje se javljaju u jednakim vremenskim intervalima. Signali pomoću kojih se određuje rastojanje, koji mogu biti u vidu impulsa ili harmonika, utisnuti su u EM talase modulacijom njihovog intenziteta. Rastojanje se određuje na osnovu određenog vremenskog intervala od emitovanja do detekcije uzimajući u obzir osnovne karakteristike emitovanog impulsa što može biti širina, vreme rasta, vreme opadanja i amplitude. Vrednost horizontalnog i vertikalnog pravca meri se elekto-optički pomoću enkodera.



Slika 3. Elektromagnetni talas

Najčešće u praksi se primenjuju panoramski skeneri, okarakterisani vertikalnim otklonom laserskog zraka pomoću ravnog rotirajućeg ogledala, odnosno horizontalnim otklonom pomoću servo motora. Njihova prednost leži u tome što obuhvataju gotovo celo vidno polje 360 stepeni obuhvata, izuzev oblast oko nogara postolja. Rešenja proizvođača Leica Geosystems Ag dostižu brzinu od hiljadu do million tačaka u sekundi, što je prikazano na Slici 4 ovog rada.

Slika 4. Laserski skeneri 3D, Leica P20 i Leica MS60 1" R2000

Zahvaljujući opsegu merenja rastojanja od 1.5 m do 2 000 m od instrumenta, prikazana oprema se može koristiti u rezervoarima čiji je prečnik 3 m, ukoliko je omogućeno pozicioniranje opreme u centru rezervoara. Meri se oblak odnosno gust set mernih tačaka koje mogu modelirati rezervoar sa više miliona tačaka u opsegu od panoramskih 360 stepeni. Oprema može da vrši automatska merenja kao i analogna, po odabranim tačkama. Za uvezivanje setova dobijenih automatskim merenjem, dovoljno je izvršiti analogno merenje na minimum 4 signalisane tačke koje su vidljive iz svih pozicija merne opreme. Povećanje broja merenja povećava tačnost modelovnogobjekta, čime se u konkretnom primeru objekat (rezervoar) kome treba sračunati zapreminu modeluje kroz više miliona tačaka, u odnosu na standardom zahtevanih više desetina.

Za potrebe ovog rada primenjen je laserski skener integrisan u sistem multi stanice Leica Nova MS60 1 R2000.

Pored 3D laserskih skeniranja, u praksi se javljaju rešenja imaging laserskih skeniranja. Jedan od vodećih rešenja predstavlja BLK360 uređaj, koji istovremeno skenira 3D oblak tačaka, preko kojih "navlači" panoramske slike, fotografije, kao i termalnu analizu skeniranog područja. Samim tim daje takozvane "Two-in-one 360º" podatke koje čine fotografsku dokumentaciju i podatke laserskog skeniranja. Opseg merenja ovog skenera je 60 metara, u kome obezbeđuje takozvane full-color panoramskefotografije prekrivene oblakom tačaka visoke tačnosti. Rešenje koje koje je korišćeno za potrebe ovog rada prikazano je na slici 5.

Slika 5. Leica BLK360Imaging laser scanner

3. KALIBRACIJA HORIZONTALNOG POLOŽENOG REZERVOARA

Međunarodna organizacija za standardizaciju ISO, u sklopu tehničkog komiteta ISO/TC 28, Petroleum products and lubricants, Subcommittee SC 2, Measurement of petroleum and related products propisuje standardne metode za etaloniranje horizontalnih cilindričnih rezervoara. Etaloniranje horizontalnih rezervoara propisano je u dva dela, gde se u drugom delu definiše unutrašnja elektro-optička metoda merenja rastojanja za potrebe etaloniranja rezervoara. Pravilnik o metrološkim uslovima za položene cilindrične rezervoare –Pravilnik, propisuje metrološke uslove koje moraju da ispunjavaju položeni cilindrični rezervoari koji se tretiraju kao merila tečnosti odnosno kao sudovi za skladištenje tečnosti kojima se može odrediti zapremina. U skladu sa Pravilnikom:

Odstupanja u vrednostima datih u tabeli zapremine pri očitavanju visine nivoa tečnosti mogu iznositi: za zapremine jednake ukupnoj zapremini rezervoara ± 0.5 % od ukupne zapremine.

Za potrebe ovog rada, rađeno je skeniranje horizontalnog rezervoara, na uzorku zapremine 49 000 litara.

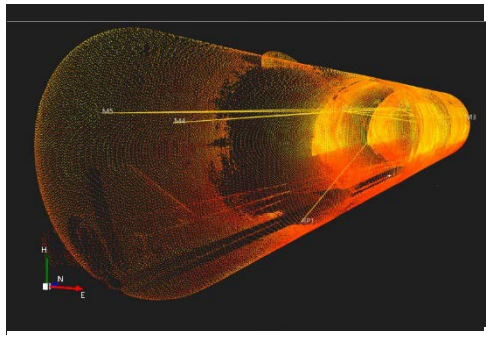
- Primenom MS60 1 R2000, dobijena je ukupna zapremina 49 269 litara, na visini punjenja 6,4 m.
- Primenom BLK360, dobijena je ukupna zapremina 48 922 litra, na visini punjenja 6,4 m.

Poredeći dve zapremine na istoj visini punjenja, može se doći do relativne greške koja iznosi, u prvom slučaju 0,5%, a u drugom slučaju 0.2%.

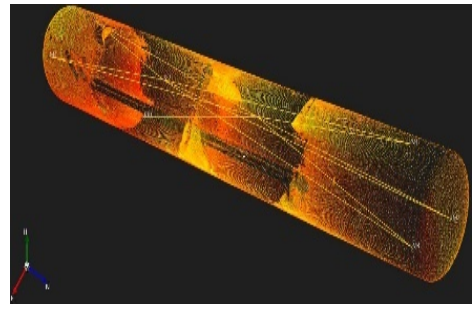
Ukoliko se uzmu uslovi pri radu u razmatranje, može se reći da je primena BLK360 daleko komfornija, budući da je skener izuzetno lagan i lak za korišćenje. Dovoljno je pritiskom na jedno dugme, u roku od 3 - 5 minuta dobiti skeniran prostor. Međutim da bi se obezbedila kompenzacija i horizontalnost skenera, neophodno je koristiti ga u kombinaciji sa totalnom stancom. Sa druge strane MS60 sampo sebi ima dimenzije standardnih geodetskih instrumenata, u odnosu na BLK360 ne zahteva upotrebu dodatne opreme.

Ono što se kod BLK360 pokazalo kao aktivnost koja nije neophodna u rezervoarima koji su podzemni i mračni, jeste uzimanje fotografskih informacija. Rezervoari su mračni, tamni i fotografije ne nose više informacija od onoga što oblak tačaka veoma kvalitetno može da pruži, u uslovima rezervoara.

Dobijeni oblak tačaka konkretnog rezervoara, prikazan je na slikama 6, 7 i 8.



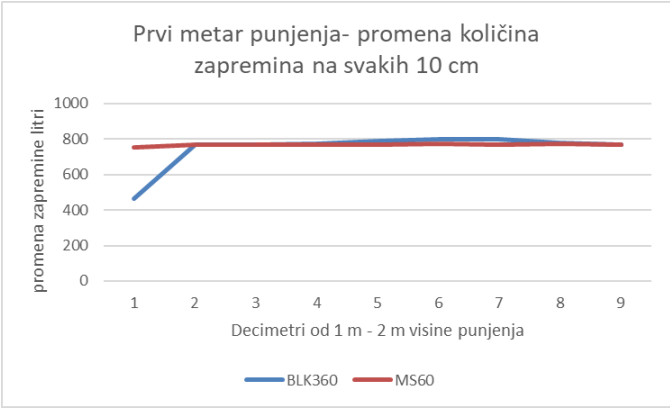
Slika 7. Oblak tačaka rezervoara



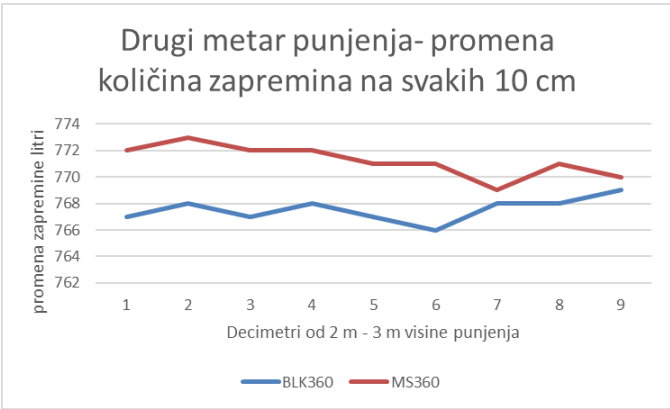
Slika 6. Geometrijski oblik rezervoara

Slika 9. Poprečni presek rezervoara

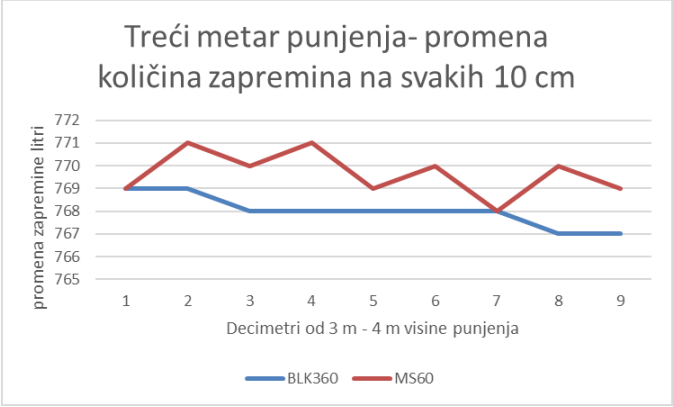
Poređenje zapremine dobijene opisanimmetodama, po principu 1:1 u ovom slučaju nije moguće, budući da su dva hardvera postavljana na dva različita merna mesta. Ono što je korisno i moguće porediti, jeste kako se iz metra u metar menja količina zapremine, na svakih 10 cm.



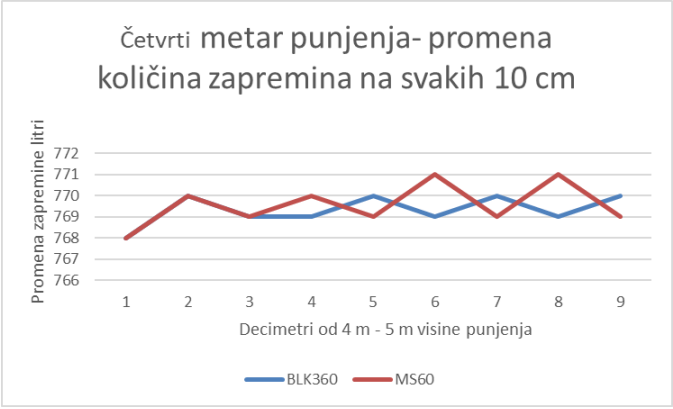
Slika 8 Promena zapremine u prvom metru



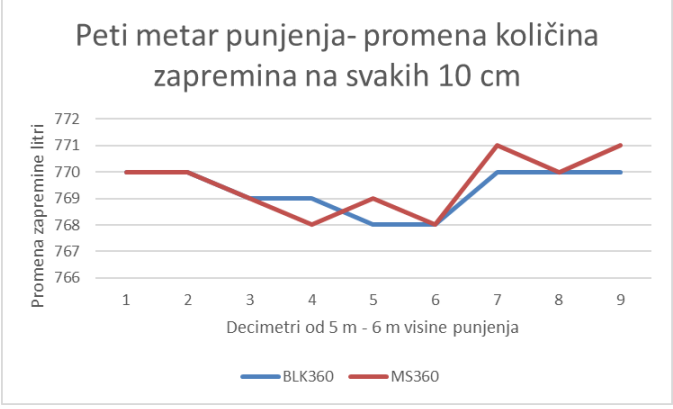
Slika 9. Promena zapremine u drugom metru



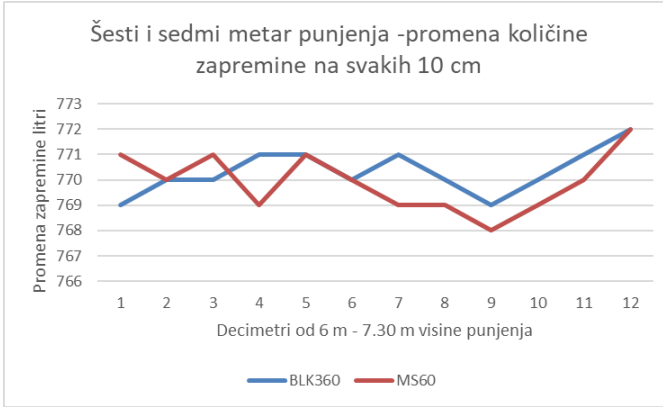
Slika 10. Promena zapremine u trećem metru



Slika 11. Promena zapremine u četvrtom metru



Slika 12. Promena zapremine u petom metru

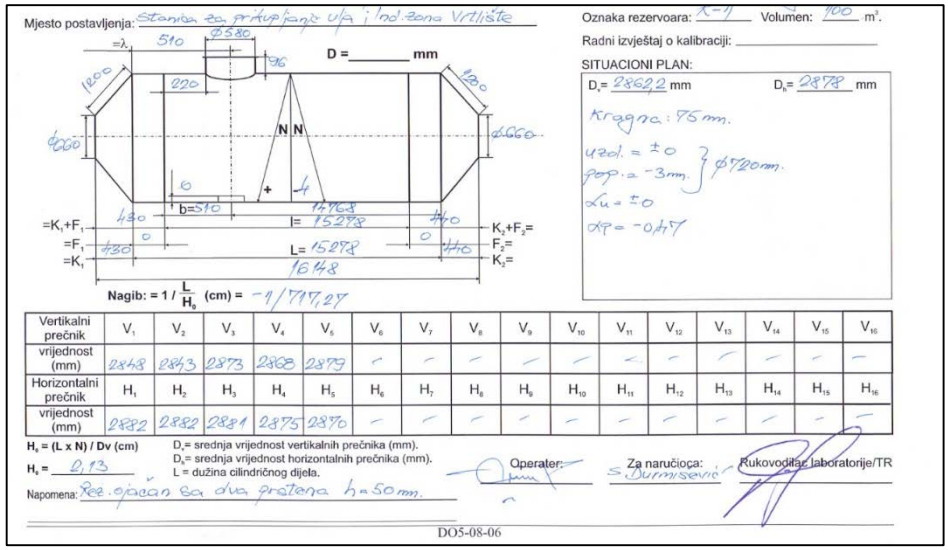


Slika 13. Promena zapremine u šestom i u sedmom metru

Pored određivanja tabele zapremine, merenje geometrijskih veličina rezervoara obuhvatilo je merenja u cilju određivanja:
1) unutrašnjih prečnika cilindričnog dela rezervoara;
2) dužine cilindričnog dela rezervoara;
3) dubine bočnog dna;
4) debljine zida rezervoara;
5) poluprečnika bočnog dna, ukoliko je to izvodljivo;
6) ukupne visine punjenja rezervoara (dužina merene vertikale);
7) nagiba horizontalne ose rezervoara.

Situacioni plan rezervora sa podacima prikupljanjim na terenu prikazan je na Slici 14 u ovom radu. Unutrašnji prečnici cilindričnog dela rezervoara sa obe laserske metode izdvojeni su iz oblaka prikupljenih tačaka, od čega su izdvojeni oni u svakom prstenu, odnosno pojasu cilindričnog dela (između šavova zavarenih limova). U svakom prstenu izdvojena su po četiri merenja prečnika, horizontalni i vertikalni prečnici odnosno na 20% i 80% širine svakog prstena rezervoara. Sračunata je srednja vrednost prečnika dobijena na osnovu četiri merenja, za svaki prsten. Pokazalo se da su obe metode dale zadovoljavajuća merenja, budući da se srednje vrednosti dva uzastopna iz dva različita seta nalaze u granicama ± 0,05 % od izmerenog prečnika ili ± 1 mm.

Dužina cilindričnog dela horizontalnog rezeroara, odnosno rastojanje između simetrala krajnjih zavarenih šavova kojima su bočna danca zavarena za omotač rezeroara, izdvojena je iz oblaka merenih tačaka, prateći 4 referentne tačke koje su označene duž rezervoara. Merenja dobijena sa dve različite tehnologije se nalaze u granicama 0,03% izmerene dužine ili +3 mm.



Slika 14. Primer praćenja geometrije i situacionog plana na terenu

Ostali navedeni geometrijski parametri su određivani termovizijskim senzorima i ultrazvučnim meračima debljine plašta, I nisu predmet testiranja merne opreme koja je u opisu ovog rada.

4. ZAKLJUČAK

Na rezervoaru čija je približna zapremina 49000 litara, ukupna zapremina na merljivoj visini punjenja rezervoara dobijena primenom laserske opreme MS60 usaglašena je sa ukupnom zapreminom dobijenom imaging laserskom opremom BLK360, što u odnosu na projektovanu zapreminu iznosi 0,5% u prvom i 0.2% u drugom slučaju.

Zapremine određene opisanim metodama imaju isti pravac prostiranja i sinhronizovanu vrednost količina zapremine po desetocentimetarskim uzorcima duž visine, što je prikazano na slikama od broja 8 do broja 13, ovog rada . Količine zapremine po centimetarskim uzorcima opisuju oblik rezervoara koji ima dva danceta konična, čime su na sredini rezervoara količine zapremine najveće, a pri dnu i pri vrhu su manje što ukazuje na sužavanje rezervoara u tim delovima.

U tabeli zapremine rezervoara uočeno je odstupanje početnih količina zapremina kod obe metode, što je uslovljeno različito odabranim mernim mestima,

Obe metode su se pokazale kaokomforne za rad, s tim da metoda Imaging lasserskog skeniranja iziskuje kombinovanu upotrebu totalne stanice i BLK360 skenera, pre samog merenja i početka skeniranja.

Obe metode su dale vizuelni pregled merljivog oblaka tačaka rezervoara kao i 3D modela iz kojeg je sračunata zapremina, što predstavlja izuzetno zahvalan pristup ocenjivanja metrološke kontrole rezervoara u budućnosti.

LITERATURA

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62| Стручни рад
Professional paper
doi 10.7251/STP1813805B ISSN 2566-4484

PRIMJENA WEB BAZIRANOG SISTEMA KROZ INTEGRACIJU WEB GIS ALATA I INFRASTRUKTURE PROSTORNIH PODATAKA U UPRAVLJANJU NEKRETNINAMA I NJIHOVOM MAPIRANJU

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Abstract:
Nekretnine su vrlo bitna grana ekonomije zbog vrlo značajnog uticaja u oblasti trgovine, prodaje i cijena u svim zemljama. Zbog nedostatka integrisanih i sveobuhvatnih informacija, najčešće ne postoji jasan i naučni trend za transakcije i metode određivanja cijena. Za ljude koji ucestvuju u industriji nekretnina ovaj nedostatak stvara mnoge probleme. Uvođenje i implementacija mapiranja, analize i upravljanja nekretninama je cilj ove studije zato što djelimično može biti rješenje za izražene probleme. Mnoge tehnologije i metode uključujući Infrastrukturu prostornih podataka (IPP), Web servise i Web GIS su korištene u ovom rješenju. Ove tehnologije i metode će se ukratko predstaviti i razmotriće se njihov odnos prema predmetu istraživanja i njihovoj ulozi i uticaju u rješavanju izraženih problema. Važnost mapiranja i analize nekretnina i njene lokacije kao jednog od najvažnijih faktora će se predstaviti kroz nekoliko primera, kao što je nekretnina imanja u Hadžićima, Sarajevo, BiH.
Keywords: nekretnine, mapiranje, IPP, Web bazirani sistem, Web Gis

THE APPLICATION OF THE WEB BASED SYSTEM BY INTEGRATING WEB GIS TOOLS AND THE SDI FOR THE REAL ESTATE MANAGEMENT AND MAPPING

Abstract:
Real estate is very important branch of the economy because of very significant impact on the area of trading, sales and pricing in all countries. There is a lack of integrated and comprehensive information and because of that many transactions and pricing methods most commonly don't have a clear and scientific trend. For the people who participate in the real estate industry this deficiency creates many problems. Introducing and implementing of the real estate mapping, analysis and managing is the goal of this study because it can be partially solution for the expressed problems. Many technologies and methods including Spatial Data Infrastructures (SDIs), Web services and Web GIS were used in this solution. These technologies and methods will be briefly introduced as well as their relation to the subject of research and the role and impact of them in solving expressed problems. The importance of mapping and analysis real estates and its location as one of the most important factors will be represent through several examples, like as property in Hadzici, Sarajevo, BIH.
Keywords: real estate, mapping, SDI, Web based system, Web Gis

1. INTRODUCTION

Real estate is very important branch of the economy because of very significant impact on the area of trading, sales and pricing in all countries. Importance of real estate in many aspects, investments and profits that may be gained in this area, have created strong impuls for creating approach in this market for different individuals and groups. A few important factors play role in this field. Deficiency of awareness of some of the participants in real estate about the property information and the non-attendance of clear and comprehensive rules and regulations for the trading and pricing of property are some of those factors.[1] Property information is at this moment completely straggling in different organizations including property registration and cadastre office and municipality offices. There is a lack of integrated and comprehensive information and because of that many transactions and pricing methods most commonly don't have a clear and scientific trend. For the people who participate in the real estate industry this deficiency creates many problems. Those problems can be growth for prices without noting specific basis. [1]

1.1. REAL ESTATE INDUSTRY

Dhe real estate industry is very complex area. Decision making, planning, implementation and usage are some of attributes that make this industry very complexed. Many professionals such as engineers, lawyers, economist, environmentalists, surveyors are involved in resolvnig different tasks that make a real estate project successfully done. WEB GIS have many applications in the real estate industry. These applications enable real estate professionals and actors to measure the impact of location and this way make intent and judgement in many areas, including site selection, construction management, residential brokerage, appraisal, facility management and market analysis. [2] Real estate companies with the most successful understand that insight and timing are also a real value of the estate and not only location. GIS will help in spreading timeliness of information for both professionals and the other publicity. The improvement provided by GIS integration may help real estate development.

1.2. SPATIAL DATA INFRASTRUCTURE (SDI)

Spatial Data Infrastructures (SDIs) refer to a set of fundamental spatial technologies, policies and standards that improves access and utilization of spatial data. One of SDI tasks is helping to spatially empower groups and the states by providing the policies. [3] It has distinctly been revealed, especially in the last ten years that spatial data requirements of today's applications or projects could be met only through an effective cooperation between different institutions or parties. One of these applications is real estate. By implementation an SDI for real estate we can access large amount of spatial data. This goal can be achieved through interoperability cooperation between different organizations associated with the property.

1.3. WEB GIS

Web GIS is a combination of web technology and Geographic Information Systems. [4] In effect it is a GIS system that uses web technologies to make data accessible to the public who has or has not any knowledge about GIS. Therefore the main objective of webGIS is informing people through interactive maps. The user interface is very simple and allows a easy navigation through the map. WebGIS projects can be create using

basic functions, e.g. zoom in and out, or by area, search for place names, and switch on and off the layers. Alternatively, a webGIS can be a bit more complex and allow the users to access the attribute table of the layer by clicking on a feature on the map, editing layers, or filtering the data. [5].

The simplest architecture of a Web GIS requires one server, with a web application, and one client that is a desktop application or web browser application that allows the user to communicate with the server. Web GIS is a model, or architectural approach, for implementing a modern GIS. It's powered by web services that deliver data and capabilities, and connect components.

Web GIS can be implemented in the cloud (using ArcGIS Online), on-premises (using ArcGIS Server), or more typically as a hybrid combination, leveraging the best of both worlds. Web GIS isn't new. It's been evolving for a long while. Innovation in GIS have made Web GIS both possible and essential.

Web GIS provides many possibility, to provide wider access to your authoritative GIS data. This enable you to move your system of inscription to a system of engagement that has everything from self-service mapping to making better decisions. It makes GIS more accessible, affordable, and pervasive.

The shift from client/server architectures to Web services enables us to connect to a world of information, from our enterprise to the Internet of Things (IoT), Big Data, and more. This way GIS going forward into real-time mode instead of being static data. Users are more agile by using Web GIS, moving from custom application development to configurable templates and web app applications. Web GIS moves us from proprietary data into open data and shared services. That aplication of web gis can empower everyone.

Web GIS system is based on the following five components:

- User Interface
- Web Server and software server
- Map Server
- Data Server
- Database

Real estate management can be much more easy by ensuring a better way of collecting, accessing, using and managing spatial data. Web-based GIS with a SDI as a framework can be a very useful tool for facilitating property management because of the need for interaction between buyers, sellers, real estate transactions agencies, decision makers and planners.

2. THE LEVELS OF THE PROPOSED REAL ESTATE WEB BASED SYSTEM

Proposed real estate web based system in this article is composed of few levels: users, server, service, data and model. The structure creates an integrated and centralized real estate web based system that provides users: buyers, sellers, real estate agencies to find, sumarize, analyze, compare and research a real estate datas and its locatons, and also provides a search by criteria or a factor or to search for the region and its characteristics by economical, demografical, geographical or some other aspects. [1] The information is with descriptive terms such as registration and also in spatial form. [2] At the end, all the gathered and found information has provided user to make or to display on the map.

2.1. USER LEVEL

User level includes system users and components of the interface. Users system consist of several groups. Those groups are buyers, sellers, real estate agencies, government, academics and researchers. Those parts of system are used by target. [1]Users apply the system and share their information with different objectives. There are restrictions in this context. For example sharing spatial information by real estate agencies is a very controversial issue. These limitations can be overcome. The user interface consists of Web pages, including map pages, query pages, data entry pages and display of information. In order to increase the efficiency and quality of the system the plug-ins available including Google Earth plug-in, Google Map plug-ins used in the system. To increase capabilities of map to appropriate spatially display to user Openlayers framework is used for writing desired applications in JavaScript.

User can find the desired property using many methods on the map: find property by approximate address, by GPS coordinates, by searching on the map page. Data sum includes all types of data that are collected from multiple sources and assembled in the form of an integrated database.This database is made up of several different databases. (database for real estate management and marketing , spatial database that includes spatial data of educational places, shopping locations, streets, health centres, religious centres, industrial and workshop centres with their attribute information). These databases can be in relation to each other and can be integrated into a common database for real estate management. The spatial database from public places and streets is also used in practise. Consciousness of the both, quality and quantity of the access to public places (educational and religious buildings, shopping centres and health centres, government places and also the name of the various streets) can have an effective and great role in real estate industry (pricing and transactions).

2.2. SERVICE LEVEL

Modern Geographic Information Systems (GIS) technology is an integrated system of computer software and data and information about the location and geography of places. GIS is used to interact with, manage and display geographic information. A Geographic Information Systems is a system that allows to analyzing, viewing, understanding, questioning, interpreting and visualizing data in so many ways that reveal relationships, samples and trends in the form of maps, globes, reports and charts and other data presentations. [2]. Recent innovations carried out in GIS technology will have a deep effect on real estate and related industries. The importance of the‘‘location’’in the real estate industry have long valued by real estate practitioners. A few practitioners have considered GIS as the tool for locational analysis and considering GIS as a visual medium. GIS can help potential buyers to target and find quickly the right house, browse listings, view at an appropriate map, and choose an real estate agent from the home computer. GIS technology will increase the productivity of existing industry operations. Also GIS lead to greater exactness of information and access to information that previously was cost prohibitive or simply unavailable.[6] These advances will provide a greater range of information and real estate decision can be made by these advances. This will benefit consumers by leading to decisions that more closely address their needs

and preferences.. However, the need for professionals with advanced technology skills, including GIS, will grow by the time [2].

2.3 MODEL LEVEL

Users can find the target property by many methods and ways on the map that are:

- Finding property by typing approximate address
- Finding property by entering GPS coordinates
- Finding property by searching on the map page

Then usesr can go to display information page by clicking in the middle of property. This page more commonly consists of two parts. The selected property information is displayed in the first part that includes information collected from organizational services (SDI) and information entered. In this article the model of interactive map has been made by Geoserver and Web Gis Tools, Arc Gis Online and the Story Map application.

3. WEB BASED REAL ESTATE SYSTEM IN PRACTICE

In this article is represented the application of the web based system using an integrated web GIS tools and the available spatial data infrastructure (SDI) on the subject real estate property, in Hadzici Municipality, Sarajevo city in Bosnia and Herzegovina (BIH). It is considered its context, location, analysis, as well as research by different criteria important for all in the real estate industry chain (buyers, sellers, real estate agencies and all interessted users). Interactive web maps of real estate locations are published, and they are at the same time maps for searching real estate properties and its location by queries and requests for specific real estate and its datas and informations. Also it is possible to find a similar real estate properties in its surrounding by using this systems. The subject real estate property is published using Geoserver, an open source software, and web Gis components, using a shape files and KML files. In this article it is considered analysis of spefic datas of the Spatial Data Infrastructure, based on important and the key factors for the real estate property. The integration of overviews of the spatial datas and informations about specific spatial datas has been done, what certainly means interoperability of the systems and the kind of BIM methodology.

3.1. GEOSERVER

GeoServer is an open source software server written in Java that allows users to share and edit geospatial data. It is designed for interoperability, it publishes data from any major spatial data source using open standards. [7] GeoServer is developed, tested, and supported by a diverse group of individuals and organizations from all around the world. GeoServer is the reference implementation of the Open Geospatial Consortium (OGC) Web Feature Service(WFS) and Web Coverage Service (WCS) standards, as well as a high performance certified compliant Web Map Service (WMS). GeoServer forms a core component of the Geospatial Web.

GeoServer was started in 2001 by The Open Planning Project (TOPP), a non-profit technology incubator wich is based in New York. A suite of tools was creating by TOPP to enable open democracy and to help make government more transparent. The first of these was GeoServer, which came out of a recognition that a suite of tools to enable

citizen involvement in government and urban planning would be greatly enhanced by the ability to share spatial data. A Geospatial Web was envisioned by the GeoServer founders, analogous to the World Wide Web. With the World Wide Web, it is possible to search for and download text. With the Geospatial Web, it can be possible to search for and download spatial data. Data providers would be able to publish their data straight to this web, and users could directly access it (indirect and cumbersome methods of sharing data that exist today).

Those involved with GeoServer founded the GeoTools project, an open source GIS Java toolkit. Through GeoTools, support for shapefiles, Oracle databases, ArcSDE integration, and much more was added. Around the same time as GeoServer was founded, The OpenGIS Consortium (now the Open Geospatial Consortium) was working on the Web Feature Service standard. It specifies a protocol to make spatial data directly available on the web, using GML (Geographic Markup Language), an interoperable data format. A Web Map Service was also created. Also a protocol for creating and displaying map images created from spatial data. Refractions Research created PostGIS, a free and open spatial database, which enabled GeoServer to connect to a free database. Also, MetaCarta originally created OpenLayers, an open source browser-based map viewing utility. Together, these tools have all enhanced the functionality of GeoServer. GeoServer can now read data from over a dozen spatial data sources and output to many different formats. Now in its second decade, GeoServer is continuing on its mission to make spatial data more accessible to all. [7]

3.1.1. Publishing a shape file in Geoserver

The figure 1 shows an published shape file. In the table of the Layer Preview by clicing on the Open Layer the published layer will be shown (as at the figure 2).

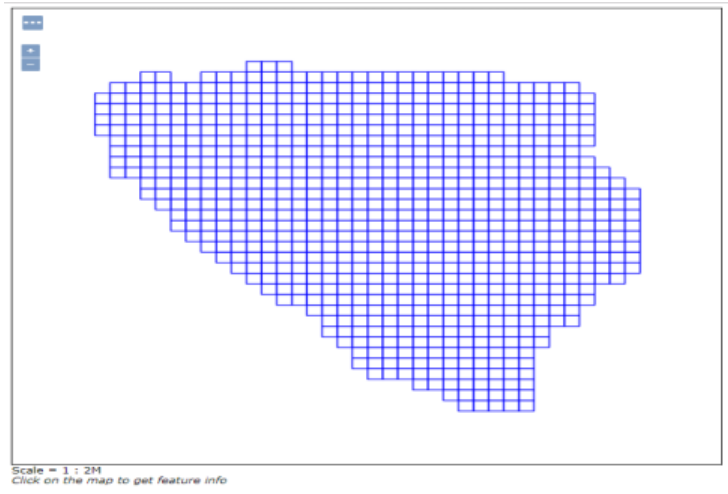
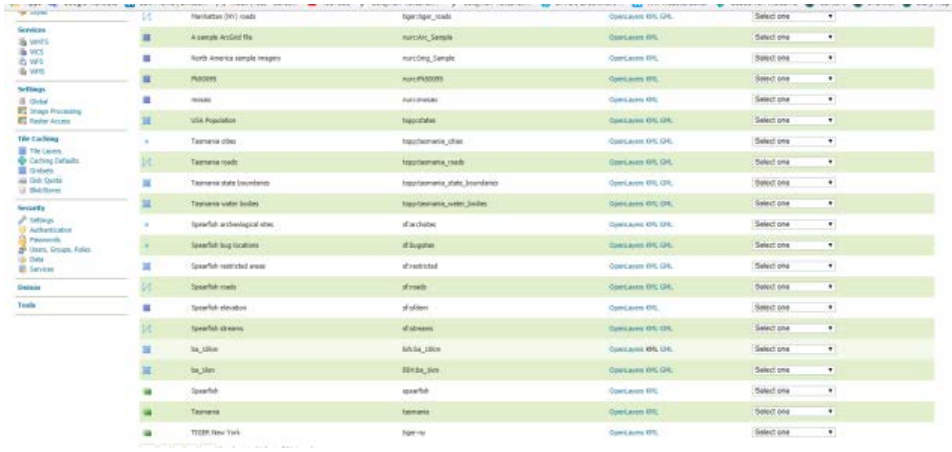


Figure 1. Shape file bih_ba_10km published in Geoserver



Fugure 2. Layer preview in Geoserver

By choosing a KML file of the published layer (bih_ba_10km) from the Layer Preview Table (shown in figure 2), a KML file of the mentioned shape will be downloaded. So, the published shape file could also be shown as a KML file in the Google Earth application.

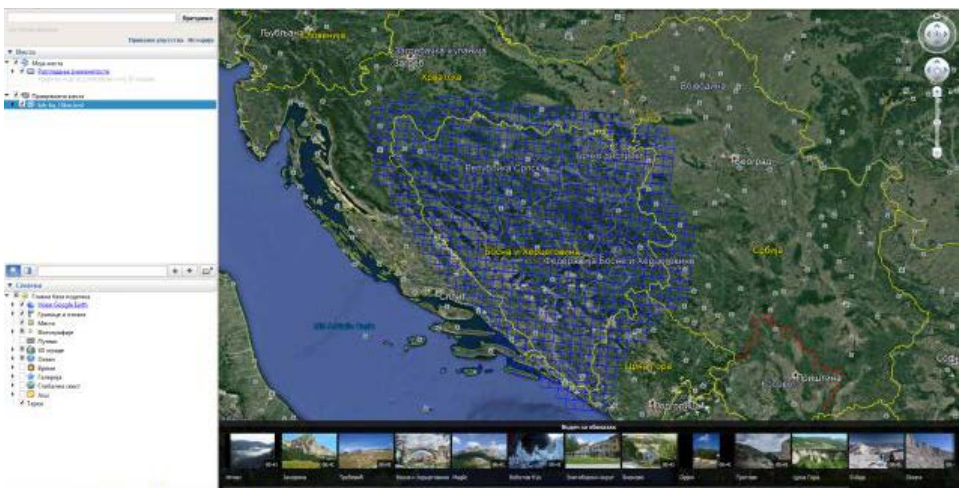


Figure 2. a KML file of the bih_ba_10km

The Google Earth application will be automatically open by clicking on the downloaded KML file. Here on the figure 2a it is shown a region of BIH with its division on the interactive 3D basemap. The subject real estate property is found by using a search options and it is visible on the preview. It is possible to label coordinate and location. By importing URL link of the property the visual connection is provided in order to better visualize (figure 3). It is also possible to add an URL of the imported picture of the

property that will apear after clicking in the middle of the property. On the Layer Preview in the Geoserver it is also possible to take a GML file.

Figure 3. The linked URL page

In the Layer preview window of the Geoserver application there is also in the same row where the name of the published layer is a small window "select one". Choosing a shape file from the droping list it is automatically a zipped shape file being download. The shape file could be open in Q GIS softwer and there edited and again publish on the Geoserver for the external users (figure 4).

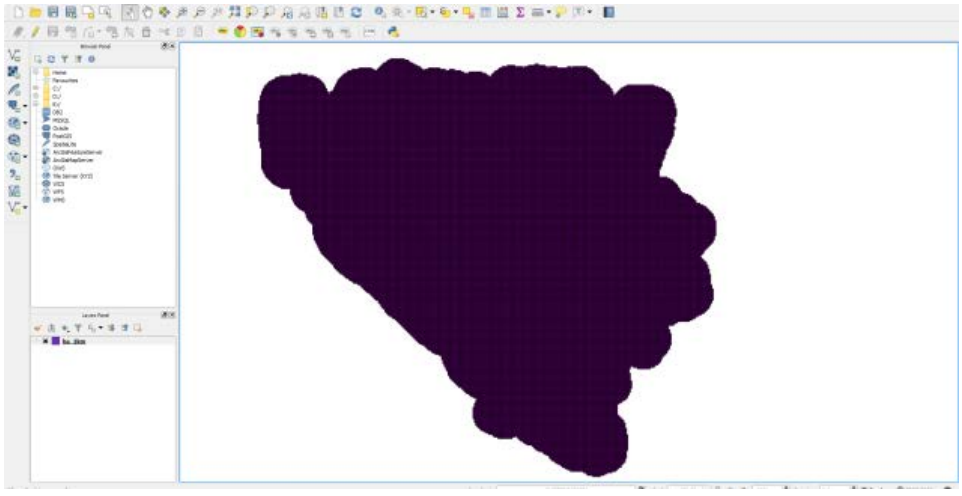


Figure 4. Shape file in QGis

Publishing a shape file with the landuse of the areas of the specific spatial units of the Bosnia and Hercegovina was the next step in this article.

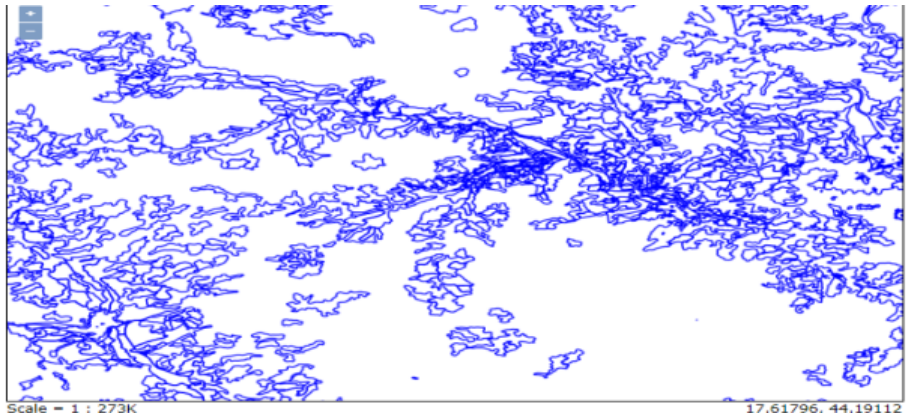


Figure 5. Published shape file of land use of spatial units in BIH

On the Layer preview window in the Geoserver the published layer of the landuse of the spatial units is shown. Choosing a KML fle from the Common Formats, the kml file will be automatically downloaded and open in Google Earth application.

The kml file will be opened in the Google Earth application as on the figure 6. Here it is posible to see what is the purpose of the land of the selected place, in this case a subject property, real estate in the Hadzici Municipality, Sarajevo,BIH. The subject place is marked and the shape file shows a purpose of the spatial unit_laduse. This maps could be saved in My places on the internet with a provided web address and could be use as a simple interactive map presentation and being helpful for the users, in this case one of the actors in the real estate industry chain.

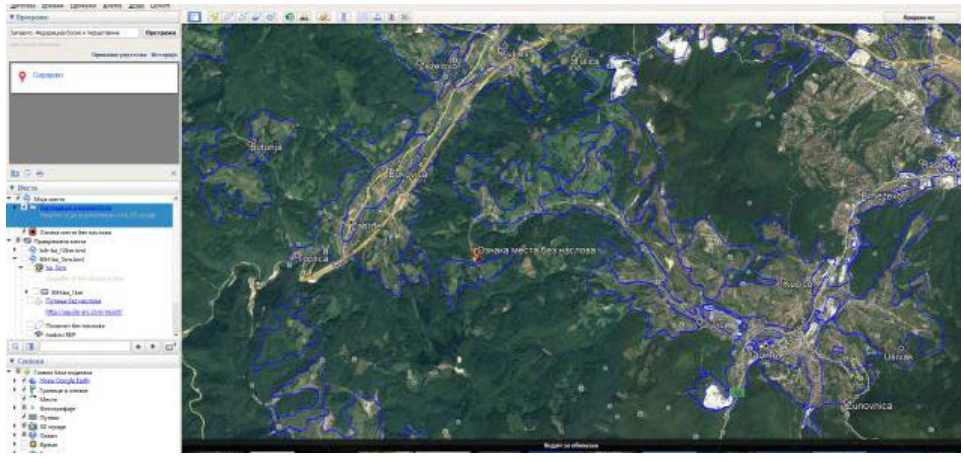


Figure 6. KML file of the land use of BIH imported in previous map

3.2. ARC GIS ONLINE

Arc Gis Online provides both, map previewing and location analytics. It also provides an interactive mapping interface to help explore location and information about them. It is cloud-based platform wich provide the catalyst needed to share information inside and outside organizations. The file imported from the kml file in the Google Earth, shown on the figure 7, shows a datas in the table that are made in the Google Earth application. All imported datas are displayed on the table below the map preview. Also the map notes made in Google Earth application is present here.The map notes are styled by the purple dots on the map (the same as it was set in the Google Earth application), figure 7.

In Arc Gis Online import/ Addin layers/ files provides making alalysis and getting results. This results are very usefull in the Real Estate Property managing and creating a clear picture for the potential costumers, menagers and other factors in the real estate industry chain.

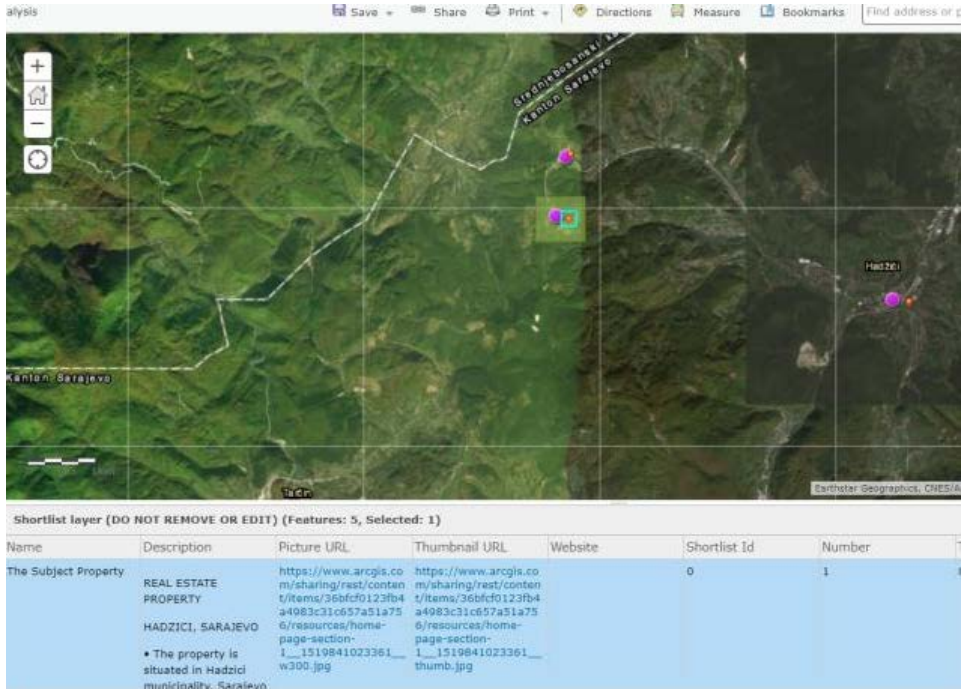


Figure 7. The zoomed area of the imported kml file

3.2.1. Importing a shape file in Arc Gis Online

In this map overview of the layer of the administration units of BIH has been imported. The shape file named BIH_adm consist of the next layers: BIH adm0, BIH adm1, BIH adm2, BIH adm3. Each of the layers represent a partition of the country BIH on smaller spatial units. The firsts partition refers on the division of the country into two entity-Federation of BIH and The Republic of Srpska. The second one refers to the division of the country into cantons, the third one into municipality and the null-layer is the shape of the state border of entire BIH. In the layer preview window it is provided accses to the

layers, its characteristics, changing styles and getting the atribute table with a datas of layer. Clicking the „Show Table“ icon appears the table with the all atribute of datas: ID, areas, the spatial division by state division criteria.

The combination of leyers and data is absolutely possible and provides many overview of teritory and the real estate property units in this case. For example, here can be use a cadastral datas and any other available government data, converted into compatible format and combine with the corresponding data unit, real estate property, to check the parcells, cadastral, municipality and any other governmaent spatial units wich is reffers to the real estate property that is considering like example in this work. All actors from the real estate industry chain could get the parcell border, its shape, area etc.

Adding a shape file in the Arc Gis Online makes an integrating process that consist of the visual overview on the map fileld with the aprropriate basemap and table datas overview. Blue line- selection of the municipality (Hadzici) -shows at the display and represent the boundary line of the Hadzici municipality-selection marker (figure 8).

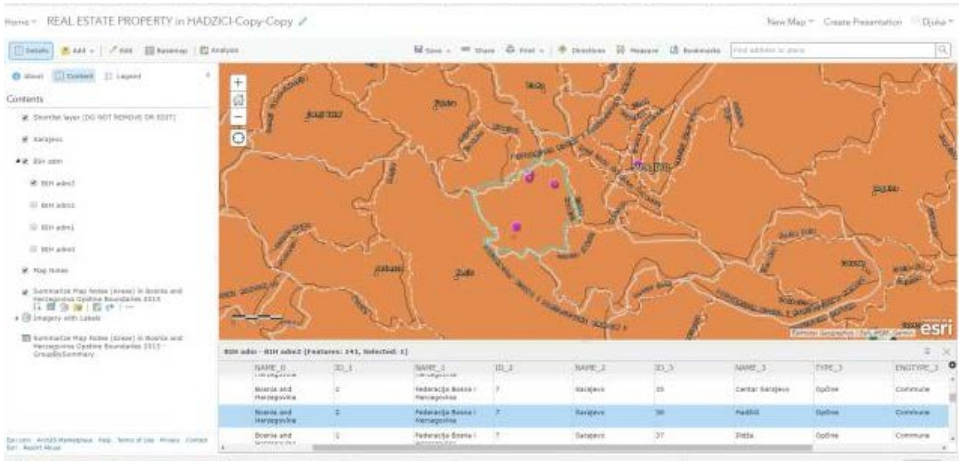


Figure 8. Importinga shape file of Administrative units of BIH

3.2.2. Analysis of the real estate data in Arc Gis Online

Location is a key factor in the success of real estate project. Most financial institutions offer value to their customers through the strategic location of their project. The location or the position of the real estate is one of the most important factors determining the value of the real estate. It is not only a geographical, but much rather an economic term, it is summing up for the totality of those environmental conditions and services that jointly influence the quality, comfort, use value and market value of the given real estate. Moreover, location is not just about finding any site but finding the best site [2]. The GIS technology can deliver the results what the investors need. By analyzing data connecting to locations, demographics, aerial photographs, traffic networks, shopping center usage, merchandise potential data, and competitive influences,the investors can find ideal locations for property. Web GIS helps the real estate industry analyze, report, map, and model the merits of one site or location over another. GIS can combine and integrate different types of information to help making better decisions and also give high quality visualization tools that can improve the understanding and enhance strategic planning.

With the utilization of GIS web mapping services it is easy to create services and give information through internet which can be an indispensable tool in marketing. These services can show additional data like school districts, social amenities, shops, crime data, or transportation links [2]. Although the geographical location of a real estate property is always the same, its suitability and market value can change significantly over the time due to change in facility around it so analysis could help in understand the market value and trends in real estate industry.

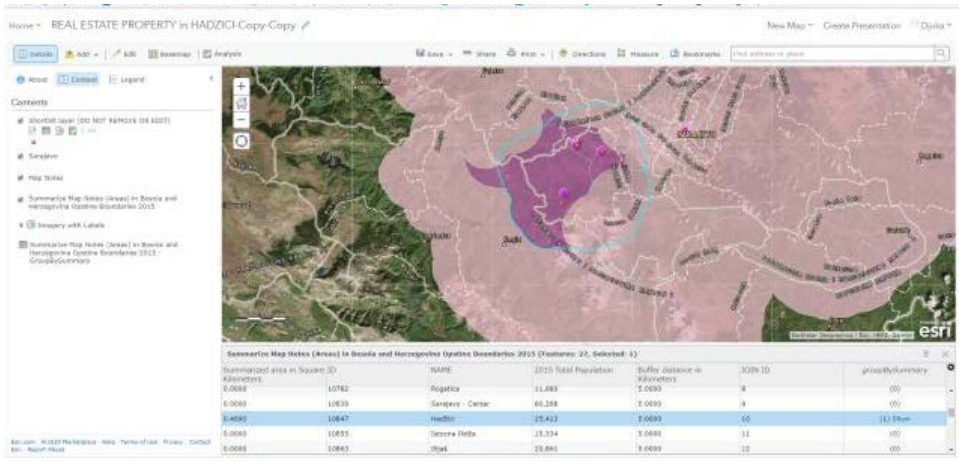


Figure 9. Analyse of searchig similar properties like subject property

Making Analysis operations choosing from the Arc Gis online Analysis list (Summarize Data, Find Locations, Data Enrichments, Analyze Patterns, Use Proximity, Manage Data) by giving apropriate queries and results from the analysis and its preview map will be displayed and available for users after publishing a map.

Feature layer generated from running the Summarize Nearby solution. Bosnia and Herzegovina Opstine Boundaries 2015 were summarized nearby Map Notes (Areas).

The query input was given by reasrching the simillar real estate properties like this one in Hadzici Municipality, Sarajevo BIH. The style of the map overview is given below on the figure 10.

Selected blue line shows the Hadzici municipality border (figure 10). The purple color shows the area with the simmilar properties, as it was requested in the query for searching that inside the Sarajevo region and its apropriated nearby location.

On the figure 11 is overview of the new analysis result shown. The Analysis operation that was used is Enriched Data servise. The query that was requested reffers to an total income in the BIH Municipality and city regions for the 2015 year. The target group or the target spatial area is area of the Sarajevo city to checking the economical environment,

what is in this case a very important fact for the Real .Estate Managing. The values is given in the data table, so the total income of the Sarajevo region is 2,874,895,239.27 BAM.

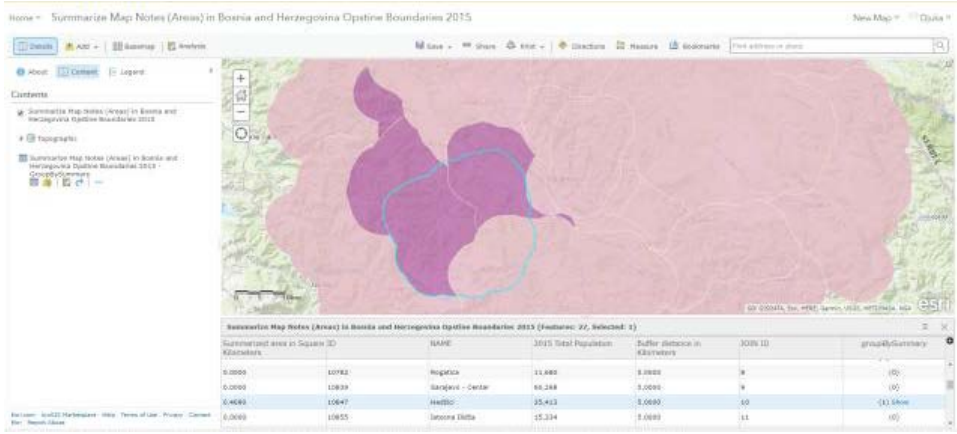


Figure 10. The border of Hadzici municipality

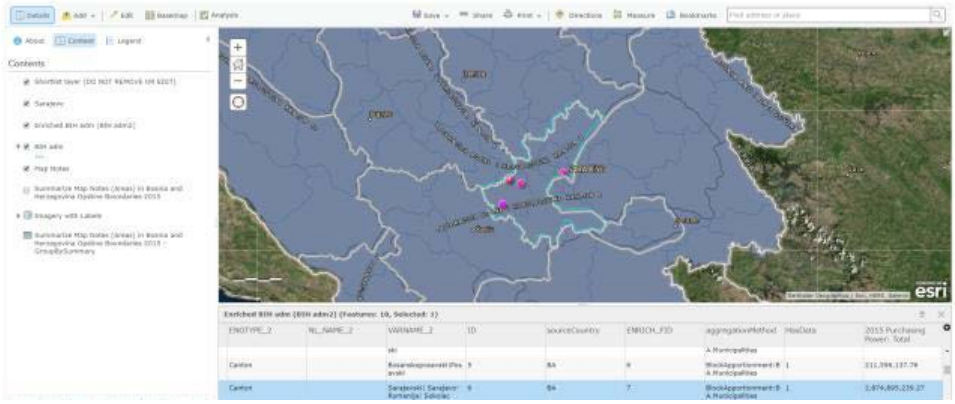


Figure 11. Analyse of Total income of the BIH municipality 2015

3.2.3. Saving and publishing the real estate maps in Arc Gis Online

The map is published together with layers of the spatial units, map notes and analysis that was done in Arc Gis Online application. The Layers ofers a searching for the specific information or result that was given throug the layer- diferent format files, shape file in this case and the results of analysis query operation that was done (figure 12,13).

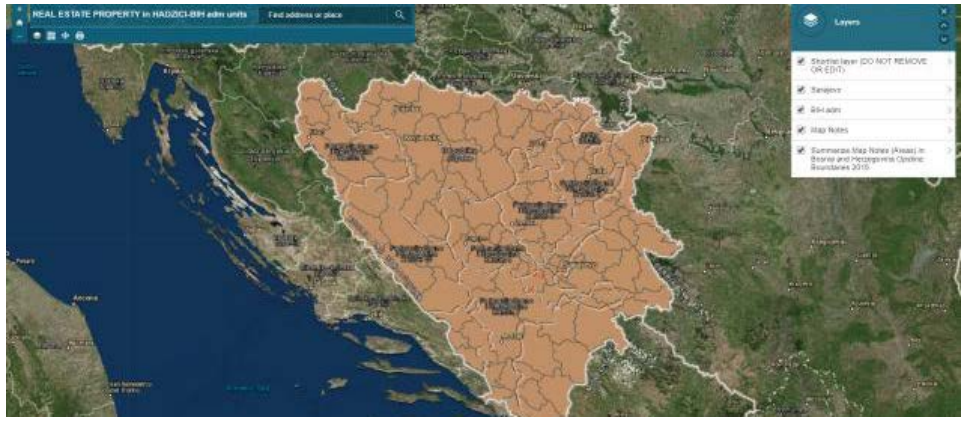


Figure 12. Publish Arc GIS Online map with administrative units of BIH

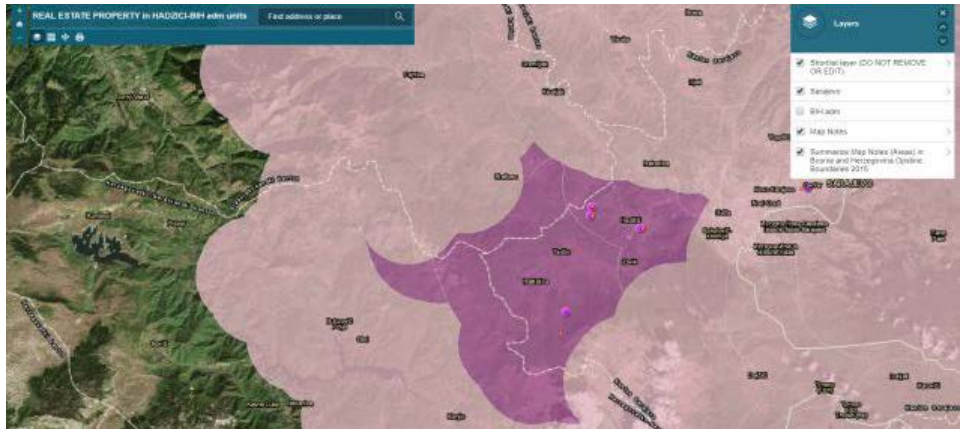


Figure 13. The results from the one of the analysis

3.2.4. The subject real estate property in Hadzici overviewed through the Story Map

The application of the Arc Gis that is used to make the overview of the subject property is Story Map Builder. Here is described a three parts of the property and locations as well. The map is good for better understanding of the property and its location. On the figure 14 is shown a part of the property in the particule tab (yelow color) with geolocations for the specified parts connected with images and textual datas. Figure 15 is display of the specific geolocation together with its datas, image and text. This software is choise of many real estate companies, such as The David Hicks Company, and they quotes this provides an interactive mapping interface to help explore locations and information about them.[9]

Figure 14. Story map of the subject property

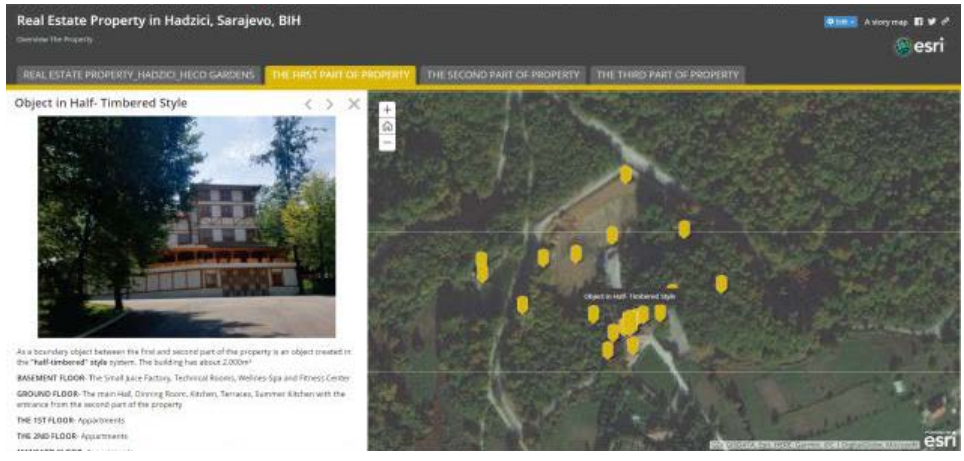


Figure 15. Story map of the subject property

4. CONCLUSION

The role of the web based system in this article, web GIS and Spatial Data Infrastructure (SDI) in collecting, retrieving, analyzing and sharing informations about real estate for usage by various users including buyers, sellers, real estate agencies was studied. Some of the applied technologies and infrastructures with some models used in recent years were applied. Implementation of the proposed real estate support system is a proper

method for various real estate users to easily access to all information about property that are assembled from different sources. Combination and modulation of web GIS and SDI with use of techniques like service composition provide a very large extent, of assertive information for various users. This information assists managing, advertising and making decision despite of distinctions and inconsistencies can be in formats and prearrangement methods and display information. Integrating this information and display it to the users prevents largely individual opinions interfering in real estate trading and pricing as well. The local utility values and the impact of that values on the trade and pricing indices get more logical process and clear direction.

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63| Стручни рад
Professional paper
doi 10.7251/STP1813821S ISSN 2566-4484

INFRASTRUKTURA GEOPROSTORNIH PODATAKA REPUBLIKE SRPSKE - ADRESNI REGISTAR I REGISTAR PROSTORNIH JEDINICA

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Rezime:

Adresni registar predstavlja jedinstven registar/skup geoprostornih i metapodataka o nazivima naseljenih mjesta, trgova i ulica, te kućnim brojevima, i o prostornim jedinicama Republike Srpske, i veoma je važna komponenta Infrastrukture geoprostornih podataka Republike Srpske. Osim osnovnih podataka o naseljenim mjestima i adresama, sadrži i podatke koji se odnose na granice katastarskih opština, matične brojeve gradova/opština, naseljenih mjesta, statističkih i popisnih krugova, i dr.

U okviru CILAP projekta jedna od komponenti je i "Podrška uspostavi adresnog registra", u koju su zbog njenog značaja i sadržaja uključeni mnogi organi, među kojima je i Republička uprava za geodetske i imovinsko - pravne poslove Republike Srpske, u čijoj se nadležnosti nalazi centralni adresni registar, dok jedinice lokalne samouprave vode lokalne adresne registre.

Ključne riječi: adresni registar, registar prostornih jedinica, IGPRS, SDI, GIS

INFRASTRUCTURE OF GEOSPATIAL DATA OF THE REPUBLIC OF SRPSKA - ADDRESS REGISTER AND REGISTER OF SPATIAL UNITS

Abstract:

The address register is a unique register/set of geospatial and metadata about names of settlements, squares and streets, house numbers, and spatial units of the Republic of Srpska. In adition to basic data on populated places and addresses, it also contains data related to the bounderies of cadastral municipalities, town/municipality identification numbers, settlements, statistical and enumeration circles, and others.

Within the CILAP project, one of the components is "Supporting the establishment of an address register", which, due to its importance and content, includes many authorities, including the Republic Administration for Geodetic and Property Affairs of the Republic of Srpska, in whose jurisdiction is the central address register, while local government units manage local address registries.

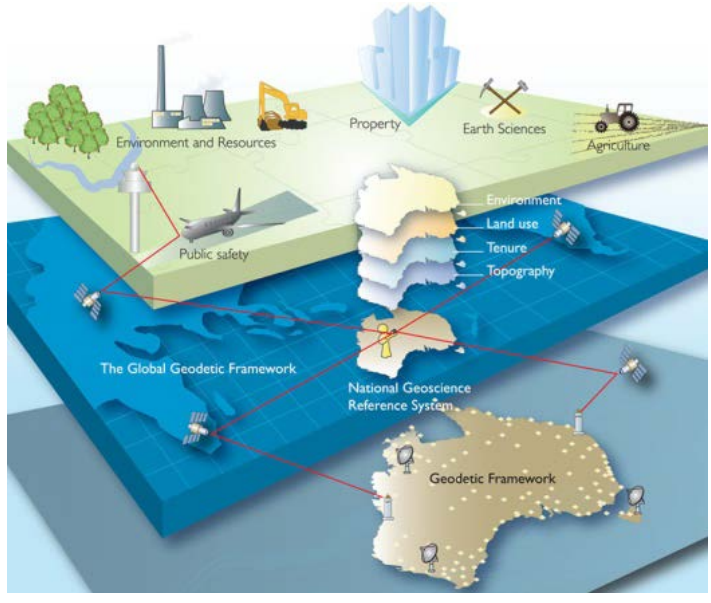
Keywords: adress register, register of spatial units, SDI RS, SDI, GIS

1. UVOD

Infrastruktura geoprostornih podataka prepoznata je kao ključna strategija za postizanje ciljeva geoinformacione industrije, koji su prvobitno usmjereni na prikupljanje i kreiranje geoinformacija, pronalazeći optimalne načine dijeljenja, distribucije i korišćenja podataka.
U ovom radu su date napomene o Adresnom registru i Registru prostornih jedinica, potrebe za njihovim formiranjem, načinom održavanja, kao i funkcionalnim karakteristikama ovih registara.

2. INFRASTRUKTURA GEOPROSTORNIH PODATAKA REPUBLIKE SRPSKE

Prostorni podaci se odnose na podatke koje je moguće povezati sa lokacijom na zemljinoj površini bilo direktno u nekom referentnom sistemu, ili posredno pomoću atributa. Dodavanjem metapodataka prostornim podacima nastaju prostorne informacije. Infrastruktura prostornih podataka (Spatial Data Infrastructure – SDI) se može definisati kao sistem prostornih podataka, metapodataka, proizvođača, korisnika i pripadajućih alata koji su međusobno povezani radi jednostavnog i učinkovitog korišćenja prostornih podataka na svim društvenim nivoima. [1]
Okvir prostornih podataka uključuje: katastar, saobraćaj, hidrografija, digitalni ortofoto (DOF), administrativne jedinice, geodetska osnova, visine, geografski nazivi. [2]



Slika 1. Okvir prostornih podataka [3]

Postoji mnogo ekonomskih potencijala koji su zaključani u zbirkama prostornih podataka i taj se potencijal ostvaruje tako što su podaci široko dostupni. Infrastrukture prostornih podataka (IPP) pružaju platformu za korisnike prostornih podataka, proizvođače i one koji njome upravljaju, kako bi učinkovitije distribuirali podatke.

Prostorni podaci u nadležnosti Republičke uprave za geodetske i imovinsko - pravne poslove su veoma važan resurs koji predstavlja osnovu u realizaciji ovakvih sistema. Infrastruktura geoprostornih podataka Republike Srpske obuhvata mnogo više od prostog skupa podataka ili baze podataka, sadrži podatke o prostoru i pripadajuće atribute, koji uključuju i vlasničke podatke, potrebnu dokumentaciju o podacima, načine za nalaženje, vizualizaciju i procjenu podataka i određene metode za pristup prostornim podacima. [4]

Bitna karakteristika Infrastrukture geoprostornih podataka Republike Srpske je interoperabilnost, i to:

- Tehnička interoperabilnost - pruža mogućnost da se podaci i servisi koriste bez posjedovanja posebnog softvera, i bez obzira na fizičku lokaciju prostornih podataka,
- Semantička interoperabilnost - postiže da svi korisnici razumiju sadržaj na isti način, a to se postiže harmonizacijom podataka u skladu sa INSPIRE specifikacijama.

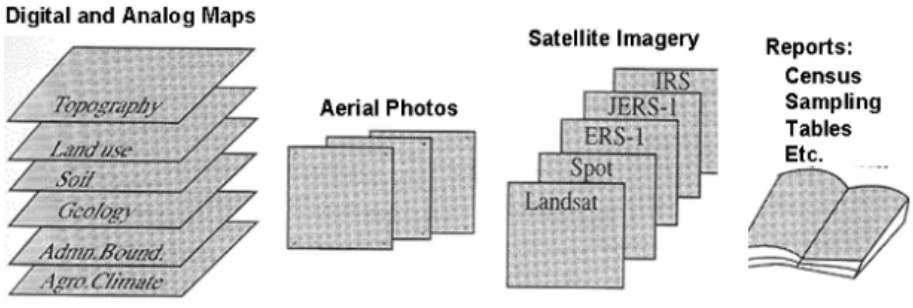
Ovim se postiže da subjekti Infrastrukture geoprostornih podataka Republike Srpske zadržavaju svoje podatke u izvornom modelu, i to u stanju u kakvom jesu, a provajderi podataka moraju izvršiti transformaciju podataka u INSPIRE model.

Nalaženje i procjena prostornih podataka definisani su putem Infrastrukture geoprostornih podataka Republike Srpske, i samim tim korisnicima je omogućena identifikacija i pristup ovoj vrsti informacija dobijenoj iz različitih izvora.

Da bi institucija servisirala podatke koje posjeduje, pružala pomoć korisnicima i održavala kompletan informacioni sistem, ona treba da posjeduje kompletnu i ažurnu bazu podataka.

To da je Uprava koordinator Infrastrukture geoprostornih podataka nameće se samom činjenicom da geodetska struka proizvodi većinu prostornih podataka, koji su ujedno i njena fundamentalna oblast.

Interoperabilnost, i smišljanje pristupnih alata do prostornih podataka je jedan od osnovnih ciljeva IGPRS, koja se osniva i održava u skladu sa Direktivom Evropske unije - Infrastructure for Spatial Information in the European Community - INSPIRE, i drugim standardima. [5]



Slika 2. Glavni izvori prostornih podataka [6]

Infrastruktura geoprostornih podataka Republike Srpske je "krov" standarda i procedura u okviru kojih se organizacije i tehnologije integrišu na podsticanje efikasnijeg korišćenja, upravljanja i proizvodnje prostornih podataka. Glavni alati sakupljanja, predstavljanja i analize prostornih podataka su geodezija i kartografija, putem

tradicionalnih i modernih kartografskih i geodetskih tehnika, koje se koriste za izgradnju, podršku i korišćenje Infrastrukture geoprostornih podataka.

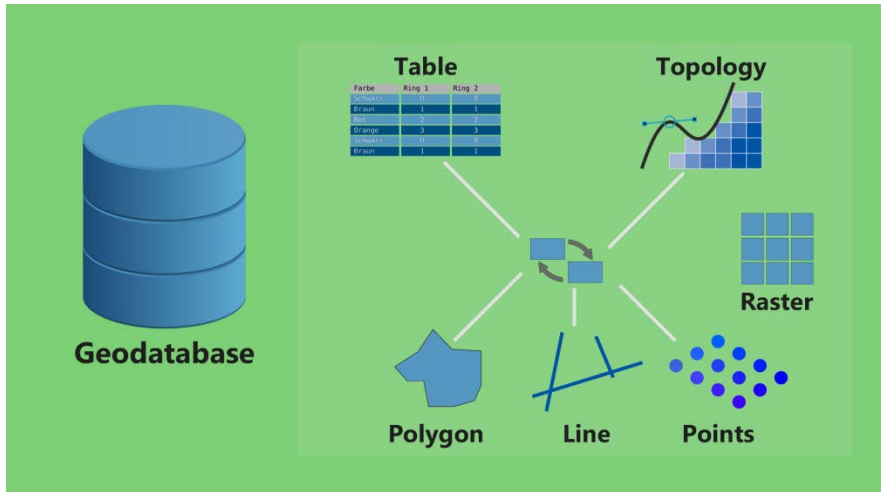
Geodetski podaci i mjerenja mogu biti korisni u Infrastrukturi prostornih podataka prilikom:

- Uspostavljanja globalnog koordinatnog sistema i datuma (za kartiranje prostornih podataka). Svaki prostorni sistem kao što je GIS ima opcije za definisanje koordinatnog sistema za prikaz i skladištenje prostornih podataka. Prostorni podaci koji nisu georeferencirani mogu biti beskorisni za praktičnu primjenu.
- Prikupljanje prostornih podataka. Preciznije, ali skupe metode metode prikupljanja prostornih podataka uključuju terestrička i GPS mjerenja.

Podaci koji potiču iz geodetskih podataka obično imaju različit format od podataka GIS-a. Geodetska mjerenja podrazumijevaju mjerenja dužina, uglova i visinskih razlika, koja se putem geodetskog ili GIS softvera konvertuju u konvencionalne prostorne baze podataka (tačke, linije, poligoni, mreže), a zatim se raznim tehnikama vrši pretraživanje, analiza i dalje procesiranje. Ovi rezultati mogu se čuvati unutar prostorne baze podataka.

Najvažnija karakteristika GIS- a jeste mogućnost provođenja prostorne analize koja se realizuje zahvaljujući vezi između prostornih i alfanumeričkih skupova podataka, odnosno lokaciji koja predstavlja osnovni zajednički ključ za prostorne relacije između atributa. Rezultati ovakvih analiza se jednostavno vizueliziraju, tako da se korisnicima omogućava razumljiv prikaz podataka u kartografskom, tabelarnom, tekstualnom i grafičkom obliku. [7]

Korištenjem GIS tehnologije uveliko je olakšana manipulacija prostornim podacima, od same pretrage, kao matične funkcije, pa do najsloženijih analiza.



Slika 3. Različiti tipovi podataka [8]

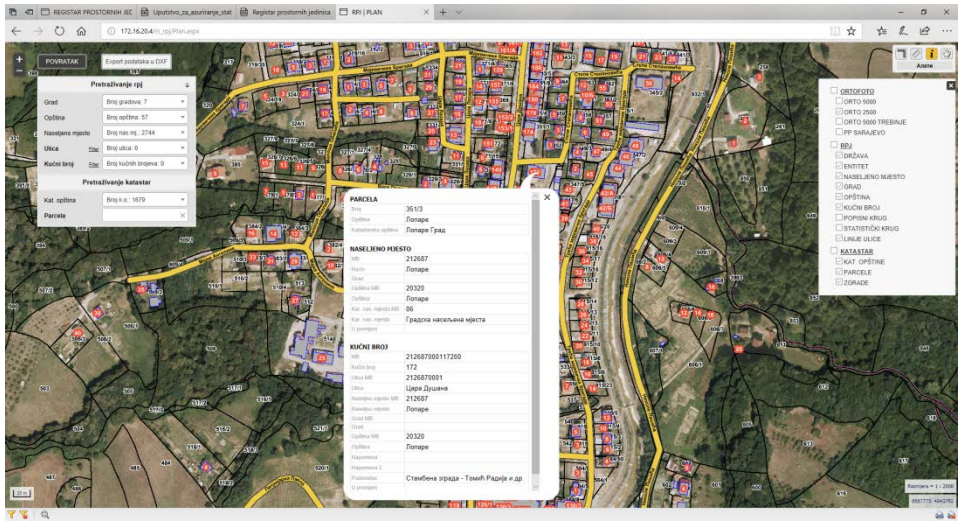
3. ADRESNI REGISTAR

Centralni adresni registar je centralni registar prostornih podataka o kućnim brojevima, nazivima ulica i trgova u naseljenom mjestu; osniva se, vodi i održava na osnovu podataka adresnih registara jedinica lokalne samouprave. [7]

Adresni registar je u nadležnosti Uprave.

Sadržaj, način uspostavljanja, vođenja, ažuriranja i distribucije i razmjene podataka adresnog registra propisuje Uprava.

Razvoj potpuno operativnog adresnog sistema i registra prostornih jedinica je jedna od veoma važnih pretpostavki za uspostavu funkcionalnog i dobro organizovanog društva. Socijalne usluge, briga o starima, usluge spašavanja i pomoći (policija, vatrogasci i hitna pomoć) i urbanističko planiranje se ne mogu vršiti na efikasan način bez tačnog sistema adresnog registra. Mogućnost da se lako nađe tačna lokacija, posebno u ruralnim i siromašnim gradskim područjima, od ključnog je značaja u pružanju nediskriminirajućih i fer usluga pomoći, i omogućava svim građanima jednak pristup vitalnim društvenim uslugama. Sve ove podatke moguće je dobiti jedino kroz kvalitetan adresni sistem. Centralni sistem adresnog registra i registra prostornih jedinica u Republici Srpskoj će pružiti pouzdane, jedinstvene podatke i omogućiti efikasnu registraciju građana i pravnih lica na tačnim i stvarnim adresama.



Slika 4. Aplikacija za adresni registar

Postojanje ažurnih i tačnih geopodataka je efikasno sredstvo za osiguranje transparentnosti i "vođenje računa o građanima". Podaci Adresnog registra i Registra prostornih jedinica kao integralni dio Infrastrukture prostornih podataka Republike Srpske, su osnova za više važnih funkcija u demokratskom društvu, kao što su mapiranje popisa, izborno mapiranje, planiranje korištenja zemljišta i planiranje infrastrukture i usluga u urbanim sredinama. Bez saznanja gdje ljudi žive, u siromašnim i izloženim područja kao i u bogatim i dobro razvijenim područjima, je nemoguće planirati i pružati efikasne javne usluge i funkcije. [9]

Aplikacija za uspostavljanje, vođenje i održavanje Adresnog registra i Registra prostornih jedinica je razvijena za potrebe administracije Adresnog registra (AR) i Registra prostornih jedinica (RPJ) u Republici Srpskoj.

Aplikacija je razvijena na osnovu važeće zakonske regulative koja jasno definiše nadležnosti i obaveze lokalnih samouprava, Republičke uprave za geodetske i imovinsko-pravne poslove, Republičkog zavoda za statistiku i Ministarstva uprave i lokalne samouprave sa ciljem uspostave sistemskog rješenja koje obuhvata

uspostavljanje modernog geoinformacionog sistema za administraciju podataka AR i RPJ.

Adrese se utvrđuju za javne, stambene i poslovne objekte i građevinske parcele. Obavezni, nerazdjeljivi elementi svake adrese su: lokacija (koordinate) i atributi (opisni podaci).

U zavisnosti od tipa geometrije lokacije, adresni registar uslovno se može podijeliti na registar objekata, registar ulica i registar trgova.

Atributi (opisni podaci) najčešće proizilaze iz hijerarhije organizacije prostornih jedinica i mogu biti osnovni atributi (kojim se jednoznačno definiše neka adresa nezavisno od lokacije) i izvedeni podaci (koji se mogu dodavati po potrebi kao dodatne informacije na osnovu prostornih ili atributskih veza). [10]

Adresni registar obuhvata kućne brojeve za stambene i poslovne zgrade, građevinske parcele, privremene objekte, poljoprivredne zgrade (ambari, silosi, štale i slično).

Utvrđivanje i označavanje kućnih brojeva vrši se u skladu sa Pravilnikom o tehničkim normativima, metodama i načinu rada, osnivanja i održavanja Centralnog adresnog registra i Registra prostornih jedinica.

Slika 5. Aplikacija za AR i RPJ, primjer za opštinu Kneževo

Označavanje naziva naseljenih mjesta, ulica i trgova i označavanje kućnih brojeva se takođe vrši u skladu sa pomenutim Pravilnikom.

Podaci Centralnog adresnog registra, kao jedan od elemenata Infrastrukture geoprostornih podataka Republike Srpske (IGPRS) dostupni su posredstvom Geoportala – centralne pristupne tačke IGPRS kao jedan od web servisa. [10]

4. REGISTAR PROSTORNIH JEDINICA

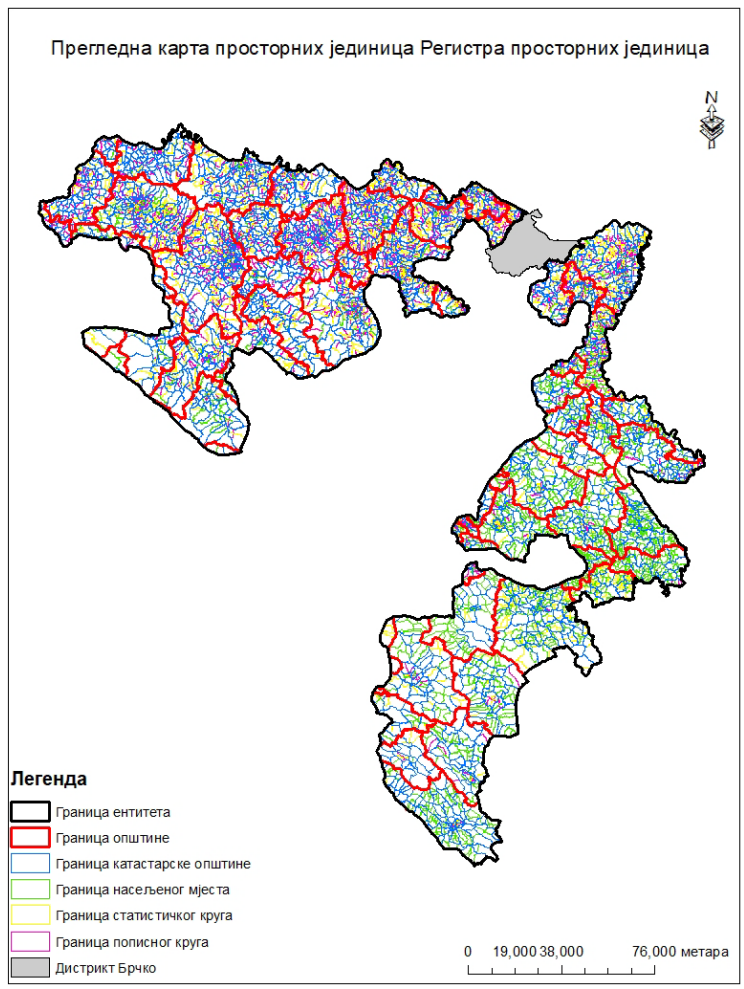
Potreba za formiranjem Registra prostornih jedinica Republike Srpske veoma je stara. Najstariji od poznatih registara je registar zemljišta, koji se može smatrati i najstarijim prostornim registrom u svijetu i kod nas. Kasnije su za državne potrebe administracije vođeni registri srezova, opština, naseljenih mjesta... Godine 1959. i 1960. izrađena je mreža statističkih krugova (tzv. statistički katastar) za potrebe sprovođenja statističkih

istraživanja i obezbjeđenja uporedivih vremenskih serija za pojedine prostorne jedinice, bez obzira na njihove promjene.

U savremenim uslovima povećanih potreba za informacijama i većih mogućnosti da se one zadovolje kvalitetno i kvantitativno, korišćenjem računara, značaj standarda, i u tome registara, veoma je porastao. Vođenjem Registra prostornih jedinica Republike Srpske, kao i povezivanje sa postojećim registrima predstavlja preduslov integrisanja cjelokupnog informacionog informacionog sistema na savremenim principima.

Osnovu Registra prostornih jedinica Republike Srpske čine geodetske podloge (topografske karte i topografsko – katastarski planovi). Vođenjem ovog registra i njegovim stalnim održavanjem u ažurnom stanju omogućava se dugoročna vremenska i prostorna uporedivost podataka svih istraživanja, za prostorne jedinice koje obuhvata i pregrupisavanje i agregovanje podataka.

Registar prostornih jedinica Republike Srpske, sa podacima o svakoj jedinici povezanim u jedan sistem, predstavljaju osnovu za formiranje baze podataka, i njihovo međusobno povezivanje u svrhe analize, planiranja, čuvanja podataka, i drugo.



Slika 6. Prostorne jedinice u RPJ

U registru prostornih jedinica obuhvata sljedeće prostorne jedinice:

- Teritorija Republike Srpske,
- Opština,
- Grad,
- Katastarska opština,
- Naseljeno mjesto (teritorijalne jedinice),
- Statistički krug,
- Popisni krug. [10]

Izvor podataka o prostornim jedinicama čine zakoni, uredbe, odluke, rješenja i drugi akti organa nadležnih za njihovo donošenje, kao i postojeći podaci o prostornim jedinicama vođenim na osnovu zakona i podzakonskih propisa u Registru prostornih jedinica koji se objavljuju u „Službenom glasniku“.

Vođenje Registra prostornih jedinica vrši Uprava, u saradnji sa Republičkim zavodom za statistiku i Ministarstvom uprave i lokalne samouprave, a na osnovu podataka kojima raspolaže, kao i podataka i registara koji su u nadležnosti drugih republičkih organa i organizacija jedinica lokalne samouprave. Ovaj registar vodi se u digitalnoj formi kao podsistem Geoinformacionog sistema Uprave, i čine ga atributivni i prostorni podaci jedinica jedinstvenog Registra prostornih jedinica.

Korisnici podataka i informacija iz Registra prostornih jedinica Republike Srpske su sva pravna i fizička lica.

5. ZAKONSKA REGULATIVA

Implementacija Geoinformacionog sistema Republičke uprave za geodetske i imovinsko - pravne poslove je započeta 2008. godine kada je Uprava izradila Stratešku studiju razvoja Geoinformacionog sistema Republičke uprave za geodetske i imovinsko - pravne poslove (IT Strategija RGURS), nakon čega je uslijedila izrada pratećih Projekata definisanih ovim studijskim dokumentom koji je usvojen i od strane Vlade Republike Srpske i pristupila implementaciji istih. Sva studijska i projektna dokumentacija je izrađena uz potpuno uvažavanje INSPIRE direktive kao i drugih standarda koji definišu oblast prostornih podataka kao što su:

- ISO TC 211 (Technical Committee ISO/TC 211, Geographic informafion/ Geomatics, tehnički komitet ISO/TC 211 zadužen za standarde iz oblasti geografskih informacija)
- OpenGIS konzorcijum (OGC).

Izrađena projektna dokumentacija je pored segmenta katastarskih evidencija u Republici Srpskoj obuhvatila i sve segmente geoprostornih podataka iz nadležnosti RGURS (geodetska osnova, kartografija, prostorne jedinice itd.), tj. kompletnu infrastrukturu prostornih podataka u Republici Srpskoj uključujući i sve poslovne procese u Upravi u cilju izgradnje elektronske Uprave - eUprava. [11]

U ovoj studiji prvi put je pomenut naziv Infrastrukture Geoprostornih podataka Republike Srpske (IGPRS). Tom studijom je naglašeno pravo na prvenstvo Republičke uprave za geodetske i imovinsko - pravne poslove da bude nosilac Infrastrukture Geoprostornih podataka Republike Srpske, a 2011. godine izrađen je projekat „Uspostavljanje IGPRS“.

2012. godine stupio je na snagu Zakon o premjeru i katastru Republike Srpske kojim je definisan obuhvat infrastrukture prostornih podataka, kao i zahtjev za usklađivanjem sa

INSPIRE direktivom i drugim standardima geoinformacija. Uprava je u Zakonu o premjeru i katastru Republike Srpske, počela da primjeljuje evropske standarde u oblasti geoprostornih podataka (INSPIRE direktiva).
Pored navedenog, Adresni registar i Registar prostornih jedinica oslanja se i na sljedeće propise:

- Zakon o teritorijalnoj organizaciji Republike Srpske,
- Uredba o naseljenim mjestima koja čine područje jedinice lokalne samouprave,
- Pravilnik o tehničkim normativima, metodama i načinu rada, osnivanju i održavanju Centralnog adresnog registra i Registra prostornih jedinica.

6. ZAKLJUČAK

Značaj geoprostornih podataka na našem području prva je prepoznala Republička uprava za geodetske i imovinsko pravne poslove, i između ostalog, time je zasluženo postala nosilac Infrastrukture geoprostornih podataka Republike Srpske.
Budući da se GIS pokazao kao brz i jednostavan za dobijanje i upravljanje prostornim informacijama, samim tim se nameće kao "prvi izbor" za održavanje Registra prostornih jedinica (RPJ), čime i geodeta dobija bitnu ulogu, budući da su upravo geodetski stručnjaci zaduženi za manipulaciju, analizu i održavanje podataka u nekom od GIS softvera.
Zajedno sa podacima Registra prostornih podataka, i Adresni registar je je dio IGPRS, i zajedno čine osnovu za upravljanje prostornim podacima, a sve u cilju ažurnih i tačnih podataka dostupnih javnosti.

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64| Стручни рад
Professional paper
doi 10.7251/STP1813832S ISSN 2566-4484

ПРОЦЈЕНА ВРИЈЕДНОСТИ СТАМБЕНИХ ОБЈЕКАТА

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Резиме:

Развијене свјетске земље имају општеприхваћене локалне и глобалне стандарде као основу за стандардизацију поступака и интернационализацију процеса процјене вриједности непокретности. У Босни и Херцеговини, не постоји јединствен и усклађен приступ процјене непокретности појединачних објеката. Кроз рад је приказан приступ, методологија и терминологија која би се требала користити код процјене стамбене непокретности. Извршена је анализа примјене двије методе процјене непокретности на једном објекту, са посебним освртом на могућност њихове примјене у зависности од средине у којој се непокретности налазе.

Кључне ријечи: процјена, трошковна метода, метода упоређења продаје

APPRAISAL OF RESIDENTIAL PROPERTIES

Abstract:

The developed world countries use generally accepted local and global standards as the basis for standardization of procedures and internationalization of the process of estimating the real estate value. In Bosnia and Herzegovina, there is no uniform and harmonized process of the real estate valuation of individual facilities. Throughout this work is presented the approach, methodology and terminology that should be used when validating residential property value. An analysis of application of two real estate appraisal methods was carried out on one propertie, with particular reference to the possibility of their application depending on the environment in which property is located.

Keywords: appraisal, cost approach, sales comparison approach

1. УВОД

Процјена имовине је кључни елемент управљања некретнинама. Како би се одређена некретнина могла пласирати на тржиште, те обрачунати порез на истој потребно је извршити њену процјену. Процјена вриједности непокретности (енг. real estate appraisal, property valuation или land valuation) представља процес формирања мишљења о вриједности на основу одговарајућег поступка. Поступак процјене вриједности односи се на одређивање тржишне вриједности на основу различитих анализа, метода, искустава, стандарда, стања тржишта и осталих релевантних карактеристика. Методе које се користе приликом процјене појединачних стамбених објеката су: тржишна метода, метода упоређења продаје и капитализације дохотка.

С обзиром да је у самој дефиницији процјена карактерисана као мишљење појединца, овај рад је и настао како би се смањила субјективност која представља урођену особину овог поступка. Многи свјетски научници су се већ давних 90их бавили тематиком како превазићи субјективност у поступку процјене, те дали одговарајуће одговоре по питању начина, законске регулативе и стандарда процјене. Како у нашем региону не постоје јединствен приступ, методолигија и терминологија овај рад је написан на основу књиге проф.др Манојла Миладиновића: "Процјена вриједности непокретности". [1]

Процјена вриједности појединачног објекта у општини Невесиње показала је каква је могућност примјене три устаљене методе процјене на примјеру породичне куће. Извршена је анализа утицаја тржишне средине, економских и социјалних аспеката на формирање коначне вриједности непокретности. Приказан је начин анализирања и писања извјештаја у складу са европским стандардима, како би се горе наведени проблем субјективности избјегао. Изведени су закључци о мјерама и политици побољшања процеса процјене, те изнесена осоновна идеја њеног развоја у будућности.

2. ОСНОВНИ ПОЈМОВИ О ПРОЦЈЕНИ

Резултат процеса процјене вриједности јесте тржишна вриједност непокретности. На основу Правилника о процјени вриједности непокретности [2] тржишна вриједност дефинише се као новчани износ за који непокретност може бити размијењена у датом тренутку на тржишту слободном вољом купца и продавца.

Важно је нагласити да се процјена данас развија у два различита, уско везана, правца: појединачна процјена и масовна процјена. Појединачна процјена односи се на процјену само једног објекта на основу једне од три методе или њиховом комбинацијом, док се масовна процјена односи на процјену великог броја објеката користећи математичку статистику.

На процјенитељу је да својим искуством и знањем процјени економичност и тачност употребе одређене методе процјене како би се добила ваљана тржишна вриједност.

3. ПРОЦЈЕНА ВРИЈЕДНОСТИ НЕПОКРЕТНОСТИ У СВИЈЕТУ И КОД НАС

Како би се избјегле велике разлике приликом процјене вриједности непокретности, те увела једнообразност процјенитељских извјештаја, међународна удружења

процјенитеља су увела одговарајуће стандарде. Најпознатији свјетски стандарди којим се регулише процјена вриједности непокретности су: RICS, TEGoVA, IVC и USPAP. Енглески краљевски институт лиценцираних процјенитеља (Royal Institut of Chartered Surveyors – RICS) објавио је 1970.године стандарде за процјену вриједности, тзв. Црвену књигу. Црвена књига садржи обавезна правила и смјернице за успостављање вриједности непокретности. The European Group of Valuers Association (TEGoVA) стандардима објављеним у документу Плава књига има циљ да одржава, побољшава и усклађује стандарде вредновања и професије процјене у Европској Унији. International Valuation Standards Council (IVSC) настала је у САД-у на иницијативу америчких и британских процјенитеља с циљем стандардизације процјене у приватном сектору. The Uniform Standards of Professional Appraisal Practice (USPAP) усвојен је 1989.године у Сједињеним Државама и садржи стандарде за све врсте услуга процјењивања, укључујући некретнине, личну имовину, пословну и масовну процјену. USPAP се ажури сваке двије године тако да процјењивачи имају информације које су им потребне како би формирали непристрасна и прецизна мишљења о вриједности. [3]

Процјена вриједности у БиХ је на самом почетку. Не постоје стандарди, норме и регулативе којим би се водили професионални процјенитељи. Тежи се да се усвајањем закона уведе масовна процјена, па је сходно томе већ донесен правилник о масовној процјени у Брчко дистрикту. [4] У Републици Српској постоји само пар прописа везаних за процјену вријености непокретности и већина их се односи на масовну процјену (Правилник о процјени вриједности непокретности, "Службени гласник Републике Српске", број 37/09; Закон о порезу на непокретности, "Службени гласник Републике Српске", број 110/08, 118/09 и 64/14). [5]

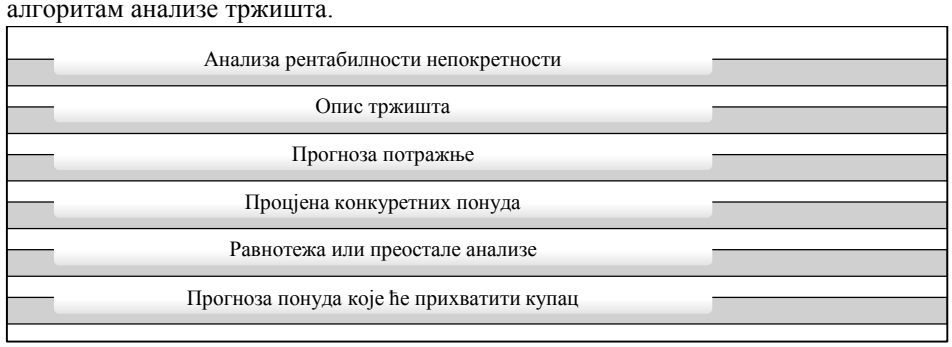
У Републици Српској тежи се ка побољшању процеса вредновања непокретности. Како би се имао увид о цијенама некретнина, у циљу процјене непокретности Републичка геодетска управа, као носилац највеће базе непокретности у републици, у склопу шведског донаторског пројекта реализовала је пројекат Регистра цијена непокретности. Регистар цијена непокретности састоји се од веб апликације и централне базе података која крајњем кориснику омогућава преглед доступних некретнина на тржишту на основу купопродајних уговора. Регистар цијена непокретности омогућава увид у стање тржишта на одговарајућој територији Републике Српске, те олакшан посао процјенитеља у смислу приступачности и поузданости информација које користи у свом даљем раду.

4. ПРОЦЕС ПРОЦЈЕНЕ ВРИЈЕДНОСТИ СТАМБЕНИХ ОБЈЕКАТА

Процес процјене представља шематски план активности на процјени. Почиње се од самог захтјева клијента за реализацију процеса процјене, а завршава писањем извјештаја од стране процјенитеља. Према Јединственим стандардима за професионалну праксу процјенитеља (Uniform Standards of Professional Appraisal Practice – USPAP, USA) проглашеним од стране америчког Савјета за процјенитељске стандарде – Фондације за процјену (Appraisal Standards Board – The Appraisal Foundation), приликом процјене вриједности непокретности, процјенитељ мора дефинисати проблем који ће бити ријешен, одредити обим радова за његово рјешење и савјесно извршити истраживања и анализе неопходне за добијање ваљане процјене. Фазе у процесу процјене су: дефиниција проблема, обим рада,

прикупљање података и опис непокретности, анализа података, мишљење о вриједности земљишта, примјена методе вредновања, коначно усаглашавање вриједносних индикација, извјештај о утврђеној вриједности. Током процеса процјене процјенитељ би требао да се придржава горе наведених корака како би процјену извршио у складу са стандардима и законском регулативом.

Први корак у процјенитељском послу јесте дефиниција проблема. Процјенитељ у овом дијелу врши идентификацију клијента, као и идентификацију процјењиване непокретности, водећи рачуна о посебним претпоставкама и хипотетичким условим. Након што дефинише проблем процјенитељ је дужан да клијенту објасни каква врста прегледа је извршена, која истраживања су спроведена и како је процјенитељ дошао до одговарајућег мишљење о вриједности. Овај извјештај ће клијента обавијестити зашто су неке чињенице унијете у извјештај, а зашто неке нису. Процјенитељ ће, након консултација са клијентом, приступити процесу прикупљања потребних података. Основи подаци односе се на четири елемента који утичу на вриједност: економски, социјални, државни и еколошки. Сваки од ових елемената треба да буде детаљно анализиран, те селектован као користан. Приликом анализе прикупљених података врши се анализа локације, анализа објекта, анализа тржишта и анализа највишег и најбољег коришћења. На слици 1 приказан је алгоритам анализе тржишта.



Слика 1. Алгоритам анализе тржишта

5. МЕТОДЕ ПРОЦЈЕНЕ

Методе вредновања садрже три опције које стоје купцу непокретности на располагању:

- куповина земљишта и изградња нове непокретности (трошковна метода);
- куповина постојеће непокретности (метода упоређења продаје);
- рентирање непокретности (метода капитализације дохотка).

5.1. ТРОШКОВНА МЕТОДА

Трошковна метода (engl. cost approach) је базирана на теорији замјене, тј.базирана је на логици по којој купац разматра куповину парцеле и изградњу нове куће умјесто куповине постојећег објекта. Овај приступ процјене примјењује се претежно на новим објектима, јер је његов приступ на старијим објектима ограничен потешкоћама у обрачуну амортизације. Амортизација је разлика између трошкова изградње и вриједности изградње на датум процјене. Тачније, аморизација је систематско умањивање вриједности имовине током њеног рока трајања. Сходно

томе, примјена ове методе на старијим објектима довешће до мање релевантних, мање поузданих и мање увјерљивих резултата. Расположиви вијек трајања објекта зависи од пројекта, трајности пројектних ставки и њиховог коришћења. За израчунавање износа амортизације на непокретности, ефективна старост се користи као бројилац у разломку гдје је именилац укупан економски вијек трајања.

У зависности од појединих елемената градње, чији је просјечан вијек трајања дефинисан, рачуна се појединачна амортизација. Неки процјенитељи покушавају да процјене преостали економски вијек трајања цијеле зграде употребом исте технике, али се онда код процедуре старосног вијека за цијелу зграду, као именилац узима субјективно мишљење, што може довести до лошег резултата. На слици 2 приказана је процедура за процјену тржишне вриједности трошковном методом.

Слика 2. Алгоритам за процјену тржишне вриједности

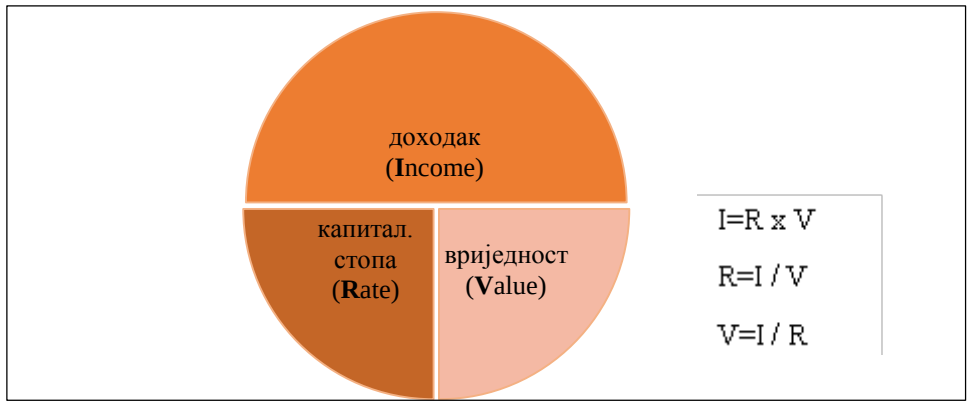
5.2. МЕТОДА УПОРЕЂЕЊА ПРОДАЈЕ

Вриједност непокретности примјеном методе упоређења продаје добија се на основу историјских продаја сличних непокретности. Процјенитељ се, користећи ову методу, ослања на чињеницу да ће се предметна непокретност продати по сличној цијени недавно продатим непокретностима на тржишту. Процес анализе упоређења продаје састоји се од низа корака. На процјенитељу је да претражи све трансакционе податке користећи различите облике информисања. Када су у питању стамбене процјене најчешћи вид претраге јесте путем јавних сервиса. Многи различити фактори утичу на продајну цијену непокретности и процјенитељи морају истражити и поднијети извјештај о томе које цијене упоредивих непокретности варирају. Усаглашени износ би требао да одражава разлике препознате од стране тржишта. Елементи упоређења су разлози због којих цијене варирају. На примјер, додавање више квадратних метара стамбене површине у кући обично повећава продајну цијену. Према томе, величина стамбене површине је елемент упоређења.

Различите врсте непокретности имају различите елементе упоређења. Постоји десет препознатљивих елемената упоређења и то: уступљена права на непокретност, финансијски услови продаје, готовински издаци настали одмах послије куповине, тржишни услови, локација, физичке карактеристике, економске карактеристике, коришћење-зонирање и покретне компонентне вриједности. Метода упоређења продаје је скоро увијек подесна код процјене тржишне вриједности. Овај приступ је адекватан када непокретност која се продаје не репрезентује највише и најбоље коришћење локације и када су садашње цијене више или падају брзо. Ова метода је непрактична код непокретности које су јединствене на одређеном подручју. У тим случајевима није могуће пронаћи довољан број упоредивих непокретности, па је трошковна метода прихватљивије рјешење.

5.3. МЕТОДА КАПИТАЛИЗАЦИЈЕ ДОХОТКА

Метода капитализације дохотка (engl. income capitalization approach) је базирана на претпоставци да су неке непокретности продате заинтересованим инвеститорима за остварење дохотка од непокретности. За инвеститора је приликом куповине било које непокретности примаран нето оствариви доходак који се мора укључити и код методе процјене. Конверзија годишњег прихода у тржишну вриједност је израђена кроз директни прорачун стопе капитализације или кроз анализу дисконтовања новчаног тока. За израчунавање стопе повраћаја инвестиција, све уложене инвестиције морају бити враћене на један или други начин. Општа капитализациона стопа је однос једногодишњег нето дохотка са вриједношћу или продајном цијеном. Дисконтне стопе, стопе добити, каматне стопе и интерне стопе повраћаја спадају у исту, генералну категорију. Оне се све користе за изражавање промјена у дохотку или вриједности током времена. Док је општа капитализациона стопа једноставан однос дохотка и продајне цијене, стопа добити или дисконтна стопа је стопа повраћаја посједовања. Другим ријечима, стопа добити коју инвестиција постиже је функција износа улагања и износа враћања сваке године. Избор коректне стопе је веома тежак и зависи од ризика и инфлације. Метода капитализације дохотка за одређивање вриједности је метода периодичног конвертовања и повраћаја тока дохотка, у актуелни укупан износ капитала, тј.тржишну вриједност. Постоје двије основне методе код конвертовања будућих готовинских новчаних токова у данашње вриједносне показатеље: директна капитализација и капитализација приноса. Директна капитализација је једноставна метода за конвертовање појединачних годишњих доходака у укупан износ капитала помоћу стопе дохотка, на основу скорашње продаје сличних непокретности које су узете или ће бити узете и упоређене са продајним цијенама са очекиваним дохотком од непокретности. Ово се реализује дијељењем нето оперативног дохотка са капитализационом стопом (Слика 3). Ово је лака техника за примјену, али је често злоупотребљена јер трговачки посредници и процјенитељи не препознају да двије непокретности могу имати исти износ дохотка, али веома различиту каматну стопу, зато што је једна на веома другачијој локацији и има мање потенцијала за вишу оцјену.



Слика 3. IRV (Net operating Income – capitalization Rate – Value) формуле

Капитализација приноса је свеобухватнији приступ за процјену непокретности него директна капитализација појединачног годишњег дохотка. Нова технологија омогућује процјенитељу да израчуна садашњу вриједност било ког будућег тока коришћењем процеса дисконтовања. Процес дисконтовања је метода оцјене садашње вриједности за будуће новчане токове.

Ова метода је погодна када је потенцијални доходак од непокретности примаран за купца. Купац појединачне породичне куће обично не размишља о потенцијалном дохотку од непокретности када доноси одлуку о куповини, тако да метода капитализације дохотка није погодна за ову процјену. Она је такође ограничена када је немогућа процјена дохотка, када није расположив продајни податак за издвајање или потврђивање стопе капитализације и када купац размишља о другим проблемима више него о потенцијалном дохотку од непокретности. Метода капитализације дохотка се најчешће примјењује на комерцијалним непокретностима.

6. ПРАКТИЧАН ПРИМЈЕР ПРОЦЈЕНЕ СТАМБЕНОГ ОБЈЕКАТА У ОПШТИНИ НЕВЕСИЊЕ

У оквиру практичног дијела вршена је процјена породичне куће у насељу Бојишта, општина Невесиње. Приказан је процес процјене породичне куће у општини Невесиње употребом двије методе процјене: трошковном методом и методом упоређења продаје. Метода капитализације дохотка је једнако кориштена метода као и двије горе наведене, али због недостатка упоредивих података није била могућа њена примјена на процјени ове непокретности.

6.1. ПРОЦЈЕНА ВРИЈЕДНОСТИ ПОРОДИЧНЕ КУЋЕ У ОПШТИНИ НЕВЕСИЊЕ

Предмет процјене је породична кућа (слика 4) у насељу Бојишта, к.о. Невесиње.

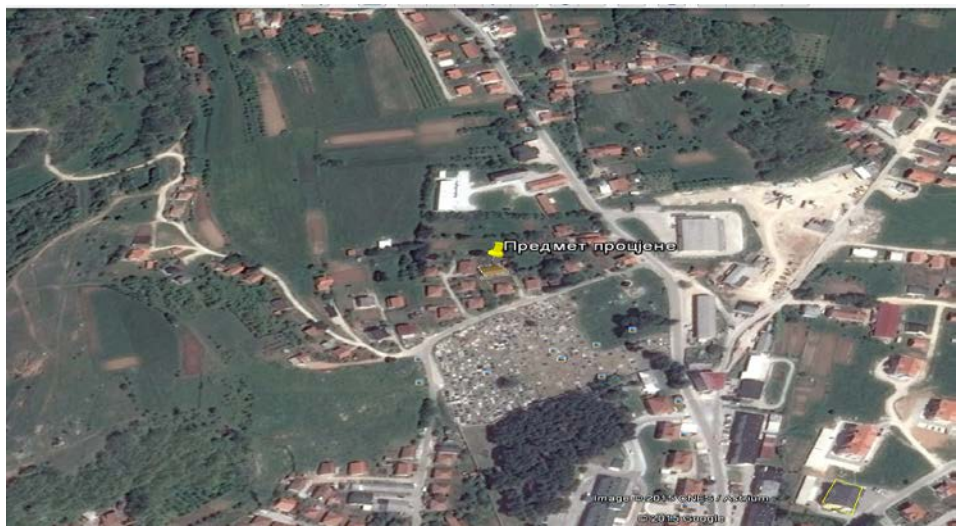
Слика 4. Изглед породичне куће

Објекат је пројектован као слободно стојећи са приземљем и подрумом. У објекту су предвиђена два стана са помоћним и стамбеним просторијама.

- Призмеље: предсобље, двије собе, кухиња, остава и купатило;
- Подрум: гаража и оставе за огријев.

На парцели објекат се поставља према урбанистичким условима, а слободан терен обрађује се зеленилом и украсним шибљем. Површина парцеле на којој је изграђена кућа износи 700 m^2.

Породична кућа налази се у насељу Бојиште. Локација објекта приказана је на слици 5. Анализирана непокретност је породична кућа са тренутним начином коришћења који одговара њеној намјени. С обзиром на локацију на којој се налази и опште карактеристике, објекат се у друге сврхе не може користити. У објекту не постоји простор који би се могао користити у комерцијалне сврхе. Такође, с обзиром на његову удаљеност од центра града, таква његова примјена би била неисплатива. Приликом поступка процјењивања породичне куће кориштени су подаци и информације добијене од стране наручиоца посла као и од управних органа јединице локалне самоуправе.



Слика 5. Приказ положаја породичне куће у општини Невесиње

Изласком на лице мјеста у пристуству власника куће, извршен је увид у предметну непокретност, снимање куће (уз фотографисање) и преузети сви неопходни подаци за израду процјене (грађевински пројекат, скице, подаци о власништву). Приликом поступка процјењивања кориштене су двије методе: трошковна и метода упоређења продаје. За процјену примјеном трошковне методе детаљно је анализиран грађевински пројекат и структура објекта у смислу кориштеног материјала и његових садашњих цијена. Методом упоређења продаје извршена је детаљна анализа података који се тичу тренутних непокретности, те односа понуде и потражње на тржишту непокретности.

6.1.1. Процјена вриједности породичне куће трошковном методом

Објекат се налази у насељу Бојишта, општина Невесиње. Од центра града удаљен је 2 km. Објекат је прикључен на водоводну, канализациону и електро мрежу. Приступ предметној некретнини је могућ како путничким, тако и теретним возилима, а могуће је и паркирање истих поред саме непокретности. У близини куће налазе се стамбени објекти сличних карактеристика и намјене. Објекат се састоји од двије етаже. Површина етаже износи $143\,m^2$. Изграђен је 1977 године. Објекат је пројектован са масовним конструктивним зидовима, зиданим у подужном малтеру 1:3:9. Према степену потреса у статичком рачуну извршено је одговарајуће обезбјеђење хоризонталним и вертикалним армирано-бетонским серклажима. Темељи су изграђени од набијеног бетона МБ 100, димензија према статичком рачуну. Међуспратна конструкција је монта, изузев степеништа и конзолних плоча које су предвиђене као пуне, армирано-бетонске плоче. Кровна конструкција је од дрвета. Фасада је од обичног малтера, прскана у боји по избору инвеститора. Сви зидови и плафони су малтерисани у два слоја. Зидови и плафони у становима обојени су посном бојом са глетовањем. У кухињи и купатилу израђен су сокла од керамичких плочица. Подови у собама и пресобљу су од храстовог паркета, а у купатилу керамичке плочице. Олуци су висећи. Сви прозорски банци, увале, ивице и стреха опшивена су поцинкованим лимом.

Водећи се грађевинским пројектом у коме је детаљно наведен опис и количина грађевинских материјала и радова, а у складу са данашњим цијенама истих добијена је коначна цијена грађења објекта. Цијене радова и материјала су изведене на основу цијена преузетих са Интернета [6], као и података добијених од стране грађевинских предузећа. У коначну цијену урачуната је и вриједност земљишта.

Табела 1. Цијена грађевинских радова и материјала породичне куће

Врста радова	Цијена у БАМ
Земљани радови	1 721,90
Бетонски радови	38 883,00
Арматура	6 660,00
Зидарски радови	28 184,95
Столарски радови	11 760,00
Керамичарски радови	835,50
Подполагачки радови	1 022,00
Лимарски радови	1 786,50
Браварски радови	720
Покривачки радови	6 571,60
Паркетарски радови	1 064,00
Молерско-фарбарски радови	2 404,43
Стаклорезачки радови	640,00
Разни радови	3 375,50
Тесарски радови	4 522,54
Електроинсталатерски радови	9 232,00
Водоинсталатерски радови	6 398,00
Цијена земљишта и документације	6 000,00
Све укупно	131 781,92

На основу претходне табеле закључује се да би цијена изградње породичне куће, на датум процјене, износила 131 781,92 ВАМ.

Како би се одредила садашња вриједност субјекта процјене потребно је узети у обзир старост објекта. Нова цијена добија се одузимањем вриједности амортизације од укупне цијене градње. У зависности од појединих елемената градње, чији је просјечан вијек трајања дефинисан, рачуна се појединачна амортизација. Иако процјенитељи примјењују и други начин, тј. одређиване амортизације без издвајања материјала у категорије, такав приступ није адекватан за процјену ове непокретности јер су поједини дијелови породичне куће реновирани, па за те дијелове није било неопходно одређивати стопу амортизације.

Стопа амортизације (А) на цријеп, чији је просјечан вијек трајања 60-80 година, а ефективна старост 38 година, износи:

$$A = \frac{38}{80} * 100\% = 47{,}5\% \qquad (1)$$

Закључује се да се од вриједности цријепа потребног за грађење одбија 47,5% и на такава начин добија се садашња вриједност цријепа. На исти начин извршено је рачунање стопе амортизације за преостале елементе градње. Сумирањем вриједности елемената градње, умањених за износ амортизација, добија се вриједност материјала потребног за изградњу објекта. Треба узети у обзир да су у табели бр.2. заједно дате вриједности грађевинских радова и материјала. Вриједност умањена за стопу амортизације додаје се цијени грађевинских радова и цијени земљишта и на тај начин добија се садашња вриједност куће.

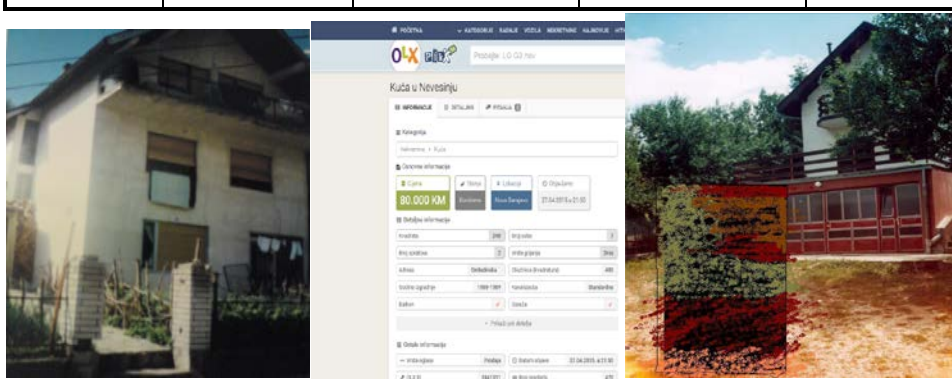
Садашња вриједност куће добијена трошковном методом износи 93 863,28 ВАМ.

6.1.2. Процјена вриједности куће методом упоређења продаје

Процјена стамбеног објекта извршена је и методом упоређења продаје. Узорак који је кориштен за одређивање вриједности обухвата три куће. Куће које су узете у обзир карактерише слична инфраструктурна опремљеност и приступачност општинским институцијама. Параметри који се односе на гријање, телефон, кабловску и интернет мрежу нису узети у обзир јер их све куће из узорка посједују, самим тим вриједност тих параметара не би утицала на коначну вриједност. Параметри који су се користили приликом рачунања вриједности непокретности су приказани у табели.

Табела 2. Параметри узорка коришћеног за креирање вриједности куће

Општина	Локација	Старост	Површина	Цијена у ВАМ
Невесиње	1	35	270	90 000
Невесиње	0,95	26	240	80 000
Невесиње	1	29	180	50 000



Слика 6. Приказ стамбених објеката на основу којих се вршило упоређивање

Математички модел који је кориштен приликом одређивања вриједности је:

$$a * x + b * y + c * z = \text{cijena} \tag{2}$$

гдје су:

a, b, c - параметри објекта, у овом случају локација, старост и површина;

x, y, z - независне промјенљиве које се добијају у X матрици на основу методе најмањих квадрата (МНК).

За примјену МНК потребно је да број мјерених величина буде већи или једнак броју непознатих величина. С обзиром на број упоредивих непокретности, а како би горе

наведени услов био испуњен, изабрана су три приоритетна параметра непокретности. Карактеристике које је процјенитељ сматрао приоритетним су:

- локација;
- старост;
- површина.

У матрици X добијају се независне промјенљиве које се користе у математичком моделу на сљедећи начин:

(параметар за локацију предмета процјене) * -30549,4545=1,25*-30549,4545;

(параметар за старост предмета процјене) * 30099,6809=0,0263*30099,6809;

(параметар за површину) * 449,7736=286*449,7736.

На основу методе упоређења продаје вриједност породичне куће износи 91 240,54 ВАМ.

6.2. АНАЛИЗА РЕЗУЛТАТА

Невесиње је општина која се налази југоистоку Републике Српске, у источној Херцеговини. Подручје општине је изразито рурално. Главне привредне гране су ратарство и сточарство. Број становника је значајно смањен у односу на попис 2013. године због великих миграција становништва у веће градове Босне и Херцеговине и иностранство. У срединама попут ове употреба одређених метода процјене је немогућа. Трошковна метода, с обзиром на старост куће, мора бити конципирана као комбинација грађевинских, архитектонских, геодетских и финансијских информација. Њена употреба захтјева велике економске и временске губитке, што у великом смањује економочиност поступка. Приликом употребе упоређења продаје процјенитељ је имао проблем са проналаском адекватног узорка на којем ће бити извршена анализа. Слаба понуда и потражња огледала се на смањеном броју параметара коришћених за добијање коначне тржишне вриједност. Анализом тржишта сусједних општина дошло се до закључка да процјенитељ није могао користити пронађене непокртености јер су социјално економски аспекти различити, па се увршћавањем параметара не би добила ваљана тржишна вриједност.

Примјеном трошковне методе и методе упоређења продаје добијене су сљедеће вриједности:

Табела 3. Вриједност куће добијена примјеном двије методе

Метода	Цијена непокретности (ВАМ)	Разлилка I и II
Трошковна метода (I)	93 863,28	2,87 %
Метода упоређења продаје (II)	91 240,54	

Усаглашавањем цијена добијених примјеном наведене двије методе долази се до закључка да је вриједност предметне непокретности око 92 551,91 ВАМ.

7. ЗАКЉУЧАК

У Босни и Херцеговини не постоје јединствени стандарди, закони и регулативе по којима се процес процјене одвија. Процес захтијева од процјенитеља да има широк спектар знања из области архитектуре, грађевинарства, геодезије, економије и права, као и да буде упознат са свјетски општеприхваћеним стандардима.

Приликом процјене непокретности у мањим, руралним срединама потребно је вршити комбинацију више метода процјене. Употреба само једне од метода би дала непотпуне и недовољно тачне резултате јер ни једна од њих у потпуности не одговара тржишној средини. Трошковна метода, као једина до сад примјењивана у овој општини, на старијим објектима је мање релевантна и мање поуздана због велике стопе амортизације. Из тог разлога потребно је вршити и методу упоређивања продаје и методу капитализације дохотка, ако за то постоје услови. Иако ће параметри коришћени приликом добијања тржишне вриједности бити знатно мањи у односу на оне који се могу прикупити у већим срединама, процјенитељском проницљивошћу и правилним избором битиних, могуће је формирати адекватан математички модел, на основу којег ће се добити ваљана тржишна вриједност.

Од највећег значаја за појединачну процјену јесте одговарајућа база о трансакцијама. Регистар цијена непокретности представља велики помак у овај области. Процјенитељу је омогућен бржи и једноставнији приступ информацијама, те њихова евентуална провјера. У општинама попут Невесиња, гдје постоји и даље двојна евиденција и гдје постоји велики број објеката изграђених без грађевинске и употребне дозволе, потребно је да се уложи велики временски и финансијски труд како би база попут ове била ажурна и поуздана.

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