СТЕП
ГРАД

Међународна конференција
Савремена теорија и пракса у градитељству XIV

International Conference on Contemporary Theory and Practice in Construction XIV **STEPGRAD**

ЗБОРНИК РАДОВА
PROCEEDINGS

stepgrad.aggf.unibl.org

11-12.06.2020.

МЕЂУНАРОДНА КОНФЕРЕНЦИЈА
САВРЕМЕНА ТЕОРИЈА И ПРАКСА У ГРАДИТЕЉСТВУ XIV

INTERNATIONAL CONFERENCE ON CONTEMPORARY
THEORY AND PRACTICE IN CONSTRUCTION XIV

ЗБОРНИК РАДОВА
PROCEEDINGS

Издавач Publisher	**Универзитет у Бањој Луци Архитектонско-грађевинско-геодетски факултет**
	University of Banja Luka Faculty of Architecture, Civil Engineering and Geodesy
За издавача On behalf of publisher	**др Бранкица Милојевић, ванр. професор** Brankica Milojević, PhD, associate professor
Уредници Editors	**др Александар Борковић, ванр. професор** Aleksandar Borković, PhD, associate professor
	др Мирослав Малиновић, доцент Miroslav Malinović, PhD, assistant professor

ЕЛЕКТРОНСКО ИЗДАЊЕ –
ДИСТРИБУЦИЈА ПУТЕМ ИНТЕРНЕТ СТРАНИЦЕ КОНФЕРЕНЦИЈЕ:
stepgrad.aggf.unibl.org
и
doisrpska.nub.rs/index.php/STPG/index

DIGITAL PUBLICATION – DISTRIBUTION THROUGH CONFERENCE WEB SITE:
stepgrad.aggf.unibl.org
and
doisrpska.nub.rs/index.php/STPG/index

Бања Лука, 2020.
Banja Luka, 2020

ISSN 2566-4484

МЕЂУНАРОДНА КОНФЕРЕНЦИЈА САВРЕМЕНА ТЕОРИЈА И ПРАКСА У ГРАДИТЕЉСТВУ XIV

СТЕПГРАД XIV

INTERNATIONAL CONFERENCE ON CONTEMPORARY THEORY AND PRACTICE IN CONSTRUCTION XIV

STEPGRAD XIV

ЗБОРНИК РАДОВА
PROCEEDINGS

Бања Лука, 11-12. јун 2020.
Banja Luka, June 11-12, 2020

ПРЕДГОВОР

Изузетно нам је задовољство написати овај Предговор за Зборник радова са међународне конференције Савремена теорија и пракса у градитељству XIV – СТЕПГРАД. Конференција је била заказана за 11. и 12. јун у Бањој Луци али је, усљед неочекиваних дешавања везаних за појаву коронавируса, морала бити отказана. Упркос томе, Архитектонско-грађевинско-геодетски факултет је одлучио да Зборник радова буде објављен према првобитном плану.

Конференција СТЕПГРАД XIV наставља традицију повезивања истраживача, наставника и стручњака из цијелог свијета, експерата грађевинарства, архитектуре, геодезије и сродних области. Чак и у оваквим ванредним околностима, Конференција је омогућила интеракцију студената, младих инжењера и научника са искуснијим члановима академске и стручне заједнице у циљу дискусије о савременим тенденцијама у градитељству. Њихов допринос је учинио овај Зборник изузетним. Објављени радови пружају увид у актуелно научно и стручно знање из рачунске механике, инжењерских конструкција, грађевинских материјала, саобраћајница, енергетске ефикасности, урбанизма, архитектуре, историје архитектуре, геодезије, образовања инжењера, итд.

Од скоро педесет достављених рукописа, 43 су прихваћена и категорисана. Сваки рад је био прегледан од стране два рецензента, члана Научног одбора. Критеријуми за одабир радова су били њихова актуелност, значај и допринос широкој области градитељства. Поред редовних радова, два позивна рада су доставили др Максимилијан Хартмут са Универзитета у Бечу и др Војкан Јовичић са Универзитета у Љубљани.

Овај Зборник радова ће послужити као корисна референца стручњацима и истраживачима те смо сигурни да ће пружити подстицај за даља истраживања у предметним областима.

Захваљујемо се свим ауторима и рецензентима на њиховом изузетном доприносу. Посебну захвалност упућујемо нашим спонзорима те свим члановима Организационог одбора и Радног тима.

Александар Борковић
Мирослав Малиновић

уредници

FOREWORD

It gives us great satisfaction to write this Foreword to the Proceedings of the International Conference on Contemporary Theory and Practice in Construction XIV - STEPGRAD. The Conference was scheduled for 11th and 12th June 2020 in Banja Luka. Due to the unfortunate course of events, caused by the spread of the coronavirus, the Conference event had to be cancelled. Nevertheless, the Faculty of Architecture, Civil Engineering and Geodesy decided to publish the Proceedings as planned.

Conference STEPGRAD XIV continues a tradition of bringing together researchers, academics and professionals from all over the world, experts in Civil Engineering, Architecture, Geodesy, and related fields. Despite these extraordinary circumstances, the Conference enables the interaction of research students, young academics and engineers with the more experienced academic and professional community to present and to discuss current accomplishments. Their contributions make these Proceedings outstanding. The published papers provide the most recent scientific and professional knowledge in the fields of Computational mechanics, Structural engineering, Building materials, Road planning, Energy efficiency, Urban planning, Architecture, History of architecture, Surveying, Education of engineers, etc.

Almost fifty manuscripts were submitted while 43 of them was accepted and categorized. Each contributed paper was refereed by the two reviewers, members of the Scientific committee. The papers were refereed based on their interest, relevance, innovation and application to the broad field of Construction. In addition to the regular papers, two invited keynote papers were delivered by Maximilian Hartmuth PhD from the University of Vienna, and by Vojkan Jovičić PhD from the University of Ljubljana.

These Proceedings will furnish the scientists and professional as an excellent reference book. We trust that it will give an impetus for further studies in all subject areas.

We thank all the authors and reviewers for their valuable contributions. Special thanks go to our sponsors and the members of Organizational committee and Working team.

Aleksandar Borković
Miroslav Malinović

Editors

ЗЛАТНИ СПОНЗОР GOLDEN SPONSOR

INTEGRAL INŽENJERING a.d.

ПРИЈАТЕЉИ КОНФЕРЕНЦИЈЕ
CONFERENCE FRIENDS

GRAĐEVINSKO PREDUZEĆE Krajina A.D.

MIXED HOLDING
"POWER UTILITY OF THE REPUBLIC OF SRPSKA"
Parent Joint-stock Company Trebinje

ОРГАНИЗАТОР ORGANISER

Универзитет у Бањој Луци
Архитектонско-грађевинско-геодетски факултет
University of Banja Luka
Faculty of Architecture, Civil Engineering and Geodesy

СУОРГАНИЗАТОРИ CO-ORGANISERS

ICOMOS International

Грађевински факултет, Тјенђин Ченгјан универзитет
School of Civil Engineering,Tianjin Chengjian University

Машински факултет, Аристотелов универзитет у Солуну
Faculty of Engineering, School of Mechanical Engineering, Aristotle University of Thessaloniki

EURAXESS International

EURAXESS Босна и Херцеговина
EURAXESS Bosnia and Herzegovina

Институт за земљотресно инжењерство и инжењерску сеизмологију, Скопље
Institute of Earthquake Engineering & Engineering Seismology, Skopje

Архитектонски факултет, Универзитет у Београду
Faculty of Architecture, University of Belgrade

Архитектонски факултет, Универзитет Црне Горе
Faculty of Architecture, University of Montenegro

Факултет техничких наука, Универзитет у Новом Саду
Faculty of Technical Sciences, University of Novi Sad

Грађевински факултет, Универзитет Црне Горе
Faculty of Civil Engineering, University of Montenegro

Национални комитет ICOMOS у Босни и Херцеговини
National Committee ICOMOS in Bosnia and Herzegovina

Грађевински факултет, Универзитет у Сарајеву
Faculty of Civil Engineering,
University of Sarajevo

Архитектонски факултет, Универзитет у Сарајеву
Faculty of Architecture, University of Sarajevo

Републички хидрометеоролошки завод Републике Српске
Republic Hydrometeorological Institute, Banja Luka

Привредна комора Републике Српске
Chamber of Commerce and Industry of the Republic of Srpska

проф. др Александар Борковић, директор Конференције
доц. др Мирослав Малиновић, замјеник директора Конференције

Associate Prof. Aleksandar Borković, PhD, Conference director
Assistant Prof. Miroslav Malinović, Deputy Conference director

ОРГАНИЗАЦИОНИ ОДБОР	ORGANISING COMMITTEE
Бранкица Милојевић, Архитектонско-грађевинско-геодетски факултет, Универзитет у Бањој Луци, предсједник	Brankica Milojević, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka, president
Тошијуки Коно ICOMOS International	Toshiyuki Kono ICOMOS International
Хаиланг Ванг Грађевински факултет, Универзитет Тјенђин Ченгјан	Hailian Wang School of Civil Engineering, Tianjin Chengjian University
Агис Пападопулос Машински факултет, Аристотелов универзитет у Солуну	Agis Papadopoulos Faculty of Engineering, School of Mechanical Engineering, Aristotle University of Thessaloniki
Laura Sancho Andres EURAXESS International	Laura Sancho Andres EURAXESS International
Марина Антић EURAXESS Босна и Херцеговина	Marina Antić EURAXESS Bosnia and Herzegovina
Радмила Шалић Институт за земљотресно инжењерство и инжењерску сеизмологију, Скопље	Radmila Šalić Institute of Earthquake Engineering & Engineering Seismology, Skopje
Будимир Судимац Архитектонски факултет, Универзитет у Београду	Budimir Sudimac Faculty of Architecture, University of Belgrade
Светислав Поповић Архитектонски факултет, Универзитет Црне Горе	Svetislav Popović Faculty of Architecture, University of Montenegro
Дејана Недучин Факултет техничких наука, Универзитет у Новом Саду	Dejana Nedučin Faculty of Technical Sciences, University of Novi Sad
Марина Ракочевић Грађевински факултет, Универзитет Црне Горе	Marina Rakočević Faculty of Civil Engineering, University of Montenegro
Љиљана Шево Национални комитет ICOMOS у Босни и Херцеговини	Ljiljana Ševo National Committee ICOMOS in Bosnia and Herzegovina
Емина Хаџић Грађевински факултет, Универзитет у Сарајеву	Emina Hadžić Faculty of Civil Engineering, University of Sarajevo
Емир Фејзић Архитектонски факултет, Универзитет у Сарајеву	Emir Fejzić Faculty of Architecture, University of Sarajevo
Сњежана Цвијић Амулић Републички хидрометеоролошки завод Републике Српске	Snježana Cvijić Amulić Republic Hydrometeorological Institute, Banja Luka
Борко Ђурић, Привредна комора Републике Српске	Borko Đurić Chamber of Commerce and Industry of the Republic of Srpska

НАУЧНИ ОДБОР

Проф. др Драган Милашиновић, Универзитет у Новом Саду, предсједник

Агис М. Пападопулос, Универзитет у Солуну
Адриана Бјелановић, Свеучилиште у Ријеци
Азра Куртовић, Универзитет у Сарајеву
Акош Торок, Универзитет технологије и економије у Будимпешти
Александар Борковић, Универзитет у Бањој Луци
Александар В. Радевић, Универзитет у Београду
Александар Савић, Универзитет у Београду
Александра Ђукић, Универзитет у Београду
Александра Крстић-Фурунџић, Универзитет у Београду
Ален Жунић, Универзитет Колумбија
Аленка Фикфак, Универзитет у Љубљани
Ана Радивојевић, Универзитет у Београду
Ања Б. Ранђеловић, Универзитет у Београду
Барбара Карлеуша, Свеучилиште у Ријеци
Биљана Антуновић, Универзитет у Бањој Луци
Биљана Шћепановић, Универзитет Црне Горе
Борислава Благојевић, Универзитет у Нишу
Бошко Д. Стевановић, Универзитет у Београду
Бранкица Милојевић, Универзитет у Бањој Луци
Бранко Божић, Универзитет у Београду
Будимир Судимац, Универзитет у Београду
Валентина Голубовић-Бугарски, Универзитет у Бањој Луци
Весна Послончец-Петрић, Свеучилиште у Загребу
Владан Ђокић, Универзитет у Београду
Властимир Радоњанин, Универзитет у Новом Саду
Влатко Шешов, Институт за земљотресно инжењерство и инжењерску сеизмологију, Скопље
Војкан Јовичић, Универзитет у Љубљани
Горан Ћировић, Универзитет у Новом Саду
Дарија Гајић, Универзитет у Бањој Луци
Дејана Недучин, Универзитет у Новом Саду
Диана Ступар, Универзитет у Бањој Луци
Драган Лукић, Универзитет у Новом Саду
Драган Маринковић, Технички универзитет у Берлину
Драган Николић, Висока грађевинско-геодетска школа Београд
Драгица Јевтић, Универзитет у Београду
Драгослав Стојић, Универзитет у Нишу
Дубравка Бјеговић, Свеучилиште у Загребу
Душан Јовановић, Универзитет у Новом Саду
Душан Продановић, Универзитет у Београду
Елша Туркушић Јурић, Универзитет у Сарајеву
Жанеса Љево, Универзитет у Сарајеву
Жељко Бачић, Свеучилиште у Загребу
Златко Карач, Свеучилиште у Загребу
Зоран Ракићевић, Институт за земљотресно инжењерство и инжењерску сеизмологију, Скопље
Зринка Баришић Маренић, Свеучилиште у Загребу

Иван Млинар, Свеучилиште у Загребу
Игор Емри, Универзитет у Љубљани
Игор Јокановић, Универзитет у Новом Саду
Илија Лалошевић, Универзитет Црне Горе
Јакоб Шуштершич, Институт за испитивање материјала и примјену, Трзин
Јасенка Чакарић, Универзитет у Сарајеву
Јелена Пејовић, Универзитет Црне Горе
Криси Посиу, Национални технички универзитет у Атини
Лара Сливник, Универзитет у Љубљани
Луција Ажман Момирски, Универзитет у Љубљани
Маја Росо Поповац, Универзитет Џемал Биједић
Максимилијан Хартмут, Универзитет у Бечу
Марија Т. Нефовска-Даниловић, Универзитет у Београду
Марина Ракочевић, Универзитет Црне Горе
Марко Иветић, Универзитет у Београду
Марко Пинтерич, Универзитет у Марибору
Мери Цветковска, Универзитет Свети Ћирило и Методије
Мехмед Чаушевић, Свеучилиште у Ријеци
Мила Пуцар, Институт за архитектуру и урбанизам
Милева С. Самарџић-Петровић, Универзитет у Београду
Милена Динић Бранковић, Универзитет у Нишу
Миленко Пржуљ, Универзитет у Сарајеву
Милена Кркљеш, Универзитет у Новом Саду
Мирјана Малешев, Универзитет у Новом Саду
Миро Говедарица, Универзитет у Новом Саду
Мирослав Малиновић, Универзитет у Бањој Луци
Нађа Куртовић-Фолић, Универзитет у Новом Саду
Наталија Беде, Свеучилиште у Ријеци
Невена Новаковић, Универзитет у Бањој Луци
Невенка Ожанић, Свеучилиште у Ријеци
Павле Крстић, Универзитет у Сарајеву
Петар Гверо, Универзитет у Бањој Луци
Саја Косановић, Универзитет у Приштини са привременим сједиштем у Косовској Митровици
Сандра Косић-Јеремић, Универзитет у Бањој Луци
Славица Стаматовић Вучковић, Универзитет Црне Горе
Слађана Миљановић, Универзитет у Сарајеву
Сњежана Максимовић, Универзитет у Бањој Луци
Хаилианг Ванг, Тјенђин Ченгјан универзитет
Хуан Луис Ривас Наваро, Универзитет у Гранади
Чедомир Зељковић, Универзитет у Бањој Луци
Ценана Биједић, Универзитет у Сарајеву
Џонгсиан Лиу, Тјенђин Ченгјан универзитет
Шима Махмуд, Универзитет Суцеког Канала
Шиникиро Накашима, Универзитет Јамагучи

SCIENTIFIC COMMITTEE

Prof. Dragan Milašinović, PhD, University of Novi Sad, chair

Agis Papadopoulos, Aristotle University of Thessaloniki
Adriana Bjelanović, University of Rijeka
Azra Kurtović, University of Sarajevo
Ákos Török, Budapest University of Technology and Economics
Aleksandar Borković, University of Banja Luka
Aleksandar V. Radević, University of Belgrade
Aleksandar Savić, University of Belgrade
Aleksandra Đukić, University of Belgrade
Aleksandra Krstić-Furundžić, University of Belgrade
Alen Žunić, Columbia University
Alenka Fikfak, University of Ljubljana
Ana Radivojević, University of Belgrade
Anja B. Ranđelović, University of Belgrade
Barbara Karleuša, University of Rijeka
Biljana Antunović, University of Banja Luka
Biljana Šćepanović, University of Montenegro
Borislava Blagojević, University of Nis
Boško D. Stevanović, University of Belgrade
Brankica Milojević, University of Banja Luka
Branko Božić, University of Belgrade
Budimir Sudimac, University of Belgrade
Valentina Golubović-Bugarski, University of Banja Luka
Vesna Poslončec-Petrić, University of Zagreb
Vladan Đokić, University of Belgrade
Vlastimir Radonjanin, University of Novi Sad
Vlatko Šešov, Institute of Earthquake Engineering and Engineering Seismology, Skopje
Vojkan Jovičić, University of Ljubljana
Goran Ćirović, University of Novi Sad
Darija Gajić, University of Banja Luka
Dejana Nedučin, University of Novi Sad
Diana Stupar, University of Banja Luka
Dragan Lukić, University of Novi Sad
Dragan Marinković, Technical University of Berlin
Dragan Nikolić, University College of Civil Engineering and Geodesy, Belgrade
Dragica Jevtić, University of Belgrade
Dragoslav Stojić, University of Nis
Dubravka Bjegović, University of Zagreb
Dušan Jovanović, University of Novi Sad
Dušan Prodanović, University of Belgrade
Elša Turkušić Jurić, University of Sarajevo
Žanesa Ljevo, University of Sarajevo
Željko Bačić, University of Zagreb, Croatia
Zlatko Karač, University of Zagreb
Zoran Rakićević, Institute of Earthquake Engineering and Engineering Seismology, Skopje
Zrinka Barišić Marenić, University of Zagreb

TABLE OF CONTENT

САДРЖАЈ

01 | Research paper I Оригинални научни рад
ISSN 2566-4484 I Doi 10.7251/STP2014001M
pages 1-9

Mihailo Muravljov, mmuravljov@gmail.com, Faculty of Civil Engineering, University of Belgrade

Petar Anagnosti, anagpetar@gmail.com, Faculty of Civil Engineering, University of Belgrade

Aleksandar R. Savić, savic.alexandar@gmail.com, Faculty of Civil Engineering, University of Belgrade

THE LABORATORY INVESTIGATIONS OF HIGH-DENSITY POLYETHYLENE DRAINS FOR APPLICATION IN TAILINGS

Abstract:

For the purposes of draining material deposited in the tailings pond under construction, there was a need to examine the properties of the high-density polyethylene drain tubes and the consisting materials in order to assess their adequacy in the specific conditions. The conducted laboratory investigations of the samples cut from the tubes included: determination of bulk density, tensile strength in the tangential direction, as well as the compressive strength in a radial direction. Representative samples of the tubes themselves were tested in two different loading dispositions, in order to record the load-deflection effects. The test results indicated the specific behavior of the tested material in service conditions.

Keywords: plastics, physical and mechanical properties, drain tubes, loading.

ЛАБОРАТОРИЈСКА ИСПИТИВАЊА ДРЕНАЖНИХ ЦЕВИ ОД ПОЛИЕТИЛЕНА ВЕЛИКЕ ГУСТИНЕ ЗА УПОТРЕБУ У ЈАЛОВИШТУ

Сажетак:

За потребе дренаже материјала одложеног на јаловишту у изградњи појавила се потреба за испитивањем карактеристика дренажних цеви од полиетилена велике густине, ради процене адекватности у конкретним условима. Спроведена испитивања материјала обухватила су одређивање запреминске масе, чврстоће при затезању у тангенцијалном правцу, као и чврстоће при притиску у радијалном правцу пружања цеви на узорцима извађеним из цеви. Узорци самих цеви испитани су при две диспозиције оптерећења у циљу снимања напонско-деформацијских ефеката. Резултати испитивања указали су на специфичности понашања конкретног материјала у условима експлоатације.

Кључне ријечи:пластичне масе, физичко-механичка својства, дренажне цеви, оптерећења.

1. INTRODUCTION

The wide use of plastic materials is enabled by their low cost, ease of production, adaptability and acceptable mechanical properties. Since the nineteenth century, many different forms of plastics were developed, replacing traditional materials such as wood, stone, clay, metals and concrete [1]. The main disadvantages of majority polymeric products include the reduced durability and overall low corrosive resistance, all connected to the properties of polymeric bonds in the product. The use of other substances such as fillers, emulsifiers and stabilizers can significantly expand the lifespan of some plastics. Therefore, plastics use is so widespread, that the plastic pollution occurs to be one of the biggest environmental concerns. Some frequently used products, such as disposable plastic bottles, bags, and other plastic containers can negatively affect the natural environment and harm plants, animals and humans. Contemporary approach to plastics manufacturing implements the principles of sustainable development, making the use of renewable materials for production of plastics more prominent [2]. This means that the affirmations of plastics can be amplified by their proper production, use and thorough knowledge of their properties.

On the basis of recent analyses, the most common thermoplastic mass produced worldwide is polyethylene and it is used for wide range of everyday applications [3]. The biggest production, according to data from 2016 [4], was Asia (53% of the worldwide production), followed by North America (20%), Europe (15%), South America (3.5%), Africa (2.5%) and other (6%). Global high density polyethylene (HDPE) market is in its steady growth, with the global annual expansion rate of approximately 3 billion US$, and was forecasted to grow more than US$84000000 by 2023. Rise in demand for plastic pipes being widely used as a substitute for domestic plumbing was recognized as the major driving force for this material in the global market. HDPE is a form of polyethylene favorable for its' high strength to density ratio. This property makes it attractive for different types of pipelines - drinkable water, sewage and drainage. The HDPE shows high water impermeability, corrosion resistance and possess significantly lower weight than many other traditional materials. It is abrasion resistant, highly resistant to stress cracks and tough. Other advantages of HDPE include good processability, lower production costs and lower transportation costs. Traditional elements for this application, concrete and steel tubes are being replaced by the HDPE, mainly due to their durability issues. The disadvantages of HDPE include high thermal expansion coefficient, bonding issues, lower strength and high deformability in comparison to traditional materials. These are the boundaries for HDPE applications, where one or more properties occur insufficient in the specific conditions. Concrete and steel remain better choices for such applications, provided that the requirements regarding durability, load bearing capacity, proper casting, placement, maintenance and other are met. To justify or rule out the use of HDPE, suitable laboratory investigations become essential, providing various simulations of exploitation conditions and data needed for assessment of material suitability.

In the case described in this study, a range of laboratory tests were performed on one type of HDPE tubes (pipes), with defined geometry and materialization, to assess the applicability in the tailings site, where significant heights of deposits are expected to occur in the future. Based on the requirements of the specific application in the tailing site, key parameters were recognized and set for the tests. The tests included following: geometrical, physical, mechanical and deformational properties. This study was conducted in several phases, with common geometrical and physical tests performed in the beginning. Following these tests, new samples were obtained from the pipes delivered on site, and the load bearing capacity and deflections under deposited soil layers were investigated. Such approach implied proper sample preparation techniques, and new testing setups, which will be explained further in the paper.

2. INVESTIGATIONS OF THE USED TUBE

Physical and mechanical properties of HDPE available in the data sheets provided by the producer are shown in the Table 1. This information includes results of tests done in accordance with standard procedures BS 4962 [5] and EN 10204 [6]. Also, impact resistance and tightness of elastomeric sealing ring joint complied with the requirements, according to the relevant standards EN 744 [7] and EN ISO 13259 [8], respectively.

Table 1. *Properties of the tested HDPE tubes*

Raw material	High density polyethylene
Appearance	Smooth surface, both inside and outside
Perforation	1/3
Outside diameter	500.0-504.5 mm
Wall thickness	55.8-61.5 mm
Ovality	2.0 mm
Collective surface	630 cm^2/m, 5.2 %/m
Distance between perforation channels	56 mm
Perforation channel width	4.8 mm
Longitudinal reversion	1.5%
Compress Test maximum force	31.2 kN
Compress Test deflection at maximum force	12.1 mm
Melt flow rate of material (tube)	0.2-1.4 g/10 min
Resistance to internal pressure	180+ hours

2.2. Physical and mechanical properties

In the first phase, the geometrical properties of the samples were measured and proved to comply with the producer's datasheet. Some of the properties given in the table 1, were not subject to testing, according to the requirement given by the client.

The investigations of basic physical and mechanical properties of the HDPE were conducted on samples shown on Figure 1.

Dimensions of the samples cut out from the pipes were roughly 40 by 160 mm, 20 mm thick, for the tensile testing. Figure 1 holds more specific geometry measurements, in mm. Tensile testing velocity was set to 50 mm/min. The samples for the compressive strength were 40 mm cubes. Both the fracture point and testing velocity were set with regard to the lateral deformation of the specimen. The compressive fracture (defined by the moment when lateral deformation was visible, with no significant increase in load) was to occur between 1 min and 5 min after the start of test.

The dimensions of the specimen were chosen in order to provide samples as big as possible, with respect to the geometry of the pipes. Although HDPE can be regarded homogeneous, this had to be proved to be true in the specific geometry and form of pipes.

The conventional cutting techniques with saw, when applied to this product, result in change of the properties of the material (mainly in the superficial 3 mm thick layer), due to the higher temperatures occurring in the process. This change is visible, due to the change into the darker shade of gray of the cut part of the material. Thus, the samples were extracted from the tubes using waterjet cutting technology, in order to provide minimal change in properties of the materials induced by cutting process.

The results of these investigations are shown in Table 2. All the tests were done in triplicate.

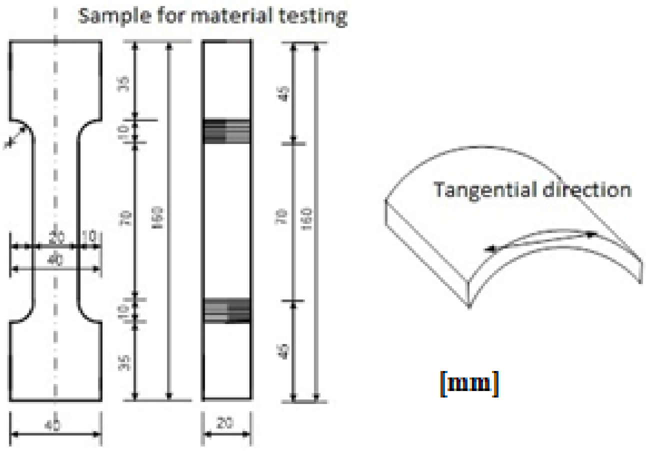


Figure 1. *Geometry of the samples for the investigations and their extraction from the HDPE tubes*

The investigation included tensile and compressive strength tests, as well as measurements of density.

Table 2. *Results of compressive strength, tensile strength and density of the HDPE*

Conducted test	Individual test results	Average (stdev)
Density (kg/m^3)	929	932 (5.20)
	929	
	938	
Compressive strength (kPa)	33.3	33.9 (0.98)
	33.3	
	35.0	
Tensile strength (kPa)	28.9	27.6 (1.28)
	26.3	
	27.7	

For measurement of dimensions, a digital caliper "Controls" with range of 100 mm and precision of 0.01 mm was used. The mass of the samples was recorded using hydrostatic balance "Kern" with range of 35 kg and precision of 0.1 g. Tensile strength was obtained on "Shimadzu" tensile testing machine with the range of 200 kN and precision of 0.1 kN. Compressive strength tests were performed with the aid of "Amsler" compressive testing machine, with the range of 20 kN and the precision of 0.1 kN. The results of these investigations are shown in table 2. After testing of compressive and tensile strength, the samples have shown substantial plastic deformation, without signs of spalling or crumbling (Figure 2).

Figure 2. *The appearance of the samples after failure in cases of testing compressive strength (left) and tensile strength (right)*

2.3. Investigations of load bearing capacity of the hdpe tube

As already noted, the intended use of the perforated tubes was for the tailings disposal area, to be filled with the 35 meters high layer of tailing soil above the tubes, with the density of approximately 2000 kg/m^3. According to that condition, exploitation requirement have arisen for the tube to withstand the load of 70 t/m^2. Having in mind that the tube was 0.5 m wide, the equivalent linear load (for 1.0 m long tube segment) was therefore $V_{rač}$ = 0.5·1.0·70.0 = 35 t/m = 350 kN/m.

Furthermore, the technical requirements for the application of the tubes in this case state the safety factor of 1.3, meaning that the tube has to withstand 30% higher load values, equivalent to the depth of 45.5 m in the tailings soil. This value is equivalent to the load of 45.5·2.0 = 91.0 t/m^2 = 910 kN/m^2 = 910 kPa for the soil with 2000 kg/m^3.

Besides the stated requirement defined for the load bearing capacity, there was another requirement regarding deformability of the tube. The deflection of the tube under the stated load was set to be lower than 30 mm, representing the ultimate deformation of 6% of the total diameter of the tube. The investigations were conducted in accordance to the standard ATV-DVWK-A 127E [9].

For this analysis, two possible dispositions were adopted for the investigation, one in which the tube had free lateral deflections, and the second one, where the lateral deflections were limited by the rigid frame. The later disposition was adopted to simulate the lateral soil pressure acting on the tube in the exploitation conditions.

2.3.1. The investigation of the tube with free lateral deflections

Due to the space limitations between the plates of the compressive testing machine, the investigation was conducted on the 25 cm long sample, with free lateral deflections of the samples, according to the disposition shown in Figure 3. The force-controlled load V was applied, while the vertical deflections Δv were measured during the process.

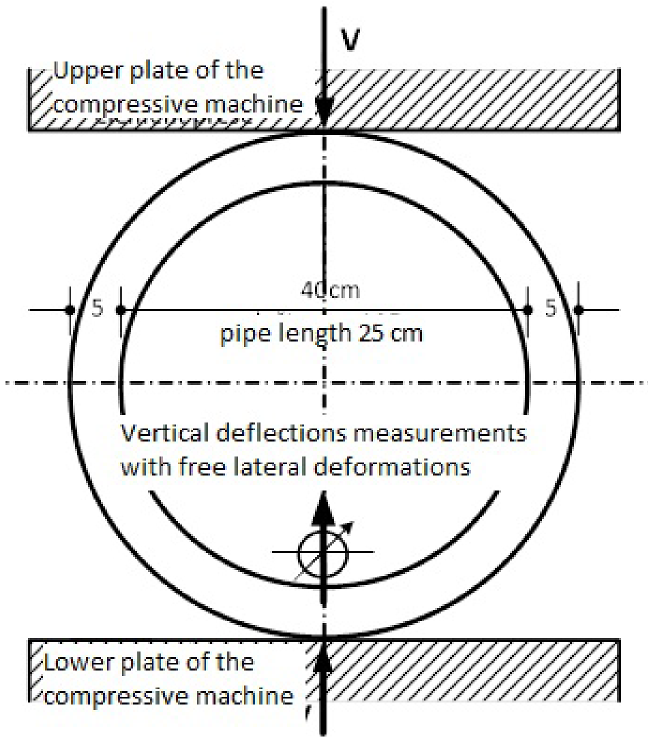


Figure 3. *Investigations of the tubes with free lateral deflections – defining the function Δv(V)*

According to the investigation plan, force V was set to grow and reach maximum value of maxV = max$V_{rač}$·0.25 = 45.5·0.25 = 11.4 t = 114 kN. Nevertheless, as the force of V = 35 kN was passed, deflections were more than 30 mm (Δv = 31.08 mm), so the further investigation was terminated at the level of V = 40 kN and deflection of Δv = 42.23 mm. The recorded function Δv(V) is shown in Table 3, while the Figure 4 illustrates the investigation setup.

Table 3. *Function Δv(V) obtained during the investigation with free lateral deflections*

V(kN)	0	5	10	15	20	25	30	35	40
Δv (mm)	0.00	2.13	5.12	8.56	12.30	17.01	23.05	31.08	42.23

Note: Values Δ_v (mm) have been obtained as the average of two measurements.

Figure 4. *One of the photographs taken at the course of the investigations*

2.3.2. The investigation of the tube with limited lateral deflections

The second setup investigation was conducted on the 25 cm long sample, with limited lateral deflections, according to the disposition shown on Figure 5. The limitation was constructed as a rigid frame, consisting of two "U" shaped steel profiles connected through the inner space of the tube by two steel rods (studs). The force-controlled load V was applied, while the vertical deflections Δ_v were measured during the process. Also, in order to provide an insight in lateral pressure, two strain gauges with 10 mm bases were used.

Table 4 contains values of Δ_v and V, obtained during this investigation. As it can be seen, the investigation was terminated at the level of 107 kN – which was very close to the limit for the maximum allowed deflection maxΔ_v of 30 mm.

Table 4. *Function Δv(V) obtained during the investigation with free lateral deflections*

V (kN)	0	10	20	30	40	50	60	70	80	90	100	107
Δ_v (mm)	0	6.14	8.08	9.65	11.22	12.74	14.43	16.31	18.79	21.75	26.23	28.78

Note: Values Δ_v (mm) have been obtained as the average of two measurements.

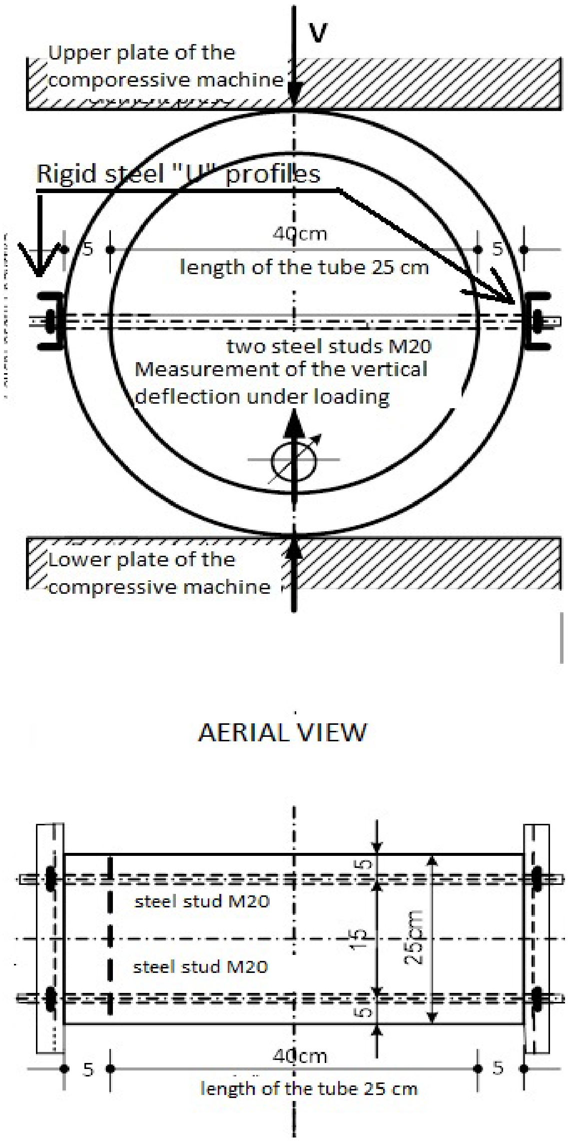


Figure 5. *Disposition of the investigation of tube with limited lateral deflections*

A graphical representation of the obtained function Δv(V) is given in Figure 6.

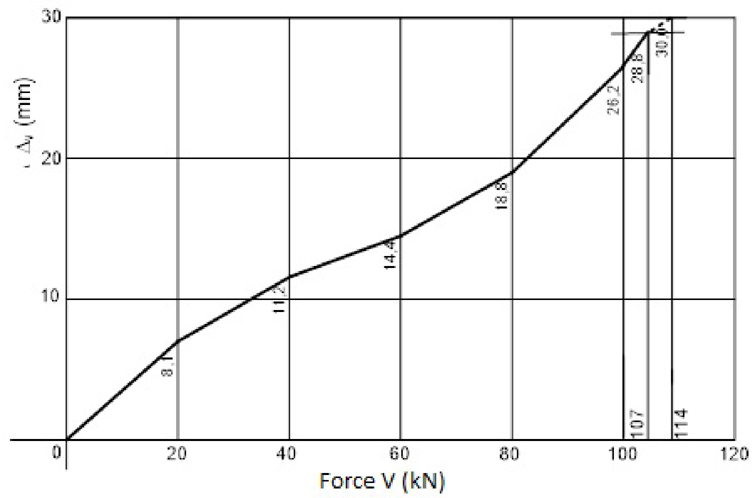


Figure 6. *The obtained function $\Delta_v(V)$ for the disposition with limited lateral deflections*

Based on the measurements made by strain gauges, the lateral deflection at the highest force was maxΔh = 0.625/2 = 0.3225 mm = 0.03225 cm. Figure 7 shows the course of the investigation with substantial change in geometry of the investigated tubes.

Figure 7. *The photographs made during the investigation of the tubes with limited lateral deflections*

3. CONCLUSIONS

The constant progress in materials enables new areas of applications with respect to the good engineering practice, economic analysis and scientific research. In boundary cases, where the suitability of the materials is in question, a wide range of investigations are needed to complement the usual standard procedures, in order to ensure specific applications and provide proper data to the responsible personnel. Having in mind the fact that many properties, including mechanical given in the table 1 were not tested according to the agreement with the user, it was concluded as follows:

- the investigated tubes had required geometry, while their material had appropriate density, tensile and compressive strengths, in accordance with this kind of HDPE;
- a maximum vertical deflection of 30 mm which relates to the 6% of the tube's deformation, was reached under load conditions of 45.5·2.0 = 91.0 t / m2 = 910 kPa;
- the stated deflection was achieved by testing a sample under the conditions of limited lateral deflection, which simulates the conservative loading case represented by linearly applied loading, while the real exploitation conditions are when the tube is expected to be surrounded (both vertically and laterally) by a tailing material, with density of 2000 kg/m^3, as distributed loading over the external tube surface.

Although the positive results obtained in these investigations enable the use of the specific HDPE tubes satisfying testing conditions, a number of challenges regarding the proper installation, handle, connection and system maintenance still remain, and have to be correctly addressed to provide confidence in this solution.

LITERATURE

[1] M. Muravljov, Građevinski materijali. Beograd: Građevinska knjiga, 2011, pp. 587

[2] C. J. Rhodes, "Plastic Pollution and Potential Solutions," Science Progress, vol. 101 (3), 2018, pp. 207-260

[3] "Plastics: The Facts 2019" Plastics Europe. [On-line]. 42. Available: https://www.plasticseurope.org/application/files/1115/7236/4388/FINAL_web_version_Plastics_the_facts2019_14102019.pdf , [May 8, 2020]

[4] https://www.plasticsinsight.com/resin-intelligence/resin-prices/hdpe/, [May 8, 2020]

[5] BS 4962 "Specification for plastics pipes and fittings for use as subsoil field drains," Standard 1989.

[6] SRPS EN 10204 "Metallic products - Types of inspection documents," Standard 2018.

[7] BS EN 744 "Plastics piping and ducting systems. Thermoplastics pipes. Test method for resistance to external blows by the round-the-clock method," Standard 1996.

[8] EN ISO 13259 "Thermoplastics piping systems for underground non-pressure applications — Test method for leaktightness of elastomeric sealing ring type joints," Standard 2010.

[9] ATV-DVWK-A 127E "Static Calculation of Drains and Sewers," Standard 2000.

02 | Research paper I Оригинални научни рад
ISSN 2566-4484 I Doi 10.7251/STP2014010B
pages 10-19

Natalija Bede, natalija.bede@uniri.hr, Faculty of Civil Engineering University of Rijeka
Neira Torić Malić, ntoric@uniri.hr, Faculty of Civil Engineering University of Rijeka

EXPERIMENTAL INVESTIGATION ON LWC WITH COMPLETE REPLACEMENT OF COURSE AGGREGATE BY EPS BEADS

Abstract:
In this paper, expanded polystyrene (EPS) lightweight concrete (LWC) was investigated. The main aim was to design EPS LWC with the specified density of 1200 kg/m^3 according to standard concrete mix proportion. Mix proportion included total replacement of the conventional coarse aggregate by maximum possible amount of EPS beads, which ensures concrete workability and prescribed density. The results demonstrated that exactly defined mixture-proportioning and casting procedure are required to achieve designed density. For designed EPS LWC mixture properties of freshly-mixed concrete and hardened concrete were analyzed. Based on test results it is concluded that designed EPS LWC can be used for structural-insulating purpose such as floors and roofs.

Keywords: EPS LWC, density, workability, mechanical properties

ЕКСПЕРИМЕНТАЛНА ИСШИТИВАЊА ЛАКОГ БЕТОНА (LWC) SA СА ПОТПУНОМ ЗАМЈЕНОМ ГРУБОГ АГРЕГАТА СА ЗРНИМА ОД ЕКСПАНИРАНОГ ПОЛИСТИРЕНА (EPS)

Апстракт:
У овом раду је испитан лагани бетон (LWC) са експандираним полистиреном (EPS). Циљ је био пројектовање EPS LWC-а специфичне густине од 1200 kg/m^3 према стандардној пропорцији бетонске мјешавине. Мјешавина укључује укупну замјену конвенционалног грубог агрегата максималном могућом количином EPS зрна, што обезбјеђује уградљивост бетона и прописану густину. Резултати су показали да је за постизање пројектоване густине потребна тачно дефинисана пропорција смјеше, те начин уградње. За пројектоване EPS LWC мјешавине анализирана су својства свјеже измијешаног бетона и очврслог бетона. На основу резултата испитивања закључено је да се пројектовани EPS LWC може користити у конструкционо-изолационе сврхе, као што су подови и кровови.

Кључне ријечи: EPS, LWC, густина, уградивост, механичке особине

1. INTRODUCTION

The density of concrete is among the most important parameters for structural behavior. Based on the density (unit weight) concrete can be classified into three categories: normal weight concrete (NWC), lightweight concrete (LWC) and heavyweight concrete (HWC). LWC may have densities ranging from 800 kg/m^3 to 2000 kg/m^3 [1]. One of the most important properties of LWC is its low self-weight. On the other hand, it's major disadvantage is reduction of strength due to decrease of density [2]. However, the compressive strength of LWC shows large oscillations ranging from 1 MPa up to 60 MPa [2]. The reason for such a big variation is the possibility of using various types and portions of lightweight aggregate. Further, the compressive strength is not only dependent on the aggregate but also on the amount and type of cement and the water-cement ratio. The amount of cement in the production of LWC is usually in the range of 150 to 550 kg/m^3 [2, 3]. The second very important property of LWC is its increased thermal resistance. The thermal insulation properties of LWC are much better than of NWC. For example, for NWC, the coefficient of thermal conductivity ranges from 1.4 to 2.9 W/mK [4]. For LWC the coefficient of thermal conductivity ranges from 0.05 W/mK for insulation up to 0.85 W/mK for structural application [4]. The water permeability of lightweight concrete is much higher compared to conventional concrete due to its larger volume of pores that absorb water more easily. Hence, compared to NWC, LWC concrete has lower strength and durability but on the other hand much better thermal and acoustic insulation properties.

Depending on the purpose of use, LWC can be classified as structural and non-structural. When LWC is to be used for structural application minimum compressive strength of 15 MPa is necessary. For the insulating purpose compressive strength of LWC is less important and ranges from 0.5 MPa to 3.5 MPa. For compressive strength between 3.5 MPa and 15 MPa application of LWC falls about midway between the structural and non-structural [2]. In this work focus was on non-structural LWC, where for a lightweight aggregate is chosen expanded polystyrene (EPS).

LWC concrete can be defined as a type of concrete with partial or complete replacement of conventional aggregate with lightweight aggregate to reduce dead loads in structures. Lightweight aggregate is defined as aggregate with a density lower than 1200 kg/m^3 [2]. Lightweight aggregates are classified as natural, such as scoria, pumice and tuff, and artificial, for instance, pearlite, clays, vermiculite, expanded shell, fly ash or expanded polystyrene (EPS) [2]. When EPS beads are incorporated in LWC as a partial or complete replacement of natural coarse aggregate it is called EPS LWC [3].

Considering the development of the construction industry there is a strong increase in consumption of raw materials and production of waste materials which both negatively impact the environment. For those reasons, the topics associated with waste management and sustainability of materials have become very popular in last few years [3-7]. Hence, having in mind these facts, EPS beads seem to be a good choice for use in the production of LWC. EPS is a closed-cell widely used polystyrene. It is a lightweight material with low water absorption and high thermal insulation properties. EPS is non-biodegradable waste material. Therefore, its disposal is very demanding and complex. Accordingly, EPS LWC in civil engineering gives a contribution to solving environmental issues [7, 8]. EPS LWC has excellent thermal and sound insulation characteristics [5,8]. Also, the workability of concrete is very poor. The major drawback of EPS LWC is its low compressive and tensile strength, which varies depending on the incorporation of beads in the concrete mixture. With increase of the EPS beads content in concrete compressive and tensile strength decrease. Because of the properties listed above, EPS LWC is a widely used in many various structural and non-structural applications in civil engineering such as floor screeds, roofs, curtain walls, partition walls, bridge decks, pavement construction, impact sound insulation, floating marine structures etc. [2-8].

The aim of this work was to produce EPS LWC with a specific density of 1200 kg /m^3 by the maximum possible portion of EPS beads. For that purpose, a straightforward mixture-proportioning of each ingredient was chosen on recommendation of a local company. The concrete mixtures were designed without conventional coarse aggregate. The required value of the density and the experimentally obtained values of trial concrete batches mixed with different casting procedures were compared. Additionally, tests of the fresh concrete mixture in terms of workability and of hardened concrete in terms of mechanical properties were conducted.

2. MATERIALS AND TESTING METHODS

Own experimental investigation was conducted to examine the required properties of EPS LWC. This section is divided into two parts. The first part, which describes mixing components and procedure to get the required density. The types of testing methods on fresh and hardened EPS LWC are described in the second part. All tests were performed according to HRN EN standards at the Faculty of Civil Engineering in Rijeka, Croatia.

2.1. Materials and mix proportions

The materials used to mix EPS LWC were locally available cement CEM II/B-M (S-V) 42,5 N, crushed limestone sand with a maximum grain size of 4 mm, EPS beads with a diameter ranging from 3 mm to 6 mm (see Figure 1), Stigopor - D additive and water. Low density of the EPS particles (approximately 15 kg/m^3) in comparison with density of sand (2700 kg/m^3) may induce sand segregation in a cement paste. Hence, to ensure a good bond between the cement matrix and EPS beads, appropriate portion of additive have been added in the fresh mixture. Three mixtures were designed until achieving the required density of EPS LWC. Hence, the first two mixtures were trial concrete mixtures named as EPS1 and EPS2 while the last one was referent mixture named EPS3. The mix proportions of the constituents of the EPS LWC mixtures were given by local company. Please note that detail data are not available due to third-party restrictions. The water to cement ratio, amount of cement and additive were kept constant for all mixtures.

2.2. Mixing and casting procedure

In this chapter only mixing procedures are described while testing results will be presented in following Chapter 3. A laboratory mixer with a maximum capacity of 150 liters was used to mix the concrete (see Figure 2). Three concrete mixtures were mixed until achieving required density.

The first trial mixture EPS1 was mixed following the procedure from the literature [8]. First, the 2/3 of the total amount of water mixed with additive was supplied to the mixer. Further, the required amount of sand was added and mixed until the mixture became homogeneous. Then, to add cement and the remaining amount of water the mixer was stopped. Finally, the total amount of EPS beads was added to cement paste and mixed until the mixture became uniform. Immediately after lightly oiled cubic molds were filled with EPS LWC without any vibration.

During the mixing procedure of the second trial mixture EPS2, the order of adding ingredients in the mixer was changed. First, additive mixed with 2/3 of the total amount of water and EPS beads were introduced in mixer. Then the required amount of sand was added and mixed for about 60 s. At the end, remaining water and cement were added and mixed until the fresh mixture was uniform. The fresh concrete was poured into prepared molds in three layers. Each layer was compacted by wooden bar uniformly over the surface of the concrete as shown in Figure 3.

The last mixture EPS3 was created with a reduced amount of EPS beads. While the amount of EPS beads was decreased by 8% (mass percentage) the amount of sand was increased by 31 % (mass percentage) to keep a constant total amount of the mixture ingredients. Hence, the volume fraction of EPS beads was reduced from 80% to approximately 70%. The amount of the remaining mixture ingredients stayed unchanged. The concrete was mixed and cast in the same way as described for the second trial mixture EPS2.

While compressive strength is the most important parameter to characterize concrete properties and it is directly related to the structure of hardened concrete, each trial mixture (EPS1 and EPS2) was used to cast three cubes with 150 mm edge for compression test. The referent concrete mixture EPS3 was used to prepare three cube specimens of 150 mm edge and three of 200 mm edge for compressive strength testing, three cylindrical specimens of 300 mm height 150 mm diameter for tensile splitting tests and three prismatic specimens 100 mm × 100 mm × 400 mm for flexural tensile testing. Specimens prepared for testing EPS3 LWC mixture are shown in Figure 4. After demolding, the specimens were cured immersed in the water tank until the day of testing.

Figure 1. *EPS beads*

Figure 2. *Fresh concrete mixture*

Figure 3. *Casting of fresh concrete*

Figure 4. *EPS3 concrete specimens*

2.3. Testing fresh concrete

Since there is no standard methodology for testing EPS LWC standards used for normal strength concrete (NSC) have been followed. Laboratory tests on fresh concrete included measurement of density following the HRN EN 12350-6 [9]. To characterize workability of EPS LWC slump test following the HRN EN 12350-2 [10] and flow table test following the HRN EN 12350-5 [11] were used.

2.4. Testing hardened concrete

Mechanical properties were tested under the same conditions as NSC but with adjusted loading rates [12-14]. The applied loading rate was chosen in such a way to obtain maximum load in the range of 2 to 5 minutes from the beginning of testing (quasi-static loading). For each test type, the failure pattern was analyzed, the maximum force at failure was recorded and the strength according to the corresponding testing standard was calculated.

2.4.1. Compression tests

For the compression tests a universal testing machine with a maximum load capacity of 3000 kN was employed (see Figure 5a). The compressive strength of concrete cube specimens of 150 mm as well as 200 mm was obtained according to HRN EN 12390-3 [12]. The loading was applied at rate of 0.05 MPa/s. A set of three (3) cubes were tested for each cube size.

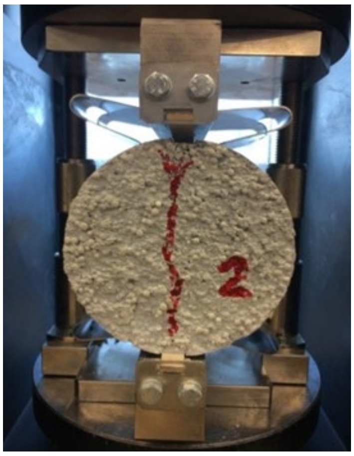
2.4.2. Tensile splitting tests

The split tensile strength test was performed according to standard HRN EN 12390-6 [13] on concrete cylinders 150 mm in diameter and 300 mm high by universal testing machine with a maximum load capacity of 3000 kN (see Figure 5b). The loading was applied with constant rate of 0.005 MPa/s. In total, three (3) specimens were tested.

2.4.3. Flexural tests

Four-point bending setup was applied to test EPS LWC specimens to evaluate flexural strength [14]. Specimens were prismatic beams with a cross-section of 100 mm × 100 mm and a span length of 300 mm. Figure 5c shows the test setup used in the flexural test. The flexural tests were carried out employing servo-controlled hydraulic machine with a maximum capacity of 300 kN. The tests were performed with the displacement control. Two Linear Variable Differential Transducers (LVDT) were used for measuring central point displacement, each on the middle of the longitudinal side of the beam as shown at Figure 5c. The loading and mid-point displacement of all three specimens were recorded during the experiment.

a) Compression tests



b) Tensile splitting tests

c) Flexural tests

Figure 5. *Test setup*

3. EXPERIMENTAL RESULTS

In this chapter results of the various tests conducted on trial mixtures and referent mixture EPS3 with achieved density, in their fresh and hardened state are presented. In the first subchapter, density and compressive strength of trial mixtures EPS1 and EPS2 are discussed. The required value of the density and the experimentally obtained values of trial concrete batches mixed with different casting procedures were compared. In the following subchapters, results obtained on the referent mixture EPS3 with achieved target density in fresh state such as workability and density and mechanical properties in the hardened state are analyzed in detail.

3.1. Trial mixtures

To determine the density of fresh concrete the molds were weighted after filling with fresh concrete according to casting procedure described in section 2.2. The measured average density of fresh EPS1 LWC was 715 kg/m^3. The average density of the second trial mixture EPS2 was obtained as 925 kg/m^3 which is 30% higher than the density of EPS1, but again the required density of approximately 1200 kg/m^3 was not achieved.

In order to test EPS adhesion to the cement paste, compressive tests are performed. The cube specimens prepared of EPS1 were tested for compressive strength at the age of 14 days. The measured mean compressive strength was only 0.7 MPa. From Figure 6a it can be observed that the surface of EPS beads was not fully covered with cement mortar resulting in poor adhesion between EPS beads and matrix. Consequently, failure took place through cement paste - EPS beads interface. On the other hand, EPS2 specimen kept structural integrity after testing the compressive strength

(Figure 6b). Moreover, it can be observed that the bond between EPS beads and cement paste was much stronger. The mean compressive strength of EPS2 cubes tested after 7 days was 2.5 MPa. Hence, considering the difference in concrete age at time of testing, it can be concluded that mean compressive strength of the second trial mixture EPS2 is even more than 3.5 times greater than the mean value of the first trial mixture EPS1.

The higher mean value of density of EPS2 with respect to EPS1 can be attributed to compaction and better distribution of the EPS beads in the mixture. Consequently, this leads to better adhesion of the EPS beads to the cement paste which at the end contributes to the increase of the compressive strength. Based on that, it can be concluded that proper mixing procedure and compaction of concrete are one of the most important parameters to achieve designed properties of EPS LWC. To obtain the required density, it was necessary to change the mixing proportion of EPS beads in concrete mixture as described in section 2.2.

a) EPS1 specimen

b) EPS2 specimen

Figure 6. *Compression test*

3.2. Fresh concrete

This section describes the investigation of fresh properties of EPS3 LWC with required density. The average density of the mixture EPS3 was 1176 kg/m^3, approximately 27% and 64% higher with respect to the trial mixtures EPS2 and EPS1, respectively. Hence, this concrete mixture is taken as referent mixture. The EPS3 LWC mixture showed a zero slump value (see Figure 7a) and flow of 34 mm from flow table test (see Figure 7b) which indicates very low workability [7]. Moreover, except flow of the concrete was restrained, the crumbling also occurred, as shown in Figure 7b.

a) Photograph of slump

b) Photograph of flow

Figure 7. *Testing fresh concrete*

3.3. Hardened concrete

This section describes the investigation of mechanical properties of referent mixture EPS3 LWC with the density of 1200 kg/m^3. All tested specimens were cast in one batch. Overview of test results and specimens used to obtain hardened material properties are summarized in Table 1. For each property exactly three specimens were tested and average values together with standard deviations are presented. Comparison of the given results are in accordance with literature for similar amounts of components and density [3]. After testing, specimens were visually inspected and failure surface was recorded. Note that all tests were performed on the saturated specimens at the age of 43 days.

Table 1. *Overview of test results*

Material Property	Specimen Type	Specimen Dimension	Mean values (S.D.) [MPa]
Compressive strength	Cube	150 mm × 150mm ×150 mm	5,3 (0,40)
	Cube	200 mm × 200 mm × 200 mm	5,9 (0,17)
Splitting strength	Cylinder	150 mm × 300 mm	0,7 (0,04)
Flexural strength	Prism	100 mm × 100 mm × 400 mm	1,3 (0,02)

3.3.2. Compressive strength

The mean compressive strength of EPS3 LWC obtained on 150 mm cube and 200 mm cube specimens amounts 5.9 MPa and 5.3 MPa, respectively. Hence, an increase of the compressive strengths of 136% with respect to the EPS2 specimens was observed. Figure 8 represents the typical failure patterns observed after the compressive strength test. It can be seen that the shape of failure patterns visually corresponded to NWC.

Figure 8. *Compression test - failure patterns*

3.3.3. Tensile splitting strength

The mean value of the splitting tensile strength equals 0.7 MPa. As expected, the splitting tensile strength is approximately 8 times lower than the compressive strength and approximately 2 times lower than flexural strength similar to by NSC. Further, EPS3 LWC exhibited the same failure behavior as NSC, by splitting along the longer side of the cylinder (Figure 9). However, EPS LWC failure mechanism is quite different from the failure of NWC. Because EPS beads are relatively weaker than the cement matrix, crack patterns go through EPS beads (Figure 9b). The EPS beads were uniformly distributed in concrete matrix as seen in Figure 9b. It can be concluded that EPS beads determine the concrete performance because their strength is lower than the strength of cement mortar and also cement paste - EPS beads interface.

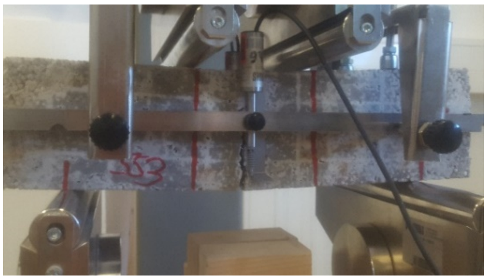
a) Typical failure mode *b) Failure surface*

Figure 9. *Tensile splitting test*

3.3.4. Flexural strength

Figure 10 shows the crack initiation and failure modes from the flexural test. It can be concluded that all failures are satisfactory i.e. failure crack is located in the range of the middle third of the distance between the supporting rollers. The mean flexural strength amounts 1.3 MPa. Further, the value of flexural tensile strength compared to compressive strength is similar as for NSC, approximately 5 times lower. Again, the failure surface shown in Figure 10 showed the typical failure mechanism for LWC.

There is not much information in the literature on the post-peak response of EPS LWC. Therefore, in this investigation, the load-displacement curves obtained for each prism are presented in Figure 11. It is interesting to observe that curves show straight pre-peak line while the post-peak response is more gradual. This result leads to the conclusion that EPS3 LWC did not have a flexural brittle behavior typically associated with the NWC.



c) Crack initiation

a) Typical failure mode *b) Failure surface*

Figure 10. *Flexural test*

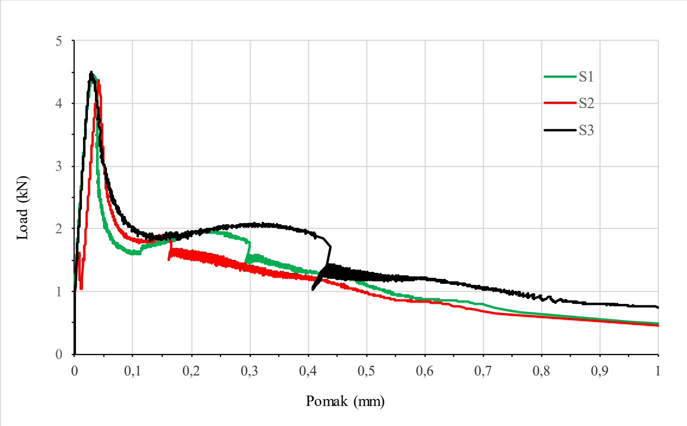


Figure 11. *Load-displacement curves*

4. CONCLUSIONS

In the present work, an experimental investigation has been carried out on EPS LWC mixtures prepared with replacement of the conventional coarse aggregate with EPS beads. A study on the fresh concrete density as well as basic mechanical properties of the designed concrete was conducted. Based on the experimental results following conclusions are made:

1. EPS LWC does not require complex techniques of production. However, the order of dosage of mixture ingredients and mixing procedures as well as proper casting method are the most important factors in the production of EPS LWC to achieve a designed quality of concrete.
2. EPS LWC without coarse aggregate show very low workability
3. For EPS LWC with a density of approximately 1200 kg/m^3, relatively low amount of cement and high amount of EPS beads, satisfactory mechanical properties are achieved. However, obtained compressive strength of approximately 5.5 MPa suggests that designed EPS LWC is not suitable in a structural application. Meanwhile, designed EPS LWC can be used for structural - insulating applications such as in floors and roofs.
4. Compressive, flexural and tensile splitting strength of EPS LWC are related in the same way as in NWC.
5. Application of EPS beads in concrete as a complete replacement of aggregate can be one of the waste disposal method and energy-saving method. Hence, this type of LWC can be considered environmentally sustainable material for non-structural application.

Designed EPS LWC will be further investigated concerning water resistance, thermal and acoustic properties.

ACKNOWLEDGEMENTS

This work has been supported in part by Ministry of Science, Education and Sports of the Republic of Croatia under the project Research Infrastructure for Campus-based Laboratories at the University of Rijeka (no. RC.2.2.06-0001).

The authors would like to express gratitude to the student Toni Pogačić from Faculty of Civil Engineering Rijeka for assistance during experimental program and to the company Holcim (Hrvatska) d.o.o for providing necessary materials.

LITERATURE

[1] HRN EN 206:2014. Beton-Specifikacija, svojstva, proizvodnja i sukladnost (EN 206:2013)

[2] D. Bjegović, N. Štirmer. Teorija i tehnologija betona. Građevinski fakultet. Sveučilište u Zagrebu. Zagreb. Hrvatska. 2015

[3] M. Kekanović, D. Kukaras, A. Čeh and G. Karaman. Lightweight concrete with recycled ground expanded polystyrene aggregate. Tehnički vijesnik 21 (2014), pp. 309-315. ISN 1848-6399

[4] S. Real, J.A. Bogas, M.G. Gomes and B. Ferrer. Thermal conductivity of structural lightweight aggregate concrete. Magazine of Concrete Research, 68 (15), pp.1-11, 2016, doi: 10.1680/jmacr.15.00424

[5] G. Bedeković, I. Grčić, A. Anić Vučinović and V. Premur. Recovery of waste expanded polystyrene in lightweight concrete production. MGPB, 2019. pp. 73-80, doi: 10.17794/rgn.2019.3.8

[6] M. Záleská, M. Pavlíková, O. Jankovský, J. Pokorný and Z. Pavlík. Lightweight concrete made with waste expanded polypropylene-based aggregate and synthetic coagulated amorphous silica. Ceramics-Silikáty 62, (3), pp.221 - 232 (2018). ISSN 1804-5847. doi: 10.13168/cs.2018.0015

[7] C.A. Johnson, E. E. Ndububa and E.O. Ikpe. An Evaluation of the Water Absorption and Density Properties of Expanded Polystyrene Sanded Concrete. Open Journal of Civil Engineering, Vol.8 No.4, 2018, pp. 524-532, doi:10.4236/ojce.2018.84037

[8] Dž. Dizdarević, E. Bolić and D. Kadić. 11th International scientific conference on production engineering. Development and modernization of production. (2017), pp.453-458

[9] HRN EN 12350-6:2009. Testing fresh concrete - Part 6: Density (EN 12350-6:2009)

[10] HRN EN 12350-2:2009. Testing fresh concrete - Part 2: Slump test (EN 12350-2:2009)

[11] HRN EN 12350-5:2009. Testing fresh concrete - Part 5: Flow table test (EN 12350-5:2009)

[12] HRN EN 12390-3:2012. Testing hardened concrete - Part 3: Compressive strength of test specimens (EN 12350-3:2009)

[13] HRN EN 12390-6:2010. Testing hardened concrete - Part 6: Tensile splitting strength of test specimens (EN 12390-6:2009)

[14] HRN EN 12390-5:2009. Testing hardened concrete - Part 5: Flexural strength of test specimens (EN 12390-5:2009)

03 | Research paper I Оригинални научни рад
ISSN 2566-4484 I Doi 10.7251/STP2014020C
pages 20-31

Vedran Carević, vedran@imk.grf.bg.ac.rs, Faculty of Civil Engineering, University of Belgrade
Jelena S. Dragaš, jelenad@imk.grf.bg.ac.rs, Faculty of Civil Engineering, University of Belgrade
Aleksandar Radević, aradevic@imk.grf.bg.ac.rs, Faculty of Civil Engineering, University of Belgrade
Dragica Jevtić, dragica@imk.grf.bg.ac.rs, Faculty of Civil Engineering, University of Belgrade
Dimitrije Zakić, dimmy@imk.grf.bg.ac.rs, Faculty of Civil Engineering, University of Belgrade

THE INFLUENCE OF DIFFERENT CURING CONDITIONS ON HVFAC RHEOLOGICAL AND MECHANICAL PROPERTIES

Abstract:

This research was conducted in order to evaluate the influence of different curing conditions on rheological and mechanical properties of high volume fly ash concrete (HVFAC) in comparison with the ordinary Portland cement concrete (OPC). Four types of concrete were made: two HVFAC and two OPC designed to have the same consistency and 28-day compressive strength for samples cured in water. Also, three different curing regimes were chosen: standard water curing (W), standard laboratory air curing (L) and curing in standard laboratory conditions using curing compound based on the polyolefin emulsion (C). The main objectives were to evaluate the influence of these curing regimes on the compressive strength, flexural tensile strength, modulus of elasticity development over time, water permeability of concrete and concrete shrinkage. The use of curing compound improved previously mentioned properties in some extent compared with the samples cured in standard air conditions.

Keywords: high-volume fly ash concrete, curing conditions, curing compound, mechanical properties, shrinkage

УТИЦАЈ РАЗЛИЧИТИХ ВРТСА НЕГЕ НА РЕОЛОШКЕ И МЕХАНИЧКЕ КАРАКТЕРИСТИКЕ БЕТОНА СА ВЕЛИКИМ САДРЖАЈЕМ ЛЕТЕЋЕГ ПЕПЕЛА

Сажетак:

Истраживање је имало за циљ да се испита утицај различитих услова неге на реолошка и механичка својства бетона направљеног са високим садржајем летећег пепела (HVFAC) у поређењу са класичним бетоном на бази цемента (OPC). Направљене су четири врсте бетона: два HVFAC и два ОПЦ који су пројектоване тако да имају исте конзистенције и 28-дневне чврстоће при притиску за узорке неговане у води. Такође, примењена су три различита режима неге бетона: стандардна нега у води (W), стандардно неговање на ваздуху у лабораторији (L) и неговање у стандардним лабораторијским условима након премазивања узорака средством на бази полиолефинске емулзије (C). Главни циљ је био да се утврди утицај оваквих режима неге на развој чврстоће при притиску, чврстоће при затезању усљед савијања, модула еластичности током времена, водонепропустљивост бетона и скупљања. Примена средства за негу је побољшала предметна својства у поређењу са узорцима негованим на ваздуху.

Кључне ријечи:: бетон са великим садржајем летећег пепела, услови неге, премази за негу, механичка својства, скупљање

1. INTRODUCTION

The immense impact of the construction industry on the environment is mainly caused by the extremely large use of raw materials, energy consumption and waste production. The use of natural stone aggregates and large carbon dioxide (CO_2) footprint from cement production are the main problems of non-sustainable concrete production. The main focus of current research done in the material science field is oriented towards finding new alternatives to conventional construction materials by using waste and recycled materials. In order to preserve natural resources and make concrete more environmentally friendly, supplementary cementitious materials (SCMs) are being increasingly used. SCMs are usually by-products obtained from different industries that possess pozzolanic activity potential. Among different SCMs, fly ash (FA) is available in local countries, it can be used without additional treatment, it has a relatively low price, and, above all, large quantities deposited in the landfills grow rapidly. The important benefit from the utilization of FA as a cement replacement is the reduction of CO_2 emissions from the Portland cement production. Approximately one ton of CO_2 is released for each ton of the Portland cement clinker [1]. A positive environmental effect of using FA in concrete is also obtained through the decrease of the amount of FA deposited in landfills and through the use of the waste material instead of natural resources for concrete production. It is for these reasons that today there is a general trend of replacing higher amounts of Portland cement in concrete.

Concretes made with high volumes of FA (HVFAC) have been researched science 1985 [2], [3]. HVFAC is usually defined as the concrete with more than 50% of fly ash in the total amount of cementitious materials. A large amount of research has been done regarding the physical and mechanical properties of HVFAC and in addition, work was also done on the evaluation of its material properties through the standards for cement concrete [4]. Furthermore, the connection between HVFAC material properties testing and conditions in practical use must be evaluated for its safe application.

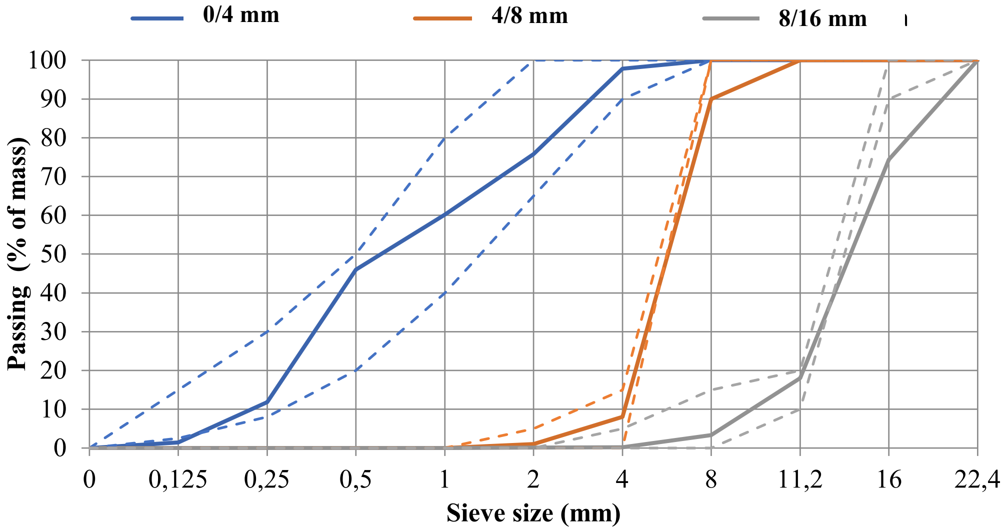
Pozzolanic material is usually defined as the material which will, in the presence of moisture, chemically react with calcium hydroxide $Ca(OH)_2$ at ordinary temperatures to form compounds possessing cementitious properties. At normal temperatures, the pozzolanic reaction is slower than the hydration of cement, so longer curing is needed for the full potential of FA to be reached [5]. It is generally recommended that HVFAC is moist cured for at least 7 days [6]. Adequate duration of moist curing helps the successful development of hydration and pozzolanic reaction, and increased curing temperatures can improve early age strengths [7]. However, results from the literature show that increased curing temperatures or steam curing, although helping the early age strength, can have adverse effect on the 28-day compressive strengths [8], [9]. In order to resolve the discrepancy of current results from literature, more studies are needed to determine the influence of different curing regimes on HVFAC properties. Furthermore, need for increased curing time and humidity recommended for HVFAC can prolong the construction time, so the possibility and efficiency of using current curing compounds in HVFAC should be evaluated.

This paper presents the research conducted in order to evaluate the influence of different curing conditions on HVFAC mechanical properties in comparison with the conventional cement concrete. Four types of concrete were made and tested: two HVFAC and two ordinary Portland cement concretes (OPC) designed to have the similar workability and 28-day compressive strength for samples cured in water. Three curing conditions were chosen for the analysis: standard water curing (W), standard laboratory air curing (L) and curing in standard laboratory conditions using curing compound based on the polyolefin emulsion to coat the samples (C). The main objectives were to evaluate the influence of these curing regimes on the compressive strength, flexural tensile strength, modulus of elasticity development over time, water permeability as well as the concrete shrinkage for both OPC and HVFAC samples.

2. MATERIALS AND CURING PROCEDURE

Both types of concrete, OPC and HVFAC, were made with the same component materials (aggregate, cement and water) and the HVFAC mixture was designed to have 50% and 57% of FA in total cementitious materials mass.

All concrete mixtures were made using tap water and river aggregate obtained from "Elita-Cop" separated into three fractions (0/4 mm, 4/8 mm and 8/16 mm) using standard sieving method. Prior to sieving and mixing, the aggregate was dried in the oven until the constant mass was reached. The sieve analysis of used aggregate is presented in Figure 1. The density of used aggregate was 2673 kg/m^3, 2578 kg/m^3 and 2602 kg/m^3 for fractions 0/4 mm, 4/8 mm and 8/16 mm, respectively.



*Dashed lines represent minimum and maximum passing for each size group according to [12]

Figure 1. *Sieve analysis of river aggregate*

Portland composite cement CEM II (class PC 20M (S-L) 42.5R) produced by "Lafarge", Beočin was used for preparation of both concrete types. This type of cement contains additions (ground slag and limestone) of up to 20% of the total mass, and there is no FA in the composition of cement. The specific gravity of cement was 3040 kg/m^3.

FA was obtained from the "Nikola Tesla B" power plant in Obrenovac, Serbia. The average specific gravity of FA determined using the pycnometer method was 2075 kg/m^3. The chemical composition of FA is presented in Table 1. In the last row of Table 1, the maximum allowed values of certain substances according to EN 450-1: 2012 [10] are presented. As it can be seen, the total quantity of $SiO_2 + Al_2O_3 + Fe_2O_3$ is higher than 70%. The quantity of particles smaller than 45µm is higher than 12%. It can be concluded that the FA used in this research met the requirements of EN 450-1:2012 for the use of FA in concrete, and according to ASTM-C618 [11] provisions could be classified as class F.

Table 1. *Chemical composition of FA (% of mass)*

SiO_2	*Al_2O_3*	*Fe_2O_3*	*TiO_2*	*CaO*	*MgO*	*Na_2O*	*K_2O*	*P_2O_6*	*SO_3*	*MnO*	*LOI*
64.14	*19.22*	*4.35*	*0.16*	*8.32*	*0.01*	*0.36*	*0.66*	*0.17*	*0.86*	*0.03*	*4.68*
-	-	-	-	-	*max 4*	*max 5*	-	*max 5*	*max 3*	-	*max 6*

The proportioning of the concrete mixtures was based on the absolute volume method. The mixing procedure began with mixing cement, FA, sand and coarse aggregate in a mixing pan for one min, then adding water during the next 30 s, and the mixing continued for approximately 5 min. The mixture was used to cast 10 cm concrete cubes for compressive strength testing, 15 × 30 cm cylinders for testing the modulus of elasticity, 15 cm cubes for testing water permeability and 12 × 36 prisms for testing of shrinkage. All samples were demoulded after 24 hours. The values of the various properties reported in this paper represent the mean value of three measurements.

After mixing, all specimens were cast in steel moulds and the concrete was compacted using a vibrating table. The first group of specimens was demoulded after 24 hours and placed in water thank (W-samples). The second group (L-samples) was cured in standard laboratory air conditions (T=20±2°C, RH=60±5°C). Curing of the third group of samples was done using the curing compound based on the polyolefin emulsion (C-samples). Namely, immediately after casting into moulds, the uncovered concrete surface of the C-specimens was sprayed with the liquid curing compound for preventing water loss in concrete. After the demoulding, all other sample sides were wrapped with plastic foil as shown in Figure 2.

Figure 2. *Sample treatment after casting (left) and C-samples treatment after demoulding (right)*

As the target values, workability class S2 and compressive strength class C25/30 (MB30) were adopted for both OPC and HVFAC mixtures. Concrete samples from each concrete mixture were additionally divided into three categories according to the applied curing procedure: OPC_1-W, OPC_1-L, OPC_1-C, HVFAC_1-W, HVFAC_1-L and HVFAC_1-C. The concrete mix designs of OPC and HVFAC mixtures are presented in Table 2.

Table 2. *Concrete mix design*

Mixture	*Water*	*Aggregate*			*Cement*	*FA*	*W/CM**
	m_v	*[0/4]*	*[4/8]*	*[8/16]*	m_c	m_{fa}	ω
	[kg/m³]	*[kg/m³]*	*[kg/m³]*	*[kg/m³]*	*[kg/m³]*	*[kg/m³]*	*[-]*
OPC_1	175	835	557	464	285	0	0.614
OPC_2	175	821	548	456	320	0	0.547
HVFAC_1	183	876	525	350	150	200	0.523
HVFAC_2	195	838	503	335	200	200	0.488

* *Water-to-cementitious materials ratio*

3. RESULTS AND DISCUSION

3.1. Workability

Concrete workability was tested using the Abrams cone method according to SRPS EN 12350-2: 2010 [13]. The average values of measured slump values are presented in Figure 3. The obtained values for the OPC and HVFAC mixtures corresponded to workability class S1 (OPC_1 and OPC_2) or S1-S2 (HVFAC_1 and HVFAC2). From the engineering point of view it can be considered that the workability of these four concretes is of the same class.

Mixture notation	Slump Δh [cm]
OPC_1	3.3
OPC_1	3.9
HVFAC_1	4.1
HVFAC_1	4.8

Figure 3. *Abrams cone slump test (left) and slump test results (right)*

3.2. Density, compressive and flexural tensile strength

Density of hardened concrete samples (Table 3) was performed according to the SRPS EN 12390-7: 2019 [14]. As expected, HVFAC had lower density compared to OPC, regardless of cement and FA amount. However, there was no significant difference in density for samples cured in the same way. The only exception was HVFAC_2 water-cured sample that had a slightly lower density (7.5% compared to HVFAC_1-W sample).

Compressive strength was determined at the ages of 7, 28 and 90 days. The test was conducted in accordance with SRPS EN 12390-3:2010 [15]. Figure 4 shows the development of compressive strength of both OPC and HVFAC mixtures cured in different regimes. At the age of 28 days all samples cured in water had similar compressive strength, which corresponded to the concrete strength class C25/30. An exception was mixture HVFAC_1, that had slightly lower compressive strength compared to other samples (approximately 15%).

Table 3 – Hardened sample density

Density, γ (kg/m³)			
Notation	**Age (days)**		
	7	28	90
OPC_1-L	2320	2277	2270
OPC_1-W	2370	2366	2397
OPC_1-C	2304	2292	2295
OPC_2-L	2322	2275	2293
OPC_2-W	2368	2357	2394
OPC_2-C	2380	2348	2310
HVFAC_1-L	2169	2188	2197
HVFAC_1-W	2331	2337	2298
HVFAC_1-C	2263	2239	2202
HVFAC_2-L	2251	2359	2164
HVFAC_2-W	2308	2162	2337
HVFAC_2-C	2256	2216	2195

In the first 7 days, OPC samples had higher compressive strength increase compared with the HVFAC, while from 7 to 90 days HVFAC showed higher increase in compressive strength. This can be explained with the fact that the pozzolanic reaction needs time and takes place after the beginning of hydration, approximately at the age of 7–14 days or later [16], [17]. The pozzolanic reaction was more pronounced from 7 to 28 days compared to period from 28 to 90 days, as a consequence of small amount of used Portland cement (150 kg/m³ and 200 kg/m³). The extent of the pozzolanic reaction in HVFAC depends on the available $Ca(OH)_2$ and water content while lower increase in compressive strength of HVFAC mixture can be explained with high FA amount and, possibly, not enough Portland cement. It can also be noticed that the influence of different curing conditions was less pronounced at early ages than in later ages, for both concrete types and especially for the OPC mixtures. This can be explained with the fact that all samples were stored in moulds for the first 24 hours and had enough water for early age strength development.

It can be seen from Figure 4. that the application of curing compound based on the polyolefin emulsion did not result in the preservation of the concrete compressive strength compared to water-cured samples, regardless of the concrete type. The L-samples and C-samples had lower compressive strength compared with the water cured samples (up to 27%). However, the use of compound based on the polyolefin emulsion reduced the compressive strength up to 10% compared to water-cured samples.

In the absence of necessary moisture content, the compressive strength decrease in the case of HVFAC samples was more pronounced compared to the OPC samples. On the other hand, all samples cured with curing compound had higher compressive strength compared to air cured samples. The influence of different curing conditions on the compressive strength analysed in this study was similar for both OPC and HVFAC mixtures. In the case of OPC samples treated with curing compound compressive strength was up to 13% higher compared to air cured samples, while in case of HVFAC samples this increase was up to 22%.

Concrete flexural tensile strength was measured using three-point bending test (Figure 5). The measured flexural tensile strength values at age of 450 days are shown in Figure 6. Flexural tensile strength follows the trends described for compressive strength. OPC samples had higher flexural tensile strength compared to HVFAC samples, for specimens cured in a same way. Differences between OPC and HVFAC samples were up to 45%, which was significantly higher than in the case of compressive strength. The highest values of flexural strength were noticed for water cured samples, while the lowest for air cured samples.

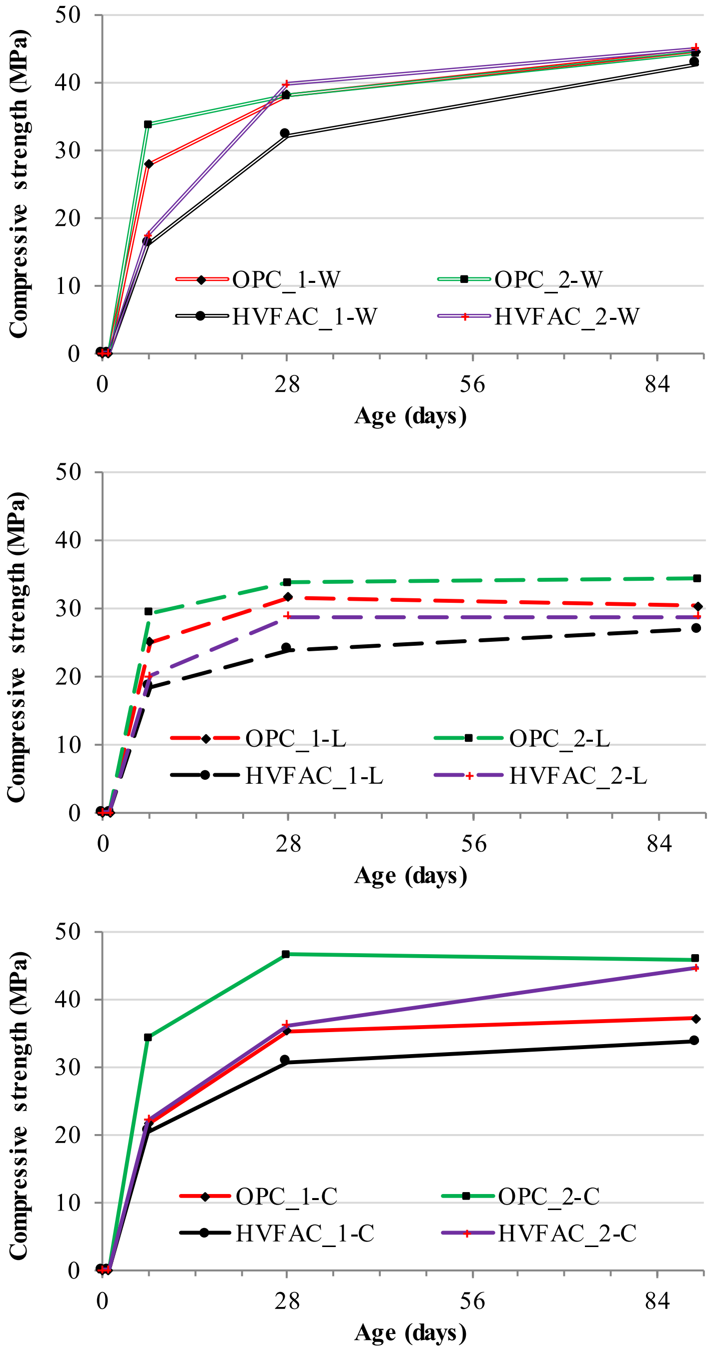


Figure 4. *Compressive strength of differently cured OPC and HVFAC mixtures*

Figure 5. *Three point bending test*

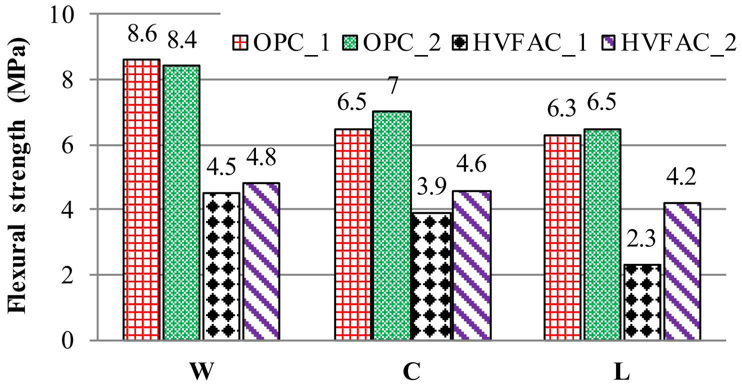


Figure 6. *Flexural tensile strength of differently cured OPC and HVFAC mixtures*

No significant difference between air cured and compound cured samples can be noticed-the differences were up to 9%. The only significant difference was in the case of HVFAC_1 - up to 41%.

3.3. Modulus of elasticity

The modulus of elasticity was tested at the age of 3, 7 and 28 days (Figure 7). The test was conducted in accordance with SRPS EN 12390-13:2015 [18]. Figure 8 shows the effect of different curing conditions on the modulus of elasticity.

Figure 7. *Measuring of modulus of elasticity*

Similar like in the case of compressive strength, the W-samples had the highest values of the modulus of elasticity at the age of 28 days. For the OPC mixtures, the L-samples and C-samples had lower 7-day modulus of elasticity compared with the W-samples, for 19% and 10%, respectively. These differences were slightly lower at the age of 28 days: 13% and 9% lower modulus of elasticity for L-samples and C-samples compared with the W-samples was obtained, respectively.

This difference was similar for HVFAC samples. The L-samples and C-samples had lower 7-day modulus of elasticity compared with the water-cured samples, for 15% and 2%, respectively. At the age of 28 days, these differences were slightly higher: 23% and 15% lower modulus of elasticity for the L-samples and C-samples compared with the W-samples was obtained, respectively. HVFAC had slower increase of modulus of elasticity in the first seven days compared with OPC samples. After 7 days the increase was more pronounced for HVFAC, especially for the water-cured samples.

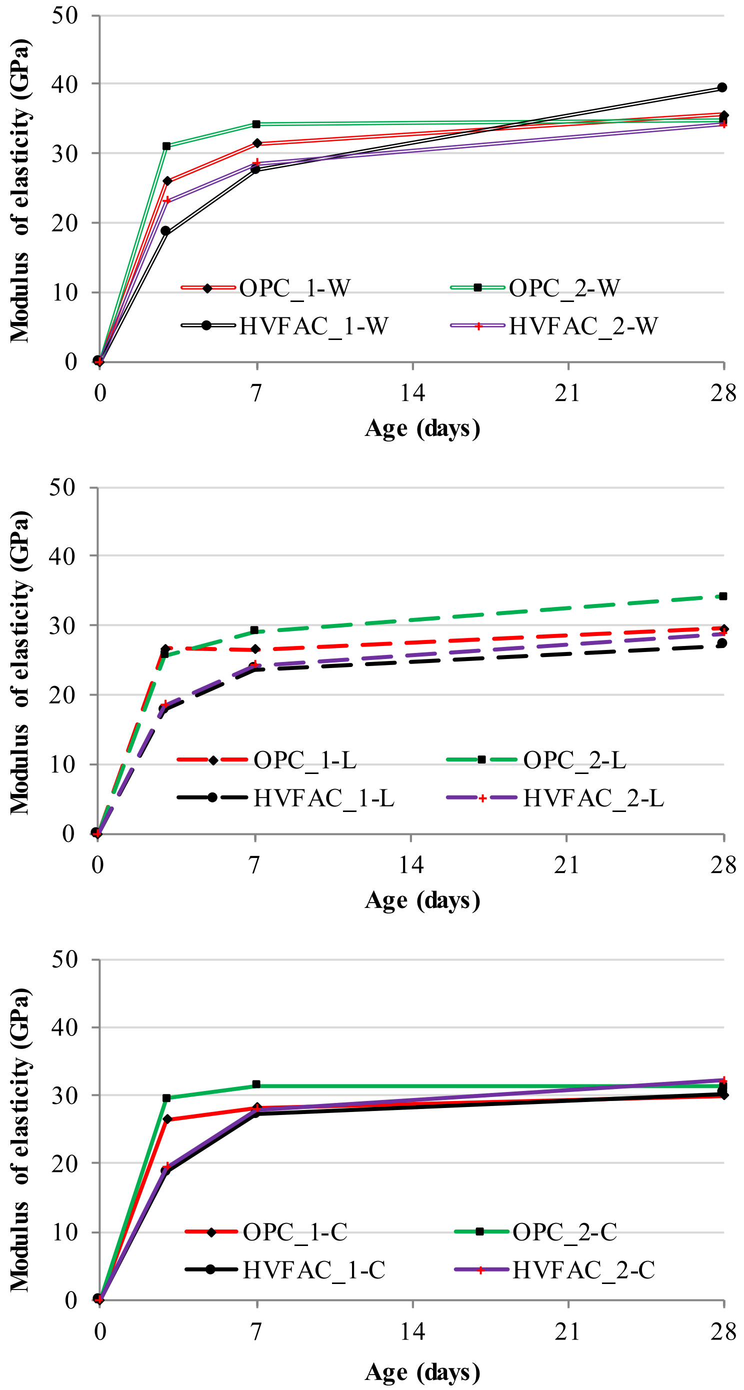


Figure 8. *Modulus of elasticity development of differently cured OPC and HVFAC mixtures*

The values of the modulus of elasticity at age of 28 days were compared with the values calculated by the empirical equation (1), as defined in EN 1992-1-1 [19]:

$$E_{cm}=22\left[\frac{f_{cm}}{10}\right]^{0.3} \tag{1}$$

where:

f_{cm} (MPa) - 28 days mean compressive strength,

E_{cm} (GPa) - modulus of elasticity at age of 28 days.

The differences between measured and calculated values range within 5%, for all curing conditions. This means that the empirical procedure defined in EN 1992-1-1 [19] can be applied for OPC and HVFAC cured on a different ways.

3.4. Shrinkage

Shrinkage measurement started at age of 7 days. Temperature and humidity conditions in the laboratory during the measurement of shrinkage was recorded and shown in Figure 9.

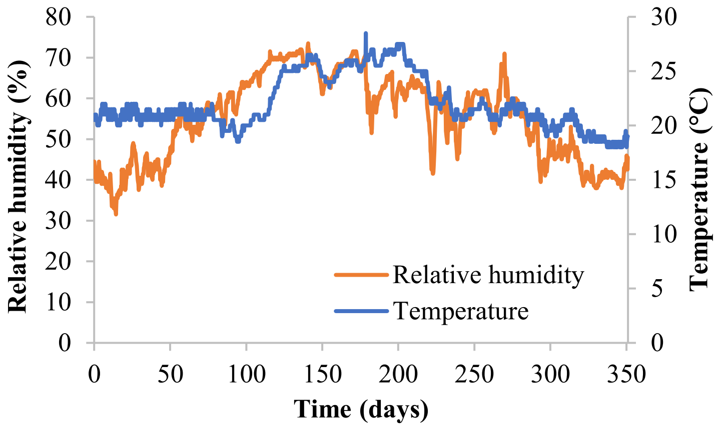


Figure 9. *Temperature and humidity conditions in the laboratory during experiment*

The average value of shrinkage measurements for air-cured samples and compound-cured samples are presented in Figures 10 and 11, respectively. As expected, HVFAC samples had lower shrinkage values compared to OPC because these concretes were made with lower cement amount. HVFAC_1 had the lowest shrinkage as a consequence of lowest cement amount.

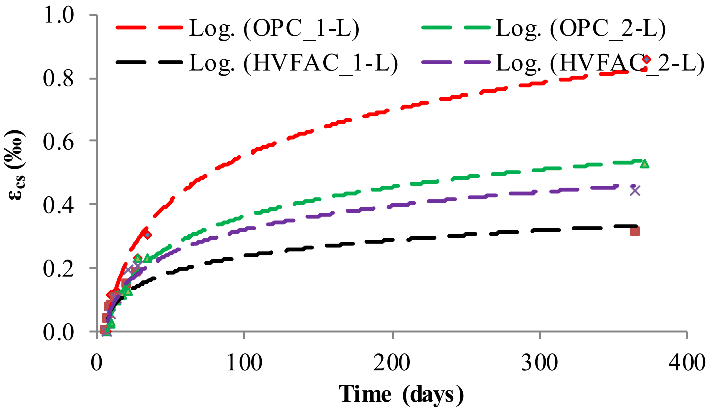


Figure 10. *Shrinkage of air cured OPC and HVFAC samples*

OPC samples cured with compound based on the polyolefin emulsion had lower shrinkage compared to air cured samples. On the other hand, the opposite result was obtained with HVFAC.

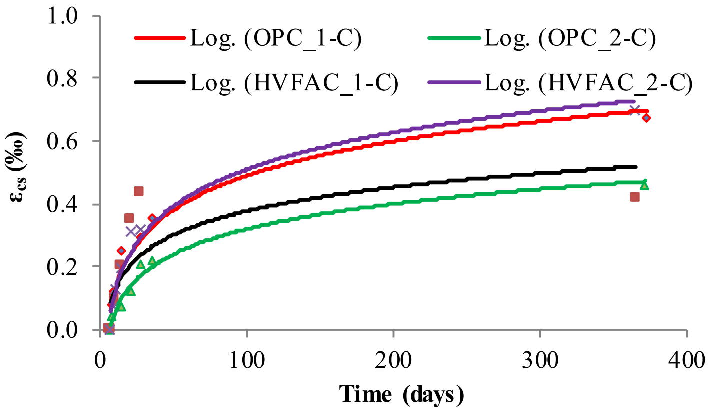


Figure 11. *Shrinkage of OPC and HVFAC samples cured based on the polyolefin emulsion*

3.5. Water permeability test

The testing of concrete water permeability was performed according to the SRPS EN 12390-8: 2010 [20]. Tested samples were exposed to water at a pressure of 5 bars for 72 hours in the laboratory conditions (T=20±2°C and RH=60%). After being exposed to water, the samples were broken and the maximum water penetration depth was measured. The obtained results are shown in Figure 12.

According to the presented results, it can be concluded that, in this particular case, the curing conditions had the highest impact on the concrete water permeability. Samples cured in water had low penetration depths (18-25 mm) which correspond to waterproof class V-III (OPC_2, HVFAC_1 and HVFAC_2) and V-II (OPC_1) according to SRPS U.M1.206:2013 [21]. In the case of concretes cured in other two ways, considerably higher water penetrations depths were measured. Samples cured with compound based on polyolefin emulsion had water penetration between 48 and 138 mm and these concretes cannot be classified as water-resistance concretes (except HVFAC_2 which correspond to waterproof class V-I). Even deeper water penetration depths were exhibited in air cured samples (between 128 and 138 mm).

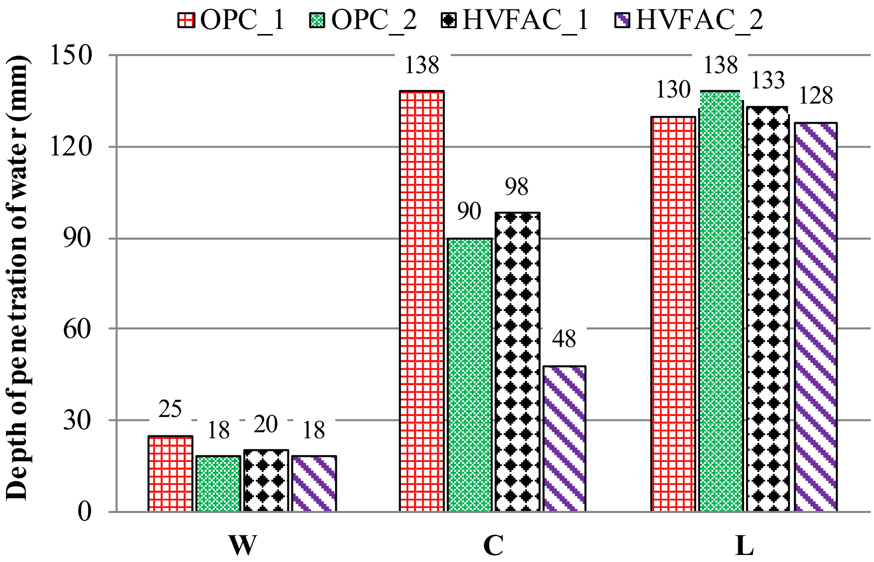


Figure 12. *Maximum depth of water penetration*

The importance of water penetration is reflected from the durability point of view, since the water penetration is directly related to concrete open porosity. This means that in case of air cured or cured with compound based on polyolefin emulsion it can be expected higher chloride penetration or carbonation depth.

4. CONCLUSION

In order to support the implementation and promotion of sustainable development and the importance of concrete curing conditions different tests were conducted on the OPC and HVFAC mixtures. Based on the presented results, the following conclusions can be made:

Concrete samples cured in water had the highest compressive strength. For HVFAC water/moist curing is recommended in order to achieve adequate compressive strength.

- For both types of concrete, water-cured samples had significantly higher flexural tensile strength and modulus of elasticity compared with the L- and C-samples.
- HVFAC samples had lowest shrinkage as a consequence of lower cement amount compared to OPC. OPC samples cured with compound based on the polyolefin emulsion had lower shrinkage compared to air cured samples. The efficacy of curing compound was lower in HVFAC samples.
- The curing conditions had the most significant impact on concrete water permeability. The OPC and HVFAC samples cured in water had the lowest water penetration. Samples cured with compound based on polyolefin emulsion had lower water penetration compared to air cured samples. However, in both cases of curing, penetration depths for L- and C-samples

was too high regardless of concrete type and these concretes cannot be classified as water-resistance concretes.

Generally, the use of the curing compound based on the polyolefin emulsion improved concrete properties (except water resistance) compared to air cured.

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".

LITERATURE

[1] A. Bilodeau and V. M. Malhotra, “High-Volume Fly Ash System: Concrete Solution for Sustainable Development,” *ACI Mater. J.*, pp. 41–47, 2000.

[2] N. Bouzoubaa and V. M. Malhotra, “Performance of Lab-Produced High-Volume Fly Ash Cements in Concrete,” *Concr. Int.*, vol. 23, no. 4, pp. 31–35, 2001.

[3] V. M. Malhotra and P. K. Mehta, *High-Performance, High-Volume Fly Ash Concrete for Building Sustainable and Durable Structures*, Third Edit. Supplementary Cementing Materials for Sustainable Development Inc., Ottowa, Canada, 2005.

[4] J. Dragaš, N. Tošić, I. Ignjatović, and S. Marinković, “Mechanical and time-dependent properties of high-volume fly ash concrete for structural use,” *Mag. Concr. Res.*, vol. 68, no. 12, pp. 632–645, 2016.

[5] S. H. Gebler and P. Klieger, “Effect of Fly Ash on the Durability of Air-Entrained Concrete,” in *Proceedings of the 2nd International Conference on Fly Ash, Silica Fume, Slag, and other Natural Pozzolans in Concrete*, 1986, pp. 483–519.

[6] M. D. A. Thomas, “Optimizing the Use of Fly Ash in Concrete,” *Portl. Cem. Assoc.*, p. 24, 2007.

[7] P. K. Mehta and O. E. Gjørv, “Properties of portland cement concrete containing fly ash and condensed silica-fume,” *Cem. Concr. Res.*, vol. 12, no. 5, pp. 587–595, 1982.

[8] B. Liu, Y. Xie, and J. Li, “Influence of steam curing on the compressive strength of concrete containing supplementary cementing materials,” *Cem. Concr. Res.*, vol. 35, no. 5, pp. 994–998, 2005.

[9] J. Payá, J. Monzó, M. V. Borrachero, E. Peris-Mora, and F. Amahjour, “Mechanical treatment of fly ashes - Part IV. Strength development of ground fly ash-cement mortars cured at different temperatures,” *Cem. Concr. Res.*, vol. 30, no. 4, pp. 543–551, 2000.

[10] CEN, *EN 450-1: Fly ash for concrete — Part 1: Definition, specifications and conformity criteria*. Brussels: European Committee for Standardization, 2012.

[11] ASTM C618, “Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete,” West Conshohocken, Pennsylvania, 2015.

[12] SRPS B.B2.010:1986 Aggregate for concrete - Technical requirements.

[13] SRPS EN 12350-2:2010 Testing fresh concrete - Part 2: Slump-test.

[14] SRPS EN 12390-7:2019 Testing hardened concrete - Part 7: Density of hardened concrete.

[15] SRPS EN 12390-3:2010 Testing hardened concrete - Part 3: Compressive strength of test specimens.

[16] L. Lam, Y. L. Wong, and C. S. Poon, “Degree of hydration and gel/space ratio of high-volume fly ash/cement systems,” *Cem. Concr. Res.*, vol. 30, no. 5, pp. 747–756, 2000.

[17] R. Siddique and P. Cachim, *Waste and Supplementary Cementitious Materials in Concrete: Characterisation, Properties and Applications*. Woodhead Publishing, 2018.

[18] SRPS EN 12390-13:2015 Testing hardened concrete - Part 13: Determination of secant modulus of elasticity in compression

[19] CEN, “EN 1992-1-1,” 1st ed., vol. 1, CEN, Ed. Belgrade: ISS, 2015.

[20] SRPS EN 12390-8:2010 Testing hardened concrete - Part 8: Depth of penetration of water under pressure.

[21] SRPS U.M1.206:2013 oncrete — Specification, performance, production and conformity – Rules for the implementation of SRPS EN 206-1.

04 | Research paper I Оригинални научни рад
ISSN 2566-4484 I Doi 10.7251/STP2014032M
pages 32-42

Ognjen Mijatović, mijatovicognjennada@gmail.com, Faculty of Civil Engineering, University of Belgrade

Zoran Mišković, zoran.miskovic@gmail.com, Faculty of Civil Engineering, University of Belgrade

Ratko Salatić, ratko.salatic@gmail.com, Faculty of Civil Engineering, University of Belgrade

Rastislav Mandić, rastislav.m@gmail.com, Faculty of Civil Engineering, University of Belgrade

Valentina Golubović-Bugarski, valentina.golubovic-bugarski@mf.unibl.org, Faculty of Mechanical Engineering, University of Banja Luka

Gabriel Relja, gabrielrelja@gmail.com, Elektroprenos BiH a.d. Banja Luka

EXPERIMENTAL ANALYSIS OF STRUCTURAL DAMPING FOR BOLTED AND WELDED SPLICE CONNECTION JOINT FOR IPE-80 STEEL PROFILE

Abstract:

Progress and demands of all types of constructions imposed the need for the development of modern structures that are lightweight, but at the same time have high damping capacity and stiffness. The consequences of these requirements are increased dynamic problems related to vibrations and dissipative processes in structure connection joints. Structural joints are the main reason for the significant reduction of the level of energy dissipation and source of structural damping so therefore they have become a subject of interest to many researchers. The aim of this paper is to present some problems regarding research of structural damping and the importance of study Contact Mechanics to better understand the problem of structural damping.

Keywords: Structural damping, dynamic properties, beam splice connections, Contact Mechanics

ЕКСПЕРИМЕНТАЛНА АНАЛИЗА КОНСТРУКТИВНОГ ПРИГУШЕЊА ВИЈЧАНЕ И ЗАВАРЕНЕ ВЕЗЕ МОНТАЖНОГ НАСТАВКА ЧЕЛИЧНОГ НОСАЧА IPE-80

Сажетак:

Напредак и захтјеви различитих врста конструкција наметали су потребу за развојем модерних конструктивних рјешења мале масе, али истовремено одговарајуће крутости и високе способности пригушивања. Посљедице ових захтјева су повећани динамички проблеми везани уз вибрације и процесе дисипације енергије у спојевима конструкција. Везе и спојеви код челичних конструкција главни су разлог значајног повећања нивоа дисипације енергије и настајања конструктивног пригушивања, па су постали предмет интереса многих истраживача. Циљ овог рада јесте представити одређене проблеме у вези с истраживањем конструктивног пригушивања, те неопходност проучавања контактне механике ради дубљег и бољег разумијевања проблематике конструктивног пригушења.

Кључне ријечи: Конструктивно пригушење, динамичке карактеристике, монтажне везе, контактна механика

1. INTRODUCTION

The exact determination of dynamic properties of real engineering structures is a rather formidable task. There are various approximate methods to evaluate the inertia, stiffness and damping properties of a structure, of which stiffness is most determinable.

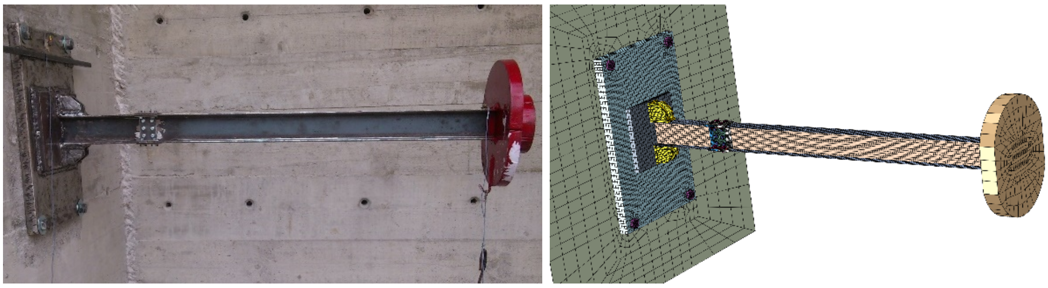


Figure 1. *Model of experimental and numerical cantilever beam with bolted splice connection joint*

On the other hand, the prediction of dissipative properties of a structure can be evaluated only experimentally, with a very careful and precise experimental setup. The complex nature of energy dissipation process stems from the nonlinear contact interaction behavior. In papers [1 - 3] authors investigated the effects of bolted and welded joints of one single connection extracted and examined separately from the main structure. They concluded that addition of bolted joints decreases the structure natural frequency by adding additional mass to the structure, and that usage bolts significantly increases the damping ratio. It is evident that using software such as the Abaqus and the Ansys, must be utilized for better definition of bolt connection mechanical property and numerical parameters. It is important to remark that by using the aforementioned software, it is not possible to accurately describe the behavior of bolted connections and energy dissipation processes, because the contact interaction of the two bodies is still not fully understood and defined. In addition to the above, we can consider Coulomb's law of friction to be exact only in certain cases.

Although many researchers have been engaged in the analysis of the structural dynamic behavior, there is still not fully explained the impact of joints on the dynamic properties of the complex structure. This paper deals with numerical verification of experimental investigation of characteristics of bolted and welded splice connection joint.

2. THEORY

As we seen in Chapter 1 of this paper, structural damping is a direct consequence of friction in joints and splice connection of steel constructions. For one to obtain an exact value of structural damping it takes accurate description of two bodies in contact behavior, that is, it is necessary accurately to define interaction of contact surfaces, which is still not sufficiently researched and done. The relationship and complexity of structural damping and contact surfaces interaction can better be comprehended if we observe Greenwood-s model [4-5]. The Greenwood-s model is based on Hertz-s contact theory and represents simple and often applied method of describing rough surfaces Fig. 2.

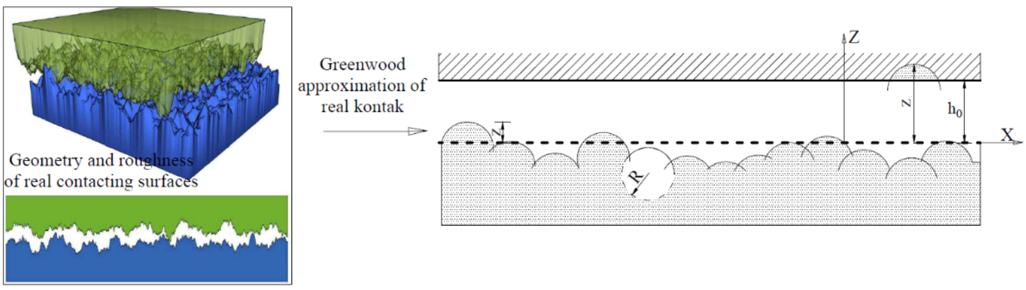


Figure 2. *Greenwood approximation of real contact*

Question that arises is how big the actual-real contact surface is, by which a contact is made, because from that directly follows the magnitude of a contact force inside the contact interaction. Based on

Hertz theory and Greenwood model we can set the basic equations of normal contact, that is, total number of points that come in contact N, surface of contact A and normal contact force FN, [4].

$$N = \int_{h_0}^{\infty} N_0 \Phi(z)\, dz \tag{1}$$

$$A = \int_{h_0}^{\infty} N_0 \Phi(z) \pi R (z - h_0)\, dz \tag{2}$$

$$F_N = \int_{h_0}^{\infty} N_0 \Phi(z) E^* R^{1/2} (z - h_0)^{3/2}\, dz \tag{3}$$

where:

- h_0 : distance from the middle level of rough surface
- z : asperity height
- R : radius of single contact asperity, as per Hertz contact theory
- N_0 : total number of asperities
- $\Phi(z)$: probability density of asperities height

Besides normal contact force, introducing in calculation the influence of tangential contact force the analysis of contact problem becomes significantly more complicated. Structural damping represents the resistance of mechanical connections joints while moving, that is, the size of the contact force of contact interaction prior to contact surface slip - Stick state, and after contact surface slip - Slip state. The complex process of elastic and plastic deformations of contact micro asperity, different magnitude of contact pressure and change in the size of actual contact surface, that is, constant change of contact geometry still represent challenge and requires further research so to better understand effects of structural damping.

On the other hand, if we observe contact of two or more bodies as an interaction of deformable continuum bodies for finite deformations we could say that analysis of contact of two or more bodies belongs to especially demanding nonlinear problems [4-7]. Nonlinearity of the analysis problem from now does not depend only on material and geometrical nonlinearity, which is usually studied in deformed bodies, but from contact conditions which are now included in the equation. Equation of balance in terms of current configuration expressed through Cauchy-s stress tensor is defined as

$$\int_{{}^tV}^{a} {}^t\tau_{ij} \delta_t e_{ij}\, d^tV = \int_{{}^tV}^{a} {}^tf_i^B \delta u_i\, d^tV + \int_{{}^tS_f}^{a} {}^tf_i^S \delta u_i^S\, d^tS \tag{4}$$

where:

- ${}^t\tau_{ij}$: Cauchy stress tensor
- $\delta_t e_{ij}$: strain tensor corresponding to virtual displacements
- δu_i : components of virtual displacement vector imposed on configuration at time t
- ${}^tV$: volume at time t
- ${}^tf_i^B$: components of externally applied force per unit volume at time t
- ${}^tf_i^S$: components of externally applied surface tractions per unit surface area at time t
- ${}^tS_f$: surface at time t on which external tractions are applied
- $\delta u_i^S = \delta u_i$: components of virtual displacement vector

Considering the contact problem, the equation of equilibrium for the N bodies in the contact on the right-hand side next to the expression of the external virtual work also contains the virtual work of the contact interaction (5). If L bodies are involved in the contacts $L = 1, \ldots, N$; where ${}^tS_c$ represents the total contact surface of each body, then the principle of virtual work for N number of bodies at time t is defined by the following expression, [7]:

$$\sum_{L=1}^{N}\left\{\int_{{}^tV}^{a} {}^t\tau_{ij}\,\delta_t e_{ij}^T\, d^tV\right\} = \sum_{L=1}^{N}\left\{\int_{{}^tV}^{a} {}^tf_i^B\delta u_i\, d^tV + \int_{{}^tS_f}^{a} {}^tf_i^S\delta u_i^S\, d^tS\right\} + \sum_{L=1}^{N}\int_{{}^tS_c}^{a} {}^tf_i^c\delta u_i^c\, d^tS \qquad (5)$$

Where part of a braces corresponds to the usual terms (4), while the last summation sign gives the force influence in a contact. As we can see contact force is represented as an exterior force. Components of this force are:

- ${}^tS_c$: complete contact area for each body L, L=1,..., Nat the time t
- ${}^tf_i^c$: component of the contact traction act over the areas ${}^tS_c$
- ${}^tf_i^S$: components of the known externally applied tractions act over the surface ${}^tS_f$
- δu_i^c : components of the virtual displacement on the contact surface

By further developing of contact virtual work in the expression (5) and by application of Hertz-Signoriny-Morau condition, expression (5) transforms from usual formulation where solution which needs to satisfy equilibrium equation goes into inequality of equilibrium which further complicates defining of contact interaction of two bodies and thus the problem of structural damping still remains unsolved [1], [2], [4]. The objective of aforementioned text is to gain basic insights in the complexity of studying contact mechanics and cause of structural damping formation. For a detailed treatment of this subject the reader should consult the literature, e.g. [4-8]

3. EXPERIMENTAL AND MODEL DESCRIPTION

This experiment is performed on the bolted and welded splice connection joints of the IPE-80 steel cantilever beam with modulus of elasticity of E = 210 GPa, and Poisson's ratio of v = 0.3, Fig. 3. IPE cantilever beam with the welded and bolted connection was rigidly bonded to the concrete wall via rigid angles and steel plate of thickness d = 20 mm and d = 30mm. The IPE cantilever beam was welded to a 20x200x200 mm connection steel plate and additionally stiffened with rigid angles. All of it is then welded together for a carrying steel plate of 550x350x30 mm. The aforementioned dimensions of the carrying steel plate have been determined so that adequate connection and support of the complete system to a 300 mm thick concrete wall could be ensured. The complete system is connected to the concrete support with four M20 bolts as shown in Fig. 2. The above-described method has achieved almost ideal clamped restraint which was primarily considered by a detailed numerical model.

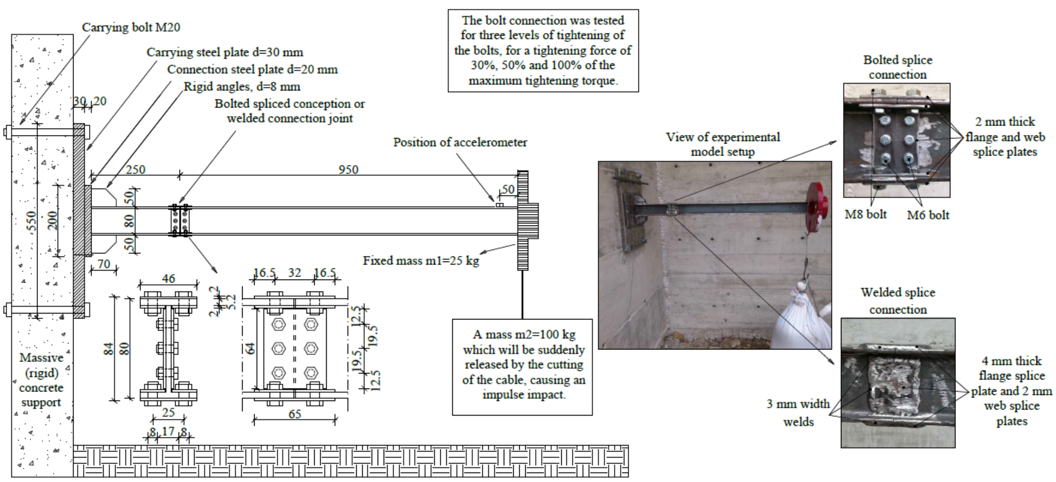


Figure 3. *Layout of tested cantilever beam with joints detail*

The splice connection is positioned near the support of the clamped beam, 250 mm from the support in order to receive as much momentum as possible. The splice connection joint should be loaded at

70 % of full capacity. In this way micro and macro slipping inside of connection contact interaction are accomplished with as little disturbing force as possible. A direct consequence of micro and macro slipping is the occurrence of structural damping due to friction in the connection joints. The bolted connection consists of the upper flange splice plate 65 x 45 x 2m in size and the two of lower small flanges splice plate 65 x 18 x 2 mm each, the web splice plates are 65 x 50 x 2 mm. The connection was made with four M8 screws for the upper and lower flanges and six M6 screws for connecting the web. The bolted connection was tested for three different tightening forces in the bolts: 30%, 50% and 100% of the maximum allowable tightening torque for M8 and M6, 8.8 bolt quality, Table 1. The tightening torque of the screws is controlled by a torque wrench with a range of 4 to 40 Nm.

Table 1. *Value of tightening torque and tightening bolt force*

	Percentages of maximum tightening torque		Tightening torque M_u [Nm]	Tightening bolt force F_p [kN]
	30 %	±4 %	7.5	5.5
	50 %		11.5	8
	100 %		23	16

The welded splice connection of the structural extension consists of one upper flange splice plate 65 x 45 x 4 mm and two web splice plates 64 x 50 x 2 mm. A mass of 25 kg is fixed at the end of the cantilever beam to reduce the natural frequencies of the beam. Each model of bolted and welded cantilever beam was excited with impulse load, accomplished with an instant released a mass of 100 kg with the cutting of the cable on which mass was hanged.

3.2. Modal testing

Modal testing was done on-site using the multi-channels acquisition system Portable Pulse 3560 C and the modal accelerometer type 4507, produced by Bruel&Kjaer. The modal hammer, type 2302-10 Endevco, was used to excite the beam. The test was conducted for cantilever beam with bolted and welded splice connection joint, clamped at the end, Figure 3. The FFT analyzer was set up to frequency bandwidth of 0-200 Hz, with a frequency resolution of 0.25 Hz and with 3 linear averaging of root mean square values of acceleration amplitude. The recorded FRF responses function for modal testing of beams are shown in Fig. 4.

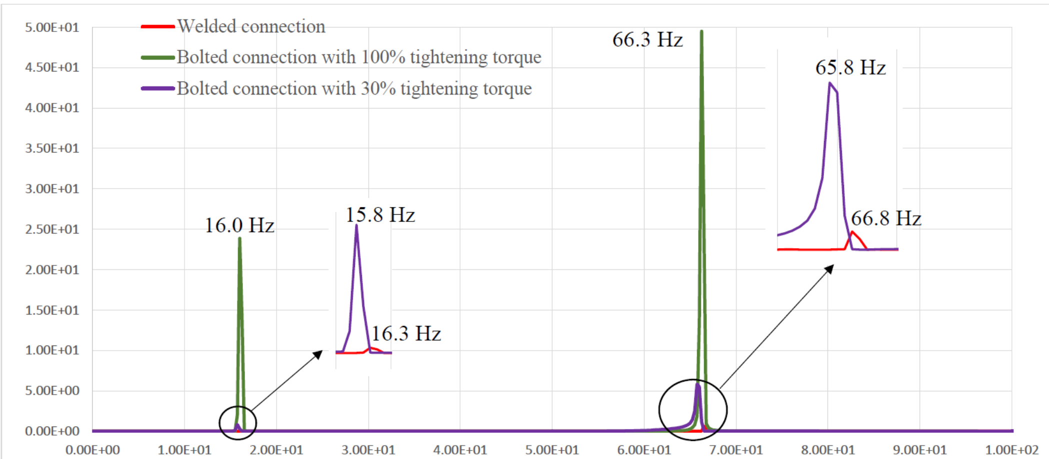


Figure 4. *FRF functions measured in modal testing for different beam models*

In Fig. 4, we can see the natural frequency values of the third and fourth oscillation modes of the cantilever beam with the bolted and welded splice connection. First two oscillation modes are not specified because of the specific setup and requirements of the experiment. An accelerometer was installed at the end of the cantilever beam in a vertical direction to provide as better as possible free vibration damped response. For the experiment of utmost important is third mod (vertical), the value of the first two modes are not clear. Because of everything mentioned above, these modes are not mentioned in the paper. The bolted connection is shown for two levels of tightening torque, 30%

and 100% of the maximum tightening torque for M8 class 8.8 bolts. As we can see in the frequency response shown there is no major difference between a cantilever beam with a bolted and a welded connection. The reason for approximately the same modal frequencies for the three connection joints with different stiffness is the low mass of the modal hammer and therefore the small disturbing force by which the beam is excited. Due to the lack of sufficiently strong disturbing force slippage within the connection contact interaction could not occur, and the influence of frictional structural damping could not be activated.

A slight oscillation of the modal frequency can be seen in the bolted connection with the tightening force of 30% of the maximum tightening torque. The occurrence of deviation is directly related to the micro and macro slipping within the contact interaction of bolts, flange and flange splice plates.

4. NUMERICAL MODELING AND VERIFICATION OF THE EXPERIMENTAL MODEL

4.1. Principles of numerical modeling

A numerical FEM model is made using the Abaqus. The aim was to build numerical models to represent experimental models as accurately as possible. The model of the beam with bolted joints was developed with a 1 mm gap between bolts and the holes. Also 2 mm gap is provided between two solid parts of the IPE-80 profile, as in the experiment setup. Friction coefficient of 0.70 was adopted for all contact interactions. The model of the beam with welded joints was developed without these gaps, similar to the experimental model connection. Welds are modeled like isolated interaction surfaces with Tie constraint option in Abaqus [9] with a width of 3 mm. With the explained procedure we have exactly defined thickness of the welds. The clamping force of 16 kN was applied at the horizontal middle surface of the bolt to the M8 bolts and 8.7 kN for M6, Fig. 5.

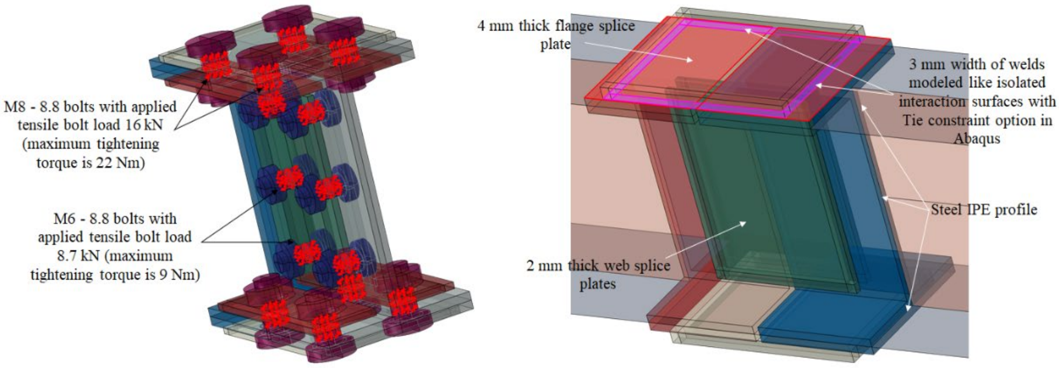


Figure 5. *Detail of application of bolt load in Abaqus - left, dental of definition of weld thickness - righ*

Choice of the element type has a great impact on analysis. After detailed analysis, numerical model built with 78 870 elements was adopted. When modeling, it is important to model a credible and accurate model with an optimal number of finite elements. It is easy to check that with poor mesh and an insufficient number of elements the required oscillation frequency can vary by up to 10%. Meshes with excessively high densities lead to costly calculations and in some cases increased numerical rigidity.

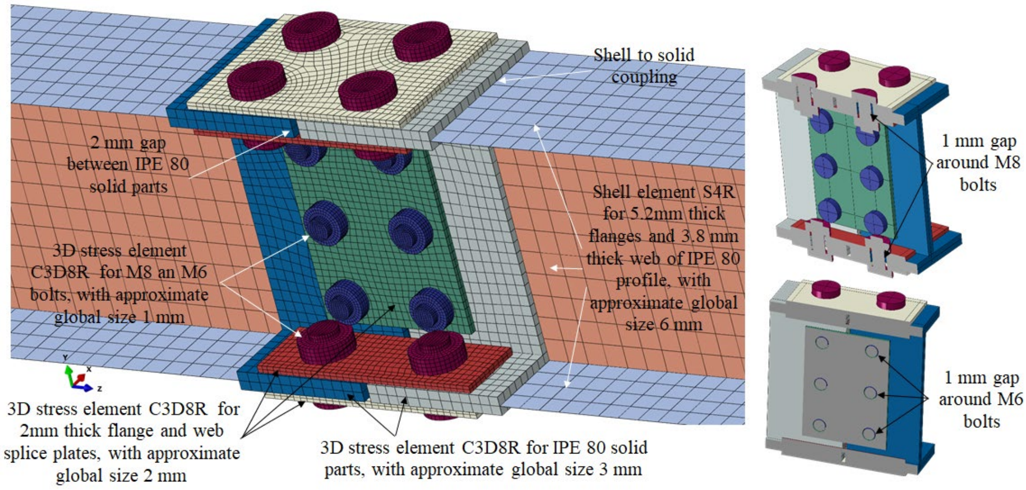


Figure 6. *Bolted splice connection geometry with element type and mesh*

The support structure and stiffening elements (concrete wall, M20 carrying bolts,3 mm thick carrying steel plate, 2 mm thick connection steel plate and rigid angles) were modeled with three-dimensional hexahedral (C3D8R) elements. IPE-80 cantilever beam profile is modeled with two-dimensional (S4R) elements [9], while bolted and welded connection detail, Fig. 6 were modeled separately with three dimensional hexahedral (C3D8R) elements and jointed with two pieces of IPE-80 profile (S4R) using options Shell to solid coupling of elements. These elements were chosen since they can provide reasonable accuracy for the stress state during non-linear behavior at contact surfaces. The mesh was defined after thorough convergence check and dimensions of elements are shown in Fig. 6. In setting up the model the contact surfaces are built with finite elements of different size, in a way that slave surface (loaded surface) has a denser FEM mesh than master surface (loading surface) region, Fig. 6. In this way, penetration between contact surfaces and initial overclosure were prevented. Also, better convergence rates were accomplished.

4.2. Numerical verification of the experimental model

As we have previously concluded, accurate experimental testing of the mechanical characteristics of the connection joints requires sufficiently precise support conditions for the experimental model in this case of the cantilever beam.

If there were some flexibility of support, even the small vibrations and displacements, the overall response of the structure would not be correct. Consequently, it would be impossible to separately study the influence of the bolted and welded splice connection on the dynamic response of the cantilever beam.

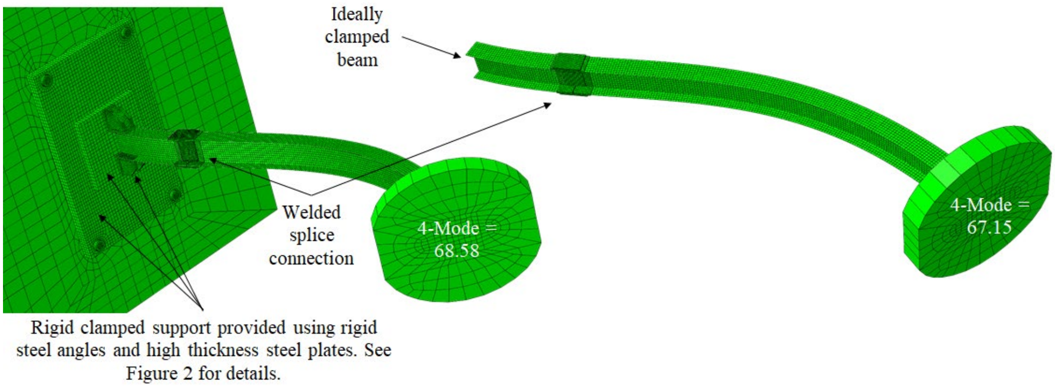


Figure 7. *Fourth modal shape of rigidly clamped support for cantilever beam and ideally clapped cantilever beam*

Numerical verification and analysis need to provide appropriate design recommendations of the elements and stiffeners to ensure that the constructed support is as close as possible to the mathematical model. By comparing the modal frequency of an ideally clamped numerical model with a numerical model designed to provide sufficiently rigid support for a cantilever beam, we will determine whether the links and stiffener are sufficient to provide clamped support.

Table 2. *Modal frequency gained based on measurements and numerical results*

Mark	Natural frequency (Hz) /mode shape type	Mode-1 (Lateral)	Mode-2 (Torsional)	Mode-3 (Vertical)	Mode-4 (Lateral)
[N1]	Numerical model - Ideally clamped beam (welded connection)	5.11 Hz	6.65 Hz	15.78 Hz	67.15 Hz
[N2]	Numerical model - rigid clamped support (welded connection)	5.28 Hz	6.74 Hz	16.03 Hz	68.58 Hz
[E1]	Experimentally tested cantilever (welded connection)			16.3 Hz	66.80 Hz
[N3]	Numerical model - rigid clamped support (bolted connection)	5.26 Hz	6.69 Hz	15.78 Hz	68.51 Hz
[E2]	Experimentally tested cantilever (bolted connection, 100 % tightening torque)			16.0 Hz	66.3 Hz

Further experimental verification and comparison of the experimentally obtained results with the numerical results showed that the construction of the experimental model has a satisfactory support stiffness, ie that an ideal clamped restraint is obtained, Fig. 7, Table 2.We can see by comparing models [N1] and [N2] from Table 2 that the first four modal frequencies of a numerical model with a designed support are higher than the frequencies of the ideally clamped model, which means that the dimensioned support stiffeners provide sufficient and slightly increased rigidity of the cantilever beam. The reasons for this difference are rigid angles, see Fig. 7 and Fig. 3, which increase the cross-section of the cantilever near the support in comparison with the ideally mathematically restrained cantilever. Further comparison of the results of the numerical model [N2] with the experimental model [E1], shows a small difference in the modal frequency, 1.68% for the third modal shape and 2.66% for the fourth modal shape.

As described earlier in Section 3.1, no significant difference was observed in the modal frequencies of the cantilever beam with the bolted and welded splice connection joint. Due to the low mass of the modal hammer and, consequently, the insufficiently large disturbing force, bolt connection was not excited and activated. The friction force respectively the tangential force within the bodies in contact was large enough to prevent the contact surfaces of the bolt connection from slipping. For the aforementioned reasons, no structural damping occurred, the cantilever with bolted splice connection joint acted as a monolithic beam, which behaves in the same way as the cantilever with the welded splice connection joint.

5. EXPERIMENTAL RESULTS AND DISCUSSION

By analyzing experimental results, it was confirmed the earlier assumption of high differences between bolted and welded joints damping. Welded connections give damping of 0.001 which is a range of material damping for steel that is, in boundaries below 0.01. Experimental results of bolted connections give structural damping in the range of 0.008 to 0.06 depending on tightening torque of bolts. The recommendation of Euro Code BS EN1998-1: 2004 section 3.2.2.2. and BS EN1998-6:2004 section 4.2.4 for standard steel constructions is damping of 0.05, while for different adopted damping further defining is needed. Depending on different authors damping vary from 0.03 to 0.10.

Accelerations in time domain along X direction are obtained for the and of the cantilever beam, where the accelerometer is positioned see Fig. 3. The envelope is obtained following equations of a system with single DOF. The equation of motion of free damped vibrations of this system, for damping less than the critical, is as follows:

$$y = \mathrm{A}e^{-\xi\omega t}\sin\left(\omega_d t\right) \tag{6}$$

where ω_d is free vibration frequency of the damped system and phase angle is $\phi = 0$

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

$$\ddot{y} = \mathrm{A}e^{-\xi\omega t}\left[\xi^2\omega^2\sin\left(\omega_d t\right) - 2\xi\omega cos\left(\omega_d t\right)\omega_d - \sin\left(\omega_d t\right)\omega_d^2\right] \tag{7}$$

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

$$\ddot{y} = \mathrm{A}e^{-\xi\omega t}\left[-\sin\left(\omega_d t\right)\omega_d^2\right] \tag{8}$$

Envelops are obtained for $\left[\sin\left(\omega_d t\right) = \pm 1\right]$

$$\ddot{y} = -\mathrm{A}e^{-\xi\omega t}\omega_d^2,\ \ddot{y} = \mathrm{A}e^{-\xi\omega t}\omega_d^2 \tag{9}$$

Unknown values are initial amplitude and damping ratio. By varying these values and harmonization of the envelope with acceleration graph, calibrated estimated values of initial amplitude and damping factor are obtained Fig.8, Fig.9 and Table 3.

Based on compared diagrams for bolted models B30, B50 and B100 there can clearly be seen the difference in structural damping. It is noticeable that the amplitudes of oscillation fit in the envelopes of linear system of single DOF only in the beginning time, that is, already after a few oscillations amplitudes of oscillation cross the envelopes and are continuing to oscillate long after a total equalization of envelopes with X-axis. Faster deviation of amplitudes for model B30 with 30% tightening force than for model B100 with 100% tightening force indicates to greater nonlinearity at B30 model than at B100.

Table 3. *Estimated value of damping for all models*

Mark	Experimental model	Damping ξ	Differ. (%)
B30	Bolted connection with 30 % of tightening torque	0.06	Difference between model B30 and B50
			100
B50	Bolted connection with 50 % of tightening torque	0.03	Difference between model B30 and B100
			650
B100	Bolted connection with 100 % of tightening torque	0.008	Difference between model B50 and B100
			275
W	Welded connection	0.001	Difference between model B100 and W
			700

Initial amplitudes of oscillation which occur after impact of impulse force are amplitudes of oscillation which originates while there was still enough energy in the beam after inducing impulse so the friction force in connections was exceeded and slipping in bolted connections has occurred which cause higher structural damping.

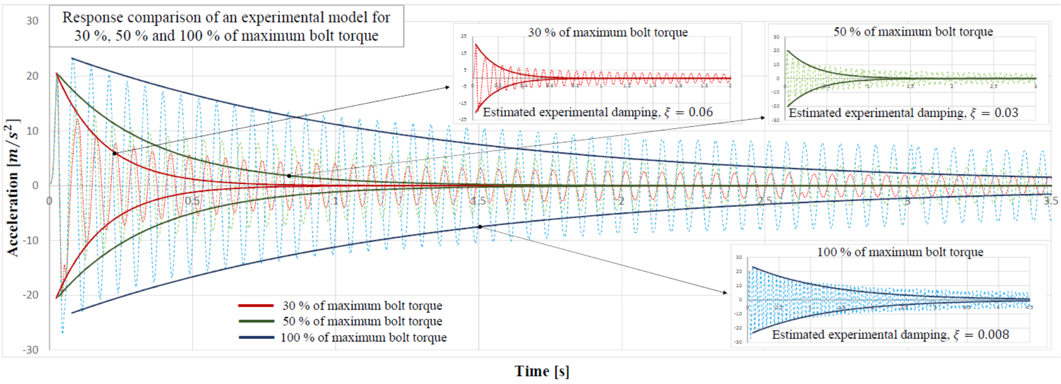


Figure 8. *Model response with envelopes for Bolted connection joint for 30 % - B30, 50 % - B50 and 100 % - B100 of the maximum bolts tightening torque*

While wasting energy the level of oscillations inside the beam and movement of contact surfaces inside bolted connection (flanges, bolts, and splice plates) is lowering so thereby also reducing damping. Cantilever beam continues to oscillate as monolithic beam without bolted connection, which can be seen from long fade out of steady stated oscillations

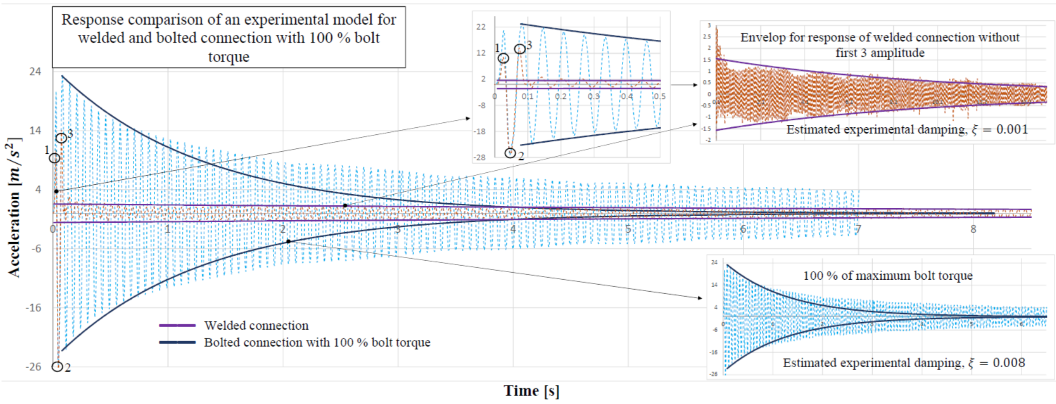


Figure 9. *Model response with envelopes for Bolted connection joint with B100 - 100 % of the bolts tightening torque and welded conception*

With further comparison of results of free damped oscillation of welded model W and bolted model B100, we see the difference in damping of 700% Table 3, Fig. 9. Interesting is to notice that there is greater difference in damping between model with 100% tightening torque B100 and welded model W, than between bolted models B100 and B30, considering that connection with tightening torque of only 30% is almost completely loose and untight.

This high difference of damping, points to significance of micro and macro slippering between surfaces of bolted connection elements. Because of usage 8.8 bolts in this experiment, macro and micro slip are occur and therefore high damping is evident.

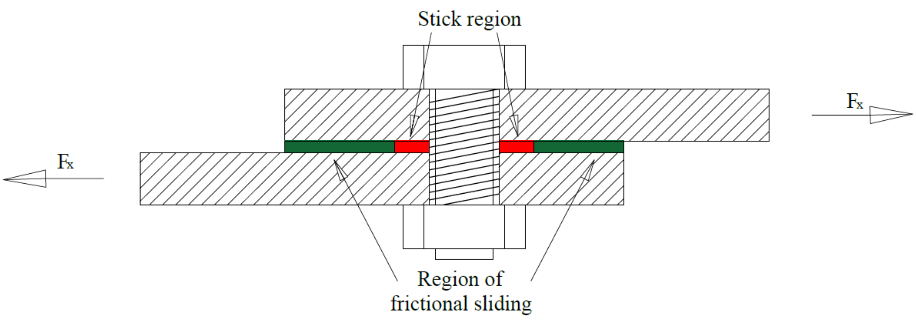


Figure 10. *Contact regions in a lap joint*

Regardless of bolt tightening level micro slipperings are always present and therefore also the occurrence of energy dissipation, that is, structural damping. With high strength bolts macro slips and movement of connection elements one in relation to the other are prevented by high tightening force of bolts Fig. 10.

Micro slips and constant process of contact asperities plastification, as well as changing of contact surfaces geometry while interacting is always present in isolated regions between bolts. We could adopt totally fixed state - Stick state, to exist only between contact surfaces in small diameter around the body of high strength bolts.

6. CONCLUSION

This paper presented a detail experimental investigation performed on a beam element. The goal was to investigate the effects of joints on the dynamic response of a structure, especially the damping characteristics. For this purpose a different cantilever beam models with welded and bolted joints were experimentally tested by means of modal testing and free decay testing. Fundamental natural frequency determined from FRF functions measured in modal testing is a little lower for a model with a bolted joint than for a model with a welded joint.

The reason for this almost insignificant difference between bolted and welded connections is because of the small weight of impact hummer and therefore the disturbing force is not large enough to excite the bolted connections joint to oscillate and activate slipping within the contact interaction of the bolted connection. Anyhow, investigated beam models were identical between each other, the influence of additional mass coming from bolts to frequency reduction was excluded. This small difference in natural frequency proves that structure with welded joint, i.e. the monolithic structure has higher stiffness compared to structure with bolted joints.

Similar results are obtained regarding damping characteristics that come from free decay test, where damping was estimated from logarithmic decrement. It's evident that the dumping for bolted connection is higher than for welded i.e. the monolithic model. The main reason for increase of damping is the contact frictional process between contact surfaces which are non-conservativ and highly nonlinear.

From this experiment, we can see the necessity of a better understanding of contact mechanics to enhance better understanding and define of structural damping.

LITERATURE

[1] Golubović-Bugarski V., Mijatović O., Guzijan-Dilber M., Desančić M., Borković A., Identification of dynamic properties of mechanical structure from measured vibration response, 6th International Congress of Serbian Society of Mechanics, June 19-21, 2017.

[2] Mijatović O., Guzijan-Dilber M., Borković A., Golubović-Bugarski V., Desančić M., ReljaG., Experimental and numerical dynamic analysis of one component of complex structure, 12th international scientific and professional conference on contemporary theory and practice in construction –STEPGRAD, Banja Luka, p.p. 35-43, 2016.

[3] Mijatović O., Desančić M., Mišković Z., Mišković Lj., Vibraciona platforma i model višespratne zgrade za dinamičko ispitivanje, 14. kongres Društva građevinskih kosntruktera Srbije - DKGS, Novi Sad, p.p. 459-468, 2014.

[4] Vladislav A. Yastrebov, “Computational Contact Mechanics – geometry, detection and numerical techniques”, Ph.D. dissertation,:Paris, MINES Paris tech, 2011

[5] K.L. Johnson, “Contact Mechanics”: Cambridge university press, 1985

[6] Wriggers P., Computational Contact Mechanics,: Berlin, Springer, 2006

[7] Klaus J.B., “Finite Element Procedures”,: Wtertovn, Prentice Hall, Pearson Education, 2016

[8] Valentin L. P., “Contact Mechanics and Friction – Physical Principles and Applications”, Berlin, Springer, 2017

[9] ABAQUS User Manual, Version 6.12, DS SIMULIA Corp, Providence RI, USA, 2012.

05 | Research paper I Оригинални научни рад
ISSN 2566-4484 I Doi 10.7251/STP2014043S
pages 43-54

Fidan Salihu, fidan.salihu@uni-pr.edu, Faculty of Civil Engineering and Architecture, University of Priština "Hasan Prishtina"

Meri Cvetkovska, user@gf.ukim.edu.mk, Ss. Cyril and Methodius University in Skopje, Faculty of Civil Engineering

PARAMETRIC ANALYSIS ON FIRE RESISTANCE OF ONE WAY SIMPLY SUPPORTED REINFORCED CONCRETE SLABS

Abstract:

The behavior of simply supported reinforced concrete slabs in fire conditions and the influence of certain parameters on their fire resistance is analysed in this paper. The influence of the slab span, concrete cover thickness and the type of reinforcement scheme are analysed. All slabs are exposed to standard fire ISO 834. The analyses are conducted by using the computer program SAFIR2016, which is based on the Finite Element Method, and the simplified procedure given in EN 1992-1-2. For the numerical analyses, two approaches are used: 2D-analysis, when the discretization is performed with beam elements and 3D-analysis, when the discretization is performed with shell elements. The 3D-analyses are performed for a meter width strip and for the real width of the slabs. The width of the slabs is adopted to be the same with the span.

Keywords: RC slab, Fire resistance, 2D and 3D analysis, SAFIR

ПАРАМЕТАРСКА АНАЛИЗА ПОЖАРНЕ ОТПОРНОСТИ СЛОБОДНО ОСЛОЊЕНИХ АРМИРАНО-БЕТОНСКИХ ПЛОЧА НОСИВИХ У ЈЕДНОМ ПРАВЦУ

Сажетак:

Предмет истраживања у овом раду је понашање слободно ослоњених армирано-бетонских плоча у пожарним условима и утицај одређених параметара на њихову пожарну отпорност. Анализиран је утицај распона плоче, дебљине заштитног бетонског слоја и шеме армирања. Све анализиране плоче изложене су стандардном пожару ISO 834. Анализа се врши коришћењем програма SAFIR2016, који се заснива на методу коначних елемената, и помоћу аналитичке методе дате у EN 1992-1-2. За нумеричку анализу се користе два приступа: 2D-анализа, када се дискретизација врши гредним елементима и 3D-анализа, када се дискретизација врши елементима љуске. 3D анализа се врши за траке ширине метар и за стварну ширину плоче.

Кључне ријечи: АБ плоче, пожарна отпорност, 2D и 3D анализа, SAFIR

1. INTRODUCTION

The fire resistance of building members is an important part of any structural and fire safety design. Floor slabs, as horizontal elements, have a very important role in providing bearing capacity, usability and stability of the building as a whole. Their proper selection and design, when they are exposed to different types of loads (mainly: permanent and variable), should provide stable and safe structure during the exploitation period.

In case of fire, floor slabs do not have only load bearing function. In most cases they are used as elements for separating the fire compartment. Where compartmentation is required, the elements forming the boundaries of the fire compartment, including joints, shall be designed and constructed in such a way to maintain their separating function during the relevant fire exposure [1]. This shall ensure, where relevant, that integrity failure does not occur, insulation failure does not occur and thermal radiation from the unexposed side is limited.

Does the floor structure meet the required fire resistance criteria mainly depends on: mechanical and thermal characteristics of the materials used for the construction; initial loading level; support conditions; dimensions of the cross section; steel ratio; concrete cover thickness and fire scenario.

A durable structure shall meet the requirements of serviceability, strength and stability throughout its design life, without significant loss of utility or excessive unforeseen maintenance. In fire conditions, as a result of a large number of real fire tests and corresponding numerical analyses, it was found out that the moment of failure of the floor structure is always followed by significant deformation (deflection). If the structure is close to the limit state, after the cooling phase the residual deflections are so great that it cannot be used without significant rehabilitation. For these reasons, during the fire action, the deformation (deflection) of the slab is limited to prescribed value. According to the ISO standard [2], this limit value is L/30 (L is the span of the slab) [3].

This paper presents the numerically achieved results for the fire resistance of one way simply supported reinforced concrete slabs with different spans, different concrete cover thickness and different reinforcement scheme. 2D-Analyses (beam element) and 3D-Analyses (shell element) by using the computer program SAFIR2016 [4] are conducted. For comparison, the slabs are analyzed by using the simplified method given in EN 1992-1-2 [5].

In order to draw a conclusion how each of the above mentioned parameters affects the fire resistance of one way simply supported reinforced concrete slabs, only the corresponding parameter is varied, and therefore in each case the reinforcement equal to the minimum required is adopted. This means that when adopting the reinforcement, the dimensions of the reinforcement bars that actually exist are not considered.

Based on the numerically achieved results, certain conclusions that can be useful for meeting the prescribed fire resistance criteria for these type of floor structures are given.

2. THERMAL ANALYSIS

Static analysis of the slab at each time interval uses the output data from the thermal analysis of the fire exposed elements, so it should be performed for a compatible finite element mesh, which means the 2D or 3D thermal analysis have to be performed by using compatible FE mesh.

Considering that in reinforced concrete slabs the temperature is changed only in direction of thickness, the cross section is discretized with rectangular elements with a width equal to the cross section of the slab. The results for the temperature distribution in the cross section of the slab are equal in case of 2D or 3D thermal analyses. Figure 1 shows the discretization of the slab cross section in 2D thermal analysis. The width of the cross section is b = 12.5 cm, and the thickness of the slab is h = 16 cm. In Figure 2 the temperature distribution in the cross section of the slab for moment t=3600 sec.=60 min. is presented.

Temperatures at the bottom side, in the middle plane and at the top side of the slab, during action of ISO 834 fire cure, are presented in Figure 3.

When simplified calculation method, given in EN 1992-1-2, is used, the temperature profile in the slab may be defined by formula given in literature [3,6]. The Standard fire curve ISO834 is given by Eq. 1, the surface temperature by Eq. 2, while the temperature at distance *d* from the slab surface is defined by Eq. 3.

$$T_f = 20 + 345 \cdot \log(8t + 1) \quad (1)$$

$$T_w = [1 - 0.0616 \cdot t_h^{-0.88}] \cdot T_f \quad (2)$$

$$T_d = [0.18 \cdot \ln(t_h/d^2)] \cdot T_w \quad (3)$$

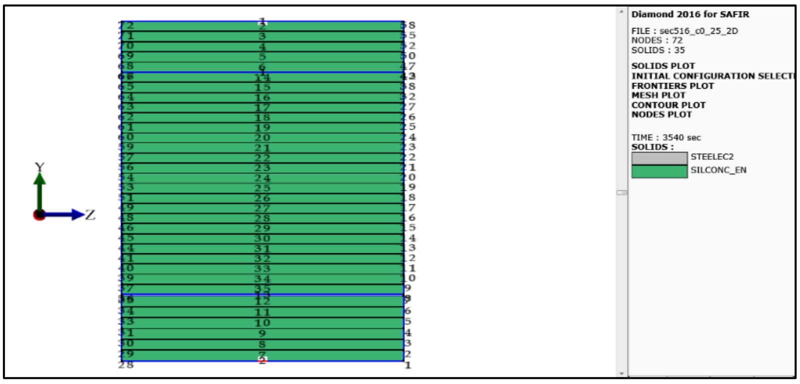


Figure 1. *Discretization of the slab cross section in 2D thermal analysis*

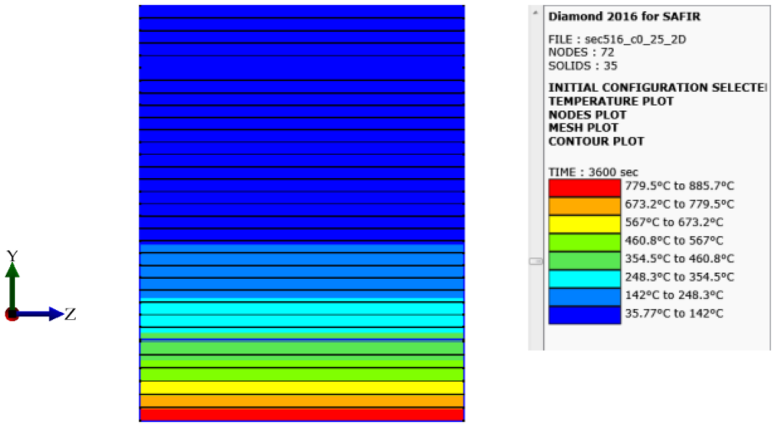
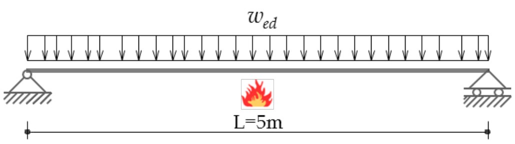


Figure 2. *Temperature distribution in the cross section of the slab for moment t=60 min.*

3. STATIC ANALYSIS

3.1. Description of the rc slab

The purpose of the analyses is to define the effect of the concrete cover thickness, the reinforcement scheme and the slab span on the fire resistance of one way simply supported slab, as one of the most important parameters that influence the fire resistance of RC slabs [7-16]. For the numerical analyses, two approaches are used: 2D-analyses, when discretization is performed with beam elements and 3D-analyses, when discretization is performed with shell elements. In case of 3D-analyses, a meter width strip is analysed and the real width of the slab is analysed. The width of the slab is adopted to be the same with the span. The analyzed RC slab is described in Figure 3. For the design actions recommendations given in EN 1992-1-2 [5] are used.



Permanent action

(self-weight is included): G_k= 5.5 kN/m^2

Variable action: Q_k= 4 kN/m^2

Slab thickness: h = 16 cm

Concrete grade: f_{ck} =30 Mpa

Steel grade: f_{yk}=500 Mpa

Figure 3. *Description of the slab geometry, load intensity and material properties*

- The design action for ambient temperature:

$$w_{Ed} = g_k \cdot \gamma_g + q_k \cdot \gamma_q = 5.5 \cdot 1.35 + 4 \cdot 1.5 = 13.425 kN/m \tag{4}$$

- The design action in case of fire:

$$w_{Ed,fi} = g_k \cdot \gamma_g + q_k \cdot \psi_1 = 5.5 \cdot 1.0 + 4 \cdot 0.6 = 7.9 kN/m \tag{5}$$

In practice, one way simply supported slabs are reinforced by placing the main reinforcement in the bottom part of the section, while only 50% of the main reinforcement is adopted as negative reinforcement and placed above the supports. The analysis has shown that, when a part of the negative reinforcement is extended along the entire span, as presented in Figure 4, better fire resistance is achieved. In this case, for 3D analysis, the slab is additionally reinforced in the middle part of the upper zone with 25% of the required positive reinforcement (Figure 4).

In case of 2D analysis, when beam elements are used, 10% of the main reinforcement is adopted as negative reinforcement.

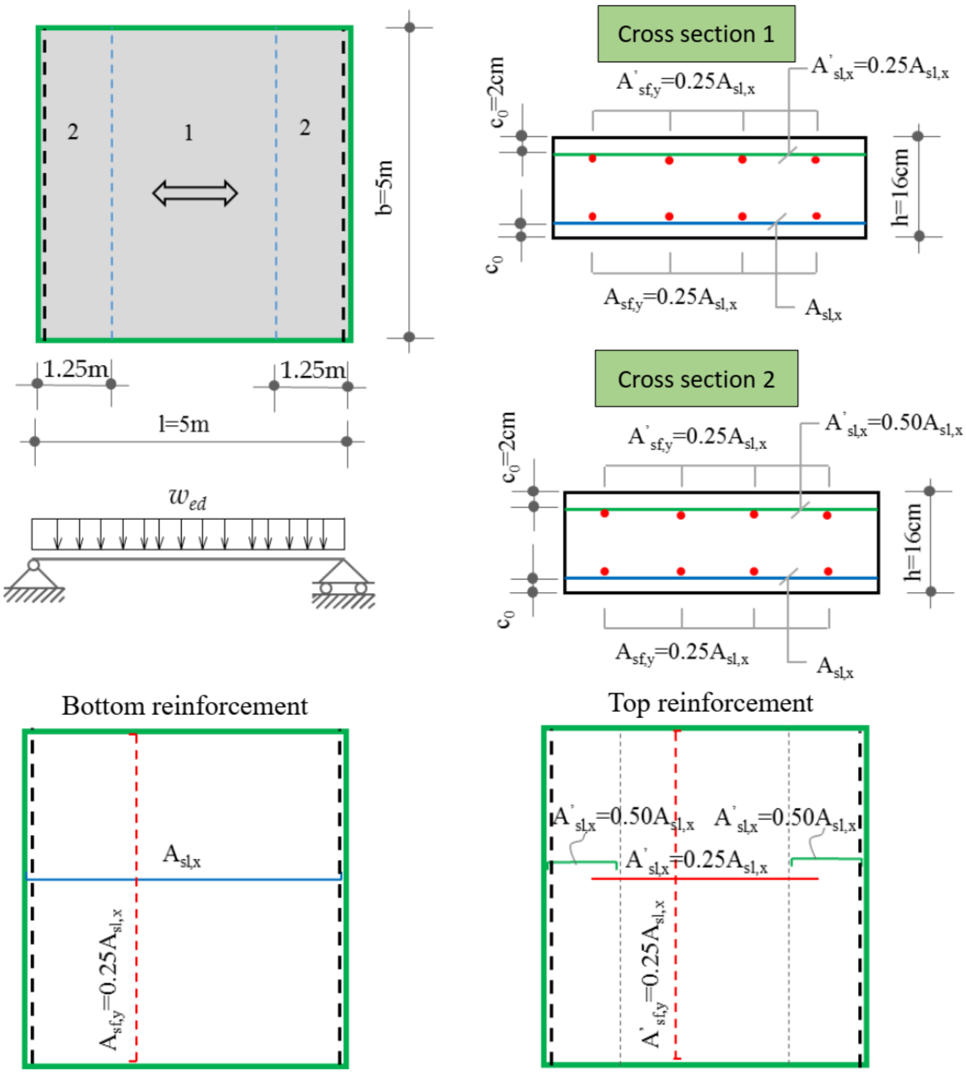


Figure 4. *Reinforcement schema for the one way simply supported slab, in case of 3D analysis*

For 3D analysis, the slab is discretized with 80 shell elements, when only a 1m wide strip is analysed, or 256 shell elements, when the slab is analysed with a real width of 5 m. The boundary conditions are shown in Figure 5.

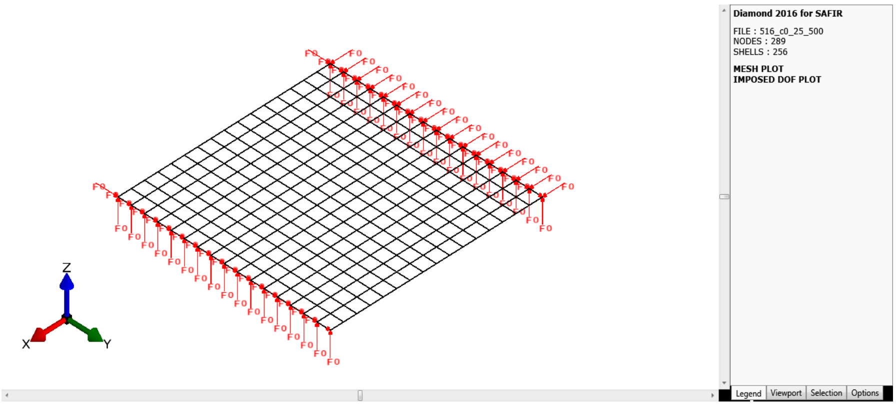


Figure 5. *3D model and boundary conditions of one way simply supported slab*

3.2. Fire resistance as function of concrete cover thickness

The concrete cover protects the reinforcement from high temperatures and has a positive effect on the fire resistance of structural elements. In case of one way simply supported slab, for analyzing these positive effects, three different values for the concrete cover thickness on the side of the fire (bottom side of the slab) are used: c_0 = 20 mm; c_0= 25 mm and c_0= 30 mm, while the concrete cover for the top reinforcement is c_0= 20 mm.

By changing the concrete cover, the lever arm of the cross section is also changed. Therefore, in order to find out the real influence of the concrete cover on the fire resistance of the analyzed slabs, the adopted reinforcement area is equal to the required one, Table 1. In such a way, the initial stresses in the reinforcement are the same for all three cases.

Table 1. *Main reinforcenet area as function of different concrete cover thickness*

Concrete cover thickness, c_0 (cm)	Adopted main reinforcement, $A_{sl,x}$ (cm^2)
2.0	7.778
2.5	8.136
3.0	8.532

The fire resistance of the one way simply supported slab mostly depends on the yield strength of the steel, i.e. the reinforcement, which is significantly reduced when the temperature is increased. The reduction coefficients are given in EN 1992-1-2 [4]. The influence of the concrete cover thickness on the reinforcement temperature is presented in Figure 6. It is obvious that as the thickness of the concrete cover increases, the temperature in the reinforcement decreases, which contributes to a smaller reduction of the yield strength of the steel and a higher bearing capacity of the slab.

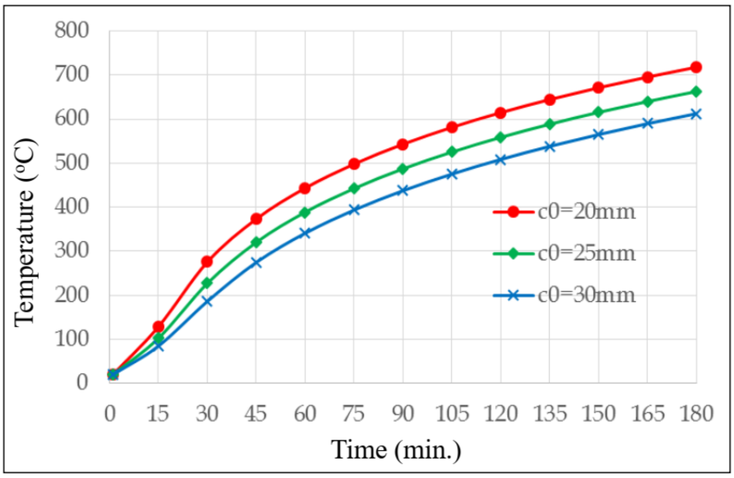


Figure 6. *Reinforcement temperature as function of the concrete cover thickness*

The vertical displacements in the middle of the span, when concrete cover thickness is 20 mm, obtained by 2D and 3D analyses, are presented in Figure 7. The time when the slab collapses is adopted as a criterion for the fire resistance and in that moment the program interrupts the calculation. Additionally, the fire resistance of the slab is determined by the simplified method given in EN 1992-1-2, and the obtained fire resistance is lower than in case of numerical analysis.

The diagrams from all three analyses show that, from the aspect of failure time, the slab has approximately the same fire resistance. In case of 3D analysis with real width of the slab, larger displacements are obtained than in case of 2D analysis, which is realistic, because the 3D analysis includes the effect of membrane forces. When the 3D analysis is performed on a strip with a width of 1 m, the number of finite elements is smaller, the time required for the analysis is shorter, but the effect of membrane forces cannot be expressed, consequently the vertical displacements are smaller than in case of 3D analysis when the real width of the slab is analysed.

From the aspect of load-bearing capacity, in order to shorten the calculation time, the fire resistance analyses can be performed on a 2D model that gives acceptable results even from the aspect of the vertical displacements. Only at moments before the failure, when the vertical displacements are significantly higher than *l/30* (criterion for maximum acceptable deflection) and the slab begins to function as a chain, the difference in displacements obtained by the two approaches decreases.

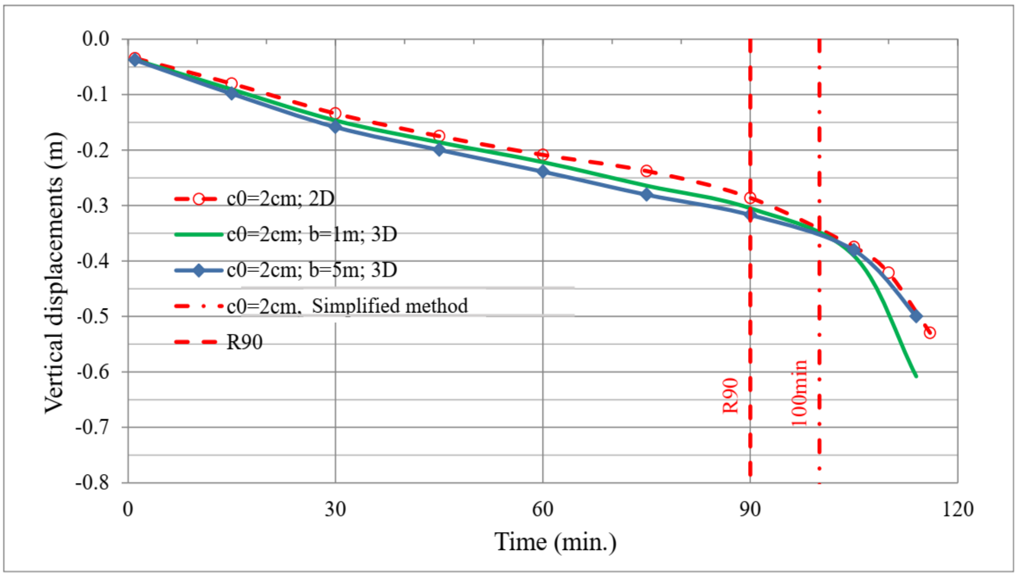


Figure 7. *Vertical displacements of one way simply supported slab with concrete cover thickness c_0=20 mm, according to 2D and 3D analyses and simplified method*

Temperature and time dependent vertical displacements of one way simply supported slab for different values of the concrete cover thickness, obtained with 2D analysis, 3D analysis for real width of the slab, and with the simplified method given in EN 1992-1-2, are presented in Figure 8. It is evident that the concrete cover thickness has a great influence on the fire resistance of the slab and on the value of the vertical displacements (deformations).

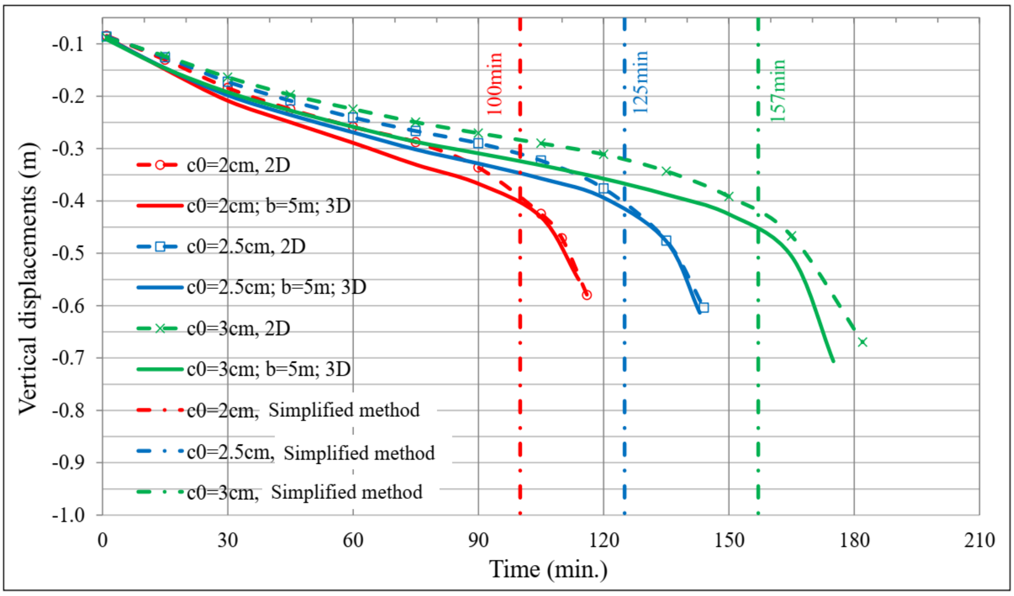


Figure 8. *Comparison of the vertical displacements of the simply supported slab exposed to fire from the bottom side, as function of the concrete cover thickness, according to 2D and 3D analyses and simplified method*

The results from the simplified calculation method, for the slab with concrete cover thickness c_0=20 mm, are presented in Figure 9. The reduction of the load bearing capacity of the slab is defined as function of the temperature of the bottom reinforcement. The moment when the load bearing capacity of the slab is equal to the bending moment for the design actions in case of fire (Equation 5), the slab collapses and this time expressed in minutes is the fire resistance of the slab.

$$M_{Ed,fi} \leq M_{Rd,fi} \tag{6}$$

In this case the fire resistance is 100 min., that means the slab satisfies the criterion R90.

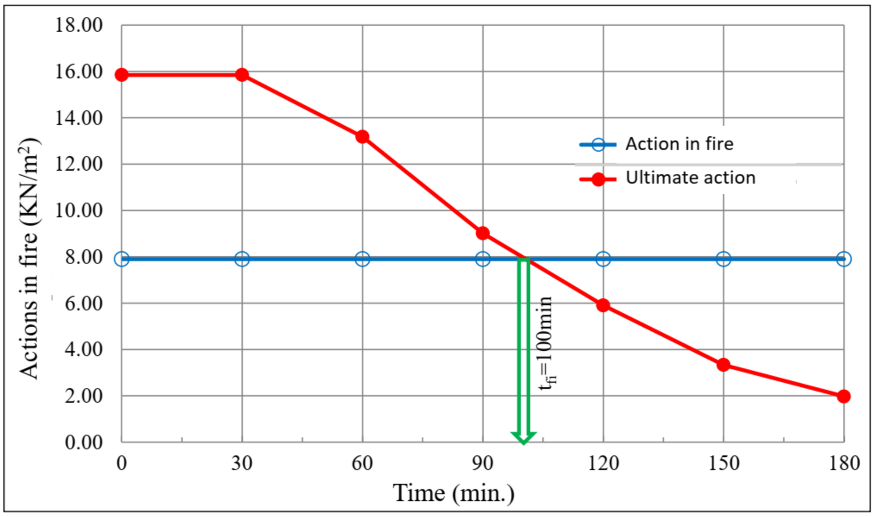


Figure 9. *Fire resistance of a one way simply supported slab with span L = 5 m and concrete cover thickness c_0=20 mm, according to simplified method given in EN 1992-1-2*

Taking under consideration that a simply supported slab is a statically determined girder, failure occurs at the moment when the maximal bending moment from external loads is equal to the bearing capacity of the slab which, as a result of high temperatures, decreases in time. The load-bearing capacity of the slab directly depends on the yield strength of the steel, i.e. the reinforcement in the lower zone of the slab which is exposed to high temperatures, For these reinforcement bars the strength and stiffness reduction is significant.

An overview of the influence of the concrete cover thickness on the fire resistance of simply supported slabs, exposed to fire from the bottom side, is presented in Table 2 and in Figure 10. The results from the aspect of bearing capacity and from the aspect of the slab vertical displacements are presented, i.e. the time when the vertical displacements reach the maximum allowed value *l / 30* (16.667 cm) is given, as a criterion for usability.

Table 2. *Fire resistance of one way simply supported slabs, according to the load-bearing criterion and the deformation criterion l / 30*

c_0 (cm)	t_{ult} (3D Analysis) (min)	t_{ult} (2D Analysis) (min)	Simplified method (min)	Displacements l/30 (min) (3D Analysis)	Displacements l/30 (min) (2D Analysis)
2.0	114	116	100	32	41
2.5	143	144	125	36	48
3.0	175	182	157	39	56

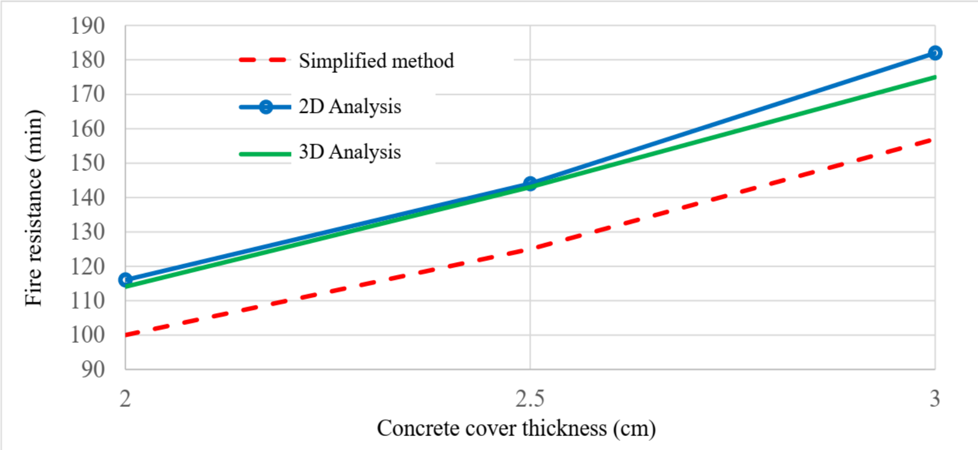


Figure 10. *Fire resistance of one way simply supported slab as function of the concrete cover thickness, according to 2D and 3D analyses and simplified method given in EN 1992-1-2*

3.3. Fire resistance as function of the reinforcement scheme

The aim of the analyses presented in this part is to clarify the influence of the nominal longitudinal reinforcement in the top zone (negative reinforcement) of the one way simply supported slab exposed to fire from the bottom side. The analyses are performed on a slab with a concrete cover thickness 25 mm. Three schemas for the top reinforcement are analysed, Figure 11.

In case of the first schema, the slab is not reinforced in the middle top zone, the schema that is most often used in practice for this type of slabs. In case of the second schema, the middle top zone is reinforced with 25% and above the support with 50% of the required main reinforcement (positive reinforcement). In case of the third schema, the top zone along the entire span is reinforced with 50% of the required main positive reinforcement. The distribution bars in all three schemas are adopted as 25% of the required main positive reinforcement. The scheme of the positive reinforcement in the bottom part of the section is the same in all three models, as it is shown in Figure 4.

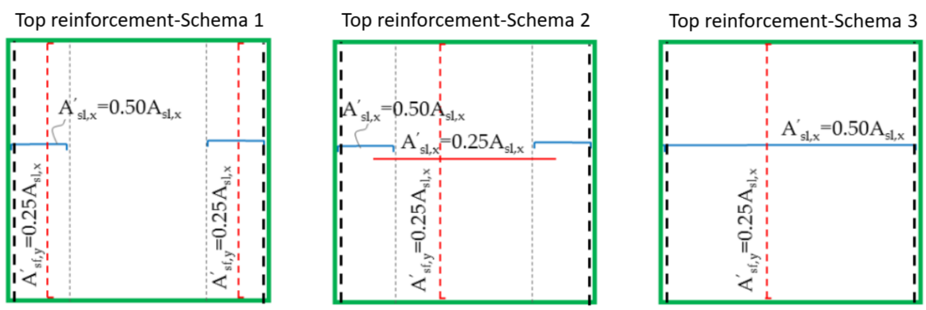


Figure 11. *Different reinforcement schemas for the top reinforcement of one way simply supported slab*

Figure 12 compares the vertical displacements in time for all three reinforcement schemas, obtained by 3D analyses with real width of the slab. The conducted analyses show that for all three reinforcement schemas, the slab shows the same behavior for up to 2 hours of fire exposure. At this time, the slab reinforced according to the second and third schema shows a slightly better behavior. The top reinforcement, although nominal, if placed along the entire span, increases the fire resistance of simply supported slabs. The reason for the better behavior of the slabs is the activation of the top nominal reinforcement for receiving the membrane forces which, at the moments when the vertical displacements are extremely large, i.e. when the slab works like a chain, grow rapidly.

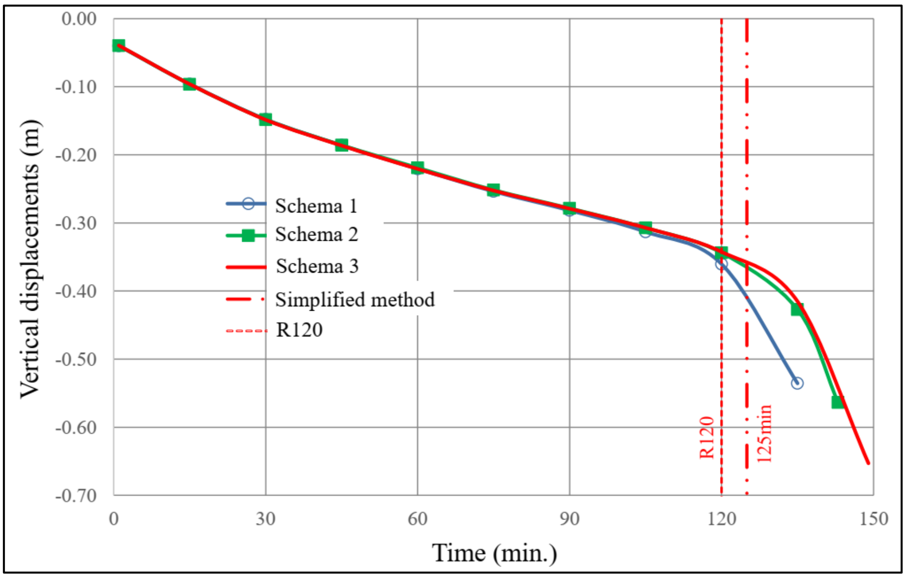


Figure 12. *Comparison of the vertical displacements of one way simply supported slabs, in case of three different reinforcement schemas for the top reinforcement*

The fire resistance of the slab, obtained by the simplified method given in EN 1992-1-2, is also presented in Figure 12, but in this calculation the load-bearing capacity of the top reinforcement is not taken into account.

Considering that the vertical displacements of the slab reinforced according to the second and third schema are the same, and that the third reinforcement schema gives only 6 minutes higher fire resistance, and the second schema is more economical, it is recommended to reinforce one way simply supported slabs by using the second reinforcement schema.

Simply supported slabs are statically determined girders and there is no redistribution of bending moments as a result of thermal actions. From this reason the effect of negative reinforcement is small, but positive.

3.4. Fire resistance as function of the slab span

In practice, in buildings, the floor slabs are usually constructed with different spans. Considering that the slabs are most often constructed with constant thickness, it is of interest to define the influence of the ratio between the thickness and the lab span on its fire resistance. In this part, one way simply supported slabs with span: l = 4 m, l = 5 m, l = 6 m, and thickness h = 16 cm, are analysed. The concrete cover for all three slabs is c_0 = 2 cm.

The loads and the material properties are presented in Figure 3. The adopted main reinforcement area is equal to the required one, which enables the initial stresses in the reinforcement to be equal in all three cases. In this way, the real influence of the ratio between the thickness and the slab span is obtained. Table 7.3 shows the adopted reinforcement area for the simply supported slabs with different spans.

Table 3. *Adopted main reinforcement area in case od different slab spans*

Slab span, L (m)	4	5	6
Adopted reinforcement are, $A_{sl,req}$ (cm^2)	*4.831*	*7.778*	*11.668*

Vertical displacements in time, up to failure, for simply supported slabs with different thickness/spam ratio, according to 2D and 3D analyses, are presented in Figure 13. It is obvious that decreasing the thickness/spam ratio results in greater deformations, but the fire resistance of the slabs is almost the same.

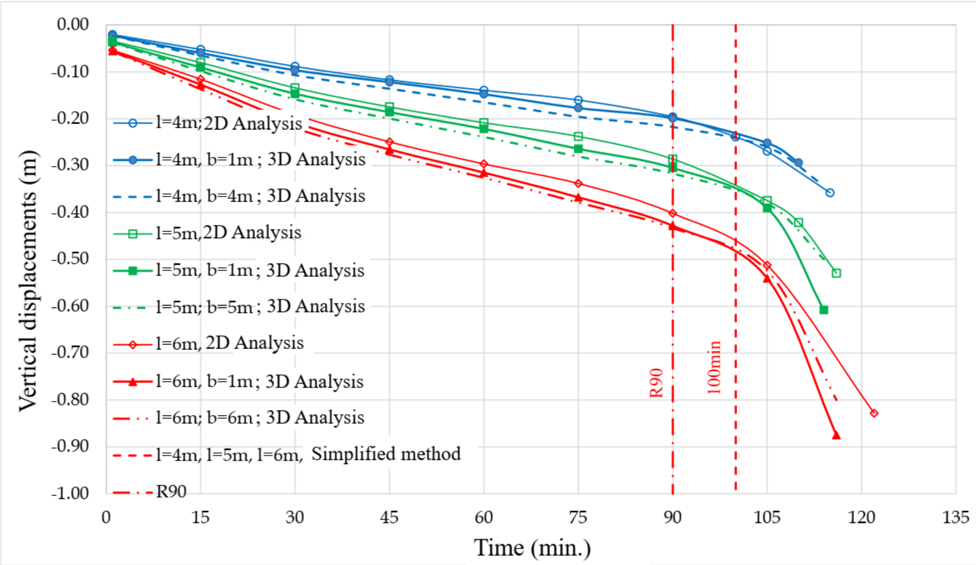


Figure 13. *Vertical displacements of simply supported slabs with spans: l = 4m, l = 5m, l = 6m, concrete cover c_0 = 2 cm, exposed to Standard fire ISO834, according to 2D and 3D analyses and according to the simplified method*

An overview of the effect of the span on the fire resistance of simply supported slabs is given in Table 4, Figure 14 and Figure 15. The fire resistance is defined according to two criteria: the load-bearing criterion (Figure 14) and the criterion based on maximum permitted deformations of the slab in case of fire (Figure 15).

From aspect of load-bearing capacity, the slabs collapse at same time. This is a result of the fact that the initial stresses in the reinforcement are the same in all three analysed slabs. As a result of same concrete cover thickness, the reinforcement temperatures are the same and the steel undergoes the same reduction of tensile strength. Having in mind that the simply supported slab is a statically defined girder, the increased and non-uniform temperature distribution in the slab cross section does not change the internal forces, i.e. the bending moments, consequently the slabs undergo the same reduction of the bearing capacity and collapse at the same time.

According to the criterion for maximum permitted vertical displacements, by increasing the span the thickness/span ration is decreased and consequently the fire resistance of the slab is decreases as a result of larger deformations (Figure 13).

The fire resistance of simply supported slabs according to the criterion for permitted deformations is significantly lower in relation to the fire resistance according to the load-bearing criterion. This is based on the fact that, due to changes in the "σ-ε" diagram for concrete and steel at high temperatures, structures in fire become more ductile and can survive significantly larger dilatations before failure than in case of ambient temperatures.

Table 4. *Fire resistance of one way simply supported slabs, according to the load-bearing criterion and the deformation criterion l / 30, as function of the span*

Fire resistance (min.)					
L (m)	t_{ult} (2D Analysis)	t_{ult} (3D Analysis)	t_{ult} (EN 1992-1-2)	Deflection *l/30* (2D Analysis)	Deflection *l/30* (3D Analysis)
4	115	114	100	55	43
5	116	114	100	41	32
6	122	116	100	32	26

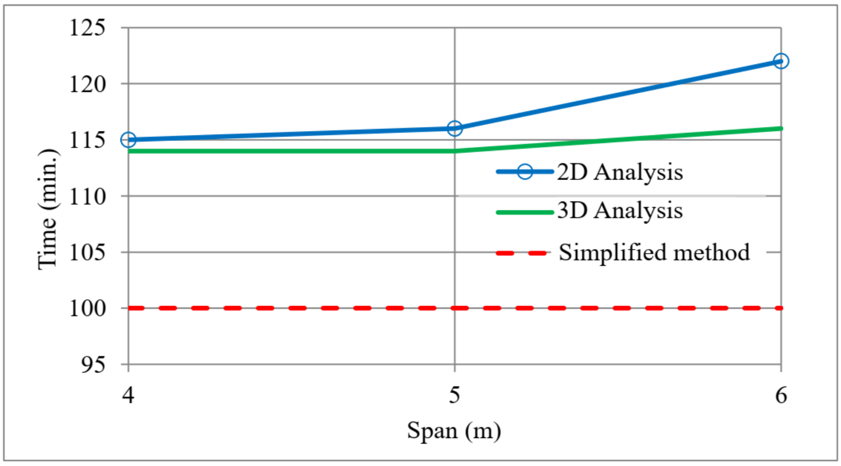


Figure 14. *Fire resistance of one way simply supported slabs, for different spans, according to 2D and 3D analyses, and according to EN 1992-1-2 simplified method*

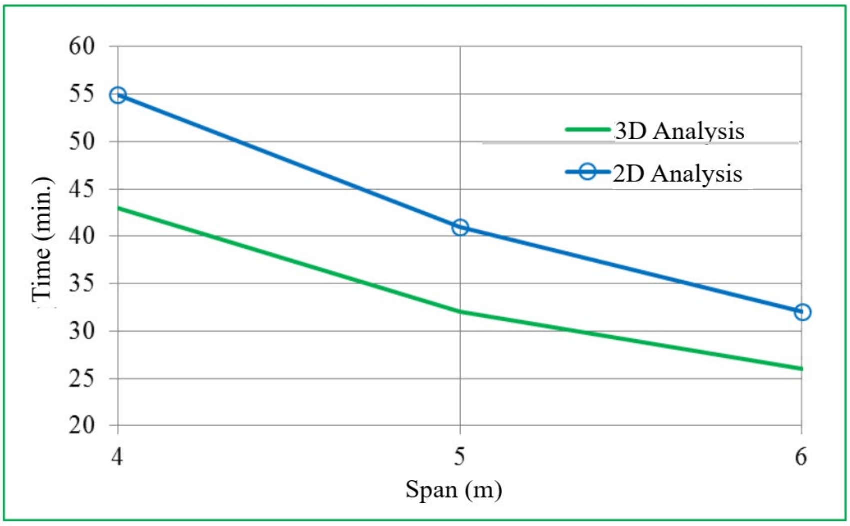


Figure 15. *Time when the vertical displacements at the mid span of the slabs with different spans reach the value l / 30, according to 2D and 3D analysis*

4. CONSLUSIONS

From the aspect of failure time, the results obtained by 2D analyses, 3D analyses for 1 m strip and 3D analyses for the real width of the slabs, are almost equal. In case of 3D analysis with real width of the slab, larger displacements are obtained than in case of 2D analysis, which is realistic, because the 3D analysis includes the effect of membrane forces. When the 3D analysis is performed on a strip with a width of 1 m, the number of finite elements is smaller, the time required for the analysis is shorter, but the effect of membrane forces cannot be expressed, consequently the vertical displacements are smaller than in case of 3D analysis for real width of the slab.

From the aspect of load-bearing capacity, in order to shorten the calculation time, the fire resistance analyses of the slabs can be performed on a 2D model that gives acceptable results even from the aspect of the vertical displacements. Only at the moments before the failure, when the vertical displacements are significantly higher than *l/30* (criterion for maximum acceptable deflection) and the slab begins to function as a chain, the difference in displacements between the two approaches decreases.

The fire resistance obtained with the simplified method given in EN 1992-1-2 is lower and is always on the side of safety. It is easy for use, but does not provide data for the vertical displacements.

Based on the parametric analyses, the following conclusions are drawn:

- The concrete cover thickness has a great influence on the load-bearing capacity of the slabs. If the concrete cover is increased by 0.5 cm, the fire resistance can be increased by up to 30 minutes, depending on the thermal characteristics of the concrete.
- The reinforcement schema for the negative reinforcement has small positive effect on increasing the fire resistance of the one way simply supported slabs. The reason for the better behavior of the slabs is the activation of the top nominal reinforcement for receiving the membrane forces which, at the moments when the vertical displacements are extremely large, i.e. when the slab works like a chain, grow rapidly.
- The span of one way simply supported slabs has an impact on their fire resistance only from the aspect of the criterion for permitted deformations, which in defining the fire resistance of structures is not taken as relevant, because the main goal is the structure to survive the fire for the prescribed time of fire action.

LITERATURE

[1] EN 1991-1-2: Eurocode 1: Actions on structures - Part 1-2: General actions - Actions on structures exposed to fire, 2002

[2] ISO, Fire Resistance Tests, Elements of Building Construction, ISO 834, International Organization for Standardization, Geneva, 1975

[3] A. Buchanan, Structural design for fire safety, Wiley, New York, USA, 2001

[4] SAFIR-Computer program, University of Liege, Belgium, 2014

[5] EN 1992-1-2: Eurocode 2: Design of concrete structures - Part 1-2: General rules. Structural fire design, 2004

[6] A.M. Sanad, S. Lamont, A.S. Usmani, J.M. Rotter, “Structural behaviour in fie compartment under different heating regimes-part 2: (slab mean temperatures)”, Fire Safety Journal, Vol. 35, pp. 117-130, 2000

[7] M. Cvetkovska, “Nonlinear Stress Strain Behaviour of RC Elements and Plane Frame Structures Exposed to Fire”, Doctoral dissertation, Ss Cyril and Methodius University in Skopje, Macedonia, 2002

[8] A. Levesque, “Fire Performance of Reinforced Concrete Slabs”, Master Thesis, Worcester Polytechnic Institute, 2006

[9] G. Wang, "Performance of Reinforced Concrete Flat Slabs Exposed to Fire", Fire Engineering Report 06/2, University of Canterbury, Christchurch, New Zealand, 2006

[10] L. Lim, "Membrane Action in Fire Exposed Concrete Floor Systems", Doctoral dissertation, Departament of Civil Engineering, University of Canterbury, Christchurch, New Zealand, 2003

[11] A. Balaji, P. Nagarajan, T.M. Madhavan Pillai, “Predicting the response of reinforced concrete slab exposed to fire and validation with IS456 (2000) and Eurocode 2 (2004) provisions”, Alexandria Engineering Journal, Vol. 55, pp. 2699–2707, 2016

[12] C.G. Bailey, “Membrane action of slab/beam composite floor systems in fire”, Engineering Structures, vol. 26, pp. 1691–1703, 2004

[13] B. Wang, Y. Dong, L. Gao, “Fire Experimental Study of Four-Edge Fixed Reinforced Concrete Slab in Fire”, Advanced Materials Research,Vols 163-167, pp 1626-1637, 2011

[14] Y. Wang, W. Guo, Z. Huang, B. Long, G. Yuan, W. Shi, Y. Zhang, “Analytical model for predicting the load–deflection curve of post-fire reinforced-concrete slab”, Fire Safety Journal, Vol. 101, pp 63–83, 2018

[15] I. A. FLETCHER, S. WELCH, J.L. TORERO, R.O. CARVEL, A. USMANI “Behaviour of concrete structures in fire”, Thermal Science, January 2007

[16] K.F. Chung, A.J. Wang, “Fire resistance design of composite slabs in building structures: from research to practice”, Structural Engineer , January 2006

06 | Research paper I Оригинални научни рад
ISSN 2566-4484 I Doi 10.7251/STP2014055O
pages 55-62

Nikola Obradović, nobradovic@grf.bg.ac.rs, Faculty of Civil Engineering, University of Belgrade

Marija Todorović, todorovicm@grf.bg.ac.rs, Faculty of Civil Engineering, University of Belgrade

Miroslav Marjanović, mmarjanovic@grf.bg.ac.rs, Faculty of Civil Engineering, University of Belgrade

Emilija Damnjanović, edamjanovic@grf.bg.ac.rs, Faculty of Civil Engineering, University of Belgrade

DIAGRAMS FOR STRESS AND DEFLECTION PREDICTION IN CROSS-LAMINATED TIMBER (CLT) PANELS WITH NON-CLASSICAL BOUNDARY CONDITIONS

Abstract:

Invention of cross-laminated timber (CLT) was a big milestone for building with wood. Due to novelty of CLT and timber's complex mechanical behavior, the existing design codes cover only rectangular CLT panels, simply supported along 2 parallel or all 4 edges, making numerical methods necessary in other cases. This paper presents a practical engineering tool for stress and deflection prediction of CLT panels with non-classical boundary conditions, based on the software for the computational analysis of laminar composites, previously developed by the authors. Diagrams applicable in engineering practice are developed for some common cases. The presented methodology could be a basis for more detailed design handbooks and guidelines for various layouts of CLT panels and different types of loadings.

Keywords: cross-laminated timber, stress, deflection, Eurocode 5, layerwise plate theory

ДИЈАГРАМИ ЗА ПРОРАЧУН НАПОНА И УГИБА CLT-ПАНЕЛА СА НЕСТАНДАРДНИМ УСЛОВИМА ОСЛАЊАЊА

Сажетак:

Појава унакрсно-ламелираног дрвета (CLT) представља прекретницу у градњи дрветом. Како је CLT нов материјал са сложеним механичким понашањем, постојећи стандарди за прорачун покривају само слободно ослоњене правоугаоне панеле. Стога су нумеричке методе неопходне у осталим случајевима. У овом раду је представљен практичан инжењерски алат за прорачун напона и угиба CLT панела са нестандарним условима ослањања, базиран на (од стране аутора) раније развијеном програму за прорачун ламинатних композита. Дати су дијаграми за поједине случајеве који су примењиви у инжењерској пракси. Ова методологија може бити основа за детаљније смернице при прорачуну CLT панела различитих облика, услова ослањања и оптерећења.

Кључне ријечи: унакрсно-ламелирано дрво, напон, угиб, Еврокод 5, слојевита теорија плоча

1. INTRODUCTION

The cross-laminated timber (CLT) is rapidly spreading in most European countries. It is an innovative material, in which timber boards are assembled in layers and glued together crosswise in order to form massive timber wall and floor panels. Since timber is an anisotropic material, gluing laminations at right angles allows for the panels to have better strength and stiffness properties in both directions compared to traditional timber. In addition, CLT has good insulation properties inherited from wood and good behavior in case of fire.

There is an ongoing trend that CLT continuously shifts the limits for tall timber buildings [1, 2]. In the early 2000s, construction with CLT increased drastically due to the green building tendency. Typical building types from CLT include multi-family apartments, multi-storey business or administrative buildings.

Mechanical properties and design procedures for CLT have been regulated via international European Technical Approvals (ETAs) started in 2006. The first activities standardizing CLT in Europe began in 2008 and the first European product standard for CLT, EN 16351 [3], has recently passed the formal vote. CLT is going to be included in the European timber design code Eurocode 5 [4]. One of the reasons for the slow progress in the development of timber design codes, and in particular, for the difficulties to fully understand the mechanics of timber materials, lies mainly in the highly complex nature of wood microstructure [5].

CLT panels are generally produced in a rectangular shape and foreseen to be line supported in one or both directions. However, as a consequence of architectural design requirements, CLT panels are often manufactured in shapes that are irregular and/or that have openings (e.g. for staircases or chimneys). Furthermore, due to structural demands, the panels are not always simply line supported on two sides, but they can have different support systems depending on the vertical members that transfer the load from the slabs to the foundations. For example, balconies are designed as cantilever slabs, while façade columns represent point supports, as shown in Figure 1.

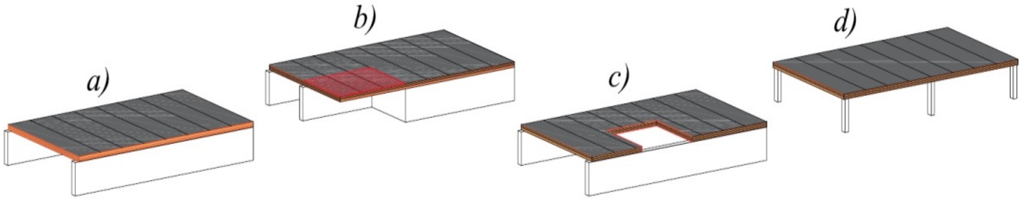


Figure 1. *Different support systems of CLT floors: (a) standard beam-like structure (b) balcony; (c) rectangular opening; (d) point supports*

1.1. Analytical design methods for clt panels

For determining stress state of CLT panels in bending (normal - σ_m, and shear stresses - τ_V), there are several commonly used analytical procedures. Most common is Gamma method implemented in Annex B of Eurocode 5 [4] and pro:Holz recommendations [6]. Besides this method, other analytical procedures are: composite theory of Blass [7], shear analogy method [8], Timoshenko [9] or laminated beam theories [10]. These methods use a simplified approach, treating the 2D structure as a beam system, which do not completely take advantage of the cross-lamination.

Gamma method accounts for the horizontal shear deformation occurring in the cross-layers and vertical shear deformation in the longitudinal layers. Longitudinal layers are taken as beam elements connected with „imaginary“ fasteners that have stiffness equal to that of rolling shear of cross layers. The stiffness properties are defined using the effective moment of inertia $I_{0,ef}$ that depends on the section properties and the connection efficiency factor γ. The Gamma method can be used for a maximum of 5 layers and it is recommended for span-to-depth (*a/h*) ratio greater than 30. If the CLT slab has more than 5 layers, the Extended Gamma Method (EGM) is required.

In the composite theory (*k*-method), strength and stiffness properties of single layers are taken into account using the so-called "composition factors" (k_i) [7]. In the method, Bernoulli's hypothesis and linear stress-strain relationship are assumed. Therefore, it doesn't consider shear deformation and it can only be used for $a/h > 30$.

1.2. Deflection prediction for clt panels

The deflection of CLT panels is derived according to Eurocode 5 [4]. Final deflection w_{fin} results from both the instantaneous (w_{inst}) and creep deflection (w_{creep}):

$$w_{inst} = w_G + \sum_{i \geq 1} \psi_{2,i} \cdot w_{Q,i}, \quad w_{creep} = k_{def} \cdot w_{inst}, \quad w_{fin} = w_{inst} \cdot \left(1 + k_{def}\right) \leq \frac{l}{300} \tag{1}$$

where w_G and w_Q are the deflections from permanent and variable loads, respectively, k_{def} is deformation factor, ψ_2 is factor for quasi-permanent value of a variable action and l is the shortest span of the CLT slab. Factor k_{def} evaluates creep deformation and takes into account the relevant service class and material type. Factor ψ_2 depends from the type of a variable action considered, that is, from its duration.

Low specific weight of timber is a disadvantage when it comes to serviceability of elements loaded out of plane, such as CLT floors, due to the possibility of uncomfortable deflections and vibrations in these elements [11]. Since serviceability limit state usually governs design of timber floors both stresses and deflections are considered in this paper.

The aim of the paper is to provide practical engineering tool for stress and deflection prediction of CLT panels with non-classical boundary conditions. Based on the previously developed software for the computational analysis of laminar composites, diagrams applicable in engineering practice are developed for some common cases. The methodology presented in the paper could serve as a basis for the development of more detailed handbooks and guidelines.

2. FINITE ELEMENT MODEL FOR STRESS AND DEFLECTION PREDICTION IN CLT PANELS

The existing analytical 2D procedures for CLT analysis are limited to the simple rectangular panels, simply supported along 2 parallel or all 4 edges. Consequently, there is a necessity to use numerical methods for the analysis of CLT panels in many cases of everyday engineering practice.

The possible solution for the above issue is the application of finite element model based on the full-layerwise theory (FLWT) of Reddy [10]. It was initially developed for the analysis of composite laminates with a thickness of h, made of n orthotropic layers. In the FLWT, the displacement field (u, v, w) of an arbitrary point (x,y,z) of the laminate is given as:

$$u(x,y,z) = \sum_{I=1}^{N} U^I(x,y)\Phi^I(z),\; v(x,y,z) = \sum_{I=1}^{N} V^I(x,y)\Phi^I(z),\; w(x,y,z) = \sum_{I=1}^{N} W^I(x,y)\Phi^I(z) \tag{2}$$

where $U^I(x,y)$, $V^I(x,y)$ and $W^I(x,y)$ are the displacement components in the I^{th} numerical layer of the plate in directions x, y and z, respectively, while N is the number of interfaces between the layers including both top and bottom surfaces. $\Phi^I(z)$ are selected to be linear layerwise continuous functions of the z-coordinate [10]. Piece-wise linear variation of all three displacement components through the plate thickness is imposed, leading to the 3D stress description of all material layers. The stresses in the k^{th} layer may be computed from the well-known lamina 3-D constitutive equations. Based on the FLWT, the displacement finite element model is derived using an assumed interpolation of the displacement field [12, 13]. Element stiffness matrix and force vector are obtained using 2-D Gauss-Legendre quadrature for quadrilateral domains. Quadratic serendipity (Q8) layered quadrilateral elements have been used in the paper. To avoid shear locking, reduced integration is used (2×2 Gauss points). The assumed piecewise linear interpolation of displacement field through the laminate thickness provide discontinuous stresses across the interface between adjacent layers. Once the nodal displacements are obtained, the stresses σ_x, σ_y, σ_z, τ_{yz}, τ_{xz} and τ_{xy} can be computed from the constitutive relations of every layer k [12, 13]. Since the interlaminar stresses τ_{yz}, τ_{xz} and σ_z calculated in this way do not satisfy continuous distribution through the laminate thickness, they are re-computed assuming the quadratic distribution within each layer for every stress component [12, 13].

3. DIAGRAMS FOR STRESS AND DEFLECTION PREDICTION IN CLT PANELS

3.1. Overview

Due to stress concentration occurrence around the openings, the driving factor for the design of CLT panels could be both stress or deformation criteria. This requires employment of refined numerical methods when designing complex-shape panels. Since one of the biggest downsides of CLT structures is price, savings could be made with more accurate design procedures like the one presented in this paper.

In this part, the finite element model presented in the previous section is used for the stress and deflection prediction in CLT panels. For the proposed numerical method to be used in structural design, it needs to be practical, which is achieved through definition of easily applicable diagrams.

Manufacturing process and transportation limitations define the panel size that can be delivered to construction sites. Therefore, panel-to panel connections, used to connect panels along their longitudinal edges and transfer in-plane forces, are mostly established on site. These connections should allow for quick and easy assembly and give almost unlimited possibilities for panels length-to-width ratios. There are various panel-to-panel connections, such as internal splines, single surface splines, double surface splines, half-lapped joint, tube connection system, etc, as shown in Figure 2.

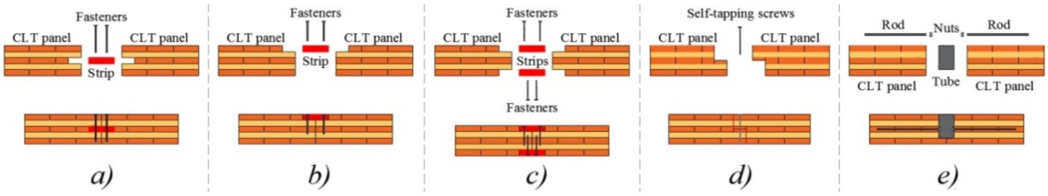


Figure 2. *Various types of CLT panel connections*

The influence of connections within the panel could be introduced in the proposed model by introducing the narrow strip of the finite elements with reduced elastic material properties, to account for the disconnection between two connected panels. This influence is not considered in the paper.

3.2. Rectangular clt panels with non-classical boundary conditions

First, rectangular CLT panels with different combinations of boundary conditions are considered (Figure 3a-c). The panels are exposed to uniformly distributed loading q_0 on the top surface. The 3-layer (L/h = 20), 5-layer (L/h = 20 and L/h = 30) and 7-layer panels (L/h = 20 and L/h = 30), are analysed (Figure 3d). The span-to-thickness ratios (L/h) have been selected in order to cover wide range of possible practical problems.

Table 1. *Mechanical properties for C24 timber class*

E_L	E_T=E_R	G_{LT}=G_{LR}	G_{RT}	ν_{LT}	ν_{LR}	ν_{RT}
11000 N/mm^2	370 N/mm^2	690 N/mm^2	69 N/mm^2	0.49	0.39	0.64

All layers are of equal thickness. Each layer is considered as a C24 unidirectional lamina, with the material properties given in Table 1 [14, 15]. The fiber direction of the outside layers for all CLT panels is parallel to the span L, while transverse layers are parallel to the B direction.

In the finite element model, boundary conditions are defined in edge nodes as: U^1=W^1=0 for the L-edges, and V^1=W^1=0 for edges parallel to B. Element size of L/10 was used. The laminas are modeled as single numerical layer, adopting the linear distribution of displacements along the lamina thickness.

Using the finite element models of the considered panels, plots of the dimensionless transverse deflection $\bar{w} = w \cdot E_T h^3 / \left(q_0 L^4\right) \cdot 1000$, dimensionless normal stress at the bottom interface in the center of the panel $\bar{\sigma}_0 = \sigma_0 \cdot h / \left(q_0 L\right)$ and dimensionless transverse shear stress at the mid surface along the B-edge of the panel $\bar{\tau}_{xz} = \tau_{xz} \cdot h / \left(q_0 L\right)$ are generated and illustrated in Figures 4-9.

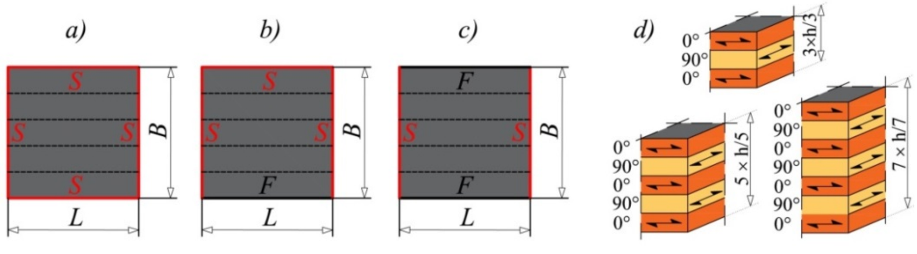


Figure 3. *(a-c): layouts of considered rectangular CLT panels with various boundary conditions; (d): considered stacking sequences. S – simply supported, F – free.*

The selected points are those where stresses and deflections reach maximum values. The obtained results are compared against the results from the same models, with boundary conditions corresponding to the plate simply supported only along B-edges (the scenario which is covered the most in technical approvals for CLT [4, 6]).

To account for the variety of B/L and L/h ratios, the following geometry ranges were used for the calculation: L = (2.7-6.3m), B = (2.7-31.5m), h_{plate} = (9-21cm), h_{layer} = 3cm.

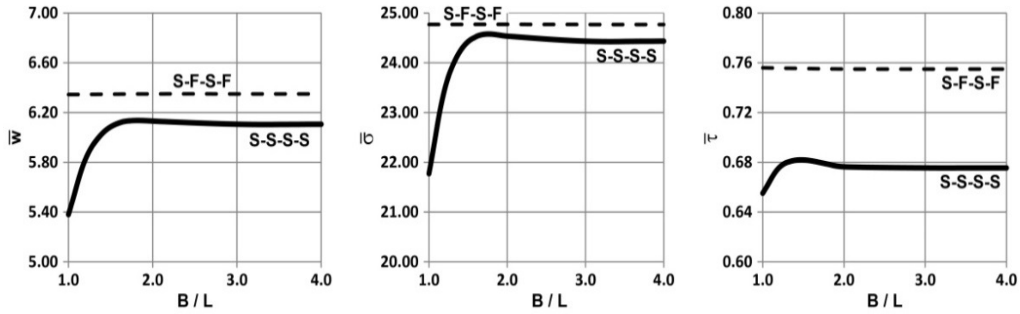


Figure 4. *Dimensionless transverse deflection, normal and transverse shear stress of 3-layer rectangular CLT panel, considering various B/L ratios and different boundary conditions*

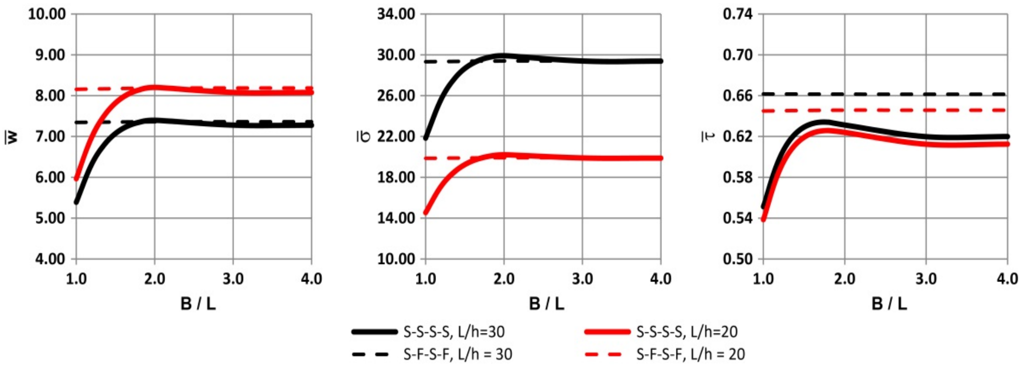


Figure 5. *Dimensionless transverse deflection, normal and transverse shear stress of 5-layer rectangular CLT panel, considering various B/L and L/h ratios and different boundary conditions*

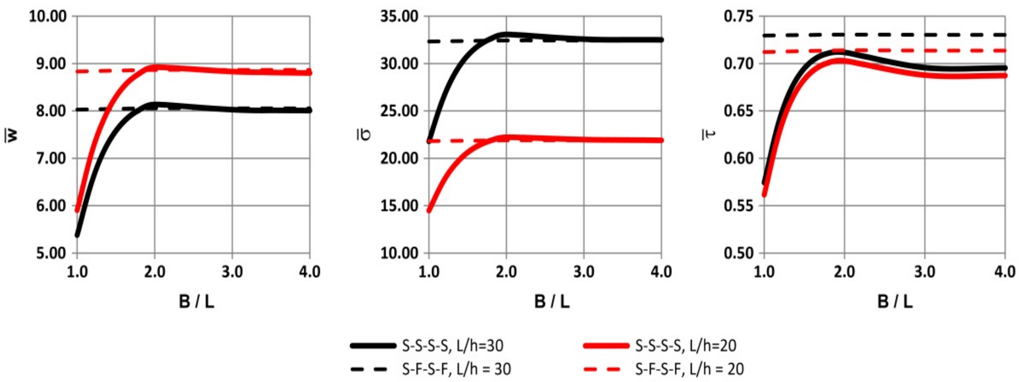


Figure 6. *Dimensionless transverse deflection, normal and transverse shear stress of 7-layer rectangular CLT panel, considering various B/L and L/h ratios and different boundary conditions*

The presented diagrams (Figure 4-6) confirm the justification of using the beam-like models for the design of CLT panels with B/L higher than 2. However, savings could be made for square-like panels, both for the deflection criterion (up to 15% for the 3-layer, 26% for the 5-layer and 32% for the 7-layer panel), and normal stress criterion (12% for the 3-layer, 25% for the 5-layer and 27% for the 7-layer panel).

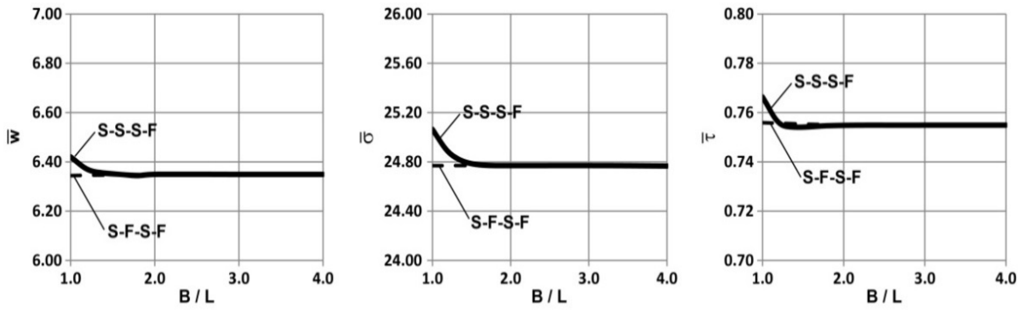


Figure 7. *Dimensionless transverse deflection, normal and transverse shear stress of 3-layer rectangular CLT panel, considering various B/L ratios and different boundary conditions*

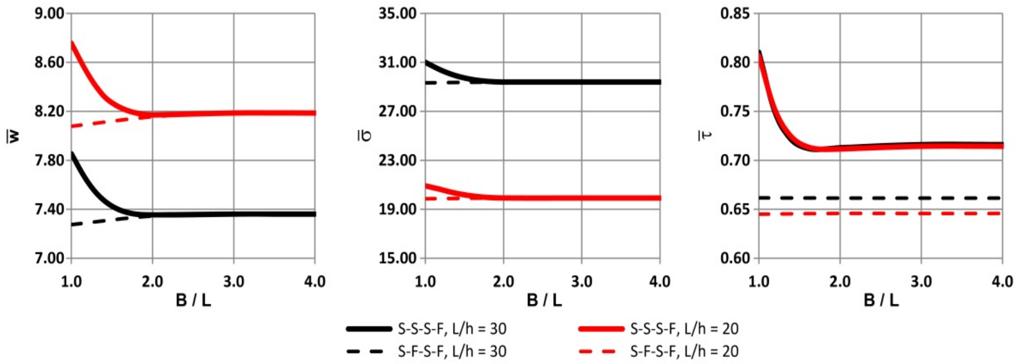


Figure 8. *Dimensionless transverse deflection, normal and transverse shear stress of 5-layer rectangular CLT panel, considering various B/L and L/h ratios and different boundary conditions*

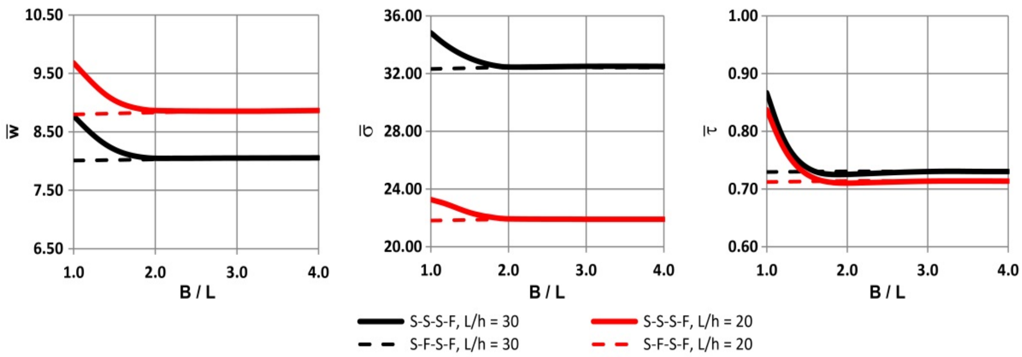


Figure 9. *Dimensionless transverse deflection, normal and transverse shear stress of 7-layer rectangular CLT panel, considering various B/L and L/h ratios and different boundary conditions*

Obviously, the effects of the transverse shear deformation are more pronounced for thick panels, illustrated by the higher relative differences in dimensionless deflections for the 7-layer than for the other considered types of panels. The diagrams shown in Figures 7-9 also confirm the justification of using the beam-like models, for *B*/*L*>2. The cross lamination effect is pronounced for square-like panels, resulting in the slight increase of $\overline{w}$, $\overline{\sigma}_0$ and $\overline{\tau}_{xz}$.

3.3. Complex-shape clt panels

The FEM-based model will be used for bending analysis of CLT panels with balcony (Figure 10). The analytical procedures [4-10] are not completely applicable in this situation, or may lead to the conservative values while designing the CLT floor. When such CLT panels are considered, the driving factor for the design could be both stress and deformation criterion.

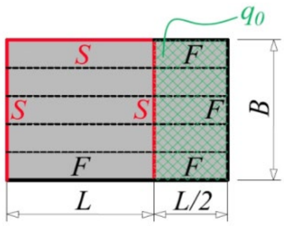


Figure 10. *Layout of CLT panel with balcony*

The panels are exposed to uniformly distributed loading q_0 on the top surface of the balcony, according to Figure 10. Note that for the panels loaded unlike the Figure 10 scheme, diagrams presented in Figures 7-9 are applicable, while for the loading over the entire panel, superposition principle could be applied. The 5-layer (L/h = 20 and L/h = 30) and 7-layer panels (L/h = 20 and L/h = 30), are considered, with the material properties elaborated in Section 3.2. The modeling approach and assignment of boundary conditions is the same as in the previous examples.

To account for the variety of B/L and L/h ratios, the following geometry ranges were used for the calculation: L = (4.5-6.3m), B = (4.5-31.5m), h_{plate} = (15-21cm), h_{layer} = 3cm.

Using the finite element models of the considered panels, plots of the dimensionless transverse deflection $\overline{w}\,(L/2,\ B/2)$ – plate center and $\overline{w}\,(3L/2,\ B/2)$ – end of the cantilever, dimensionless normal stress at the top interface $\overline{\sigma}_0\,(L,\ B/2)$ and dimensionless transverse shear stress $\overline{\tau}_{xz}\,(L,\ 0)$ at the mid surface are generated and illustrated in Figures 11-12.

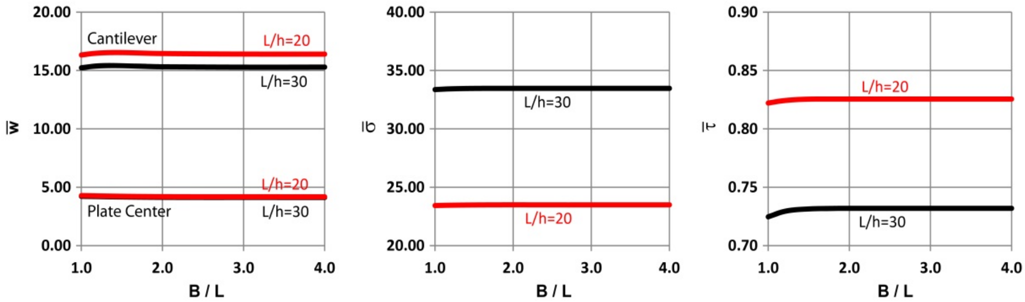


Figure 11. *Dimensionless transverse deflection, normal and transverse shear stress of 5-layer CLT panel with balcony, considering various B/L and L/h ratios*

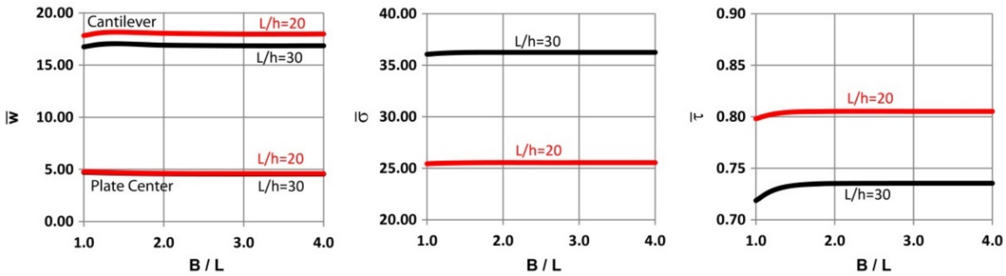


Figure 12. *Dimensionless transverse deflection, normal and transverse shear stress of 7-layer CLT panel with balcony, considering various B/L and L/h ratios*

4. CONCLUSIONS

The paper provides diagrams for the prediction of stresses and deflections in cross-laminated timber (CLT) panels with non-classical boundary conditions, under uniformly distributed loading, derived based on the previously developed software for the computational analysis of laminar composites. The methodology presented in the paper could serve as a basis for the development of more detailed handbooks and guidelines, covering various layouts of CLT panels, different types of loadings and introducing a variety of timber classes. Beside the presented diagrams applicable in static analysis of such structures, the same methodology could be applied for systematic overview of dynamic properties of CLT panels.

Based on the conducted research, some conclusions are derived:

- The justification of using the beam-like (S-F-S-F) models for the design of CLT panels is confirmed for the ratios *B*/*L* higher than 2.
- The effects of transverse shear deformation must be accounted by using refined plate theories when analyzing the thick (i.e. 7-layer) panels.
- Considerable savings could be made for square-like panels (*L*~*B*), both for the deflection and stress criteria, by introducing the effects of 2-way load carrying mechanism.
- Using the superposition principle, more layouts of CLT floors could be designed by combining the diagrams for simple combinations of boundary conditions.

ACKNOWLEDGMENTS

The financial support of the Ministry of Education, Science and Technological Development of the Republic of Serbia, through the project TR-36048, is acknowledged. The full license of GiD software is provided by the Institute for Structural Mechanics, Ruhr University Bochum.

LITERATURE

[1] Cvetković R, Stojić D, Krasić S, Marković N. Innovative structural CLT system in projecting and building of student houses. Facta Universitatis – series Architecture and Civil Engineering 2015; 13(1): 57-64.

[2] Jeleč M, Varevac D, Rajčić V. Cross-laminated timber (CLT) – a state of the art report Građevinar 2018; 70: 75-95.

[3] European Committee of Standardization (CEN). EN 16351: timber structures – Cross Laminated Timber –requirements, Bruxelles, Belgium, 2015.

[4] European Committee of Standardization (CEN). EN 1995-1-1: Eurocode 5: Design of timber structures - Part 1-1: General - Common rules and rules for buildings, Bruxelles, Belgium, 2004.

[5] Flores EIS et.al. Analysis of cross-laminated timber by computational homogenization and experimental validation. Composite Structures 2015; 121: 386-394.

[6] Walner-Novak M, Koppelhuber J, Pock K. Cross-Laminated Timber Structural Design, ProHolz, Austria, 2014.

[7] Blass HJ, Fellmoser P. Design of solid wood panels with cross layers. Proceedings of the World Conference on Timber Engineering WCTE 2004, Lahti, Finland, 2004.

[8] Kreuzinger H. Platten, Scheiben und Schalen – ein Berechnungsmodell für gängige Statikprogramme. Bauen mit Holz 1999; 1:34.

[9] Timoshenko SP. On the correction for shear of the differential equation for transverse vibrations of prismatic bars. The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science, Series 6, Volume 41, Issue 245, 1921.

[10] Reddy, JN. Mechanics of laminated composite plates and shells: Theory and analysis. 2nd edition, CRC Press, Boca Raton, Florida, 2003.

[11] Chulain CU, Sikora K, Harte AM. Influence of connection systems on serviceability response of CLT timber flooring. Proceedings of the World Conference on Timber Engineering WCTE16. Vienna, Austria, 2016.

[12] Marjanović M, Damnjanović E. Bending analysis of cross-laminated-timber (CLT) panels using layered finite elements. In: Praščević Ž, Pejović R, Salatić R, Nefovska-Danilović M (Eds.): "Theory of Civil Engineering Structures", Faculty of Civil Engineering, University of Belgrade, Faculty of Civil Engineering, University of Montenegro, Academy of Engineering Sciences of Serbia. Belgrade, 2019, 91-100.

[13] Damnjanović E, Marjanović M. Three-dimensional stress analysis of laminated composite plates using FLWT-based finite elements. Proceedings of the 7th International Congress of Serbian Society of Mechanics. Sremski Karlovci, Serbia, June 24-26, 2019.

[14] European Committee of Standardization (CEN). EN 338: Structural Timber – strength classes. Bruxelles, Belgium, 2009.

[15] Hearmon R.. The elasticity of wood and plywood. Forest Products Research Special Report No. 7, HMSO London, 1948.

07 | Research paper I Оригинални научни рад
ISSN 2566-4484 I Doi 10.7251/STP2014063J
pages 63-70

Miloš M. Jočković, milosjockovic32@gmail.com, Faculty of Civil Engineering, University of Belgrade

Marija Nefovska – Danilović, marija@grf.bg.ac.rs, Faculty of Civil Engineering, University of Belgrade

ISOGEOMETRIC – BASED DYNAMIC ANALYSIS OF BERNOULLI – EULER CURVED BEAM SUBJECTED TO MOVING LOAD

Abstract:

In this paper dynamic analysis of a curved Bernoulli – Euler beam subjected to a moving load is presented. Moving load is modelled as a single force with constant magnitude and direction, which moves along its trajectory. Plane curved Bernoulli – Euler beam element is formulated using isogeometric approach where both the displacement field and geometry of the beam are described using NURBS basis functions. Behavior of the beam element is defined and studied in the case of linear formulation where displacements and displacement gradients are assumed to be small. Validation of the proposed approach is presented for the plane curved beam subjected to moving load with constant velocity, magnitude and direction.

Keywords: isogeometric Bernoulli – Euler curved beam, moving load, linear analysis

ДИНАМИЧКА АНАЛИЗА РАВАНСКЕ ИЗОГЕОМЕТРИЈСКЕБЕРНУЛИ – ОЈЛЕРОВЕ КРИВЕ ГРЕДЕ ОПТЕРЕЋЕНЕ ПОКРЕТНИМ ОПТЕРЕЋЕЊЕМ ПРИМЕНОМ ИЗОГЕОМЕТРИЈСКОГ ПРИСТУПА

Сажетак:

У овом раду приказана је динамичка анализа криволинијског Бернули – Ојлеровог гредног носача оптерећеног покретним оптерећењем. Покретно оптерећење је дефинисано као концентрисана сила константног интензитета, правца и смера, која се креће по својој трајекторији. Раванска криволинијска греда је формулисана применом изогеометријског приступа где се поље померања описује истим функцијама као и геометрија конструкције, НУРБС функцијама. Анализа утицаја покретног оптерећења на конструкцију се врши у условима малих померања и градијената померања, тј. у условима линеарне анализе. Валидација приказаног приступа је дата на примеру раванске криволинијске греде која је оптерећена покретним оптерећењем константног интензитета, правца, смера и брзине кретања.

Кључне ријечи: изогеометријска Бернули – Ојлерова крива греда, покретно оптерећење, линеарна анализа

1. INTRODUCTION

Moving load generates dynamic response, which can be critical for bridges and cranes amongst others. This load, generated by the moving mass on the structure, is usually modelled as a gravitational force with constant magnitude and direction [1, 2]. Using this formulation the inertial part of moving mass is neglected which can be significant in some cases [3]. It is essential to define moving load trajectory and its position of the structure at each time. In linear dynamic analysis, the assumption that the moving load trajectory matches the undeformed structure geometry is valid and will be used in this formulation.

Curved structure geometry can be defined using CAD (*Computer Aided Design*) software packages, which are based on NURBS (*Non Uniform Rational B-Spline*) functions. These rational functions are used for their capability to exactly represent shapes of conical sections like circle, ellipse, parabola, hyperbola as well as free form curves. Consequently, the trajectory of the moving load can be obtained exactly using the NURBS basis functions.

Most of the software packages for structural analysis are based on finite element method (FEM). In order to apply FEM, physical domain of a structure has to be discretized, forming mesh of finite elements. This discretization is obtained from the structure's geometrical model. If the analysis results are not accurate, finer mesh is required which is obtained from the geometrical model of the structure. Back and forward procedure between the structural geometry and analysis model can use great computational and time resources, which represent a disadvantage of the FEM.

In order to overcome this disadvantage, the isogeometric approach (IGA) has been developed by Hughes and his co-workers [4] where solution space is formed using the same basis functions - NURBS that are used for geometry description. The focus of IGA utilization is on curved structural elements. For several years great effort has been devoted to the formulation of a Bernoulli – Euler curved elements for static and dynamic analysis [5 – 7].

In this paper dynamic analysis of a curved plane Bernoulli - Euler beam subjected to a moving load is presented. The trajectory of a load matches the beam geometry, which has been defined using NURBS basis functions. This assumption is valid for linear dynamic analysis. Plane curved beam is defined using Bernoulli – Euler beam theory as presented in [7]. All necessary elements have been implemented in MATLAB [8] and used to calculate dynamic response. The results obtained using the presented formulation are compared with the results from the literature.

2. BASICS OF NURBS

Geometry of a plane curve $\mathbf{C}(\xi)$ can be represented using NURBS parametrization as:

$$\mathbf{C}(\xi) = \sum_{i=1}^{n} R_{i,p}(\xi)\,\mathbf{C}_i \tag{1}$$

where ξ represents the independent parameter, $R_{i,p}(\xi)$ is the i-th NURBS basis function of degree p, while $\mathbf{C}_i$ is the i-th control point defined in Cartesian coordinate system. As can be noticed, basis vectors are defined in parametric domain using so-called knot vector composed of non-decreasing sets (ξ_i) of coordinates in parametric domain, called knots. NURBS functions as rational functions are constructed from B – Spline functions as:

$$R_{i,p}(\xi)=\sum_{i=1}^{n} \frac{N_{i,p}(\xi)\cdot w_i}{\sum_{j=1}^{n} N_{j,p}(\xi)\cdot w_j} \tag{2}$$

where w_i is i-th function weight. B – Spline functions are polynomial functions obtained using Cox de Boor algorithm. For the case of zero degree the B – Spline functions are defined as:

$$N_{i,p}(\xi) = \begin{cases} 1, & \text{if } \xi \in [\xi_i,\xi_{i+1}[\\ 0, & \text{otherwise} \end{cases} \tag{3}$$

while for the polynomial degree greater than zero:

$$N_{i,p}(\xi) = \begin{cases} \dfrac{\xi - \xi_i}{\xi_{i+p} - \xi_i} N_{i,p-1}(\xi) + \dfrac{\xi_{i+p-1} - \xi}{\xi_{i+p+1} - \xi_{i+1}} N_{i+1,p-1}(\xi), & \text{if } \xi \in [\xi_i, \xi_{i+p+1}[\\ 0, & \text{otherwise} \end{cases} \tag{4}$$

B – Spline functions have a property of non – negativity, partition of unity, and with adequate choice of knot vector, interpolator property at the domain boundary. The properties of B – Spline functions are inherited for NURBS basis functions, which is important for beam formulation. In Figure 1 plane curve with an arbitrary shape defined using four control points and adequate NURBS basis functions has been presented. More about B – Spline and NURBS functions and their properties and utilization can be found in [9].

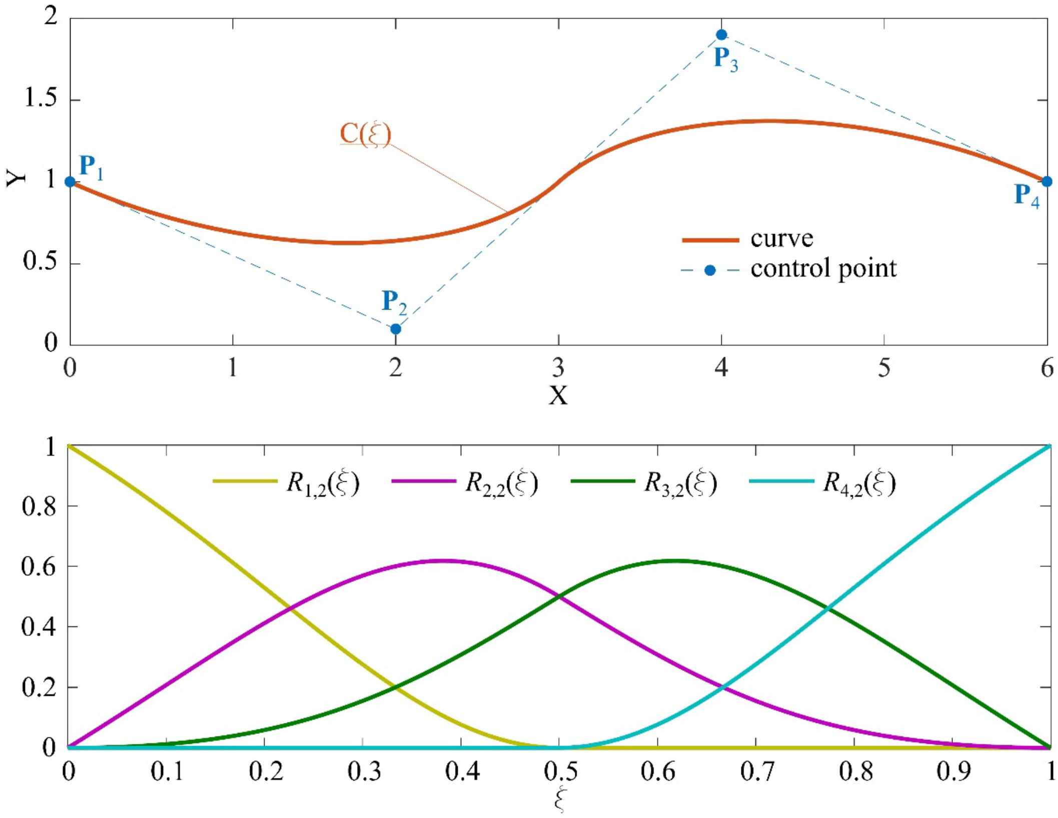


Figure 1. Plane curve and corresponding NURBS basis functions

3. BEAM GEOMETRY

Due to the assumption of undeformable beam's cross section, all beam quantities are defined at beam's centerline. Centerline of curved beam is curve line which can be parametrized using NURBS parametrization as:

$$\mathbf{r}(\xi) = \sum_{i=1}^{n} \mathrm{R}_{i,p}(\xi)\, \mathbf{r}_i \tag{5}$$

where $\mathbf{r}(\xi)$ is the position vector of beam's centreline, while $\mathbf{r}_i$ is the i-th control point, Figure 2. Using well-known relations of differential geometry [10] the basis vectors of plane curve are defined as:

$$\mathbf{g}_1 = \mathbf{r}_{,1} = \frac{d\mathbf{r}}{d\xi} = \frac{d\mathbf{r}}{ds}\frac{ds}{d\xi} = \mathbf{t}\frac{ds}{d\xi} = \mathbf{t}\sqrt{g_{11}} \tag{6}$$

$$\mathbf{g}_2 = \frac{\mathbf{K}}{K} = \frac{1}{K}\frac{d\xi}{ds}\frac{d}{d\xi}\left(\frac{\mathbf{g}_1}{|\mathbf{g}_1|}\right) \tag{7}$$

where $\mathbf{g}_1$ vector is the general non-unit vector collinear to tangent vector $\mathbf{t}$, $\mathbf{g}_2$ is the normal vector perpendicular to tangent vector thus lies in beam's cross section, $\mathbf{K}$ is the curvature vector with its modulus K, while s represents the arc – length coordinate. Metric tensor of presented reference frame is obtained as:

$$g_{ij} = \begin{bmatrix} g_{11} & 0 \\ 0 & 1 \end{bmatrix},\ det\left(g_{ij}\right) = g_{11} = g \tag{8}$$

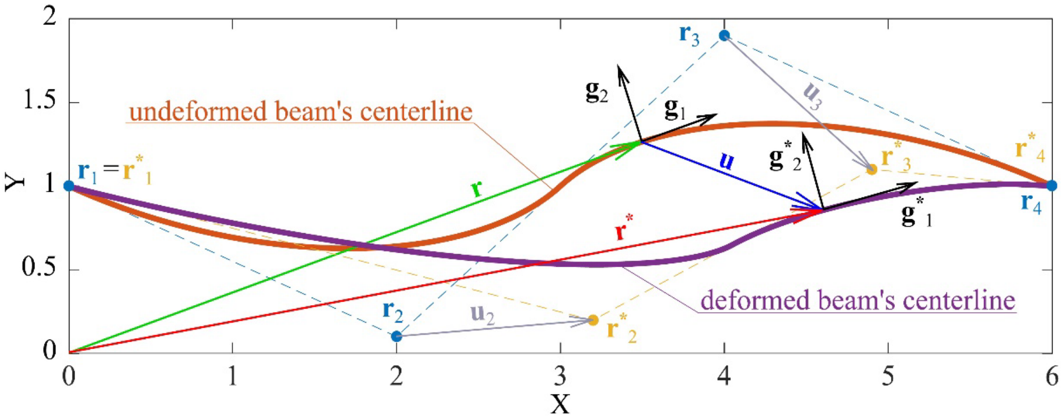


Figure 1. Undeformed and deformed beam's centerline

First derivative of basis vectors with respect to the parametric coordinate is obtained using Frenet – Serret relation as:

$$\begin{bmatrix} \mathbf{g}_{1,1} \\ \mathbf{g}_{2,1} \end{bmatrix} = \begin{bmatrix} \Gamma^1_{11} & gK \\ -K & 0 \end{bmatrix} \begin{bmatrix} \mathbf{g}_1 \\ \mathbf{g}_2 \end{bmatrix} \tag{9}$$

where $\Gamma^1{}_{11}$ is Christoffel symbol of the second kind. Using the frame of reference, the position vector of an arbitrary point of beam is obtained as:

$$\tilde{\mathbf{r}} = \mathbf{r} + \eta \mathbf{g}_2 \tag{10}$$

where η represents the coordinate axis in the direction to the beam's cross section principle axis. From previous relation the basis vectors of an arbitrary point are:

$$\tilde{\mathbf{g}}_1 = (1\text{-}\ \eta K)\mathbf{g}_1 \tag{11}$$

$$\tilde{\mathbf{g}}_2 = \mathbf{g}_2 \tag{12}$$

As can be noticed, second basis vector is independent on the point position due to the assumption of rigid cross section. Metric tensor of an arbitrary point is obtained as:

$$\tilde{g}_{ij} = \begin{bmatrix} g_0\, g_{11} & 0 \\ 0 & 1 \end{bmatrix},\ g_0 = (1\text{-}\ \eta K)^2 \tag{13}$$

4. ISOGEOMETRIC BERNOULLI – EULER BEAM FORMULATION

Position vector of beam's centerline in deformed configuration is given as:

$$\mathbf{r}^* = \mathbf{r} + \mathbf{u} \tag{14}$$

where $\mathbf{u}$ represents the displacement vector of beam's centreline, Figure 2. If both undeformed and deformed beam configurations are parametrized using the same parametrization, then the displacement vector is defined as:

$$\mathbf{u}(\xi) = \sum_{i=1}^{n} R_{i,p}(\xi)\,\mathbf{u}_i = \sum_{i=1}^{n} R_{i,p}(\xi)\,u_i^m \mathbf{i}_m \tag{15}$$

Eq. (15) represents the main property of the isogeometric approach where geometry and solution space are defined using the same basis functions.

Using convective system of reference, the deformation of the beam is contained in the deformation of beam's basis vectors as:

$$\mathbf{g}_m^* = \mathbf{g}_m + \mathbf{u}_m \tag{16}$$

In addition, displacement field of an arbitrary point is given as:

$$\tilde{\mathbf{u}} = \mathbf{u} + \eta \mathbf{u}_2 \tag{17}$$

Correspondingly, acceleration and displacement variations of an arbitrary beam point are given as:

$$\tilde{\mathbf{a}} = (\ddot{\tilde{\mathbf{u}}}) = \ddot{\mathbf{u}} + \eta \ddot{\mathbf{u}}_2 \tag{18}$$

$$\delta\tilde{\mathbf{u}} = \delta\mathbf{u} + \eta\,\delta\mathbf{u}_2 \tag{19}$$

As mentioned before, the beam formulation is given in the convective system of reference. Thus, the axial deformation term of the deformation tensor is obtained as:

$$\tilde{\varepsilon}_{11} = \frac{1}{2}\left(\tilde{g}_{11}^* - \tilde{g}_{11}\right) = g_0[(1+\eta K)\varepsilon_{11} - \eta\kappa] \tag{20}$$

where terms ε_{11} and κ represent respectively the strain deformation of the beam's centreline and bending deformation about the axis $\mathbf{g}_2$:

$$\varepsilon_{11} = \frac{1}{2}\left(g_{11}^* - g_{11}\right) \tag{21}$$

$$\kappa = \overline{K}^* - \overline{K} = \mathbf{g}_2 \cdot \left(\mathbf{u}_{1,1} - \Gamma_{11}^1 \mathbf{u}_{,1}\right) \tag{22}$$

In this paper, generalized Hook's law is used in order to define relation between stress and deformation terms:

$$\tilde{\sigma}^{ij} = \frac{E}{1+v}\left(\tilde{g}^{ik}\tilde{g}^{jl}\tilde{\varepsilon}_{kl} + v\tilde{g}^{ij}\tilde{g}^{11}\tilde{\varepsilon}_{11}\right) \tag{23}$$

where E is Young's modulus, while v represents the Poisson's coefficient. In order to obtain equations of motion, the principle of virtual work is used:

$$\int_V \rho\tilde{\mathbf{a}}\cdot\delta\mathbf{u}dV + \int_V \mathbf{S}:\delta\mathbf{E}dV = \int_l \mathbf{f}\cdot\delta\mathbf{u}dx \tag{24}$$

where ρ is the mass density, $\mathbf{S}$ is the second Piola-Kirchoff stress tensor, $\delta\mathbf{E}$ is variation of the Green-Lagrangian strain tensor, while $\mathbf{f}$ is the external load. Applying Eqs. (18), (19), (20) and (23), the governing equation of moving load problem on curved beam is obtained:

$$\mathbf{M}\ddot{\mathbf{q}} + \mathbf{K}\mathbf{q} = \mathbf{Q} \tag{25}$$

where $\mathbf{M}$ is the mass matrix, $\mathbf{K}$ is the stiffness matrix, $\mathbf{Q}$ is the vector of equivalent control forces, while $\mathbf{q}$ is the displacement vector of the control points. In order to solve Eq. (25), numerical step by step integration has been applied based on the finite difference method. Also, for calculation of mass and stiffness matrices, given in [7], as well as vector of equivalent forces, reduced numerical integration [11] has been applied and implemented in original MATLAB [8] code.

5. MOVING LOAD

Moving load is a spatially varying load, which generates dynamic response of a structure. This load can be modelled as a single force with constant magnitude ($\mathbf{f}_0$) and direction, which moves along a beam with velocity V_ξ:

$$\mathbf{f}(t) = \mathbf{f}_0 \cdot \delta\left(\xi - V_\xi t\right),\ V_\xi = \frac{d\xi}{dt} = \frac{V}{\sqrt{g}} \tag{26}$$

where V_ξ and V are the velocity magnitudes given in NURBS and arc - length parametrizations, respectively. Point moving load transformed with respect to the integration points is presented in Figure 3.

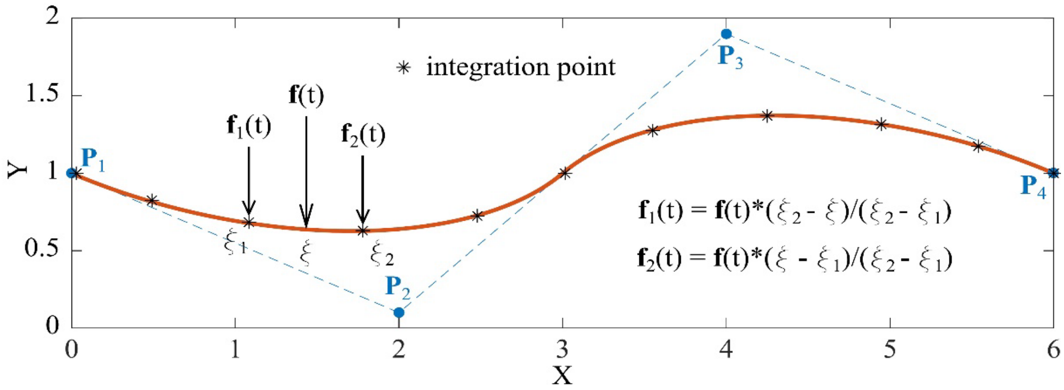


Figure 2. Moving load distribution on integration points

6. NUMERICAL EXAMPLE

To illustrate and validate the proposed method, dynamic analysis of simply supported plane curved beam subjected to the moving load is carried out. Geometry, material properties and load of the beam are given in Figure 4. Beam geometry is generated using the following control points:

$$\mathbf{r}^{\mathrm{T}} = \begin{bmatrix} 0 & 5 & 10 \\ 0 & 5\cdot\tan(\pi/6) & 0 \end{bmatrix} \tag{27}$$

and NURBS basis functions of degree 2 constructed using knot vector $\boldsymbol{\xi}^{\mathrm{T}} = [0\ \ 0\ \ 0\ \ 1\ \ 1\ \ 1]$ and weights $\mathbf{w}^{\mathrm{T}} = [1\ \ \sin(\pi/3)\ \ 1]$. Applied force has magnitude of 0.106 *kN* and moves along the beam with velocity $V = 8.1$ *m/s*.

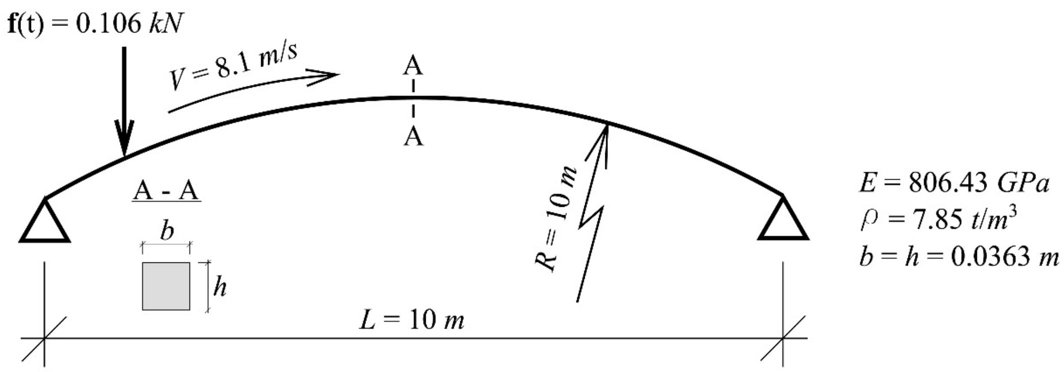


Figure 3. Simply supported curved beam subjected to the moving load with constant velocity and magnitude

The convergence of the presented approach has been investigated using the *h* – refinement, which is achieved by knot insertion in the parametric domain. By applying this refinement procedure, the geometry of structure remains unchanged while the number of degrees of freedom (DOF) increases.

In this example, four beam models are analyzed with different number of DOFs: Model 1 (10 DOFs), Model 2 (22 DOFs), Model 3 (42 DOFs), Model 4 (82 DOFs). In Figure 5, time history of the displacement at the position of the moving load is presented. The results converged in Model 3 with 42 DOFs. However, some discrepancies have been noticed in comparison with the results reported in [3]. These discrepancies occurred due to the applied beam model based on Timoshenko theory.

7. CONCLUSIONS

In this paper the dynamic analysis of a curved plane Bernoulli – Euler beam subjected to a moving load is presented. The moving load is modelled as a point force with constant magnitude and direction, while the curved beam is modelled using the isogeometric approach. It is assumed that the moving load trajectory matches the shape of the undeformed beam. In order to validate presented formulation the numerical example of a moving load on a curved plane beam has been carried out. Good agreement between the results obtained using the presented approach and the results from the literature has been shown. For future research, the dynamic analysis of a plane curved beam subjected to a moving mass will be investigated. In addition, the influence of moving load and mass can be extended to the case of spatial curved beam element.

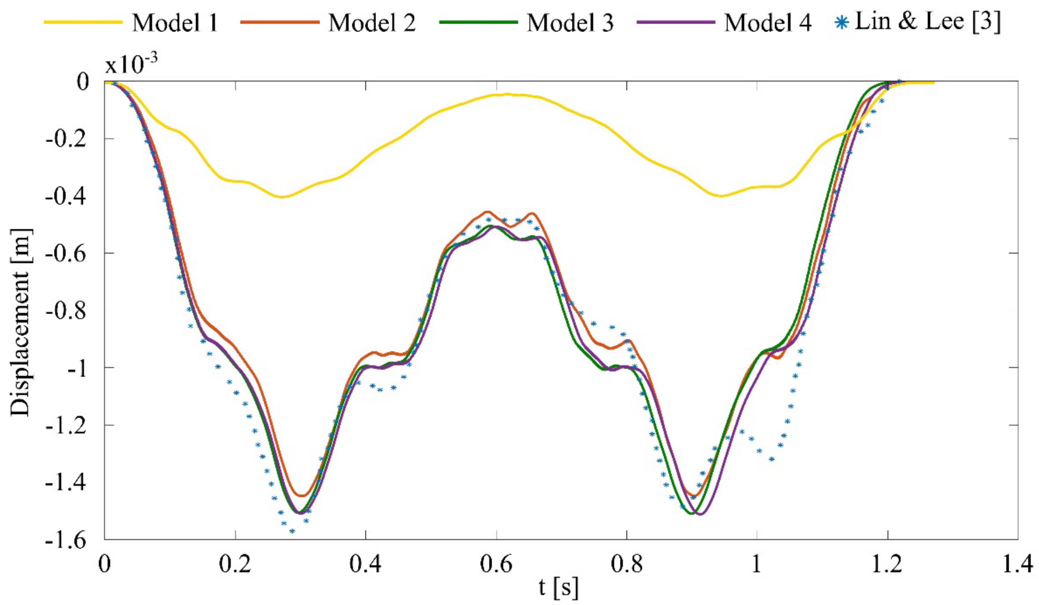


Figure 4. Vertical displacement of beam at the position of the moving load

LITERATURE

[1] J. –S. Wu, L. –K. Chiang, "Dynamic analysis of an arch due to a moving load", Journal of Sound and Vibration, vol. 269, pp. 511 – 534, 2004.

[2] M. R. Rostam, F. Javid, E. Esmailzadeh, D. Younesian, "Vibration suppression of curved beams traversed by off – center moving loads", Journal of Sound and Vibration, vol. 352, pp. 1 – 15, 2015.

[3] S. – M. Lin, K. – W. Lee, "Instability and vibration of vehicle moving on curved beams with different boundary conditions", Mechanics of Advanced Meterials and Structures, vol. 23 (4), pp. 375 – 384, 2016.

[4] T. J. R. Hughes, J. A. Cottrell, Y. Bazilevs, "Isogeometric analysis: CAD, finite elements, NURBS, exact geometry and mesh refinement", Computer Methods in Applied Mechanics and Engineering, vol. 194 (39 – 41), pp. 4135 – 4195, 2005.

[5] G. Radenković, Isogeometric Theory of Structures (in Sebian), University of Belgrade – Faculty of Architecture, 2014, pp. 1 – 307.

[6] A. Borković, S. Kovačević, G. Radenković, S. Milovanović, M. Guzijan – Dilber, "Rotation – free isogeometric analysis of an arbitrary curved plane Bernoulli – Euler

beam", Computer Methods in Applied Mechanics and Engineering, vol. 334 , pp. 238 – 267, 2018.

[7] M. Jočković, M. Baitsch, M. Nefovska – Danilović, "Free vibration analysis of curved Bernoulli – Euler beam using isogeometric approach", in Proceeding of 6th International Congress of Serbian Society of Mechanics, 2017, pp. S1c1 – S1c10.

[8] MATLAB, version R2013, Matick, Massachusetts: The MathWorks Inc.; 2013.

[9] L. Piegl, W. Tiller, The NURBS Book, Springer, 1997, pp. 1 – 646.

[10] M. P. do Carmo, Differential Geometry of Curves and Surfaces, Prince – Hall, 1976, pp. 1 – 503.

[11] C. Adam, T. J. R. Hughes, S. Bouabdallah, M. Zarroug, H. Maitournam, "Selective and reduced numerical integrations for NURBS – based isogeometric analysis", *Computer Methods in Applied Mechanics and Engineering*, vol. 284 , pp. 732 – 761, 2015.

08 | Research paper I Оригинални научни рад
ISSN 2566-4484 I Doi 10.7251/STP2014071M
pages 71-76

Snježana Maksimović, snjezana.maksimovic@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

Nebojša Đurić, nebojsa.djuric@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

Ivan Vanja Boroja, ivan-vanja.boroja@etf.unibl.org, Faculty of Electrical Engineering, University of Banja Luka

Sandra Kosić-Jeremić, sandra.kosic-jeremic@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

SOME RECURRENCE FORMULAS FOR A NEW CLASS OF SPECIAL POLYNOMIALS AND SPECIAL FUNCTIONS

Abstract:

In this paper we used a new class of special functions and special polynomials which are solutions different Sturm Liouvile differential equations of second order. These functions form a basis of a space of square integrable functions over set of a real numbers. We investigated some properties of these polynomials and established some recurrence formulas. Using a new class of special functions, we obtained some useful summation formulas and recurrence formulas.

Keywords: differential equations, recurrence formulas, special functions, special polynomials

НЕКЕ РЕКУРЗИВНЕ ФОРМУЛЕ ЗА НОВУ КЛАСУ СПЕЦИЈАЛНИХ ПОЛИНОМА И СПЕЦИЈАЛНИХ ФУНКЦИЈА

Сажетак:

У раду смо користили нову класу специјалних функција и специјалних полинома који су рјешења различитих Штурм Лиувилових диференцијалних једначина другог реда. Те функције формирају базу простора квадратно интеграбилних функција. Испитали смо неке особине таквих полинома и добили рекурзивне релације са њима. Користећи нову класу специјалних функција добили смо корисне формуле за сумирање, као и рекурзивне релације са таквим функцијама.

Кључне ријечи: диференцијалне једначине, рекурзивне формуле, специјалне фунције, специјални полиноми

1. INTRODUCTION

Orthogonal polynomials (Hermite, Laguerre, etc, [1-6]) and orthonormal functions (Hermite, Laguerre, etc [7], [8]) are very useful and have many applications in engineering. Orthogonal polynomials play an important role in the study of wave mechanics, heat conduction, electromagnetic theory, quantum mechanics and mathematical statistics. Some of those polynomials are used in the field of construction, for example for the beam bending test [9]. Hermite polynomials are readily applied in computational mechanics for a spatial discretization of the kinematic field. Standard applications include structural analysis of beams [10] and shells [11].

A recurrence relation is an equation that defines a sequence based on a rule that gives the next term as a function of the previous term (or terms). The simplest form of a recurrence relation is the case where the next term depends only on the immediately previous term. A recurrence relation can also be higher order *k*>2, where the term a_{n+1} could depend not only on the previous term a_n but also on earlier terms $a_{n-1}, a_{n-2}, \dots, a_{n-k+1}$ [12]. *Recursive techniques are very useful for calculation.* In [4] are given many recursive relations with orthogonal polynomials (orthogonal polynomials have three order recursive relations). Motivation for this paper is to establish recurrence formulas for a new class of special polynomials and special functions introduced in [2].

A special polynomials of the form

$$F_0(x) = 1$$

$$F_{2n}(x) = Re((x-i)^{2n}) = \sum_{k=0}^{n} (-1)^{n+k} \binom{2n}{2k} x^{2k} \quad (1)$$

$$F_{2n-1}(x) = Im((x-i)^{2n}) = \sum_{k=1}^{n} (-1)^{n+k+1} \binom{2n}{2k-1} x^{2k-1}$$

are studied in [3]. Although they are non-orthogonal, they play important role because are enumerators of rational functions of the form

$$f_{2n}(x) = \frac{F_{2n}(x)}{(x^2+1)^{n+1/2}},\ f_{2n-1}(x) = \frac{F_{2n-1}(x)}{(x^2+1)^{n+1/2}},\ n \in N\ . \quad (2)$$

It is shown in [2] that these functions are solutions of the Sturm-Liouville differential equation

$$(1+x^2)^2 y''(x) + 4x(1+x^2)y'(x) + (1+2x^2+4n^2)y(x) = 0$$

and form an orthonormal basis of $L^2(R)$ space.

2. PRELIMINARIES AND NOTATION

We use the following notation: N, R, C for sets of natural, real and complex numbers, respectively. By *i* we denote the imaginary unit, *Re(z)* and *Im(z)* means the real part and the imaginary part of the complex number z, respectively. By $L^2(R)$ [13] we mean the space of square integrable functions over R, that is

$$L^2(R) = \left\{ f: R \to C \middle| \int_{-\infty}^{\infty} |f(x)|^2 dx < \infty \right\}$$

In [3] are determined generating functions for polynomials $F_n(x), n \in N$ and obtained very useful and interesting summation formulas. Also, it is proven in [3] that special polynomials $F_n(x), n \in N$ satisfy ($\forall x, t \in$ R)

$$\sum_{n=0}^{\infty} \frac{F_{2n}(x)}{(2n)!} t^{2n} = \cos t \cosh(xt) \quad (3)$$

$$\sum_{n=1}^{\infty} \frac{F_{2n-1}(x)}{(2n)!} t^{2n} = -\sin t \sinh(xt) \quad (4)$$

If we put $t = 1$ in (3) and (4) we obtain

$$e^x = \sinh(x) + \cosh(x)$$

$$e^x = \frac{1}{\cos 1} \sum_{n=0}^{\infty} \frac{F_{2n}(x)}{(2n)!} - \frac{1}{\sin 1} \sum_{n=1}^{\infty} \frac{F_{2n-1}(x)}{(2n)!} \quad (5)$$

Below are some formulas proven in [3].

For every *x,t∈R* it holds that

$$\sum_{n=0}^{\infty} (-1)^n \frac{F_{2n}(x)}{(2n)!} t^{2n} = \cos(xt) \cosh(t) \quad (6)$$

$$\sum_{n=1}^{\infty} (-1)^n \frac{F_{2n-1}(x)}{(2n)!} t^{2n} = \sin(xt) \sinh(t) \quad (7)$$

If we put $t = 1$ in (6) and (7) we obtain

$$\cos(x) = \frac{1}{\cosh 1}\sum_{n=0}^{\infty}(-1)^n \frac{F_{2n}(x)}{(2n)!} \tag{8}$$

$$\sin(x) = \frac{1}{\sinh 1}\sum_{n=1}^{\infty}(-1)^n \frac{F_{2n-1}(x)}{(2n)!} \tag{9}$$

For every $x,\ t\in R$ it holds that

$$\sum_{n=0}^{\infty}\frac{F_{2n}(x)}{n!}t^n = e^{x^2t-t}\cos(2xt) \tag{10}$$

$$\sum_{n=1}^{\infty}\frac{F_{2n-1}(x)}{n!}t^n = -e^{x^2t-t}\sin(2xt) \tag{11}$$

3. RECURRENCE FORMULAS FOR SPECIAL POLYNOMIALS

Research with a new class of special polynomials is in its infancy. There are no recurrence relations with them, so in this section we give some interesting recursive relations with special polynomials $\boldsymbol{F_n(x), n \in N}$.

Proposition 3.1: For special polynomials $F_n(x), n \in N$ it holds that

$$F'_{2n+2}(x) = 2(n+1)(xF_{2n}(x) + F_{2n-1}(x)) \tag{12}$$

$$F_{2n+2}(x) = (x^2-1)F_{2n}(x) + 2xF_{2n-1}(x) \tag{13}$$

$$xF'_{2n}(x) = n((x^2+1)F_{2n-2}(x) + F_{2n}(x)) \tag{14}$$

Proof: If we derivate equation (10) by x we obtain (we can derivate since it converge for ($\forall x \in$ R))

$$\sum_{n=0}^{\infty}\frac{F'_{2n}(x)}{n!}t^n = (e^{x^2t-t}\cos(2xt))'_x = 2xte^{x^2t-t}\cos(2xt) - 2te^{x^2t-t}\sin(2xt)$$

$$= 2xt\sum_{n=0}^{\infty}\frac{F_{2n}(x)}{n!}t^n + 2t\sum_{n=1}^{\infty}\frac{F_{2n-1}(x)}{n!}t^n = \sum_{n=0}^{\infty}\frac{2xF_{2n}(x)}{n!}t^{n+1} + \sum_{n=1}^{\infty}\frac{2F_{2n-1}(x)}{n!}t^{n+1}$$

$$= \sum_{n=1}^{\infty}\frac{2xF_{2(n-1)}(x)}{(n-1)!}t^n + \sum_{n=2}^{\infty}\frac{2F_{2(n-1)-1}(x)}{(n-1)!}t^n = 2xF_0(x)t + \sum_{n=2}^{\infty}\frac{2xF_{2n-2}(x) + 2F_{2n-3}(x)}{(n-1)!}t^n$$

From above equations we have

$$F'_0(x) + F'_2(x)t + \sum_{n=2}^{\infty}\frac{F'_{2n}(x)}{n!}t^n = 2xF_0(x)t + \sum_{n=2}^{\infty}\frac{2xF_{2n-2} + 2F_{2n-3}}{(n-1)!}t^n$$

Since $F_0(x) = 1 \Rightarrow F'_0(x) = 0$ and $F_2(x) = x^2 - 1 \Rightarrow F'_2(x) = 2x$ we have

$$\sum_{n=2}^{\infty}\frac{F'_{2n}(x)}{n!}t^n = \sum_{n=2}^{\infty}\frac{2xF_{2n-2}(x) + 2F_{2n-3}(x)}{(n-1)!}t^n.$$

This implies $F'_{2n}(x) = 2n(xF_{2n-2}(x) + F_{2n-3}(x)), n\geq 2$, so we obtain (12). To get (13) we derivate (10) by t, so we have

$$\sum_{n=1}^{\infty}\frac{F_{2n}(x)}{(n-1)!}t^{n-1} = (x^2-1)e^{x^2t-t}\cos(2xt) - 2xe^{x^2t-t}\sin(2xt)$$

$$= (x^2-1)\sum_{n=0}^{\infty}\frac{F_{2n}(x)}{n!}t^n + 2x\sum_{n=1}^{\infty}\frac{F_{2n-1}(x)}{n!}t^n$$

$$\sum_{n=0}^{\infty}\frac{F_{2n+2}(x)}{n!}t^n = (x^2-1)F_0(x) + \sum_{n=1}^{\infty}\frac{(x^2-1)F_{2n}(x) + 2xF_{2n-1}(x)}{n!}t^n$$

$$F_2(x) + \sum_{n=1}^{\infty}\frac{F_{2n+2}(x)}{n!}t^n = (x^2-1)F_0(x) + \sum_{n=1}^{\infty}\frac{(x^2-1)F_{2n}(x) + 2xF_{2n-1}(x)}{n!}t^n$$

Since $F_0(x) = 1$ and $F_2(x) = x^2 - 1$, from the last equality we obtain (13).

Notice that

$$\frac{\partial}{\partial x}\sum_{n=0}^{\infty}\frac{F_{2n}(x)}{n!}t^n = 2xte^{x^2t-t}\cos 2xt - 2te^{x^2t-t}\sin\ 2xt \tag{15}$$

$$\frac{\partial}{\partial t}\sum_{n=0}^{\infty}\frac{F_{2n}(x)}{n!}t^n = (x^2-1)e^{x^2t-t}\cos 2xt - 2xe^{x^2t-t}\sin 2xt \tag{16}$$

If we multiply (15) by x and (16) by (-t) we obtain

$$t(x^2+1)e^{x^2t-t}\cos 2xt = x\frac{\partial}{\partial x}\sum_{n=0}^{\infty}\frac{F_{2n}(x)}{n!}t^n - t\frac{\partial}{\partial t}\sum_{n=0}^{\infty}\frac{F_{2n}(x)}{n!}t^n$$
$$t(x^2+1)\sum_{n=0}^{\infty}\frac{F_{2n}(x)}{n!}t^n = x\sum_{n=0}^{\infty}\frac{F'_{2n}(x)}{n!}t^n - t\sum_{n=1}^{\infty}\frac{F_{2n}(x)}{(n-1)!}t^{n-1}$$
$$(x^2+1)\sum_{n=0}^{\infty}\frac{F_{2n}(x)}{n!}t^{n+1} = \sum_{n=0}^{\infty}\frac{xF'_{2n}(x)}{n!}t^n - \sum_{n=1}^{\infty}\frac{F_{2n}(x)}{(n-1)!}t^n$$

$$(x^2+1)\sum_{n=1}^{\infty}\frac{F_{2n-2}(x)}{(n-1)!}t^n = xF_0'(x) + \sum_{n=1}^{\infty}\frac{\frac{xF'_{2n}(x)}{n} - F_{2n}(x)}{(n-1)!}t^n$$

Since $F_0'(x) = 0$ we obtain (14).

Proposition 3.2: For special polynomials $F_n(x), n \in N$ it holds that

$$F'_{2n+1}(x) = 2(n+1)(xF_{2n-1}(x) - F_{2n}(x)) \tag{17}$$
$$F_{2n+1}(x) = (x^2-1)F_{2n-1}(x) - 2xF_{2n}(x) \tag{18}$$
$$xF'_{2n+1}(x) = (n+1)((x^2+1)F_{2n-1}(x) + F_{2n+1}(x)) \tag{19}$$

Proof: The proof is similar like those in Proposition 3.1. To obtain (17) we derivate (11) by x, and to get (18) we derivate (11) by t. Relation (19) we obtain on the same way as in Proposition 3.1 (see (15) and (16)).

4. RECURRENCE FORMULAS FOR SPECIAL FUNCTIONS

In this section we give some generating functions for a new class of special functions $f_n(x), n \in N_0$. Using these sumation formulas we obtain interesting recursive formulas for $f_n(x), n \in N_0$.

Proposition 4.1: For special functions $f_n(x), n \in N_0$ and $|t| < 1$ it holds that

$$\sum_{n=0}^{\infty} f_{2n}(x)t^n = \frac{1}{\sqrt{x^2+1}}\frac{x^2(1-t)+1+t}{x^2(1-t)^2+(1+t)^2} \tag{20}$$

$$\sum_{n=1}^{\infty} f_{2n-1}(x)t^n = -\frac{1}{\sqrt{x^2+1}}\frac{2xt}{x^2(1-t)^2+(1+t)^2} \tag{21}$$

Proof: We use geometric series $\sum_{n=0}^{\infty} x^n = \frac{1}{1-x}, |x| < 1$. Taking real and imaginary parts in

$$\sum_{n=0}^{\infty} f_n(x)t^n = \frac{1}{\sqrt{x^2+1}}\sum_{n=0}^{\infty}\left(\frac{x-i}{x+i}\right)^n t^n = \frac{1}{\sqrt{x^2+1}}\frac{1}{1-\frac{x-i}{x+i}t}$$
$$= \frac{x+i}{\sqrt{x^2+1}\big((x-xt)+i(1+t)\big)} = \frac{1}{\sqrt{x^2+1}}\left(\frac{x^2(1-t)+1+t}{x^2(1-t)^2+(1+t)^2}\right)$$
$$- i\frac{1}{\sqrt{x^2+1}}\left(\frac{2xt}{x^2(1-t)^2+(1+t)^2}\right)$$

we obtain (20) and (21).

Proposition 4.2: For special functions $f_n(x), n \in N_0$ it holds that $(\forall t \in R)$

$$\sum_{n=0}^{\infty}\frac{f_{2n}(x)}{n!}t^n = \frac{1}{\sqrt{x^2+1}}e^{\frac{x^2-1}{x^2+1}t}\cos\frac{2xt}{x^2+1} \tag{22}$$

$$\sum_{n=1}^{\infty}\frac{f_{2n-1}(x)}{n!}t^n = -\frac{1}{\sqrt{x^2+1}}e^{\frac{x^2-1}{x^2+1}t}\sin\frac{2xt}{x^2+1} \tag{23}$$

Proof: Taking real and imaginary parts in

$$\sum_{n=0}^{\infty}\frac{f_n(x)}{n!}t^n = \frac{1}{\sqrt{x^2+1}}\sum_{n=0}^{\infty}\left(\frac{x-i}{x+i}\right)^n\frac{t^n}{n!} = \frac{1}{\sqrt{x^2+1}}e^{\frac{x-i}{x+i}t} = \frac{1}{\sqrt{x^2+1}}e^{\frac{x^2-1}{x^2+1}t-\frac{2xt}{x^2+1}i}$$
$$= \frac{1}{\sqrt{x^2+1}}e^{\frac{x^2-1}{x^2+1}t}\left(\cos\frac{2xt}{x^2+1} - i\sin\frac{2xt}{x^2+1}\right)$$

we obtain (22) and (23).

Proposition 4.3: For special functions $f_n(x), n \in N_0$ it holds that

$$f_{2n+2}(x) = \frac{x^2-1}{x^2+1} f_{2n}(x) + \frac{2x}{x^2+1} f_{2n-1}(x) \tag{24}$$

$$f_{2n+1}(x) = \frac{x^2-1}{x^2+1} f_{2n-1}(x) - \frac{2x}{x^2+1} f_{2n}(x) \tag{25}$$

Proof: If we derivate (21) by $t \in R$, we obtain

$$\sum_{n=1}^{\infty} \frac{f_{2n}(x)}{(n-1)!} t^{n-1} = \frac{x^2-1}{(x^2+1)^{\frac{3}{2}}} e^{\frac{x^2-1}{x^2+1}t} \cos\frac{2xt}{x^2+1} - \frac{2x}{(x^2+1)^{\frac{3}{2}}} e^{\frac{x^2-1}{x^2+1}t} \sin\frac{2xt}{x^2+1}$$

$$= \frac{x^2-1}{x^2+1} \sum_{n=0}^{\infty} \frac{f_{2n}(x)}{n!} t^n + \frac{2x}{x^2+1} \sum_{n=1}^{\infty} \frac{f_{2n-1}(x)}{n!} t^n$$

$$\sum_{n=0}^{\infty} \frac{f_{2n+2}(x)}{n!} t^n = \frac{x^2-1}{x^2+1} \sum_{n=0}^{\infty} \frac{f_{2n}(x)}{n!} t^n + \frac{2x}{x^2+1} \sum_{n=1}^{\infty} \frac{f_{2n-1}(x)}{n!} t^n$$

$$f_2(x) + \sum_{n=1}^{\infty} \frac{f_{2n+2}(x)}{n!} t^n = \frac{x^2-1}{x^2+1} f_0(x) + \sum_{n=1}^{\infty} \left(\frac{x^2-1}{x^2+1} f_{2n}(x) + \frac{2x}{x^2+1} f_{2n-1}(x) \right) \frac{t^n}{n!}$$

Since $f_0(x) = \frac{1}{\sqrt{x^2+1}}, f_2(x) = \frac{x^2-1}{(x^2-1)^{\frac{3}{2}}}$ we obtain (24).

If we derivate (23) by $t \in R$, we obtain

$$\sum_{n=1}^{\infty} \frac{f_{2n-1}(x)}{(n-1)!} t^{n-1} = -\frac{x^2-1}{(x^2+1)^{\frac{3}{2}}} e^{\frac{x^2-1}{x^2+1}t} \sin\frac{2xt}{x^2+1} - \frac{2x}{(x^2+1)^{\frac{3}{2}}} e^{\frac{x^2-1}{x^2+1}t} \cos\frac{2xt}{x^2+1}$$

$$\sum_{n=0}^{\infty} \frac{f_{2n+1}(x)}{n!} t^n = \frac{x^2-1}{(x^2+1)^{\frac{3}{2}}} \sum_{n=1}^{\infty} \frac{f_{2n-1}(x)}{n!} t^n - \frac{2x}{x^2+1} \sum_{n=0}^{\infty} \frac{f_{2n}(x)}{n!} t^n$$

$$f_1(x) + \sum_{n=1}^{\infty} \frac{f_{2n-1}(x)}{n!} t^n = \sum_{n=1}^{\infty} \left(\frac{x^2-1}{x^2+1} f_{2n-1}(x) - \frac{2x}{x^2+1} f_{2n}(x) \right) \frac{t^n}{n!} - \frac{2x}{x^2+1} f_0(x)$$

Since $f_1(x) = \frac{-2x}{(x^2+1)^{\frac{3}{2}}}$ we obtain (25).

5. CONCLUSION

Recursive relations play important role in calculus. Classical orthogonal polynomials have recurrence formulas of the third order. A new class of non-orthogonal polynomial is not yet investigated and there are not recurrence relations with them. In this paper recurrence formulas (13), (18) of the fourth order with a new class of special polynomials are obtained. Also, we considered a new class of special functions and obtained some generating functions for them (20)-(23) and fourth order recurrence relations (24), (25).

ACKNOWLEDGMENT

This work is supported by the Project 19.032/961-103/19. of the Republic of Srpska Ministry for Scientific and Technological Development, Higher Education and Information Society.

LITERATURE:

[1] P. Beckmann, Orthogonal Polynomials for Engineers, Golem PrJ, first edition 1973.

[2] N. Đurić, S. Maksimović, "One class of special polynomials and special functions in L2 (R)", NSJOM, 1, 81-91, 2019.

[3] N. Đurić, S. Maksimović, "Summation formulas using a new class of special polynomials",2020 19th International Symposium INFOTEH-JAHORINA (INFOTEH), East Sarajevo, Bosnia and Herzegovina, 1-4, 2020.

[4] A. Erdelyi, Higher trancendental functions, McGraw Hill, 1953.

[5] D. Gómez-Ullate, N. Kamran and R. Milson, "An extended class of orthogonal polynomials defined by a Sturm-Liouville problem". J. Math. Anal. Appl. 359, 1, 352-367, 2009.

[6] G.Szegö, Orthogonal polynomials. American Mathematical Society Colloquium Publications, Vol. 23. Revised ed. American Mathematical Society, Providence, R.I., 1959.

[7] J. Boyd, "Spectral Methods Using Rational Basis Functions on an Infinite interval", Journal of computational physics , 69, 112-142, 1987.

[8] E.I. Moiseev, A.P. Prudnikov, "On a complete orthonormal system of special functions", Journal of Computational and Applied Mathematics 49, 201-206, 1993.

[9] F. Pampaloni and J. Enderlein, "Gaussian, Hermite-Gaussian, and Laguerre Gaussian beams: A primer. Oct 2004, physics/0410021 (26.02.2020).

[10] F. Armero, J. Valverde, "Invariant Hermitian finite elements for thin Kirchhoff rods: The linear plane case", Computer Methods in Applied Maechanics and Engineering, 213-216, 427-457, 2012.

[11] A. Borković, S. Kovačević, D. Milašinović, G. Radenković, O. Mijatović, V. Golubović-Bugarski, "Geometric nonlinear analysis of prismatic shells using the sem-analytical finite strip method", Thin-Walled Structures, 117, 63-88, 2017.

[12] Nykamp DQ, "Recurrence relation definition." From Math Insight. http://mathinsight.org/definition/recurrence_relation (26.02.2020).

[13] L. Schwartz, Functional analysis. Courant Institute of Mathematical Sciences, New York University, 1964.

09 | Research paper I Оригинални научни рад
ISSN 2566-4484 I Doi 10.7251/STP2014077O
pages 77-90

Oleg Odalović, odalovic@grf.bg.ac.rs, Faculty of Civil Engineering, University of Belgrade
Danilo Joksimović, jokso9@yahoo.com, Faculty of Civil Engineering, University of Belgrade
Dušan Petković, dpetkovic@grf.bg.ac.rs, Faculty of Civil Engineering, University of Belgrade
Marko Stanković, stankovic.d.marko@gmail.com, Faculty of Civil Engineering, University of Belgrade
Sanja Grekulović, sanjag@grf.bg.ac.rs,

EVALUATION AND TAILORING OF GLOBAL GEOPOTENTIAL MODELS IN THE DETERMINATION OF GRAVITY FIELD IN SERBIA

Abstract:
Within this paper, we evaluated the quality of three Global Geopotential Models entitled: EGM96, EGM2008, and GOCO05c. The models were evaluated by using 1001 terrestrial discrete values of height anomalies determined by Global Navigation Satellite Systems and normal heights, which we considered to be true values within this research. In addition to the quality evaluation, we tailored the models by using more than 80000 free air anomalies. The results obtained from the evaluation and tailoring indicate that by using the GOCO05c it is possible to determine a set of anomaly heights across Serbia, which are in agreement with terrestrial values with an average value of -7 cm, the standard deviation of ±9 cm and with the range of 44 cm.
Keywords: Global Geopotential Model, Tailoring, height anomalies

ОЦЕНА И ТЕЈЛОРОВАЊЕ ГЛОБАЛНИХ ГЕОПОТЕНЦИЈАЛНИХ МОДЕЛА ПРИ ОДРЕЂИВАЊУ ГРАВИТАЦИОНОГ ПОЉА НА ТЕРИТОРИЈИ СРБИЈЕ

Сажетак:
У оквиру рада оцењен је квалитет три глобална гепотенцијална модела: EGM96, EGM2008 i GOCO05s. Квалитет модела је тестиран коришћењем 1001 условно тачних вредности дискретних вредности аномалија висина које су претходно одређене применом (комбиновањем) Глобалних навигационих сателитских система и нормалних висина. Поред наведеног, модели су и прилагођени територији Србије коришћењем више од 80000 аномалија слободног ваздуха. Резултати добијени из наведених одређивања указују да се применом модела GOCO05c могу одредити аномалије висина на територији Србије које апроксимирају терестрички одређене аномалије висина са средњом вредношћу од -7 cm, стандардном девијацијом од ±9 cm и то у оквиру распона од 44 cm.
Кључне ријечи: Глобални геопотенцијални модел, прилагођавање, аномалије висина

1. INTRODUCTION

Earth's gravity potential can be represented in the form of addition of two scalar functions 5.[4]:

$$W = V + \Phi, \tag{1}$$

where V is the gravitational potential generated by the Earth's mass, and Φ is centrifugal potential generated by angular rotation of the Earth's body.

From the other side, potential W can be described as the addition of normal potential U and anomalies potential T 5.[4]:

$$W = U + T. \tag{2}$$

When normal potential U is adequately defined 5.[6] than determination of potential W can be treated trough functionals of anomaly potential: *anomaly height* and *free air anomaly*.

For any point P situated on the physical surface of the Earth height anomaly ζ (Figure 1) is given by Bruns equation

$$\zeta_P = \frac{T_P}{\gamma_Q}, \tag{3}$$

and free air anomaly Δg_p (Figure 2) as

$$\Delta g_p = g_p - \gamma_Q, \tag{4}$$

where T_P is anomaly potential at point P, g_P is gravity value measured at the surface of the Earth and γ_Q is normal gravity value at the telluroid 5.[10].

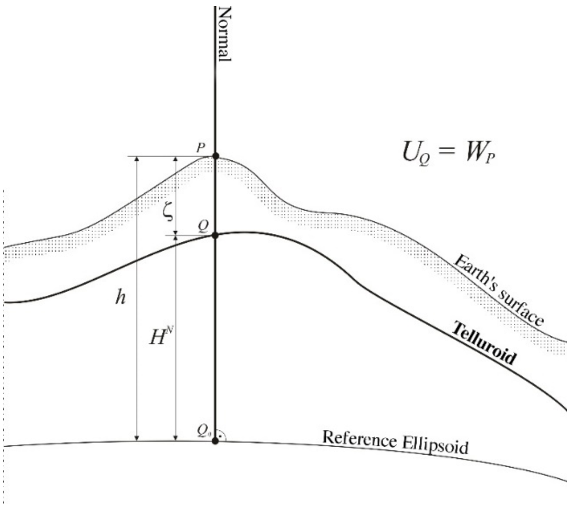


Figure 1. *Physical surface of the Earth, normal height, anomaly height, telluroid and reference (level) ellipsoid*

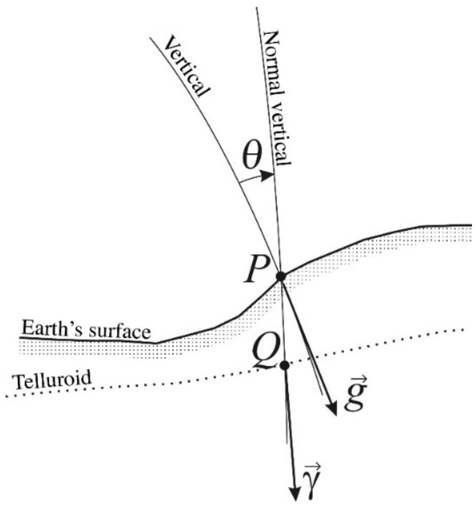


Figure 2. *Gravity and normal gravity vectors at the physical surface of the Earth*

The value of normal gravity at telluroid is given by

$$\gamma_Q = \gamma_0\left(1 - \frac{2}{a^{REF}}\left(1 + f^{REF} + m_\gamma - 2f^{REF}\sin^2\varphi'\right)H_P^N + \frac{3}{(a^{REF})^2}\left(H_P^N\right)^2\right), \tag{5}$$

where γ_0 is the normal gravity value on the reference ellipsoid, a^{REFF} semi-major of the reference ellipsoid, f^{REF} flattering of the ellipsoid, m_γ centrifugal force divided by gravitational acceleration at the equator, φ' ellipsoidal latitude representing by ellipsoid normal and H_P^N normal height. Gravity value on the reference ellipsoid is defined by the well-known formula of Somigliana 5.[10]:

$$\gamma_0 = \frac{1 + k \sin^2 \varphi'}{\sqrt{1 - (e^{REFF})^2 \ \sin^2 \varphi'}}, \tag{6}$$

$$k = \frac{b^{REFF}}{a^{REFF}} \frac{\gamma_a}{\gamma_b} - 1, \tag{7}$$

and m_γ as centrifugal force divided by gravitational acceleration at the equator by:

$$m_\gamma = \frac{(\omega^{REFF})^2 \ (a^{REFF})^2 b^{REFF}}{GM^{REFF}}, \tag{8}$$

where ω^{REFF} is the rotational velocity of the reference ellipsoid, b^{REFF} small semi-major of the reference ellipsoid, GM^{REFF} is gravitational constant times the total mass of Earth for reference ellipsoid and γ_a and γ_b are normal gravity at the equator and at the pole, respectively.

The height anomaly ζ_P defined by equation (1*)* can be treated in a purely geometrical way in definition of normal heights H^N by (Figure 1):

$$H_P^N = h_P - \zeta_P \,, \tag{9}$$

where h_P is the ellipsoidal height at point P. The ellipsoid height in the last equation can be nowadays determined by GNSS (Global Navigation Satellite System) technology and the anomaly height can be determined, besides lots of other geodetic approaches, by methods or techniques 5.[6], 5.[12], by using *only* appropriately selected Global Geopotential Model (GGM).

This approach gives us an opportunity to replace, to some admissible level of accuracy, complicated and hard works in the determination of normal heights throughout the creation of the levelling networks of high precision, by the elegant, fast and economical way.

2. GLOBAL GEOPOTENTIAL MODELS

During the last 50 years, large numbers of GGMs are created by a great number of individual researches or by a lot of different institutions across the world. From more than 170 publicly available GGMs for this research, we decided to test just three of all of them, entitled: EGM96, EGM2008, and GOCO05c.

The *Earth Gravitational Model 1996* (EGM96) is a set of coefficients of spherical harmonic expansion of gravity potential completed to degree and order N=M=360 5.[2]. The Model has been developed in the United States of America (USA) as a result of the cooperation of the following institutions: National Imagery and Mapping Agency – NIMA, National Aeronautics and Space Agency Goddard Space Flight Center – NASA GSFC and Ohio State University – OSU. EGM96 is a composite solution consisting of the following parts: Low-degree combination model to degree 70, Model with BD (block-diagonal) approach from degree 71 to 359 and Model with NQ (Numerical Quadrature) approach at degree 360. This model is based on a large amount of data, such as surface gravity data, Satellite-to-Satellite tracking data (TDRSS, GPS), altimeter data from ERS-1 and GEOSAT Geodetic Mission and conventional tracking data, including observations acquired by SLR, TRANET, and DORIS systems. The model contains about 130000 coefficients of spherical harmonic expansion and the estimated values of their standard deviations. The model was used to compute geoid undulations accurate to better than one meter and realize WGS84 as a true three-dimensional reference system. EGM96 was also used for advanced geophysical researches, gravity field modeling and for precise local and global geoid computation.

The official *Earth Gravitational Model 2008* (EGM2008) has been publicly released by the National Geospatial-Intelligence Agency (NGA) EGM Development Team 5.[8]. The model represents a spherical harmonic model of the Earth's gravitational potential, which is developed by the least-squares, the combination of the ITG-GRACE03S gravitational model and its associated error covariance matrix, with the gravitational information obtained from a global set of area-mean free-air gravity anomalies defined on a 5 arc-minute equiangular grid. This grid was formed by merging terrestrial, altimetry-derived, and airborne gravity data. Over areas where only lower resolution gravity data were available, their spectral content was supplemented with gravitational information implied by the topography. EGM2008 is complete to degree and order 2159 and contains additional coefficients up to degree 2190 and order 2159. Over areas covered with high-quality gravity data, the discrepancies between EGM2008 geoid undulations and independent GPS/Leveling values are on the order from ±5 cm to ±10 cm. EGM2008 vertical deflections over the USA and Australia are within ±1.1 arc-seconds to ±1.3 arc-seconds of independent astrogeodetic values. These results indicate that EGM2008 performs comparably with contemporary detailed regional geoid models. EGM2008 performs equally well with other GRACE-based gravitational models in orbit computations. Compared to EGM96, EGM2008 represents an improvement by a factor of six in terms of resolution, and by factors of three to six in terms of accuracy, depending on gravitational quantity and geographic area. At the time it was developed, EGM2008 was a milestone and a new paradigm in global gravity field modeling.

GOCO05c (*Gravity Observation Combination*) is a GGM which represents a gravity field model computed as a combined solution of a satellite-only model and a global data set of gravity anomalies, constituting a global 15’x15’ grid. It is fully resolved up to the 720 degree and order based on fully normal equation systems. It has been elaborated by the GOCO group (TU Munich, Bohn University, TU Graz, Austrian Academy of Science, University of Bern). GOCO05c represents the first model that’s applying regionally varying weights. Also, GOCO05c is the first combined gravity field model that is independent of EGM2008 that contains GOCE data of the whole mission period. Data sets used for this model are data from gravity field model GOCO05s, fully resolved up to degree and order 280, Altimetric Gravity Anomalies and Terrestrial Gravity Anomalies. Having in mind that it had to ensure a stable, normal equation system which has to be a complete observation data grid 15’x15’, the remaining 20% of Earth’s surface missing data had to be filled with fill-in data sets such as the NIMA96 data set of the Defense Mapping Agency and the Goddard Space Flight Center data. As this data couldn’t cover all the missing data, the remaining regions were filled with band-limited gravity anomalies computed from GOCO05s up to degree and order 220. The GOCO05c model combination model was computed by a rigorous solution of the fully occupied normal equation system and not on block-diagonal approximation. A detailed description of the estimated method used for the estimation of spherical coefficients for this model can be found in 5.[1]. In GOCO05c model the transition from satellite to terrestrial data takes place between degrees 140 and 240, depending on the quality of terrestrial data. As it was said before, it is independent of EGM2008 with the exception of two coefficients $\bar{C}_{720,0}$ $\bar{C}_{720,720}$, which have been used for regularization. It has been shown that GOCO05c model can at least achieve a level of accuracy of existing high-resolution models. On the other hand, it has to be mentioned that GOCO05c model should not be applied in geophysical interpretations in a region where fill-in data have been used since in some areas it does not meet high-accuracy requirements.

All three models are publicly available due to the activity of the International Center for Global Geopotential Model Services (ICGEM) established under the authority of the International Association of Geodesy (IAG) via the International Centre for Global Earth Models website.

3. MATHEMATICAL BACKGROUND AND APPLICATION OF GGM

Gravity potential W can be expanded in the functions of the spherical harmonics:

$$\begin{aligned} W(r,\theta,\lambda) = {} & \frac{GM^{REF}}{a^{REF}} \sum_{n=0}^{N_{max}} \left(\frac{a^{REF}}{r}\right)^{n+1} \sum_{m=0}^{n} \begin{pmatrix} \bar{C}_{nm}^{ELL} \cos(m\lambda) \\ + \bar{S}_{nm}^{ELL} \sin(m\lambda) \end{pmatrix} \bar{P}_{nm} \cos(\theta) \\ & + \frac{1}{2}(\omega^{REF})^2 r^2 \sin^2\theta, \end{aligned} \tag{10}$$

where r, θ and λ are the spherical coordinates, n and m are degree and order of spherical harmonic coefficients, $\bar{C}_{nm}^{ELL}$ and $\bar{S}_{nm}^{ELL}$ are normalized spherical harmonic coefficients referring to the constants of the reference ellipsoid,

$$\begin{Bmatrix} \bar{C}_{nm}^{ELL} \\ \bar{S}_{nm}^{ELL} \end{Bmatrix} = \left(\frac{GM^{GGM}}{GM^{REF}}\right)\left(\frac{a^{GGM}}{a^{REF}}\right)^n \begin{Bmatrix} \bar{C}_{nm}^{GGM} \\ \bar{S}_{nm}^{GGM} \end{Bmatrix}, \tag{11}$$

$\bar{C}_{nm}^{GGM}$ and $\bar{S}_{nm}^{GGM}$ are normalized spherical harmonic coefficients referring to the constants of selected GGM, GM^{GGM} is gravitational constant times the total mass of the selected GGM, a^{GGM} is the equatorial radius for the selected GGM and $\overline{P}_{nm}\cos(\theta)$ are normalized associated Legendre functions of degree n and order m defined by equations:

$$\overline{P}_{n0}\cos(\theta) = \sqrt{2n+1}\,P_{n0}\cos(\theta)\,, \tag{12}$$

$$\overline{P}_{nm}\cos(\theta) = \sqrt{\frac{2(2n+1)(n-m)!}{(n+m)!}}\,P_{nm}\cos(\theta), \tag{13}$$

where $P_{nm}\cos(\theta)$ are ordinary Legendre functions defined by

$$P_{nm}(t) = \frac{1}{2^n n!}(1-t^2)^{\frac{m}{2}}\frac{d^{n+m}}{dt^{n+m}}(t^2-1)\,, \tag{14}$$

where $t = \cos(\theta)$.

The normal potential U also can be expanded in an analogous way into spherical harmonics:

$$U(r,\theta,\lambda) = \frac{GM^{REF}}{a^{REF}}\sum_{n=0(2)}^{8}\left(\frac{a^{REF}}{r}\right)^{n+1}\overline{C}_n^{REF}\,\overline{P}_n\cos(\theta) + \frac{1}{2}(\omega^{REF})^2 r^2\sin^2\theta, \tag{15}$$

where coefficients $\overline{C}_n^{REF}$ are given by

$$\overline{C}_{2k}^{REFF} = \left(-1^k\right)\frac{3(e^{REFF})^{2k}}{(2k+3)(2k+1)\sqrt{4k+1}}\left[1+\frac{2}{3}k\left(1-\frac{m_\gamma\, e'^{REFF}}{3q_0}\right)\right], \tag{16}$$

where e'^{REFF} is the second numerical eccentricity od reference ellipsoid and

$$q_0 = \frac{1}{2}\left[\left(1+\frac{3}{(e'^{REFF})^2}\right)\tan^{-1}(e'^{REFF}) - \frac{3}{e'^{REFF}}\right], \tag{17}$$

In order to obtain of anomaly height ζ_P at point P using equations (10) and (15) it is necessary, by definition of Molodensky, to find point Q at the normal vertical where the normal potential U is equal to potential W at the point P e.g. to find a point Q in which is satisfied conditions:

$$U_Q = W_P, \tag{18}$$

the anomaly height ζ_p is simply the distance along the normal vertical between the point P and the point Q.

All of these equations are applied for calculation of anomaly height at 1001 points (Figure 3) located at the surface of the Earth where the terrestrial value of anomaly heights are determined by

$$\zeta_P^{GPS/dh} = h_p - H_P^N, \tag{19}$$

where h_p is ellipsoidal height determined by GNSS and H_P^N are normal height determined by the combination of geometrical levelling and measured gravity values. The basic statistical data for differences $\zeta_P^{GPS/dh}$ are shown in Table 1.

Figure 3. *Spatial distribution of GPS/dh points*

Table 1. *Basic statistical of $\zeta_P^{GPS/dh}$ (N = 1001, units: m)*

Parameter		**Minimum**	**Maximum**	**Average**	**Standard deviation**
$\zeta_P^{GPS/dh}$		42.33	46.41	44.64	0.85

After calculations of $\zeta_P^{GPS/dh}$ equations from (10) to (18) were applied for all of three selected GGMs and three sets of differences were calculated:

$$R_j = \zeta_i^j - \zeta_i^{GPS/dh} \tag{20}$$

where j *index* denotes one of the GGMs (EGM96, EGM2008 or GOCO05c) and i is the index which denotes running point, from 1 to 1001. The basic statistical data, the general shape of surfaces and histograms of calculated differences are given in the following table and figures.

Table 2. *Basic statistical data of differences R (N = 1001, units: m)*

Parameter	**Minimum**	**Maximum**	**Average**	**Standard deviation**	**Range**
R_{EGM96}	-2.02	0.38	-0.86	0.61	2.40
$R_{EGM2008}$	-0.49	0.17	-0.13	0.09	0.66
$\boldsymbol{R_{GOCO05c}}$	**-0.33**	**0.20**	**-0.05**	**0.10**	**0.54**

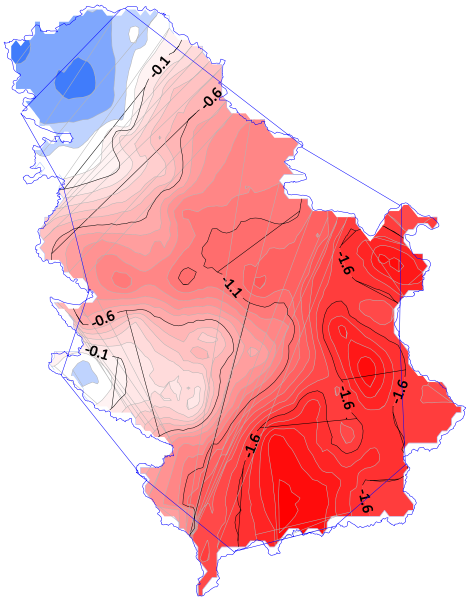


Figure 4. *General shape of the differences* R_{EGM96}

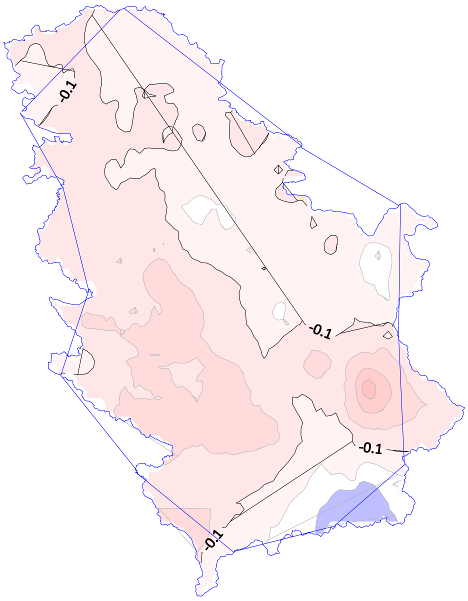


Figure 5. *General shape of the differences* $R_{EGM2008}$

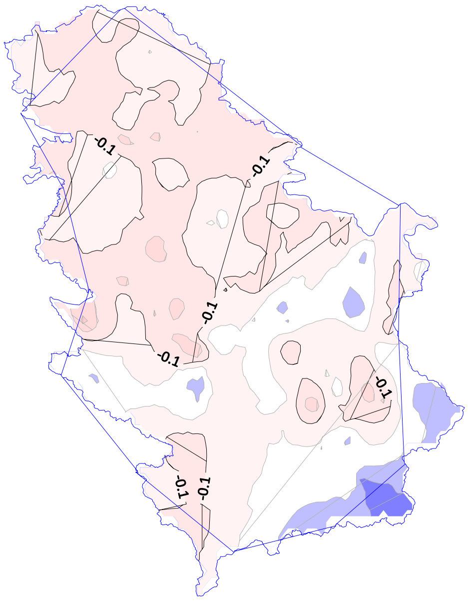


Figure 6. *General shape of the differences* $R_{GOCO05c}$

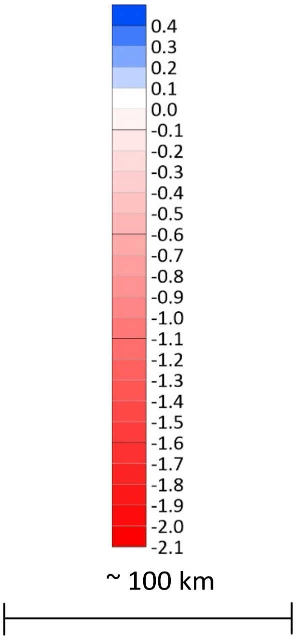


Figure 7. *Colors and scale for figures 4, 5 and 6*

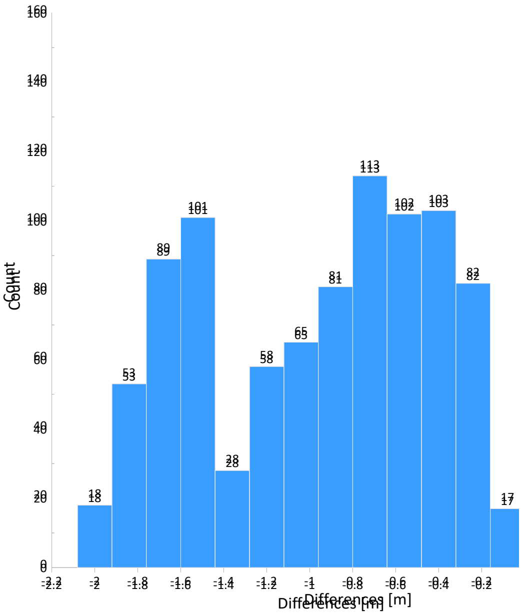


Figure 8. *Histogram of the differences* R_{EGM96}

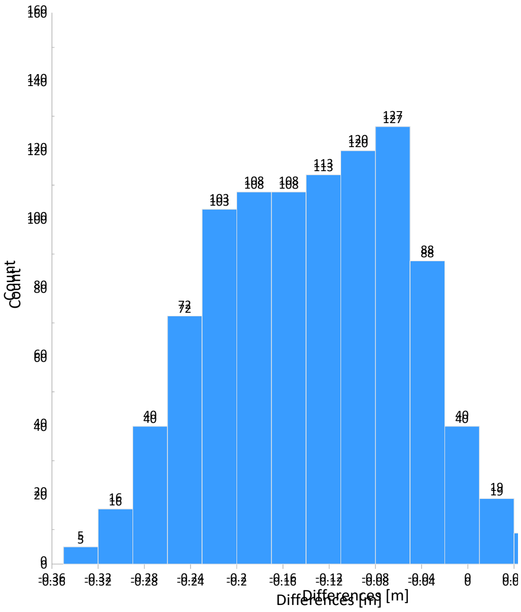


Figure 9. *Histogram of the differences* $R_{EGM2008}$

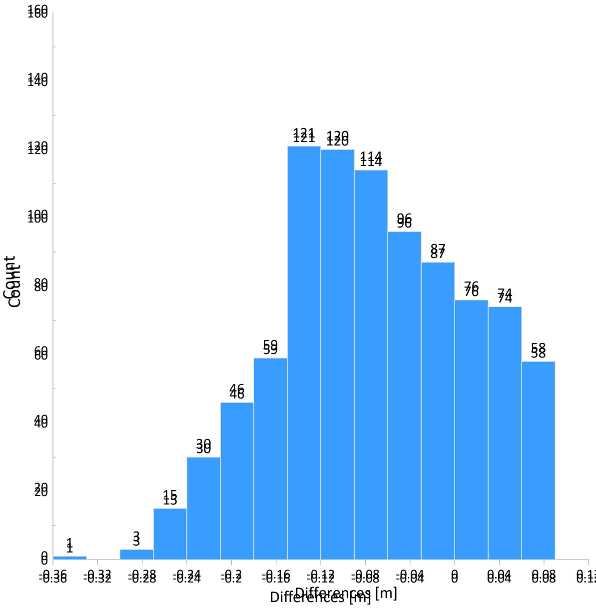


Figure 10. *Histogram of the differences* $R_{GOCO05c}$

4. TAILORING OF THE GLOBAL GEOPOTENTIAL MODEL

In this research, tailoring of the GGM meant adapting an existing set of coefficients of the GGM by using gravity anomalies from the territory of Serbia, in such a way that we can approximate the anomaly height at any point in the territory of Serbia with a new set of coefficients to the greatest possible extent.

Step by step description of the tailoring procedure was performed as follows.

From a database of the gravimetric survey of Serbia, more than 80000 measured values were collected (Figure 1) and the free air anomaly at all points was calculated by using equation (4). The territory of Serbia is divided into l quasi quadratic subareas Δ, bounded by latitudes and longitudes with spatial resolution of 5 arc minutes in the both directions (from the East to the West and from the South to the North). All free air anomalies were divided into l sets of anomalies in accordance to their positions across newly formed subareas. For each l sets, the average value of free air anomalies were calculated using the equation:

$$\overline{\Delta g} = \frac{1}{N_A}\sum_{i=1}^{N_A} \Delta g_i \,. \tag{21}$$

where N_A is the number of free air anomalies in the Δ subareas. We treated the calculated average value as the average value of the anomaly at the mean point of each Δ subarea.

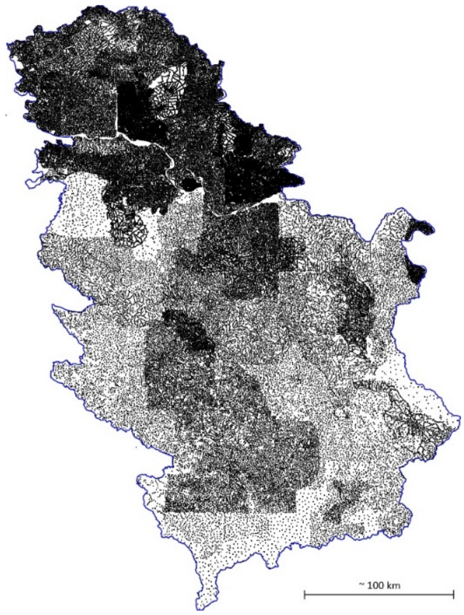


Figure 1: Spatial distribution of measured gravity values

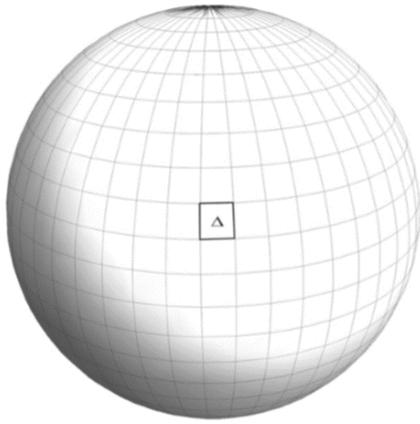


Figure 2: Δ area as the part of the Earth surface (or the part of the unit sphere)

Average free air anomaly, for any of Δ subareas, is also possible to calculate by using the coefficients of the GGM according to 5.[11]:

$$\overline{\Delta g}_{GGM} = \frac{GM}{r^2}\sum_{n=2}^{N_{max}} (n-1)\left(\frac{a}{r}\right)^n \beta_n \sum_{m=0}^{n} \begin{pmatrix} \overline{\Delta C}_{nm}^{ELL}\cos(m\lambda) \\ +\,\overline{S}_{nm}^{ELL}\sin(m\lambda) \end{pmatrix} \overline{P}_{nm}\cos(\theta), \tag{22}$$

where β_n is a function defined by 5.[9]

$$\beta_n = \frac{1}{1-\cos(\psi_0)} \int_{\cos(\psi_0)}^{1} P_n(t)dt, \tag{23}$$

and ψ_0 is the radius of the area Δ. For calculated average values, the difference is given by:

$$\delta = \overline{\Delta g} - \overline{\Delta g}_{GGM}, \tag{24}$$

and this difference we used as basic information for tailoring coefficients of a GGM to terrestrial anomalies at the territory of Serbia by the equation:

$$\begin{Bmatrix} \delta\bar{C}_{nm}^{ELL} \\ \delta\bar{S}_{nm}^{ELL} \end{Bmatrix} = \frac{1}{4\pi}\iint_{\sigma} \frac{\bar{r}^2}{GM}\left(\frac{\bar{r}}{a}\right)^n \frac{1}{(n-1)\beta_n}\,\delta \begin{Bmatrix} \cos(m\lambda) \\ \sin(m\lambda) \end{Bmatrix} \bar{P}_{nm}\cos(\theta)\,d\sigma, \tag{25}$$

For l areas Δ we can improve the tailoring of coefficients by summing the effects of all differences $\delta_i, i = 1, \ldots, l$ by:

$$\begin{Bmatrix} \delta\bar{C}_{nm}^{ELL} \\ \delta\bar{S}_{nm}^{ELL} \end{Bmatrix} = \frac{1}{4\pi}\sum_{i=1}^{l} \frac{\bar{r}_i^{\,2}}{GM}\left(\frac{\bar{r}_i}{a}\right)^n \frac{1}{(n-1)\beta_{n,i}}\,\delta_i \iint_{\Delta\sigma} \begin{Bmatrix} \cos(m\lambda) \\ \sin(m\lambda) \end{Bmatrix} \bar{P}_{nm}\cos(\theta)\,d\sigma, \tag{26}$$

or equivalently by:

$$\begin{Bmatrix} \delta\bar{C}_{nm}^{ELL} \\ \delta\bar{S}_{nm}^{ELL} \end{Bmatrix} = \frac{1}{4\pi}\sum_{i=1}^{l} \frac{\bar{r}_i^{\,2}}{GM}\left(\frac{\bar{r}_i}{a}\right)^n \frac{1}{(n-1)\beta_{n,i}}\,\delta_i \cdot$$
$$\cdot \int_{\lambda_{W_i}}^{\lambda_{E_i}} \begin{Bmatrix} \cos(m\lambda) \\ \sin(m\lambda) \end{Bmatrix} d\lambda \int_{\theta_{N_i}}^{\theta_{S_i}} \bar{P}_{nm}\cos(\theta)\sin(\theta)d\theta\,d\sigma, \tag{27}$$

and finally, calculate the new set of coefficients of adapted or tailored GGM:

$$\begin{Bmatrix} \bar{C}_{nm}^{ELL} \\ \bar{S}_{nm}^{ELL} \end{Bmatrix}_T = \begin{Bmatrix} \bar{C}_{nm}^{ELL} \\ \bar{S}_{nm}^{ELL} \end{Bmatrix} + \begin{Bmatrix} \delta\bar{C}_{nm}^{ELL} \\ \delta\bar{S}_{nm}^{ELL} \end{Bmatrix}. \tag{28}$$

This set of coefficients we used in the calculation the anomaly heights ζ and the differences R_j by equations from (10) and (18).

In addition, and in order to achieve better tailoring of the coefficients, the described procedure can be performed repeatedly (in iterations), forming after each cycle of new differences (*24*) and new coefficients (28), whereby it is necessary to introduce a criterion (or criteria) to limit the number of iterations.

In this research, we adopted criteria in the following way. After each iteration several sets of data were calculated:

1. Sets of differences with terrestrial anomaly heights (GPS/dh)

$$\left(\Delta\zeta_j\right)^i = \left(\zeta_j^{GGM}\right)^i - \zeta_i^{GPS/dh}, \tag{29}$$

   where *i* is the label of the current iteration and the *j* is the number of running difference of GPS/dh, $j = 1, \ldots, 1001$,

2. Difference between the average values of the sets $\left(\Delta\zeta_j\right)^i$ and $\left(\Delta\zeta_j\right)^{i+1}$,
3. Difference between standard deviations of the sets $\left(\Delta\zeta_j\right)^i$ and $\left(\Delta\zeta_j\right)^{i+1}$,

For the last iteration, we adopt the one which satisfied the following conditions:

$$\left|\overline{(\Delta\zeta)^i} - \overline{(\Delta\zeta)^{i+1}}\right| \approx 1\text{ cm},$$

$$\left|\sigma_{(\Delta\zeta)^{i}} - \sigma_{(\Delta\zeta)^{i+1}}\right| \approx 1\text{ cm}.$$

where $\overline{(\Delta\zeta)}$ is the average value of the set and $\sigma_{\Delta\zeta}$ is its standard deviation.

By applying all the above equations selected GGMs were tailored. EGM96 was tailored after 4 iterations and EGM2008 and GOCO05c after only 3 iterations. The basic statistical data, the general shape of differences and histograms of differences for all tailored GGMs are shown in the following tables and figures.

Table 3. *Basic statistical data of $\Delta\zeta$ sets calculated by original and by tailored EGM96 coefficients throughout the iteration (number of data $N = 1001$)*

$N_{max} = 360, n_{min} = 37$					
Parameter	**EGM96**	**Iteration**			
		0	1	2	3
Minimum	-2.02	-1.41	-1.23	-1.17	-1.14
Maximum	0.38	0.04	0.01	0.02	0.02
Average	-0.86	-0.69	-0.61	-0.58	0.57
Standard deviation	0.61	0.27	0.24	0.23	0.23
Range	2.40	1.45	1.24	1.19	1.17

Table 4. *Basic statistical data of $\Delta\zeta$ sets calculated by original and by tailored EGM2008 coefficients throughout the iteration (number of data $N = 1001$)*

$N_{max} = 2190, n_{min} = 281$					
Parameter	**EGM2008**	**Iteration**			
		0	1	2	3
Minimum	-0.49	-0.34	-0.35	-0.35	
Maximum	0.17	0.12	0.11	0.10	
Average	-0.13	0.12	-0.13	-0.13	-
Standard deviation	0.09	0.09	0.09	0.09	
Range	0.66	0.46	0.45	0.45	

Table 5. *Basic statistical data of $\Delta\zeta$ sets calculated by original and by tailored GOCO05c coefficients throughout the iteration (number of data $N = 1001$)*

$N_{max} = 720, n_{min} = 281$					
Parameter	**GOCO05c**	**Iteration**			
		0	1	2	3
Minimum	-0.33	-0.33	-0.31	**-0.31**	-
Maximum	0.20	0.14	0.13	**0.13**	

Average	-0.05	-0.06	-0.07	**-0.07**	
Standard deviation	0.10	0.09	0.09	**0.09**	
Range	0.54	0.47	0.44	**0.44**	

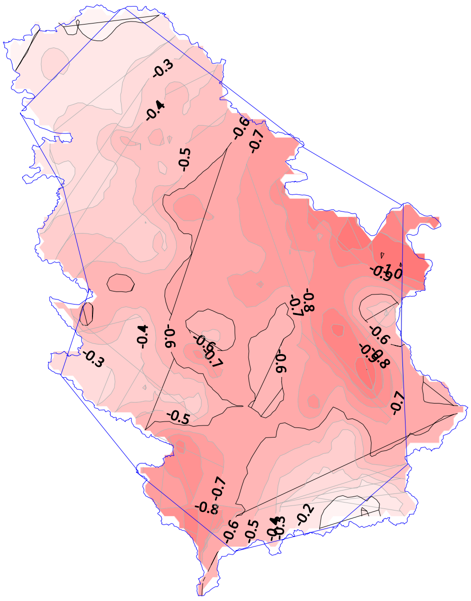


Figure 3: General shape of the differences R_{EGM96} *after tailoring of* EGM96

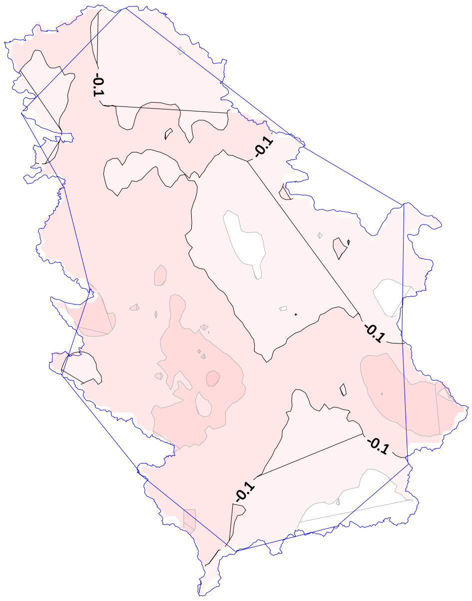


Figure 4: General shape of the differences $R_{EGM2008}$ *after tailoring of* EGM2008

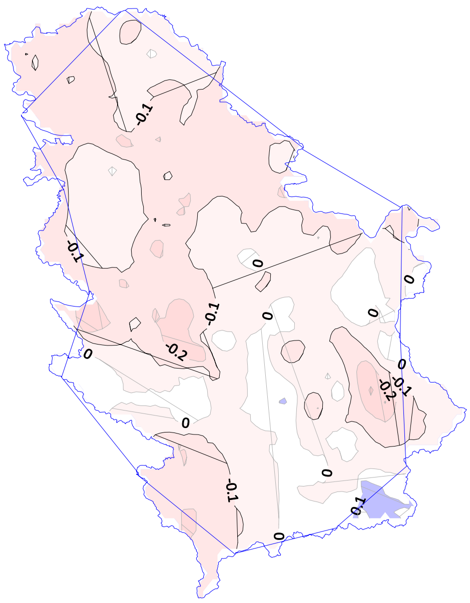


Figure 5: General shape of the differences $R_{GOCO05c}$ *after tailoring of* GOCO05c

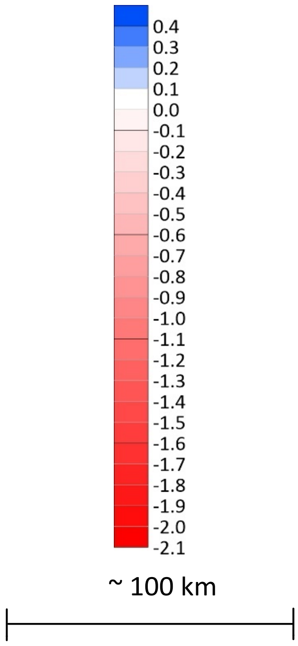


Figure 6: Colors and scale for figures 13, 14 and 15

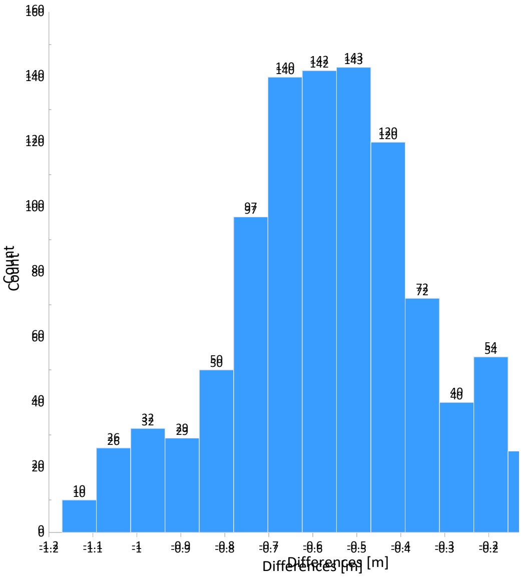


Figure 7: Histogram of the differences R_{EGM96} after tailoring of EGM96

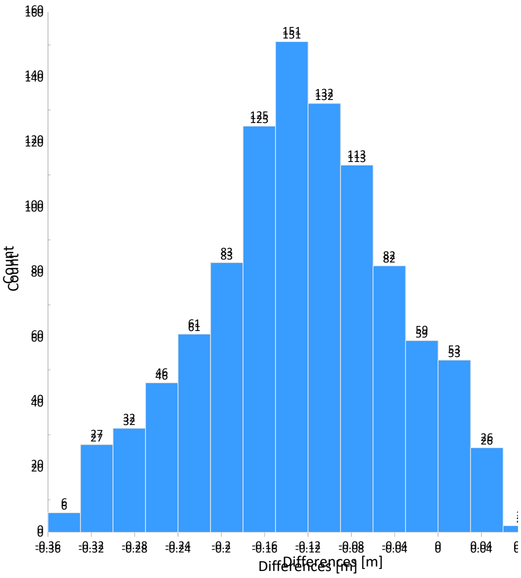


Figure 8: Histogram of the differences$R_{EGM2008}$ after tailoring of EGM2008

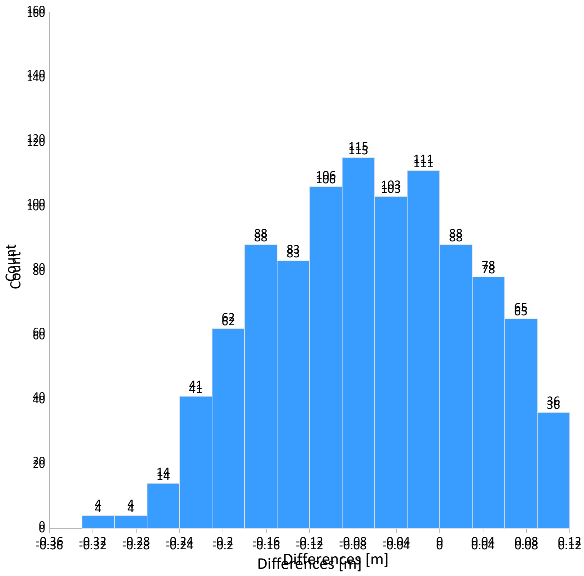


Figure 9: Histogram of the differences $R_{GOCO05c}$ after tailoring of GOCO05c

5. COMMENTS, CONCLUSIONS AND FUTURE ACTIVITIES

This paper presents research dedicated to the evaluation of the quality of three Global Geopotential Models: EGM96, EGM2008, and GOCO05c for the territory of Serbia. The evaluation was done by using 1001 terrestrial discrete values of height anomalies, determined by GNSS and normal heights, wherein further research these values were adopted as true values. From detailed quality evaluation, results have shown that the best approximation of height anomalies for the territory of Serbia gives GOCO05c. In addition to the quality evaluation, tailoring of models was performed using more than 80,000 free air anomalies, relatively regularly distributed over the territory. The models were tailored by free air anomalies but for the purposes of quality evaluation, the same 1001 terrestrial height anomalies were used. After performed evaluation and a final comparison of results, it can be concluded that with the Global Geopotential Model GOCO05c is possible to determine set of anomaly heights across the territory of Serbia, which are corresponding with terrestrial values with an average value of -7 cm, the standard deviation of ±9 cm within range of 44 cm.

LITERATURE

[1] Fecher T, Pail R, Gruber T (2015) Global gravity field modeling based on GOCE and complementary gravity data. Int J Appl Earth Obs 35:120–127.

[2] F.G. Lemoine, S.C. Kenyon, J.K. Factor, R.G. Trimmer, N.K. Pavlis, D.S. Chinn, C.M. Cox, S.M. Klosko, S.B. Luthcke, M.H. Torrence, Y.M. Wang, R.G. Williamson, E.C. Pavlis, R.H. Rapp, and T. R. Olson. The Development of the Joint NASA GSFC and the National Imagery and Mapping Agency (NIMA) Geopotential Model EGM96. NASA/TP-1998-206861, July, 1998.

[3] GOCE Level 2 Product Data Handbook, Doc. Nr: GO-MA-HPF-GS-0110, Issue: 4.3, Date: 09.12.2010, Page 77.

[4] Heiskanen, W. A., and H. Moritz., Physical Geodesy, W.H. Freeman and Co., San Francisco, 1967.

[5] Molodensky, M. S. (1958). New methods of studying the figure of the earth. Bulletin Géódésique (1946-1975), 50(1), 17–21.

[6] Moritz, H., Advanced Physical Geodesy, Herbert Wichmann Verlag Karlsruhe, Abacus Press Tundbridge Wells Kent, 1980.

[7] Moritz, H., The Geodetic Reference System 1980, Bulletin Géodésique 58 ("The Geodesist's Handbook 1984"), p. 388 – 389, 1984.

[8] Pavlis, N. K., Holmes, S. A., Kenyon, S. C., and Factor, J. K., The Development and Evaluation of the Earth Gravitational Model 2008 (EGM2008), Journal of Geophysical Research-Solid Earth – Geodesy and Gravity/Tectonophysics, Vol. 117, first published: 19 April 2012 https://doi.org/10.1029/2011JB008916

[9] Sjoberg L., A Recurrence Relation For The β_n- Function, Bulletin Géodésique, 54, p. 69-72, 1980.

[10] Torge, W.: Geodesy. 3. ed., de Gruyter, Berlin, 2001.

[11] Weber, G., and H. Zomorrodian, Regional Geopotential Model Improvement For The Iranian Geoid Determination, Bulletin Géodésique, 62, p. 125-141, 1988.

[12] Ye Cai Li, Optimized Spectral Geoid Determination, The University Of Calgary, Calgary, 1993.

10 | Research paper I Оригинални научни рад
ISSN 2566-4484 I Doi 10.7251/STP2014091S
pages 91-98

Mileva Samardžić-Petrović, mimas@grf.bg.ac.rs, Faculty of Civil Engineering, University of Belgrade

Jovan Popović, popovic@grf.bg.ac.rs, Faculty of Civil Engineering, University of Belgrade

Uroš Đurić, udjuric@grf.bg.ac.rs, Faculty of Civil Engineering, University of Belgrade

Biljana Abolmasov, biljana.abolmasov@rgf.bg.ac.rs, Faculty of Mining and Geology, University of Belgrade

Marko Pejić, mpejic@grf.bg.ac.rs, Faculty of Civil Engineering, University of Belgrade

Miloš Marjanović, milos.marjanovic@rgf.bg.ac.rs, Faculty of Mining and Geology, University of Belgrade

PERMANENT GNSS MONITORING OF LANDSLIDE UMKA

Abstract:

The Umka landslide is one of the biggest inhabited active landslides in Serbia. The Umka landslide activity has been monitored for a period longer than 85 years, by various geotechnical and geodetic techniques. Since 2010, landslide activity has been continuously monitored by automated permanent Global Navigation Satellite System (GNSS) based monitoring system in real time. Furthermore, since 2018 landslide activity has been monitored by GNSS kinematic positioning of a set of characteristic points as well as by UAV (Unmanned Aerial Vehicle) photogrammetry. The main issue of this paper is the presentation of the results gained with GNSS kinematic positioning of characteristic points of Umka landslide within three observation epochs.

Keywords: landslide, permanent monitoring, GNSS

ПЕРМАНЕНТНО ПРАЋЕЊЕ КЛИЗИШТА УМКА

Сажетак:

Клизиште Умка је једно од највећих насељених активних клизишта у Србији. Активност клизишта Умка се прати већ више од 85 година, различитим геотехничким и геодетским техникама. Од 2010. године, активност клизишта се континуирано прати у реалном времену аутоматизованим перманентним системом за праћење базираним на Глобалним навигационим сателитским системима (ГНСС). Поред тога, од 2018. године активност клизишта се додатно прати кинематичким ГНСС одређивањем положаја скупа карактеристичних тачака као и применом UAV фотограметрије. Главни циљ овог рада је приказ резултата опажања три мерне епохе добијених ГНСС кинематичким позиционирањем карактеристичних тачака клизишта Умка.

Кључне ријечи: клизиште, перманентно праћење, ГНСС

1. INTRODUCTION

Over the past two decades, driven by the development of geodetic instruments for data acquisition and technology for data processing in real time, a wide range of different types of complex monitoring automated systems found its use in various engineering disciplines. The Global Navigation Satellite System (GNSS) based monitoring system is one of the widely used systems, used in order to assess the dynamics of the landslide phenomenon and potentially prevent possible disasters [1-5].

Considering the importance of the Umka urban area permanent monitoring, automated GNSS monitoring system was established in March 2010. This was a part of the technological development project "The application of GNSS and LIDAR technology for infrastructure facilities and terrain stability monitoring", financed by Ministry of Education, Science and Technological Development of the Republic of Serbia, and the collaboration between University of Belgrade, Faculty of Mining and Geology and Faculty of Civil Engineering, Institute of Transportation CIP, The Highway Institute and company Vekom. The detailed descriptions of the technical part and the main characteristics of the established automated GNSS monitoring system can be find in Erić et al. [6].

Generally, the Umka monitoring system consists of GNSS network and supporting software solutions. The first part of the system, the network, consists of several reference points and one object (monitoring) point on which GNSS stations (sensors) are mounted. The object point is located on the landslide body, mounted on the house roof. Reference points are located outside the landslide area and they are the integral part of the Active Geodetic Reference Network of Serbia (AGROS), which is a permanent GNSS service for accurate satellite positioning over the Republic of Serbia territory. The second part of the system are the two Leica Geosystems software solutions: GNSS Spider and GeoMoS (Geodetic Monitoring System), used in order to monitor the dynamics of landslide in real time, with observation rate of 30 seconds.

The observed GNSS monitoring results, as well as the correlations between precipitation and Sava river level with landslide dynamics were presented in numerous publications [5-9]. Despite the numerous interruptions over the period of almost ten years of permanent monitoring (which are expectable due to the system complexity), the dynamic of Umka landslide is successfully determined and analyzed through time [1].

The main shortcoming of the system is already discussed in previous publications and it concerns only one observed object point. Consequently, in order to further analyze the Umka landslide dynamic, in March 2018, a passive GNSS network consisting of four stable points surrounding landslide area is realized. The landslide area is discretised by 62 properly stabilized characteristic points. Between March 2018 and April 2019, three observation epochs were completed: Epoch 0 - at the end of March 2018, Epoch 1- in late November 2018 and Epoch 3 - in early April 2019. At the same time during the Epoch 1 and Epoch 2, two UAV (Unmanned Aerial Vehicle) photogrammetry epochs were executed as well, but the results are not presented within this paper.

Apart from the geodetic survey method, the dynamic of landslide Umka is investigated by various geotechnical techniques [10]. However, the primary focus of this paper is the presentation of the results derived by GNSS kinematic positioning of characteristic points of Umka landslide during three measuring epochs.

2. LANDSLIDE UMKA

Umka is a suburban settlement in the municipality of Čukarica in the city of Belgrade, the capital of Serbia. According to the 2011 census report, there were 5270 inhabitants, 1709 households with the average number of members per household of 3.08 [11]. Landslide Umka is formed on the right Sava river bank It occupies part of Umka settlement and represents one of the largest inhabited active landslides in Serbia (Figure 1.). Despite the fact that the landslide is active and has been threatening people's lives for decades, more than 490 inhabitants are still living on the body of landslide [10]. Furthermore, the state road M26 (from Belgrade to the border with the Federation of Bosnia and Herzegovina) is also affected by Umka landslide. More specifically, 1.7 km of this state road is crossing the landslide body. According to the available data regarding the traffic volume [12] average annual daily traffic across the landslide body for the year 2018 is 13970 vehicles per day and is showing increasing trend. Considering the possible disasters, the Umka landslide is one of the most investigated landslides in Serbia. It is systematically and continuously monitored by different geotechnical and geodetic techniques for decades.

According to geotechnical investigations at 2005 by the Highway Institute, Umka landslide surface is 0.83 km^2, with maximum length of cca. 1.66 km, maximum width of cca. 0.88 km and maximum depth of slip surface of 26 m [1]. The derived results of geotechnical investigations of the Umka landslide were published by many authors and some of them are Vujanić et. al. [13,14], Ćorić et. al. [15], Jelisavac et. al. [16]. In addition to geotechnical investigations, the dynamics of Umka landslide was investigated by various geodetic survey techniques, among which are aero photogrammetry [17], UAV photogrammetry [10] and automated permanent GNSS monitoring [1, 5-9].

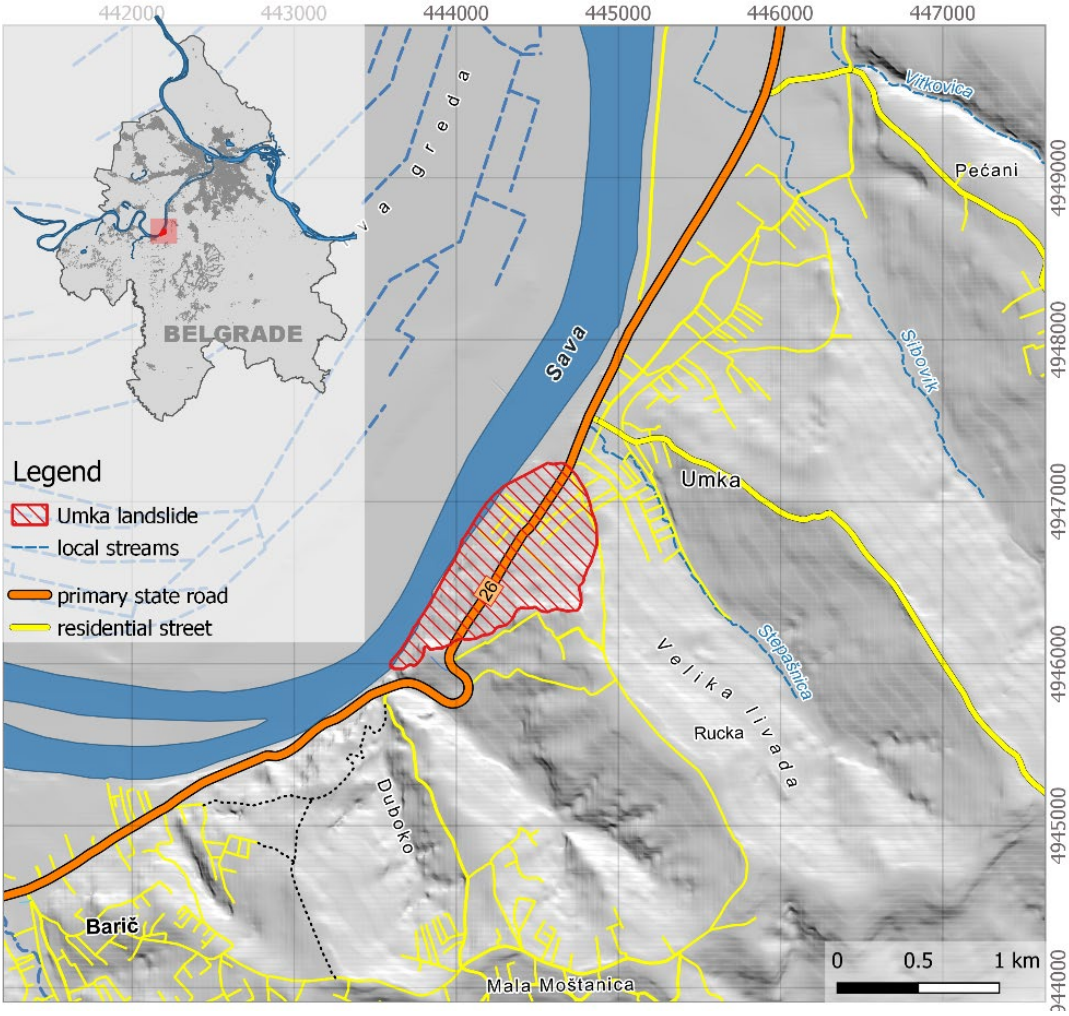


Figure 1. *Location of Umka landslide.*

3. GNSS MONITORING OF UMKA LANDSLIDE

For the purpose of Umka landslide monitoring, different geodetic procedures were applied during last 10 years:

1. Automated permanent monitoring of the position change for a single permanent GNSS station in the landslide area in relation to the three-surrounding stable GNSS permanent stations of the national GNSS service, AGROS;
2. Monitoring of the position change for the set of characteristic points on the landslide area, in relation to the set of stable points surrounding the landslide area, using GNSS kinematic positioning, in the selected time moments (measuring epochs);
3. Comparison of a digital terrain models, created form UAV photogrammetry in the GNSS kinematics positioning epochs.

Considering that the main issue of this paper is the presentation of the results gained with GNSS kinematic positioning of characteristic points of Umka landslide, the second procedure, as well as the obtained results, will be explained in *more detail further* below. In order to compare the displacements obtained from two applied GNSS techniques, for the first procedure (automated GNSS monitoring), only a brief overview will be given *further* below as well. The third procedure will not be discussed within this paper.

3.1. Automated gnss monitoring

As already explained in section Introduction, in March 2010 automated GNSS monitoring system was established on Umka landslide. Despite the numerous interruptions over the period of almost ten years of permanent monitoring, the system was successfully used in order to track the dynamics of Umka landslide in real time. In general, the derived data of automated monitoring are analyzed for two time periods separately, due to the relocation of the object point on December 2013 [1]. The first time period from the beginning of the monitoring, March 2010, to the December 2013; and the second time period from the September 2014 to the date (Figure 2.).

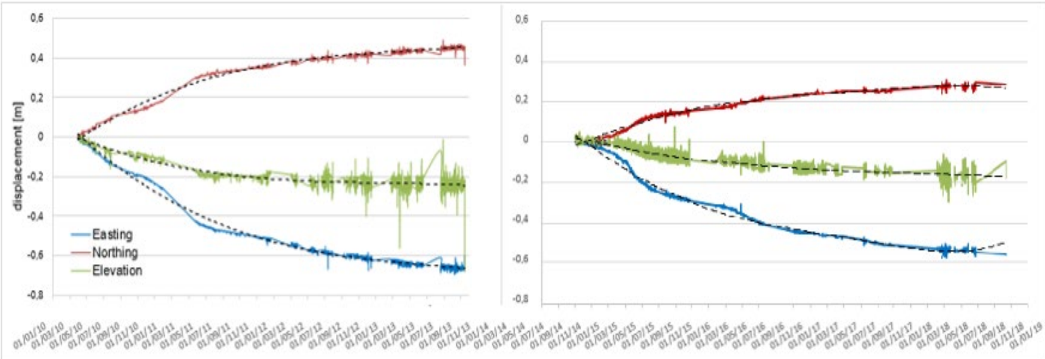


Figure 2. *Displacement of object point from March 2010 to December 2013 (left figure) and from September 2014 to end of December 2018 (right figure), for 12h interval.*

During the first time period (Figure 2. and Table 1.) the total 2D displacement was 84 cm towards the northwest. Furthermore, during the same period, the vertical displacement was nearly -30 cm. During the second time period (Figure 2.) the object point has moved 63 cm towards the northwest and the vertical displacement was nearly -16 cm. Generally, both graphics indicate that the Umka landslide is moving continuously and significantly towards the northwest, i.e. towards the Sava river. The average annual 2D displacement was approximately 22 cm and 15 cm, for first and second time period, respectively, with the same direction of movement. Considering the dynamic of the movement, Umka landslide can be characterized as slow to very slow [9].

Table 1. *Cumulative displacement of object points from March 2010 to December 2013 and from September 2014 to end of December 2018*

Time period	ΔE [m]	ΔN [m]	D [m]	ν (°)	Δh [m]
March 2010-December 2013	-0.67	0.45	0.80	304	-0.22
September 2014 -December 2018	-0.56	0.29	0.63	297	-0.16

3.2. GNSS monitoring by characteristic set of points

As already emphasized, the main shortcoming of the automated GNSS monitoring system used is only one observed object point. Therefore, in order to further analyze the Umka landslide dynamics, a passive GNSS network consisting of four stable points was established at the end of March 2018. Stable points were positioned out of landslide body (Figure 3.). Three stable points (S1, S3 and S4) are located on right bank of the Sava river, and point S2 is located on left bank of the Sava river. Point S1 is stabilized using steel benchmark in asphalt, point S2 is stabilized using massive wooden stake (in loose terrain, embankment), existing stabilization of official state traverse network (P771) was used for point S3, while for point S4 existing trigonometric stone benchmark (1/P16) was used. All stable points were used as a base points for relative kinematic GNSS positioning with post-processing. In addition, the S4 had the additional purpose as a base for real-time kinematic positioning.

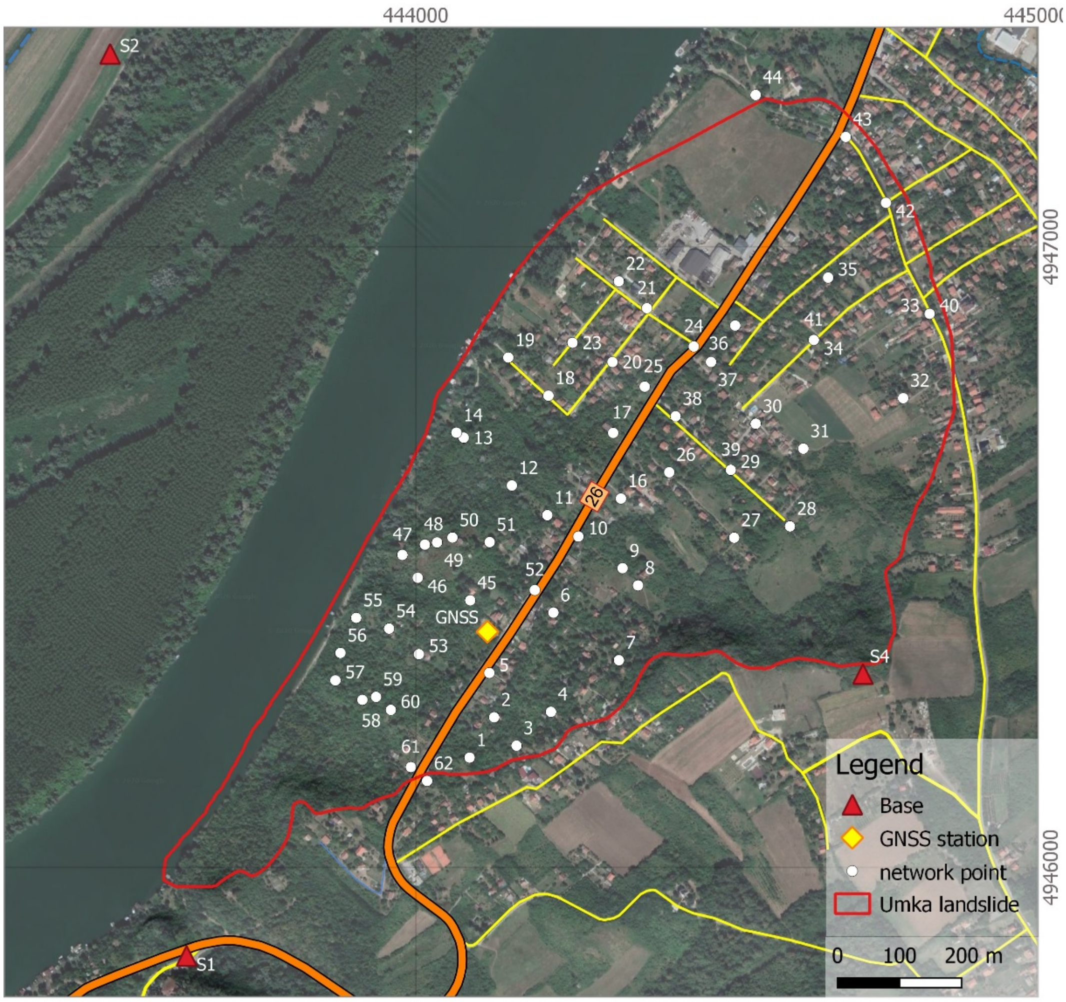


Figure 3. *Position of passive GNSS network points and 62 characteristic points of Umka landslide.*

In order to monitor the Umka landslide using geodetic methods, 62 points were established on the landslide body (Figure 3). Landslide points are stabilized using steel benchmarks in asphalt, wooden stakes in loose terrain or carved crosses in concrete. Point locations were selected ensuring that the points are homogeneously distributed over the area of activity (as much as the field conditions allow), the points are permanently stabilized without the possibility of easily falling out of bed or moving, and there is a good open sky visibility. Together with the stabilization of 62 landslide points, 20 orientation points for UAV photogrammetric imaging were also stabilized in a convenient arrangement, on locations visible from the air and photo-signalized by colored circles, about 20 cm in diameter.

Initial, zero observation epoch was made immediately upon the stabilization of landslide points, at the end of March 2018. After the Epoch 0, two more series of observations were made: Epoch 1 in late November 2018 and Epoch 2 in early April 2019. The months of April and November were chosen because of the reduced vegetation and landslide dynamics, which largely depend on the Sava river level and groundwater levels in the landslide body. For each epoch, after the four base points are proven to be stable since the Epoch 0, landslide point positions were determined by post-processing of kinematic GNSS observations with respect to all four stable (base) points, with each landslide point determined twice (two data collections, each with 30 epochs with a 1 second interval of observation). Comparisons and averaging were made between multiple solutions for a single landslide point position. More specifically, the final landslide points coordinates (E, N, h) were estimated by calculating the arithmetic mean for all four kinematic GPS / GLONASS solutions, with experimental standard deviation $\sigma_E = 3$ mm, $\sigma_N = 4$ mm, $\sigma_h = 11$ mm, for all three epochs. The real-time kinematic solutions from the base station S4 were intended to assure that postprocesed kinematic solution exists. After obtaining the coordinates for each landslide point in an individual epoch, the displacements (ΔE, ΔN, Δh) between Epoch 0 and Epoch 1 and between Epoch 0 and

Epoch 2 were calculated. Subsequently, the magnitude of the displacement vector and the azimuth of its direction were calculated and thus the relevant kinematics data for each point in two epochs were obtained (Figure 4.).

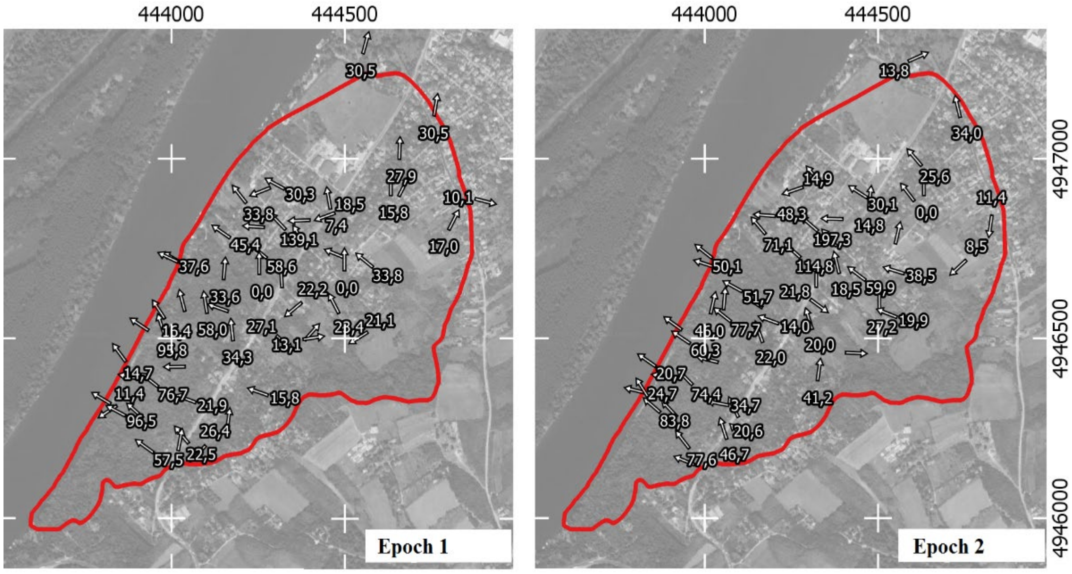


Figure 4. *Vectors of displacement of landslides Umka points from April 2018-November 2018 - Epoch 1 (left figure) and from April 2018 to April 2019 - Epoch 2 (right figure).*

For seven landslide points (6, 15, 19, 34, 40, 43 and 49) presented on Figure 3. there was no solution in any observation epoch, or they have been destroyed. One point (39) had no solution after the first observation epoch, while the three points (29, 41 and 59) had no solution after the second observation epoch. Based on the results presented on Figure 4, it can be concluded that the majority of obtained displacement azimuths are in the expected zone for the Umka landslide (270 °-360 °). As indicated by the results of automated GNSS monitoring system, the landslide body moves toward the Sava river. Due to the large number of characteristic points, only points with horizontal displacements (D) larger than 6 cm, during the time period from April 2018 to April 2019 are presented in Table 2. During the time period from April 2018 to November 2018 the horizontal displacements ranged from 0 cm to 13.9 cm, while the maximum vertical displacement was -23.4 cm. During the time period from April 2018 to April 2019, the horizontal displacements ranged from 0 cm to 19.7 cm, and the maximum vertical displacement was -30.1 cm.

Table 2. *Displacement of characteristic landslide points from April 2018 to November 2018 and from April 2018 to April 2019*

Point	April 2018 to November 2018				April 2018 to April 2019			
	ΔE [mm]	ΔN [mm]	D [mm]	Δh [mm]	ΔE [mm]	ΔN [mm]	D [mm]	Δh [mm]
4	-46,3	-46,8	65,8	**-234**	-72,0	-39,3	82,0	**-301**
13	-33,8	18,9	38,7	-65	-57,8	18,1	60,6	-87
17	-46,0	36,3	58,6	-53	-86,7	75,3	114,8	-116
18	-37,8	25,3	45,4	-39	-47,1	53,3	71,1	-98
25	**-97,7**	**99,0**	**139,1**	-83	**-151,3**	**126,6**	**197,3**	-128
38	-33,2	50,2	60,2	-44	-49,2	55,2	73,9	-78
45	-64,4	-0,9	64,4	-66	-74,4	18,1	76,6	-106
46	-30,4	90,8	95,8	-52	-50,7	32,8	60,3	-120
51	-9,7	57,2	58,0	-21	-61,6	47,4	77,7	-86

53	-61,4	45,9	76,7	-85	-53,3	51,9	74,4	-115
58	-85,8	44,2	96,5	-67	-64,5	53,5	83,8	-110
60	-57,5	49,9	76,1	24	-72,3	73,3	103,0	-99
61	-47,3	32,8	57,5	-49	-48,4	60,6	77,6	-130

The horizontal displacements of approximately 21% of all points ranged from 0 to 2 cm, 33% ranged from 2.01 to 4 cm, 23% from 4.01 to 6 cm, and 33% larger than 6 cm. The largest horizontal displacements were noted in the zone along the road M26 and right below it towards the Sava river, for both epochs.

4. CONCLUSION

During last ten years, in order to monitor Umka landslide three different procedures were applied: automated GNSS monitoring system, GNSS monitoring of characteristic landslide points and UAV photogrammetry. Established automated GNSS monitoring system of Umka landslide in March 2010 represents a huge step forward in monitoring landslides in Serbia. Period of almost ten years of continual monitoring is priceless regarding the real-time analysis of dynamics of Umka landslide.

In order to overcome the shortcoming of the established GNSS monitoring system and to analyze the Umka landslide dynamic in more detail, in March 2018, a passive GNSS network of four stable points and of 62 characteristic landslide points were further designed and realized. Up to this time, three observation epochs were completed with the aim of three-dimensional positioning of characteristic landslide points.

The data obtained using this methodology represent very reliable monitoring results with a high density of points from which it is possible to perform more detailed analysis for the entire landslide area. Precision of the observations and the processing results is higher for the horizontal displacements (5 mm) than the vertical (11 mm) and is conditioned by GNSS positioning characteristics, ie the fact that GNSS positioning precision is more than two times lower in height than horizontal position.

Considering the dynamics of the movement, derived from automated permanent GNSS monitoring system, Umka landslide can be characterized as slow to very slow. Therefore, obtained precision of displacement exceeds the required one of 2 cm. The main disadvantage of this methodology is repeatability. An observation epoch requires greater manpower engaged on the field and minimum five geodetic class GNSS receivers, which represents financial, logistical and often technical challenge. After the analysis of the dynamics of the Umka landslide, it is concluded that the third observation epoch should be realized in April 2020.

In general, each of these applied procedures, automated GNSS monitoring, GNSS monitoring of characteristic landslide points and UAV photogrammetry, has an important role in designing of the technology for landslide activity monitoring and results interpretation. The usage of the single permanent GNSS station provides information on landslide activity at any time moment and defines the spacing between the measuring epochs for the other procedures. GNSS kinematic positioning provides precise information about the values of movements in the representative set of discreet landslide points. The role of UAV photogrammetry is to obtain continuous information for the entire landslide territory in order to choose the density and spatial layout of a set of characteristic points.

LITERATURE

[1] B. Abolmasov, M. Pejić, M. Samardžić-Petrović, U. Đurić and S. Milenković, “Automated GNSS monitoring of Umka landslide review of seven years experience and results”, in Proc. Advances in Landslide Research: Proceedings of the 3rd Regional Symposium on Landslides in the Adriatic Balkan Region, 2017, pp. 65-71.

[2] A. Cina and M. Piras, M., “Performance of low-cost GNSS receiver for landslides monitoring: test and results”, Geomatics, Natural Hazards and Risk, vol. 6(5-7), pp. 497-514, 2015.

[3] C. Castagnetti, E. Bertacchini, A. Corsini and A. Capra, “Multi-sensors integrated system for landslide monitoring: critical issues in system setup and data management“, European Journal of Remote Sensing, vol. 46(1), pp. 104-124, 2013.

[4] P. Zhou, B. Zhou, J. Guo, D. Li, Z. Ding and Y. Feng, “A demonstrative GPS-aided automatic landslide monitoring system in Sichuan Province”, Positioning, vol. 1(09), 2005.

[5] B. Abolmasov, S. Milenković, B. Jelisavac and V. Vujanić, “Landslide Umka: The First Automated Monitoring Project in Serbia”, in Landslide Science and Practice. Margottini C, Canuti P, and Sassa K, Ed. Berlin, Heidelberg: Springer, 2013, pp. 339-346.

[6] V. Erić, B. Božić, M. Pejić, B. Abolmasov and J. Pandžić, “Permanent geodetic monitoring of the Umka Landslide using GNSS techonology and GeoMoss system”, in Proce. 2nd Regional Symposium on Landslides in the Adriatic-Balkan Region : 2nd ReSyLAB 2015, 2017, pp. 43-48.

[7] B. Abolmasov, S. Milenković, B. Jelisavac, V. Vujanić, Pejić M and M. Pejović, “Using GNSS sensors in real time monitoring of slow moving landslides-a case study”, in Landslides and Engineered Slopes: Protecting Society through Improved Understanding, Proceedings of the 11th International and 2nd American Symposium on Landslides and Engineered Slopes, Banff, Canada 1(2), 2012, pp.1381-1385

[8] B. Abolmasov, M. Marjanović, S. Milenković, U. Đurić, B. Jelisavac and M. Pejić, “Study of slow moving landslide Umka near Belgrade, Serbia (IPL-181)”, in Workshop on World Landslide Forum, Springer, Cham, 2017., pp.419-427.

[9] B. Abolmasov, S. Milenković, M. Marjanović, U. Đurić and B. Jelisavac, “A geotechnical model of the Umka landslide with reference to landslides in weathered Neogene marls in Serbia”, Landslides vol.12(4), 2015, pp. 689-702.

[10] U. Đurić, B. Abolmasov, M. Marjanović, M. Samardžić-Petrović, M. Pejić, N. Brodić, J. Popović – IPL Project 181 – Study of slow moving landslide Umka near Belgrade, Serbia – progress report for 2017 & 2018

[11] Statistical Office of the Republic of Serbia “Census of population, households and dwellings in the Republic of Serbia in 2011” (2011) Internet: https://www.stat.gov.rs/en-us/oblasti/popis/, (Jan. 10, 2020)

[12] PE Roads of Serbia “Mreža državnih puteva IA reda Republike Srbije, prosečan godišnji dnevni saobraćaj - PGDSU 2018. godini (Preliminarni rezultati)” (2018) Internet: https://www.putevi-srbije.rs/images/pdf/brojanje/2018/DP-IB-PGDS-2018.pdf, (Jan. 23, 2020).

[13] V. Vujanić, N. Livada and D. Božinović, “On an old landslide in Neogene Clays on the right bank of the Sava near Belgrade”, in Proc. of 4th international symposium on landslides, Toronto, Canada, 1984, vol 2, pp 227–233.

[14] V. Vujanić, N. Livada, M. Jotić, S. Gojković, J. Ivković, D. Božinović, D. Sunarić and J. Šutić, (1981) “Klizište “Duboko” na Savi kod Beograda”, Zbornik radova Simpozijuma istraživanje i sanacija klizišta, Bled, 1981, Knjiga 1:119–134 (in Serbian).

[15] S. Ćorić, D. Božinović, V. Vujanić, M. Jotić and B. Jelisavac, “Geotechnical characteristics of old landslides in Belgrade area”, In: K. Senneset, Ed. in Proc. of the 7th International symposium on landslides, 1996, Vol 2, Balkema, Rotterdam, pp 689–694

[16] B. Jelisavac, S. Milenković, V. Vujanić and P. Mitrović, “Geotechnical investigations and repair of the landslide Umka - Duboko on the route of motorway E-763 Belgrade–South Adriatic”, in InternationalWorkshop-Prague-Geotechnical days, Prague, 2006.

[17] B. Abolmasov, U. Đurić, R. Pavlović and B. Trivić, “Tracking of slow moving landslide by photogrametric data-a case study”, in Proc. Landslides and Engineered Slopes: Protecting Society through Improved Understanding, Proceedings of the 11th International and 2nd American Symposium on Landslides and Engineered Slopes, vol.1(2), 2012, pp.1359-1363.

11 | Research paper I Оригинални научни рад
ISSN 2566-4484 I Doi 10.7251/STP2014099S
pages 99-112

Dragoljub Sekulović, dragoljub.sekulovic@fpsp.edu.rs, Faculty of Information Technology and Engineering, University Union "Nikola Tesla"

Miloš Basarić, ivan.garic@yahoo.com, Military Geographical Institute, Belgrade

Ivan Garić, mbasaricbp@gmail.com, Military Geographical Institute, Belgrade

THE FLOOD THREAT MAPPING OF THE KOLUBARA RIVER BASIN USING THE LEICA ALS80HP LASER SCANNER

Abstract:

Every year, floods cause great damage in the Republic of Serbia. The lack of solutions for flood risk management and prevention during their escalation causes great financial deficit. One of the solutions for achieving stability in this sphere is creating a map of flood threats and risk according to the European Flood Directive. The task of the IPA2014 action is the creation of those maps using the latest technology in laser scanning of terrain, or LiDAR sensors. Scanning the terrain from air using the aforementioned technology gathers data which by later processing results in very precise digital models of terrain which are used as the foundation for mapmaking.

Key words *:Flood, Map of flood threats, LiDAR, IPA2014, Hazard maps*

КАРТИРАЊЕ УГРОЖЕНОСТИ ОД ПОПЛАВА СЛИВА РЕКЕ КОЛУБАРЕ ПРИМЕНОМ ЛАСЕРСКОГ СКЕНЕРА LEICA ALS80HP

Сажетак:

Поплаве сваке године нанесу велике штете у Републици Србији. Недостатак решења за управљање ризицима и превенцију од поплава приликом њихове ескалације изазивају велике буџетске дефиците. Једно од решења за постизање стабилности у овој сфери јесте израда карата угрожености и ризика од поплава сходно Европској директиви о поплавама. Задатак пројекта ИПА2014 јесте израда тих карата применом најсавременије технологије у области ласерског скенирања терена односно LiDAR сензора. Снимањем терена из ваздуха користећи поменуту технологију прикупљају се подаци који у каснијој обради резултују врло прецизним дигиталним моделима терена који служе као основа за израду карата.

Кључне ријечи: поплава, карта угрожености од поплава, LiDAR, ИПА2014, карте хазарда

1. INTRODUCTION

Flooding is the most catastrophic natural phenomena causing extensive damage to human life, environment, and infrastructure. Although it cannot be prevented, it is possible to reduce the risk of true flood modeling. The constant problem with flooding activity in the Republic of Serbia, particularly the flooding that happened in May 2014, lead to the conclusion that the process of risk management and especially flood prevention must be taken very seriously at the national level, as well as raising awareness of the issue.

Flood modeling techniques are mostly based on the Digital Terrain Model (DTM) and projected water level [1, 2], therefore the reliability and accuracy of flood risk maps are highly dependent on the accuracy and resolution of DTM model. Remote sensing, covering a large geographical area at the different spatial, spectral and temporal resolution, provides a large amount of data that has been extensively used for flood management.

Airborne light detection and ranging (LiDAR) have become a widely-used remote sensing method that provides a rapid collection of high-resolution topographical datasets. LiDAR has become one of the most used data sources in flood modeling [3, 4]. However, all those applications are built around the generation of DTM using a raw point cloud. The point cloud is represented as a set of 3D points where each point Pi is a vector of its coordinates (Xi, Yi, Zi). The raw LiDAR point cloud contains the ground and non-ground points. The DTM refers to a bare earth surface created by interpolation of ground points therefore the classification of point cloud need to be performed. The classification methods can be divided into filtering algorithms [5] (mostly based on geometrical features of 3D ground points) and deep learning algorithms [6].

Flood prevention in the Kolubara river basin is just one small piece of the puzzle of comprehensive flood prevention in the Republic of Serbia. Therefore, the IPA2014 action which is executed by many state institutions from different areas is a great chance to approach the problem of flooding more seriously.

The main aim of this paper is to present in detail the process of creating a flood threat map using descriptive metodology, based on a local territorial framework, the Kolubara river basin. The whole process is viewed from a general perspective, due to the technological impossibility to view the details of the process from a local level. On the other hand, the whole process of making a flood threat map of the Kolubara river basin within the IPA2014 action is still ongoing, so at the time of writing a map of flood threat of the Kolubara river basin does not exist. Therefore, analisys of the maps quality and accuracy itself cannot be done. It should be noted that some period of time after the publication of this map will be possible to analyze their engagement and usage.

Cartographic idea for a flood threat map at a local level of the Kolubara for the wider area of the city of Valjevo is enclosed.

2. GEOGRAPHICAL STUDY OF THE KOLUBARA RIVER BASIN

The Kolubara river basin lies in the northwest part of Serbia. „The shape of the basin is roughly rectangular and is lined with low or middling mountains of the Valjevo and Sumadija region. On the fourth side, northward, the gently rolling hills spread out into the Pannonian plain. Kolubara is the last tributary of the river Sava, flowing into it 27km upstream from Belgrade. The mouth of Kolubara lies at 76m above sea level, while the highest point of the south river divide is Povlen, located at 1346m above sea level" [7]. On the territory of the Kolubara river basin are the parts or whole territories of the following municipalities: Obrenovac, Barajevo, Sopot, Lazarevac, Koceljeva, Vladimirci, Šabac, Osečina, Ub, Lajkovac, Mionica, Ljig, Aranđelovac, Gornji Milanovac and Kosjerić, as well as the city of Valjevo with a population of 335.000 people [7] (Figure 1).

"The Kolubara river basin has a very unfavorable water regime, created by the hydro-meteorological, topographic, geological, and hydraulic conditions in the basin. Unfavorable temporal and spatial distribution of precipitation and great drop of its tributaries with an unfavorable distribution of hydrographical flow network, regularly cause fast and concentrated confluence of waters on a proportionally short section of Kolubara's central valley. The hydrographical network is such that it enables large quantities of waters from the tributaries to coincide in the central part of the Kolubara valley, with spilling of floodwaters on the spacious plain. The unfavorable condition of sudden water inflow is amplified by the insufficient permeable power of the Kolubara river bed in the plain to be able to take such a vast concentrated flow into the main recipient – the river Sava, which causes frequent flooding in the valley" [7].

Figure 1. *Kolubara river basin [7]*

The floods in the Kolubara river basin have always been an ongoing issue. The most extreme examples are the floods from 2014 and a flood that caused similar damage in 1926. Besides those, numerous examples tell us that Kolubara and its tributaries tend to flood multiple times per decade.

3. THE METHODOLOGY OF CREATING A FLOOD THREAT MAP AND A FLOOD RISK MAP

The methodology of creating a threat map and a flood risk map was defined by regulation from 2017 ("Regulation on determining the methodology for the creation of a threat map and flood risk map") which defines the basic rules of its creation. The methodology defines some concepts which concern this paper, which should be highlighted [8]:

- *flood*–temporary water coverage of ground that is usually not covered by water, and includes flooding by outer waters and floods by inner waters;
- *flood area* – area at risk of flooding;
- *significant flood area* – flood area where significant flood risks are present or can appear;
- *flood threat map* – cartographic display of flood area borders, water depth and, if needed, speed of water in certain flood scenarios, and
- *geographic information system (GIS)* – computer system meant for collection (integration), processing, managing, analysis, display and maintaining spatial information.

A map of flood threat by inner waters for a specific scenario must show [8]:

- flood area border,
- water depth, in four classes (depths <0,5 m; 0,5 – 1,5 m; 1,5 – 4 m; и >4 m), and
- existing facilities for protection against flooding by outer waters.

The flood area border is defined by transferring the computational level of water to the GIS environment. It is a vector (polygon), obtained by a cross-section of the water mirror plain with a digital terrain model. Flood area borders and water depth, in case of internal water flooding, are determined by using the available meteorological, topographical and other data depending on the requirements of the models applied to the calculation. Water depth in a certain flood scenario is the difference between the water level and the digital terrain model. „It is recommended that the risks within the border of the realistic area are displayed with polygons/lines/dots/marks in different colors, while risks in the potential flood area are marked in the same way, in lighter shades of the same colors" [8].

These maps should be available to the public administration body which is in charge of spatial planning to consider different scenarios and make decisions.

After the catastrophic floods that hit the Republic of Serbia in 2014, which have caused the most damage in the Kolubara basin, the Republic of Serbia quickly started developing active measures of flood prevention. The Republic of Serbia saw a chance for establishing the technological framework by using the pre-accession funds of the European Union (IPA funds). In the wake of those efforts and with the support of the European Union (EU) the IPA2014 action was started (IPA – Instrument for Pre-Accession Assistance).

The IPA2014 action represents the initiative of the Republic of Serbia and EU in the rehabilitation of the damage made by the catastrophic flooding that impacted the western part of Serbia due to heavy rainfall in the third week of May 2014 and prevention of further potential flooding in the future. That help is reflected in the items of the action document which the European Commission set to the Government of the Republic of Serbia which states that the EU will donate 62 million euros and provide guidelines for project implementation. During the May 2014 floods 200 mm of rain fell in the area of west Serbia in just a week, which equals three months of continued rainfall under regular circumstances. Along with rainfall in the rest of Serbia, that impacted the rise of water levels of the rivers Sava, Tamnava, Kolubara, Jadar, West Morava, Great Morava, Mlava and Pek. During the flood, around 32.000 people were evacuated from their homes, and around 1,6 million people were directly or indirectly involved in providing various kinds of aid towards rehabilitation and prevention of further consequences, both privately and within relevant institutions [9]. The European Directive on flood risk assessment and management together with the Directive 2000/60/EC practically reduces activities regarding flood risk into three-element procedures: *preliminary flood risk assessment, risks assessment within which threat maps and flood risk maps are made, and plans for flood risk management* [10, 11]. In accordance with that, one part of the obligation is the creation of the mentioned maps. This paper concerns the creation of flood threat charts and not flood risk charts, and its contents are oriented accordingly.

The carriers of the project are also the Ministry of Agriculture, Forestry and Water Economy, Republic Water Directorate, Republic Geodetic Authority, Ministry of Defense - Military Geographical Institute (MGI) and Air Force capacities and air defense of the Serbian Armed Forces, Republic Hydro-meteorological Service of Serbia, public water management companies „Srbijavode” and „Vode Vojvodine” [12].

„The Ministry of Defense is recognized as the carrier of the implementation of the project, while the Military Geographical Institute is recognized due to its achievements in the field of cartography as the national cartography institution capable of performing the necessary measurements in their capacity, as well as collecting and initially processing the terrain data required for the creation of flood threat chart. For that purpose, and according to the specification of the Republic Geodetic Authority and Military Geographical, the EU has approved the acquisition of equipment for realization of the necessary aero photogrammetry and LiDAR scans, and the realization of fieldwork and further processing of the measured/collected field data” [9].

This paper deals with the entire process of collecting and processing the data for the needs of creating a flood threat map, which can be described in the following phases:

- Defining the area of the survey in accordance with the Preliminary flood risk assessment for the territory of the Republic of Serbia.
- Flight planning to scan the area of interest using the LiDAR system.
- Scanning the area of interest using the LiDAR system.
- Orientation, calibration and other operations of initial processing the collected data
- Point cloud classification.
- Generating digital terrain models.
- Generating hydrographic and hydrological models.
- Map creation process.
- Integration into the Water information system (WIS).

In all those phases, the integration of the data from local government, relevant and authorized institutions and field works should be gained. The ultimate contribution of these maps and hydrological and hydrographic models within digital terrain models (on which the map rests) is to create conditions for an improved early warning and flood forecasting system as well as to advance the development of flood risk management plans through implementation in the WIS.

4. THE TECHNOLOGY OF CREATION OF A THREAT MAP OF THE KOLUBARA RIVER BASIN

4.1. The technological base for measuring and collecting data

„Laser scanning of the terrain is a modern technology for acquiring spatial data in the form of coordinate points in space. In regards to the type of scanning, laser scanning can be terrestrial and aerophotogrammetrial. In both cases, collected data can be used for the construction of digital, two-dimensional sketches or 3D models, whether it is a digital terrain model or a model of a separate object. The ultimate advantage of this method is high accuracy and speed. When it comes to laser scanning of terrain from air, it is done from an aerial platform which can be a helicopter, airplane, or an unmanned aerial vehicle. The significance of spatial data and their application is increasing. This especially applies to the creation of 3D city models, various engineering projects, collecting DTM data for the needs of ortophotoreproduction and creation of geodetic bases of large and middle-size” [9].

“Laser scanning is not a replacement for the existing techniques of geodetic survey but is an alternative which can be used is most geodetic operations. The scanning is done by the already familiar method of registering the distance and angle of a certain point in the study area. The result of laser scanning is a group of three-dimensional XYZ points which is called a point could. The spatial distance between adjacent recorded points within a point cloud depends on the proximity of the recorded object and the technical specifications of the instrument itself ” [13]. Along with spatial data a point cloud can also contain the intensity of the color reflected from the surveyed surface. The color data are determined based on the intensity of the reflected beam and the records of the camera which is an integral part of the laser scanner [13].

LiDAR is a synonym for the laser method of terrain survey. The name LiDAR is an acronym made form „Light Detection And Ranging” which would describe the method of distance detection aimed at examining the Earth’s surface [14]. With this method, the distance is measured based on light, or laser impulse. In combination with data from the aerial platform system and orientation, we generate precise three-dimensional data about the topology of the Earth's surface and their characteristics, which is what forms the digital terrain model – DTM [9, 14]. The basic components of the LiDAR system are a laser scanning unit, GPS receptors on a platform and at a ground station, a unit of the inertial navigational system with the inertial measurement unit (IMU) and a data storage and processing unit [15, 16].

The ALS80HP, in the name of the laser scanner used for the IPA2014 action Leica, stands for „Airborne Laser Scanner” which is a laser scanner meant for recording from an airborne platform, while the HP defines a model for general-purpose recording meant for altitudes up to 3.500 m above ground [16].

4.2. Laser SCANNING USING THE LEICA ALS80HP SYSTEM

When speaking about aero photogrammetry and LiDAR technology recording, we are speaking about sensors that are mounted on aerial platforms. Those platforms can be airplanes, helicopters, satellites, unmanned or any other aerial vehicles.

4.2.1. Flight plan concept and distance exploration method

As the LiDAR survey, projected within the IPA2014 action, need to be done using an airplane, the explanation of the flight planning concept will be made for that example. To conduct an aero photo survey and scanning of terrain by airplane it is necessary to determine numerous parameters that will ensure that the procedure is as efficient as possible, and the product of recording as precise and relevant as possible [17]. For the needs of the IPA2014 action for laser scanning of around 9.4km^2 the following instructions are given [18]:

- Point density must be greater than or equal to 5 points per meter square for plains areas and greater or equal to 8 points per meter square for hilly areas.
- The ratio of mean point distance in the direction of flight line (dx, Along-track mean spacing) and mean point distance relative to the direction of flight (dy, Cross-track mean spacing) must not be greater than 2 to 3 to ensure the homogeny of the collected data.
- Laser scanning should be done with a projected 30% cross overlap of scanning lines. Deviation from the realized scanning lines cross overlap must not be greater than a third of the cross overlap.

- The GNSS station network „AGROS" of the Republic Geodetic Authority needs to be used. The distance between the aircraft and the permanent (or virtual) GNSS station at all scanning points (including the turnaround of the aircraft) must not be greater than 30km. To conduct laser scanning at least two permanent (or virtual) GNSS stations are to be used.
- The tilt of the aircraft during turnaround for next row scanning must not be greater than 25^{o}, to avoid an unfavorable satellite constellation.
- During data collection, the „8" flight procedure must be applied before and after the completion of LiDAR scanning.

To fulfil these requirements, it is necessary to plan the flight path the airplane will be taking, at what speed and altitude, and that explain the essentiality of the flight plan. An indispensable component required for flight planning is the base – the DTM. It is recommended to always use the most accurate available DTM of the recorded area. If we do not have one or it does not exist, we can use the global DTM – Shuttle Radar Topography Mission (SRTM). The accuracy of the SRTM is significantly lesser than digital terrain models at national or local levels, but it can still provide support during flight planning [17].

4.2.2. The realisation of terrain scanning using the LEICA ALS80HP system

Flight realization and terrain survey is done in accordance with separating the recorded territory into polygon „strips" (Figure 2). That is the actual shape defined by a point from the project task set by the IPA2014 action regarding the ratio of mean point distance in the direction of flight and relative to the flight line. In the middle of each strip, we can define a flight line that is used to graphically representation of every flight plan. The survey is done in order, by flight lines, so that the airplane does a turnaround after every recorded line to record the next line in the opposite direction. The surveyed territory on two adjacent flight lines has a cross overlap of 30% because it is necessary to ensure the comprehensiveness of the recorded content during recordings on all flight lines [17].

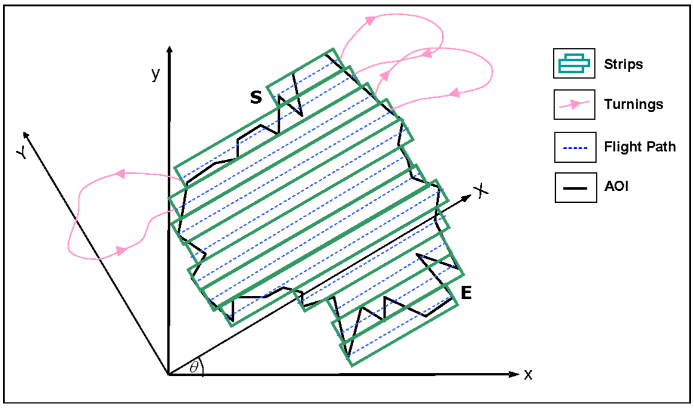


Figure 2. *Graphic display of flight plan with recording range marks by flight lines [17]*

Flight planning requires the optimal relation between the laser scanner, the aircraft, the navigation subsystem, terrain characteristics, and other components. Also, the flight plan defines the manner of turning to the next flight line, the angle of airplane rotation while turning as well as the process of initiating the systems for starting and finishing the recording. As stated above, the tilt while turning to scan the next strip must not be greater than 25^{o} to avoid an unfavorable satellite constellation [16, 17]. The flight path trajectory during one recording is shown in Figure 3. A red rectangle on the image marks the parts of the flight path to which the "8" procedure refers to the project task. It represents a mandatory procedure during flight, before and after completion of LiDAR scanning which initiates and stops the IMU laser scanner subsystem during recording [16, 17]. Underlined in red are the permanent stations of the AGROS network, which must not be at more than 30 km distance at any point of recording (including the aircraft turnaround), whether they are permanent or virtual [16]. The Active Geodetic Reference Network of Serbia (AGROS) is a network developed on the territory of the Republic of Serbia as support for performing precise positioning. It consists of 30 permanent GNSS stations which are used for continuous GNSS observation, positioned at an approximate distance of around 70 km, which are mostly placed on local cadastre buildings. The network was created in 2005 by the Republic Geodetic Authority in cooperation with the Faculty of Technical Sciences from Novi Sad. The path which the airplane took to reach the area of recording can be seen in Figure 2. That path is particularly curved due to the density of air traffic, another factor that is taken into account for recording planning. There is another important detail when it comes to initial turnings and permanent stations, and it is that the distance between the initial turnings and permanent stations must not be greater than 20 km which is recommended by the manufacturer, and the maximum distance between the final point of the recorded area and the station is 30 km for the needs of the project [17].

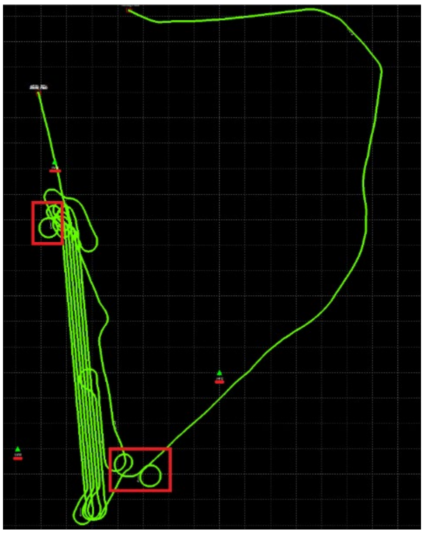


Figure 3. *Flight trajectory display during recording with marks for initial turns and permanent stations [17]*

The Kolubara river basin area meant for recording is large and demanding. Many tributaries that figure into the basin and Kolubara's meander influenced the recording so that it has to be done partially by areas. It is required that the Kolubara be recorded in 7 parts, as well as recording some of its tributaries separately [17]. Figure 4 shows the areas of recording the Kolubara basin by polygons.

Figure 4. *Sectioning the Kolubara river basin into recording areas [17]*

An image of the study area does not tell us much about the method of recording or approaching the area. In Figure 4 we have a display of sectioning the area of recording with flight lines figured for every territorial unit (Figure 5) [17]. The image displays the complexity of planning the recording of the entire territory, considering the variety of angles of flight lines for each territorial unit.

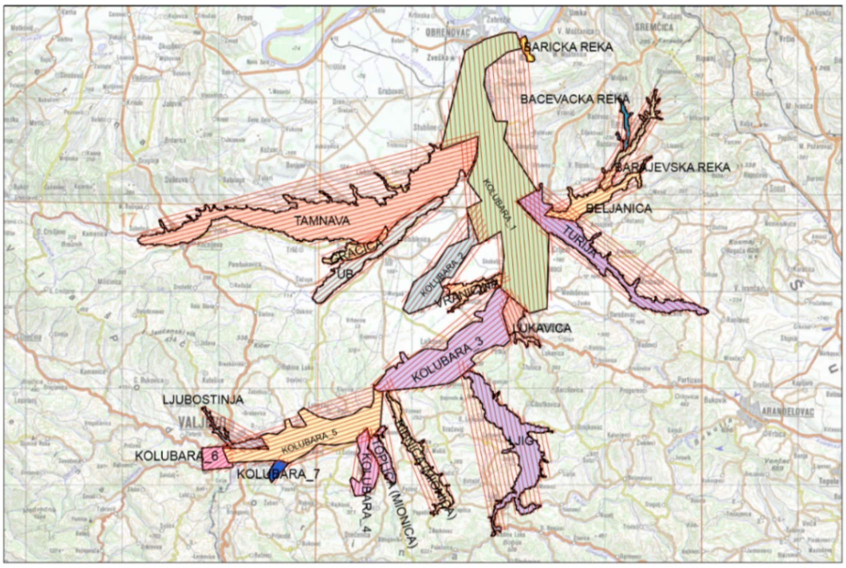


Figure 5. *Flight line display on worksites of Kolubara water basin [17]*

4.3. Processing the data collected by using the laser scanner leica als80hp

Immediately after executing the flight and laser scanning, it is required to conduct the preliminary data control of the GPS/INS systems, which includes checking for interruptions in data collection, controlling for data coverage of the area of interest, control of data collection interval and controlling the minimal number of satellites during the scanning. Obtained data is also controlled through checks of data coverage of the area, checks of completeness and accuracy of collected data and checking the density of the collected point cloud. Also, after the realization of the flight and scanning, the graphic part of the conducted flight plan is created and it contains the border of the scanned area, marked scan lines and executed flight directions and the absolute height of the realized flight for every scan line. The used geodata has the same characteristics as the one used for flight planning. If these preliminary checks find errors and omissions, it is necessary to conduct the scanning of those areas again. The goal of data processing is the creation of the DTM, which will be spoken of afterward [17].

Processing the data collected by using the laser scanner, is done in the software package of the company Leica with the programs MissionPro, FlightPro, NovAtel Inertial Explorer, CloudPro and also in the software package Terrasolid, which contains the programs TerraScan, TerraPhoto, TerraMatch and TerraModeler [16, 17].

4.3.1. Processing the recorded data

Trajectories of the flight provide us with information about the position and placement of the laser scanner for every point during the data collection in GPS and IMU. When we enter the trajectories and points it is necessary to connect every point with a precisely determined flight line. That way every point receives information regarding its creation and time [17].

The first step in data processing is the initial classification of points from the point cloud, which is automated to a certain extent. That means that the points are being sorted in accordance with their height into basic point categories. The classification results are preliminary, i.e. this classification is initial; however, it is important since represents a starting point for the final classification process in the later stages by classes like the ground point, low vegetation, middle vegetation, high vegetation, buildings, low points, very high points, water, and bridges [19].

As raw data, the point cloud was an undefined group of points without the ability to recognize the nature of objects present on the terrain as possible after the classification. Figure 6 shows the display of the point cloud after the classification from two perspectives was conducted.

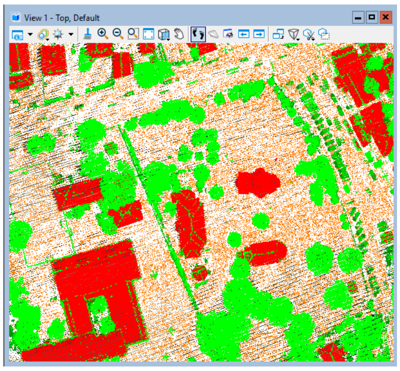
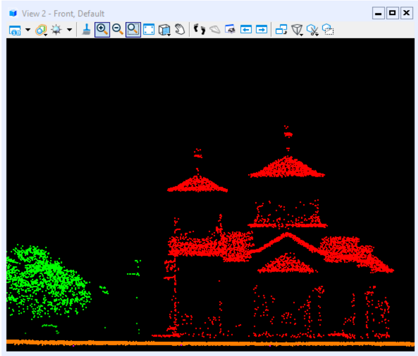



Figure 6. *The display after the classification from above (left) and from ground level (right) [19]*

After that, the relative orientation is conducted, which represents determining the position of the scanner during the survey in relation to the plane. It is performed by using data collected by the IMU during the flight, and concerns the movement of the plane across the three axes during the flight, explained in the part of the paper concerning the instruments. The next processing phase is HRPM correction which represents the correction of the factor of plane movement across the three axes during the flight (Heading-Yaw shift, Roll shift, Pitch shift) and the Mirror Scale parameter which represents the factor of the reflective mirror in the sensor [17].

During data processing calibration parameters are also introduced. According to the manufacturer's specification related to terrain calibration of the system, to achieve the highest accuracy of results, it is required to calibrate the system during one period of operational work. That means that after every change (conducting the scanning from the air by using other sensors, reinstallation of the system inside the aircraft...) the calibration needs to be done. Also, calibration must be executed in order to have a guarantee of the surveying consistency for the large projects. After that, absolute orientation is done, which creates the spatial reference and the referential frame for scanned points, in accordance with points scanned on the terrain. Absolute orientation is conducted according to the grid of Ground Control Points which are scanned on the terrain of the study area using GPS technology [17].

The elevation of points is expressed in ellipsoidal heights due to the nature of GPS technology. Because of that, the heights at the end of the process are reduced to geoid heights, for which global parameters of the RGA are used, and are universal for the entire territory of Serbia [17].

In order to make a recorded point cloud as suitable as possible, the classification of the points will create conditions for the most appropriate use of the data and creation of the DTM which represents the foundation of the flood threat map [18]. Point cloud classifications concerning the IPA2014 action is conducted by the Republic Geodetic Authority [18, 19].

Basic principles for DTM creation are stated in the Technical specifications for preparation of the DTM used for hydraulic modeling during the process of flood threat map creation, which is made for the needs of the IPA2014 action. The following requests for creation of the DTM were defined by the Technical specifications [18]:

- The spatial resolution of the DMT should be 1,0 x 1,0 meter (GRID);
- Absolute elevation accuracy of the final product (DTM) on open terrain, made of durable material (concrete, gravel, landscaped area, etc.) and tilted no more than 20% needs to be better or equal to 0.15 meters;
- Absolute elevation accuracy of the final product (DTM) on terrain covered with tall grass, crops, shrubbery, trees and other forms of dense vegetation, as well as on densely populated areas needs to be better or equal to 0,30 meters. In areas with distinctly dense vegetation, swamps and on terrain with extreme configuration, the absolute elevation accuracy can be lower;
- The horizontal accuracy of the final product (DTM) needs to be better or equal to 0,5 meters;
- DTM as a final product will be delivered in a resolution of 1 m and ESRI ASCII raster grid format and in ASCII (xyz) format;
- Structural lines of high-value objects are delivered in ESRI 3D shape format; and

- Data composed of a defined class of objects of importance is delivered in the shape of point clouds generated by automatic classification and in ASCII (xyz).

In addition to the data collected using laser scanning, for map creation, the updated topographic maps, results of hydro-meteorological observation and hydrographical surveys are needed.

In order to create a quality digital orthophoto for the needs of the IPA2014 a digital aerophotommetric camera, Leica ADS80 was used. The time between the data collection by using the laser and aerophotommetric systems cannot be larger then 15 days. A digital orthophoto is necessary during Point Cloud classification, as all ambivalences and doubts encountered during the processing of points are eliminated by evaluating the terrain using an orthophoto of identical terrain [18]. Data collected by using the aerophotommetric method for the needs of the digital orthophoto creation is conducted in accordance with the provisions of article 7 to article 81 of the Regulation of topographic measurements and topographic-cartographic creations [20].

4.4. Integration of data for creation of A flood threat map of kolubara river basin within the IPA2014 ACTION

The integration of data for the creation of the flood threat map in the Republic of Serbia within the IPA2014 action presents a very important process composed of hierarchically orientated activities through which the data is passed to finalize the project or more precisely the final result – the flood threat map (FTM). Besides the flood threat maps, this project also has a goal of creating flood risk maps (FRM). The process of their creation is regulated by the Agreement of cooperation on the realisation of activities from the Action document for flood consequences relief, within the Instrument for Pre-Accession Assistance of the EU – IPA2014. Cooperation is achieved within the following institutions: Public Investment Management Office (PIMO), Ministry of Agriculture, Forestry and Water Economy – Republic Water Directorate (RWD), Republic Geodetic Authority, Ministry of Defence (MOD), Republic Hydrometeorological Service of Serbia (RHMS), Public Water Management Companies „Srbijavode" and„Vode Vojvodine".

The Agreement of cooperation defines a consulting body in the form of a foreign company with experience in developing flood risk maps. After taking over the processed data, the consulting company would create maps and within a detailed methodology that is in harmony with the general methodology of the Regulation on determining the methodology for the creation of a threat map and flood risk map. Also, the consultant has an obligation to train staff of the homestate water companies in the field of flood thret mapping. In this way, local water utilities would be introduced into the process of mapping so that could be done indepentent in future projects.

The institution operating within the Ministry of Defence is the Military Geographical Institute as an establishment that deals with research and development and production work in the fields of geodesy, photogrammetry, cartography, geographic information systems, cartographic reproductions, metrology and other geodisciplines with the goal of creating topographic materials [12, 21].

5. CREATION OF THE FLOOD THREAT MAP OF THE TEST AREA OF A PART OF KOLUBARA RIVER BASIN

The flood threat maps provide information about flood area borders, appropriate depth and/or water velocity for floods that have a certain probability of occurrence. The creation of these maps is achieved by using different techniques, such as hydrological and hydraulic modeling, based on a precisely mapped river bed and the surrounding coastal area. The process of generating these maps is quite complex and requires a very long creation period, as well as significant funding [8, 21].

These maps are created in accordance with the requirements pertaining to areas with potentially significant risk of flooding, defined in the European directive on the assessment and management of flood risks 2007/60/EC. This directive mandates the following [11]:

- Flood threat maps will include geographic areas that may be flooded according to the following scenarios:
- Floods with low occurrence chance, that is an extreme event scenario,
- Floods with a medium occurrence chance (time-reversal period ≥100 years),
- Floods with a high occurrence chance, if required.
- The following elements will be displayed for every scenario from paragraph 3:
- Flood reach (Boundaries of the flooded area),

- Flood depth distribution (water level),
- As necessary, flow velocity or rate of flow.

Flood threat maps as a result of the IPA action should display the results of the analysis of at least three high water appearance scenarios – with time-reversal periods of 50, 100 and 1000 years and in that way include floods with high, medium and low occurrence chance. Estimates of floods with time-reversal periods of 50 and 100 years take into account already existing embankments and as a result show *realistic flood zones* (threat maps). In cases where there is a danger of embankment collapse, a separate, appropriate hydraulic calculation is allowed for, and as a result, *Potential Flood Zones* are derived from it. However, calculations of floods with a time-reversal period of 1000 years do not take into account the existence of embankments (it is considered that they are significantly damaged by flooding and no longer stop overspill from the original river bed). The flood zones defined in this manner show the area of *Potential Threat* from extremely high waters [22].

Flood threat maps are a great help when setting priorities in the implementation of active measures and their possible funding, taking into consideration all relevant factors (population, socio-economic factors, environmental protection, etc.). Based on this and suitable analyses it is possible to identify the best options and sets of measures for minimizing the risk of floods. The most important activities are spatial planning and development control, goods system management (flood prevention, retention areas, river systems, roads, etc.), preparations for flood occurrences (flood detection, forecast, planning for emergencies), flood incident management and response (Notifying and alarming the population about flooding, emergency services activities, activities of health services and и authorities in charge of flood risk management, public involvement (organizations for community support). Those goals, as well as the measures for their implementation, will, in general, ensure that the Plan for flood risk management enables assessment, evaluation and in the end the reduction of hazards and flood risks in the best possible way. Besides that, these maps are used as aids when planning the construction and development of villages and cities [21]. All in all, these maps will serve to illustrate the expected final results of the implementation of suggested optimal flood risk management system within the IPA2014 action.

In order to show the entire process of flood threat of the Kolubara river basin map creation, activities on a specific test area are presented in this paper. To achieve the most representative illustration of all principles contained in this very complex process, the choice of the test area will be the city of Valjevo.

5.1. Flood threat map for test area creation procedure

To better understand the concept of creation of a flood threat map, we must review how the creation of such a map appears from a cartography standpoint while respecting the institutional framework of European directive which poses certain standards for creation.

5.1.1. Cartographic review of flood threat map creation

The cartographic display on these maps will contain all the usual elements of the main content, the topographic surface of the area, as well as roads, railroads, objects, borders, river bed area. Also, they can contain protective infrastructure and markings for a water accumulation area in case of flooding. These maps are derived from previously created hydraulic 2D and 1D models, statistical analysis, observation, and all of that based on digital terrain models. Water depth is represented on the map according to time-reversal and is stated quantitatively [22, 23].

Flood area borders are entered on the map – water level notch lines and terrain. The spatial distribution of the depth of flooding, shown in shades of blue, contains at least 3 classes, their borders defined according to criteria of traversability and the possibility of rescue. Depth display with 4 classes is the example with intervals 0,0 to 0,5 m; 0,5-1,5 m; 1,5-4,0 m, and > 4,0 m. In practice, a darker blue color is used to display floods of greater depth, while a lighter blue is used to display floods of lesser depth. This kind of display is clarified by the bathymetric scale in the legend so that the meaning of every shade is explained in accordance with the relevant cartographic rules [24, 26].

The European directive on the assessment and management of flood risks 2007/60/EC decrees that the ratio should be suitably adjusted and is not strictly defined, which gives the authors the freedom to decide on the best ratio [11].

5.1.2. Creation of the flood threat map ilustration process for a test area

The city of Valjevo is the optimal choice for a test area for a flood threat map for many reasons, and most of all because in the event of Kolubara flooding this area would sustain significant damage [8].

The tested area should encompass the entire territory of the city to better envision the comprehensive consequences of flooding in an urban and suburban area. When it comes to mapping creation for a tested area, it only represents the cartographic completion of the data collection and analysis process, which is done in segments for the whole Kolubara river basin. Taking into account only the data within the tested area, a representative sample was created – a flood threat map of the city of Valjevo. The map creation process was performed in the ArcGIS software package, which is an adequate choice considering the wide application it offers and the ability to integrate different types of data that are created during data collection and processing. A representative sample of a flood threat map of Valjevo on an orthophoto base with a spatial distribution of the depth of flooding displayed in different colors is included in the Addition. (Addition). The average elevation of Valjevo 185 meters above sea level.

5.2. Course of works and analysis of mapping resources

The World Bank has made a Grant Agreement with the Republic of Serbia, which defines that 3.689.750 euros should be allocated for this part of the project. Most of the technological acquisition was towards the Military Geographical Institute within the Ministry of Defence and Republic Geodetic Authority. These institutions represent the foundations when it comes to creating a flood threat map, considering that the project is based on LiDAR technology which rests upon the process of data collection and processing, which is conducted within activities of the Military Geographical Institute and the Republic Geodetic Authority [25].

The anticipated deadline for the completion of mapping the threat and risk of flood on the national level is the year 2020 so that the flood risk management plans could be implemented in 2021, to "catch up" with the 6-year cycle of map updating which is provided by the European directive on floods and Water Law of the Republic of Serbia [8, 21].

„Assessments reveal that the total consequences of the damage in the mentioned May 2014 floods amount to 1.525 billion euros, where 885 million euros (57%) of the total damage was too destroyed physical goods, and 640 million euros (43%) are losses in production or economy. Taking into account other areas which were indirectly impacted by the flooding, the number rises to 1.7 billion euros in damages" [21].

This quantitative illustration lets us put into perspective the ratio of invested financial resources against the potential damage which can be prevented or mitigated. Comparative analysis can confirm that all investment into flood prevention will return manifold [25].

6. CONCLUSION

Creation of the flood threat of the Kolubara river basin map, as well as maps of flood threats in general by using LiDAR technology required great dedication and work consistency as well as job training for data collection and processing. As a result of those activities, by processing the *point cloud* data, a DTM of very high accuracy is created (10 cm), serving as a quality base for the creation of flood threat maps [12, 18]. By integrating the data collected using other methods of geodetic survey and scanning (topographic and digital orthophoto bases, profiles of riverbeds, data from hydrographic and hydrological surveys), a quality base for the creation of hydrographic and hydrological models and flood threat maps is produced.

Application possibilities of the LiDAR technology and laser system Leica ALS80HP in the process of creation of these maps according to the requirements of the IPA2014 action are indisputable.

The main aim of this paper has also been achieved and in the practical part of the paper, the process for the creation of the flood threat for the local territorial framework (part of the Kolubara river basin) has been realized and described. The entire process of creation of the Kolubara river basin flood threat maps within the IPA2014 action is still on-going. For that reason, in the practical part of the paper, flood threat maps for the wider area of the city of Valjevo were created at the local level of the Kolubara river basin.

The role and importance of flood threat maps are indisputable. However, their creation represents just one phase in the entire process. Many other science and infrastructure activities are necessary for implementing flood risk management plans. Even though it is financially demanding, investing funds into the entire system of hydrographic and hydrological models, flood threat and flood risk maps, contributes to a proactive approach in flood prevention and protection. By using the Leica ALS80HP system, the process of high quality and accurate data collection is made significantly easier and notably faster, which brings to the end result – quality threat and flood risk maps. Comparative analysis can determine that the invested financial resources are justified in relation to potential flood damage. By implementing the IPA2014 action the potential damage can be prevented or mitigated, and the potential expenses of flood damage repair annulled or greatly reduced [21].

The Republic of Serbia needs to have professional staff capable of project implementation and tasks concerning management and flood risk prevention, and that is the great significance of the IPA2014 action, which would create a kind of initial national experience. Complete protection from floods does not exist, but with the correct approach and national strategy, it is possible to greatly reduce the consequences of the damage to their inevitable occurrence.

Due to still unfinished IPA2014 actions, the idea for further research is given with a focus on thorough methodological analisys of the project actions as well as analisys of completed flood threat maps.

LITERATURE:

[1] Ogania, J.L., Puno, G.R., Alivio, M.B.T., Taylaran, J.M.G., „Effect of digital elevation model's resolution in producing flood hazard maps", *Global Journal of Environmental Science and Management*, vol. 5(1), pp. 95-106, 2019.

[2] Saksena, S. and Merwade, V., „Incorporating the effect of DEM resolution and accuracy for improved flood inundation mapping", *Journal of Hydrology*, vol. 530, pp. 180-194, 2015.
Jakovljević, G. and Govedarica, M., „Water Body Extraction and Flood Risk Assessment Using LiDAR and Open Data", Chapter in Book „*Climate Change Adaptation in Easten Europe, Springer*, pp. 93-111, 2019.

[3] Shen, D., Qian, T., Chen, W., Chi, Y. and Wang, J. A., „Quantitative Flood-Related Building Damage Evaluation Method Using Airborne LiDAR Data and 2-D Hydraulic Model", *Water*, vol. 11(5):987, pp. 1-19, 2019.

[4] Zeybek, M. and Sanlioglu, I., „Point Cloud Filtering on UAV Based Point Clouds", *Measure*, vol. 133, pp. 99-111, 2018.

[5] Jakovljević, G., Govedarica, M., Alvarez-Taboada, F. and Pajic, V., „Accuracy Assessment of Deep Learning Based Classification of LiDAR and UAV Points Clouds for DTM Creation and Flood Risk Mapping", *Geosciences*, vol. 9(7):323, 2019.

[6] Mladenović, M., *A study on the improvement of water protection in the Kolubara River basin*, Institute for water management „Jaroslav Černi", Belgrade, pp. 1-4 and 179-182, 2015.
Regulation on determining the methodology for the creation of a threat map and flood risk map, Official Gazette of the Republic of Serbia, 13/2017.

[7] Cvijetinović, Z., *Terrain digital modeling*, University of Belgrade, Faculty of Civil Engineering, Belgrade, 2008.

[8] Directive 2000/60/EC of the European Parliament and of the Council of 23. October 2000. establishing a framework for Community action in the field of water policy, 22/12/2000.

[9] Directive 2007/60/EC of the European Parliament and of the Council of 23. October 2007. on the assessment and management of flood risks, Official Journal of the European Union L288, pp. 27-34, 6.11.2007.

[10] Agreement of cooperation on the realisation of activities from the Action document for flood consequences relief, within the Instrument for Pre-Accession Assistance of the EU – IPA2014.

[11] Miler, M., Đapo, A., Kordić, B. and Medved, I., „Terrestrial laser systems", *Student papers* of the *Faculty of Geography of the University of Zagreb*, vol. 10, pp. 35-38, 2007.

[12] Petrović, Đ., *Non conventional techniques of aerial survey*, Military Technical Academy, Belgrade, 2005.

[13] Jelovac, A. and Ružić, M., „LiDAR technology and visualization", *Conference in account of the 20th anniversary of the Faculty of Science, University of Banja Luka*, Banja Luka, pp. 338-343, 2017.

[14] oshttps://leica-geosystems.com/products/airborne-systems/lidar-sensors/leica-als80-airborne-laser-scanner, [01.03. 2020].

[15] Milonjić, Z., *LiDAR data collecting and analysis*, Military Geographical Institute, Internal edition, Belgrade, 2019.

[16] Project task for collecting data with LiDAR technology in a purpose of creating digital terrain model of significant flood areas, Republic Geodetic Authority, 95-252/2015.
Živković, Z., *Digital terrain modelling using LiDAR data*, Republic Geodetic Authority, Internal edition, Belgrade, 2019.

[17] Milonjić, Z., „*Instruction for making digital orthophoto*", Military Geographical Institute, Belgrade,p2017.
Official Gazette of the Republic of Serbia – „International agreements'', br. 19 (29. december 2014), Action document for flood consequences relief, within the Instrument for Pre-Accession Assistance of the EU – IPA2014.

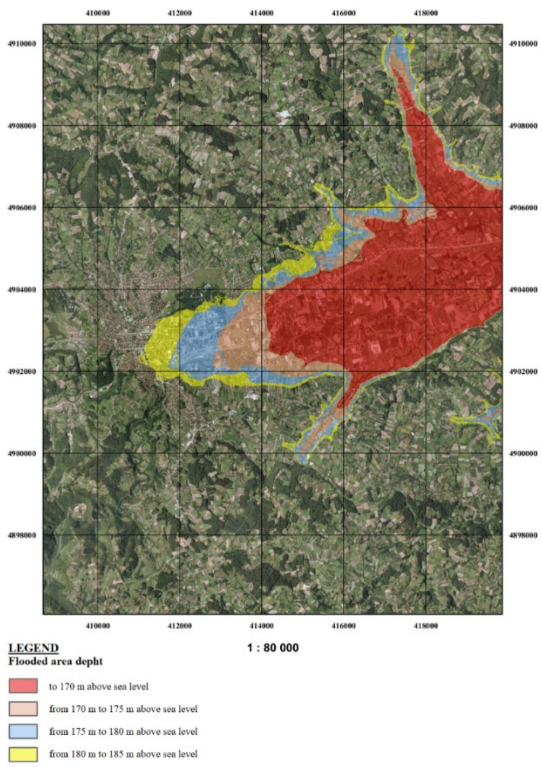
[18] Republic of Serbia, Republic Water Directorate, Technical specifications for preparation of digital terrain model for hydraulic modelling in process of creating flood threat maps, Republic Water Directorate, 337-00-00401/2015-07.

[19] Jovanović M., Prodanovic D., Plavsic J. and Rosic N., *Problems in creating flood threat maps*, University of Belgrade, Faculty of Civil Engineering, Belgrade, 2014.

[20] http://ec.europa.eu/environment/water/flood_risk/pdf/MS%20examples.pdf, [28.01.2020]

[21] http://www.obnova.gov.rs/latinica/zakoni-i-uredbe, Serbian Goverment Directory, Public Investment Managment Office, Annex 4 of Action document for flood consequences relief, within the Instrument for Pre-Accession Assistance of the EU–IPA2014, Details per EU funded operation [02.02.2020].

APPENDIX



12 | Research paper I Оригинални научни рад
ISSN 2566-4484 I Doi 10.7251/STP2014113M
pages 113-126

Ankica Milinković, ankica.milinkovic@vekom.com, VEKOM Geo d.o.o. Belgrade

Sanja Tucikešić, sanja.tucikesic@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

Kornelija Ristić, kornelija.ristic@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

VERIFICATION, CALIBRATION AND CONFORMITY ASSESSMENT OF ROTATING LASERS APPLIED IN BUILDING AND SURVEYING MEASUREMENT TASKS

Abstract:

This paper specifies field procedures described by international norm ISO 17123-6, to be adopted when determining and evaluating the quality of rotating lasers and their ancillary equipment when used in building and surveying measurements for levelling tasks. It will be shown analysis and statistical tests in order to check the conformity of the equipment with the selected specifications. Also, this paper will promote the leveling systems delivered for complete quality verification of rotating lasers, as an automated reference laboratory system.

Keywords: quality, rotating laser, calibration, verification, statistical test, conformity, measuring

ВЕРИФИКАЦИЈА, ЕТАЛОНИРАЊЕ И ОЦЕНА УСАГЛАШЕНОСТИ РОТАЦИОНИХ ЛАСЕРА КОРИШЋЕНИХ У ПОСЛОВИМА ИЗГРАДЊЕ И ПРЕМЕРА

Сажетак:

Овај рад описује теренске поступке описане међународним нормом ИСО 17123-6, које треба усвојити приликом одређивања и оцене квалитета ротационих ласера и њихове помоћне опреме када се користе у изградњи и геодетским мерењима за послове нивелисања. Показаће се анализа и статистички тестови како би се проверила усаглашеност опреме са одабраним спецификацијама. Такође, овај рад ће промовисати мерни нивелациони систем који се успоставља за потпуну верификацију квалитета ротирајућих ласера, у виду примене аутоматизованог лабораторијског референтног система.

Кључне ријечи: квалитет, ротациони ласер, калибрација, верификација, статистички тестови, усаглашеност, мерење

1. INTRODUCTION

According to the International document *ISO 10012:2003 Measurement management systems — Requirements for measurement processes and measuring equipment,* only effective and efficient measuring management system is able to secure a quality of equipment, competent to reduce the appearing risk of incorrect measuring results. There are specifies generic requirements and guidance for the management of measurement and metrological processes, used to support and demonstrate compliance of equipment with metrological requirements. It specifies quality management requirements of a measurement management system that can be used by an organization performing measurements as part of the overall management system, and to ensure metrological requirements are met. Methods applied in measuring management process cover a wide range of activities, from the verification to the statistical techniques. All that activities describe one measuring management system as a set of interconnected or interacting elements required to achieve metrological validation and continuous management of measurement processes. For quality assurance, not only quality control is sufficient, but also a systematic approach that involves defining and providing other important factors: metrology, standardization, reliability, quality control, i.e.: personnel, methods and techniques, technical equipment, information, etc. In the system of integral quality management, metrology plays a prominent role in providing measurements of the physical quantities that characterize quality. From the metrological point of view, the focus is on providing measurement methods, measuring instruments (standards), measuring conditions and data processing methods of measuring.

Operators have obligations to use measuring equipment in way that secure accurate measurements, as well as they are responsible for both technical conformity of equipment and assuring the quality of delivered results. They ought to keep equipment in good technical shape, according to the methods specified in the manufacturer's handbooks. Even though operators do all checks on the field, equipment should be officially tested and calibrated in regarding to recognized procedures described in national or international relevant documents, norms, by-laws. Further, reporting of calibration and testing results could show statements of conformity, with respect to the specifications required whether from investors, custodies, or any stakeholders.

This paper specifies field procedures described by international norm ISO 17123-6:2012 Optics and optical instruments — Field procedures for testing geodetic and surveying instruments — Part 6: Rotating lasers, to be adopted when determining and evaluating the quality of rotating lasers and their ancillary equipment when used in building and surveying measurements for levelling tasks. The first one procedure provides an estimate as to whether the precision of a given item of rotating-laser equipment is within the specified permitted deviation, according to ISO 4463-1. The second one procedure provides the best achievable measure of precision of a particular rotating laser, the deflective deviation from the true horizontal, and both components of the deviation of the rotating axis from the true vertical. In the end, it will be shown analysis and statistical test in order to check the conformity of the equipment with the selected specifications. At the same time, paper will promote extra the leveling systems delivered for complete quality verification of rotating lasers, as an automated reference laboratory system.

2. QUALITY ASSURANCE OF MEASURING EQUIPMENT

There are three general principles that apply in considering the quality assurance aspects of instruments and equipment. The first is that the equipment should be capable of doing the job required of it. The second principle is that all equipment should be kept in optimal condition for use as needed. This implies both preventive maintenance and control over the use of the equipment by personnel. The third principle is that equipment should be frequently monitored and evaluated, what implies calibration [1]. Calibration means operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication [2]. Understanding and quantifying the uncertainty of measurements as well as measurement errors, are critical to maintaining quality of equipment.

2.1. Uncertainty of measurements and measurement errors

The most important concept to understand is that all measurements have uncertainty. In fact, it can be never known the exact true value of anything, all measurements are actually estimated, and have some uncertainty. The difference between a measurement result and the true value is the measurement error. Since the true value is unknown, also can't know the error: these are unknowable quantities. All what can be quantified are the results of measurements and these always have some uncertainty, even if this uncertainty is very small. On the Figure 1 is shown interpretation of uncertainty and measurement error [3].

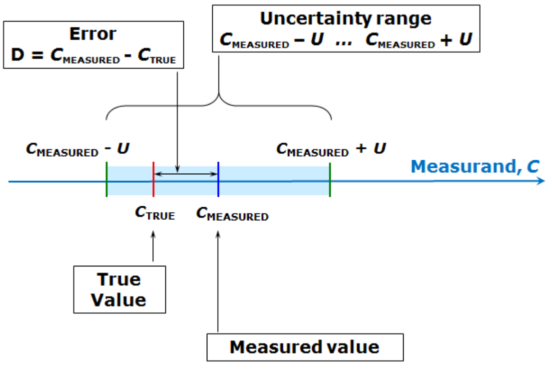


Figure 1. *Interrelations between the concepts true value, measured value, error and uncertainty. (Figure source given in Literature [3])*

There are two widely used methods to quantify the uncertainty of a measurement. Calibration laboratories and scientific institutions normally carry out Uncertainty Evaluation according to the Guide to the Expression of Uncertainty in Measurement (GUM). The GUM method involves first considering all of the influences which might affect the measurement result. A mathematical model must then be determined giving the measurement result as a function of these influence quantities. By considering the uncertainty in each input quantity and applying the 'Law of Propagation of Uncertainty' an estimate for the combined uncertainty of the measurement can be calculated. The GUM approach is sometimes described as bottom-up, since it starts with a consideration of each individual influence. Each influence is normally listed in a table called an uncertainty budget which is used to calculate the combined uncertainty. Industrial measurement processes are typically evaluated using a Measurement Systems Analysis (MSA) approach, as recommended within the Six-Sigma methodology, and usually following the guidelines of the Automotive Industry Action Group (AIAG) MSA Reference Manual. MSA involves performing Gage Studies in which repeated measurements are compared with a reference under different conditions to determine the bias, repeatability and sometimes reproducibility. In the Chapter 4 of this paper will be presented Type A GUM method of uncertainty measurement estimation during the procedure of rotating laser calibration.

Calibration and the associated concept of traceability are the fundamental aspects of uncertainty, where calibration is a comparison with a reference, and the uncertainty of this comparison must always be included. A traceable measurement is one which has an unbroken chain of calibrations going all the way back to the primary standard. A measurement is traceable if there is an unbroken chain of calibrations back to the primary standard (In the Figure 2 is illustrated one traceability chain in general).

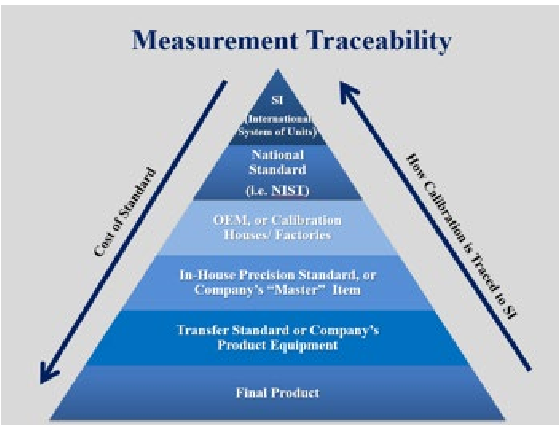


Figure 2. *Traceability chain (Figure source given in Literature [4])*

All measurements must be traceable back to the same standard to ensure that parts manufactured in different countries will fit together. In this process, national and international metrology institutions as well as competent calibration laboratories play the main roll.

The uncertainty of measurements arises from different sources. Some of these will lead to a consistent error, or bias, in the result. For example, the unknown error present when an instrument was calibrated will lead to a consistent error whenever it is used. This type of effect is known as a systematic uncertainty leading to a systematic error. Other sources will lead to errors which change randomly each time a measurement is made. It is conventional to divide random uncertainty into repeatability, the random uncertainty of results under the same conditions, and reproducibility, the random uncertainty under changed conditions. The conditions can never be exactly the same or completely different so the distinction is somewhat vague. The types of conditions which might be changed are making the measurement at a different time, with a different operator, a different instrument, using a different calibration and in a different environment. Once determined the uncertainty (or 'accuracy') of a measurement can apply this to decide whether a part conforms to a specified tolerance.

Each measurement is associated with the determination of numerous values of physical quantities by which the regularities of the phenomena under study are realized. Measuring a quantity means to determine its numerical relationship with another of the same size, with the adoption of a unit of measure. When measuring, data on different physical quantities must be provided: discrete and continuous, constant and variable, dependent and independent. Therefore, measurement is considered to be a process of physically equating a given value with its physical value taken for a unit of measure. The result of the measurement is presents as quantitative information about the basic properties of a measuring object, obtained as a result of a physical process with a certain degree of accuracy. Each measurement process is accompanied by inevitable measurement errors. Depending on the degree of perfection of knowledge, the means of measurement and the conditions under which the measurement is conducted, the size of these errors is also different. The result of each measurement occurs as a function of two independent quantities, one reflecting the true value of the measured size, and the other, representing the error of its measurement. Therefore, the measurement error of some size should be considered as the difference between the measurement results and the true value of the measured size. The true value of the measured size is unknown to the technique of measurement. The reason for this is the imperfection of the criterion. With the reduction of the measurement error, we are increasingly approaching the true value of the measured size.

The measurement error of some quantity is directly related to the accuracy and precision of the measurement. Measurement accuracy means, in the general case, the quality or validity of the measurement, ie. the degree of closeness between the measurement results and the true value of the measured size. The accuracy of a measurement of some quantity is all the greater the smaller the error of its measurement. Therefore, the measurement error of the given size is quantitatively expressed. Measurement accuracy is defined by the repeatability of measurement results, ie the degree of scattering or mutual matching of individual measurement results. These results are obtained by successive, multiple repetitions of a measurement operation over a measuring size, whose value is time independent (constant). This means that the precision of a measurement is greater if there is less dispersion of the individual values of the measurement results in the set of results of repeated measurements, or if the mutual agreement of these values is greater, what is presented on the Figure 3.

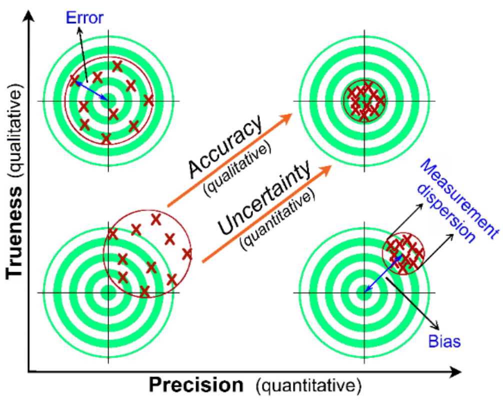


Figure 3. *Accuracy and Precision (Figure source given in Literature [10]*

3. QUALITY ASSURANCE OF MEASURING RESULTS OBTANED USING AN ROTATING LASER

Construction lasers are used as an accurate level reference during any layout process. In surveying and construction, the laser level is a control tool that includes a laser beam projector which is affixed to a tripod, leveled, and rapidly spun to indicate a horizontal plane. The laser beam projector has a rotating head with a mirror that sweeps the laser beam around a vertical axis. Some mirrors are self-leveling, while others can be manually adjusted.

Figure 4. *Rotating and linear lasers levels(Figure source given in Literature [5]*

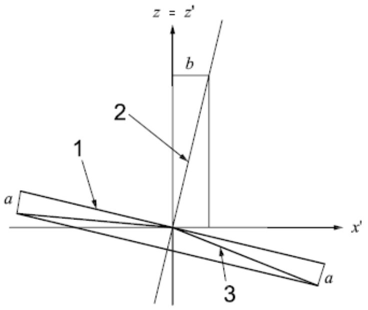
Rotating laser levels are used for construction projects indoors to shoot a 360-degree horizontal or vertical beam around a room, or outdoors to be used with a laser detector and grade rod for excavation for both digging down or building up. There are a variety of rotating laser levels to choose from, (Figure 4). It can be manually-leveling using a mounted bubble level, electronically self-leveling which uses a pendulum leveling system, or automatically self-leveling which uses electronics and gears to find level. Rotating laser levels project a beam of light 360-degrees, allowing the user to establish a horizontal or vertical plane. In fact, this beam of light is really a single dot of light that can rotate between 100 and 1,100 rmp, giving the appearance of a 360-degree chalk line. The beam of light is created by a diode, which in this case is simply a semiconductor which produces light when current passes through it. Color is technically determined by the wavelength of the laser, the laser diode actually, which is measured in nanometers (nm), one billionth of a meter, because of its very small length. The spectrum of color visible to the human eye is between 380 nm (purple) and 750 nm (red). Typically, the color of the laser is red (635 nm) or green (532 nm) which is near the center of the visible spectrum, making it the most visible to the human eye. The intensity of the laser is determined by the level of laser light power which is measured in milliwatts (mw), 0.001 or one-thousandth of a watt [5].

Before commencing surveying, it is important that the operator investigates that the precision in use of the measuring equipment is appropriate to the intended measuring task. The rotating laser and its ancillary equipment shall be in known and acceptable states of permanent adjustment according to the methods specified in the manufacturer's handbook, and used with tripods and levelling staffs as recommended by the manufacturer. The results of measuring are influenced by meteorological conditions, especially by the temperature gradient. An overcast sky and low wind speed guarantee the most favourable weather conditions. The particular conditions to be taken into account may vary depending on the location where the tasks are to be undertaken [7]. Rotating lasers have to be verified and calibrated before application.

The 6^{th} part of the ISO 17123 norm describes two different field procedures for calibration of rotating leveling lasers. The first one, called the simplified test procedure provides an estimate as to whether the precision of a given item of rotating-laser equipment is within the specified permitted deviation, according to ISO 4463-1. This test procedure is normally intended for checking the precision of a rotating laser to be used for area levelling applications, for tasks where measurements with unequal site lengths are common practice, e.g. building construction sites. Since, the simplified test procedure is based on a limited number of measurements, therefore, a significant standard deviation and the standard uncertainty (Type A), respectively, cannot be obtained, this method won't be analyzed here.

The second one, called the full test procedure shall be adopted to determine the best achievable measure of precision of a particular rotating laser and its ancillary equipment under field conditions, by a single survey team. Further, this test procedure serves to determine the deflective deviation, *a*, and both components of the deviation of the rotating axis from the true vertical of the rotating laser (see Figure 5 and Figure 6, source of Figures given in Literature [7]). The possible deviations of a rotating laser may be modelled as shown in Figure 7. Full test procedure is intended for determining the measure of precision in use of a particular rotating laser. This measure of precision in use is expressed in terms of the experimental standard deviation, *s*, of a height difference between the instrument level and a levelling staff (reading at the staff). This experimental standard deviation corresponds to the standard uncertainty of Type A:

$$s_{ISO\_ROLAS}=u_{ISO\_ROLAS} \quad (1)$$



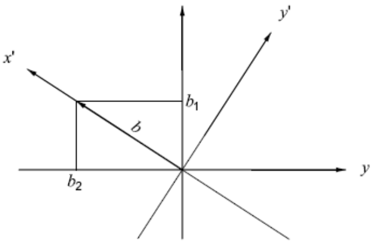


Figure 5. *(Left)Vertical plane through x'*

Figure 6. *(Right)Horizontal view-top view*

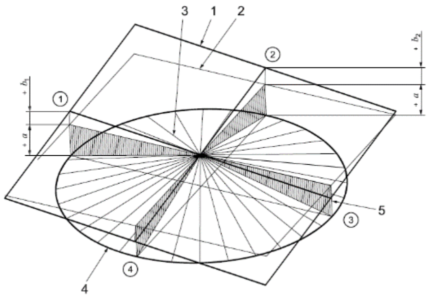


Figure 7. *Model of instrument deviations*

(Figures 5., Figure 6., and Figure 7. source given in Literature [7])

Further, this procedure may be used to determine:

- the standard uncertainty as a measure of precision in use of rotating lasers by a single survey team with a single instrument and its ancillary equipment at a given time;
- the standard uncertainty as a measure of precision in use of a single instrument over time and differing environmental conditions;
- the standard uncertainties as a measure of precision in use of several rotating lasers in order to enable a comparison of their respective achievable precisions to be obtained under similar field conditions.

Statistical tests should be applied to determine whether the experimental standard deviation, s, obtained belongs to the population of the instrumentation's theoretical standard deviation, σ, whether two tested samples belong to the same population, whether the deflective deviation, a, is equal to zero, and whether the deviation, b, of the rotating axis from the true vertical of the rotating laser is equal to zero.

3.2. Calibration procedure

The procedure described in the ISO norm taking in account the next: To keep the influence of refraction as small as possible, a reasonably horizontal test area shall be chosen. The ground shall be compact and the surface shall be uniform; roads covered with asphalt or concrete shall be avoided. If there is direct sunlight, the instrument and the levelling staffs shall be shaded, for example by an umbrella. Two levelling points, A and B, shall be set up approximately 40 m apart. To ensure reliable results, the levelling staffs shall be set up in stable positions, reliably fixed during the test measurements, including any repeat measurements. The instrument shall be placed at the positions S1, S2 and S3. The distances from the instrument's positions to the levelling points shall be in accordance with Figure 8, source of Figure given in Literature [7]. The position S1 shall be chosen equidistant between the levelling points, A and B (40/2 = 20 m). For the full test procedure, i = 4 series of measurements should be performed. In each series, three instrument setups S1, S2 and S3 are chosen, according to the configuration given in Figure 8. At any setup n = 4 sets of readings are taken. Each set consists of two readings x_{Aj}, and x_{Bj}, namely to rod A and to rod B. After each set, the orientation of the instrument has to be changed clockwise about 90°. Hence one series consists of j = 3 × 4 = 12 readings for each rod. In order to ensure that the instrument deviation *b* is aligned properly during the measurements, the instrument has to be oriented at the three positions S1, S2 and S3 in the same direction and the sense of rotation has to be maintained.

With each new setup of the chosen reference direction (reference marks on the tripod head), the instrument shall be relevelled carefully. If the instrument is provided with a compensator, care shall be taken that it functions properly. It is recommended to assign the four orientations of the instrument on the ground plate, according to measurement organization shown in Table 2. The numbering of the 12 measurements can be represented for each measuring set. All readings shall be taken in a precise mode according to the recommendations of the manufacturer.

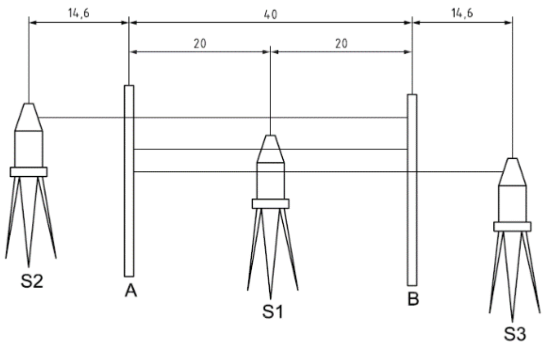


Figure 8. *Configuration of the test line for the full test procedure*

Apart of technical description of ISO 17123-6 document, there is one laboratory reference system for interpretation of this calibration procedures, so called Leica CalMaster systems. According to Leica Geosystems manufacturer of geodetical equipment, as well as rotating laser levels.

In order to create a horizontal sighting in the described measuring configuration, the readings at the levelling staffs for selected sighting distances can be corrected in respect of the deviations a and b (see Table 1).

Table 1. *Corrections of the readings*

Direction	Distance		
	14,6	20	54,6
1	0,365(a + b1)	0,500(a + b1)	1,365(a + b1)
2	0,365(a + b2)	0,500(a + b2)	1,365(a + b2)
3	0,365(a - b1)	0,500(a - b1)	1,365(a - b1)
4	0,365(a – b2)	0,500(a – b2)	1,365(a – b2)

From the observation formulae for the i_{th} series, the residuals, r_1 to r_{12}, are obtained (see Table 2).

Table 2. *The residuals r1 to r12*

P=2	P=0,5	P=0,5
$r_1 = h - b_1 - (x_{B,1} - x_{A,1})$	$r_5 = h + a - b_1 - (x_{B,5} - x_{A,5})$	$r_9 = h - a - b_1 - (x_{B,9} - x_{A,9})$
$r_2 = h + b_2 - (x_{B,2} - x_{A,2})$	$r_6 = h + a + b_2 - (x_{B,6} - x_{A,6})$	$r_{10} = h - a + b_2 - (x_{B,10} - x_{A,10})$
$r_3 = h + b_1 - (x_{B,3} - x_{A,3})$	$r_7 = h + a + b_1 - (x_{B,7} - x_{A,7})$	$r_{11} = h - a + b_1 - (x_{B,11} - x_{A,11})$
$r_4 = h - b_2 - (x_{B,4} - x_{A,4})$	$r_8 = h + a - b_2 - (x_{B,8} - x_{A,8})$	$r_{12} = h - a - b2 - (x_{B,12} - x_{A,12})$

where

p is the weighting factor for one reading at the levelling staff (p = 1 for a sighting distance of 40 m);
h is the height difference between the levelling staffs B and A.

Table 3. *Organization of measurement*

Instrument setups for each series, i=1, .., 4	A__S1__B	A_ S2______B	A_______S3_B
Set n orientation, n=1, …, 4	Readings x_{Aj}, x_{Bj}, j=1, …, 4	Readings x_{Aj}, x_{Bj}, j=5, …, 8	Readings x_{Aj}, x_{Bj}, j=9, …, 12
Set 1 →	x_{A1} x_{B1}	x_{A5} x_{B5}	x_{A9} x_{B9}
Set 2 ↓	x_{A2} x_{B2}	x_{A6} x_{B6}	x_{A10} x_{B10}
Set 3 ←	x_{A3} x_{B3}	x_{A7} x_{B7}	x_{A11} x_{B11}
Set 4 ↑	x_{A4} x_{B4}	x_{A8} x_{B8}	x_{A12} x_{B12}

For the interpretation of above, producer of geodetic instruments, Leica Geosystems has developed laboratory reference systems for rotating laser levels calibration, Leica CalMaster. CalMaster is an intuitive and compact system to check and adjust rotating lasers and issue calibration reports, checking and calibration system in the industry to issue the ISO 17123-6 certification for repeated accuracy and reliability of rotating lasers. The system consists of a specially modified and programmed Leica Sprinter level, CalMaster software, interface to communicate with rotating lasers and accessories. Figure 9.

Figure 9. *Leica CalMaster laboratory calibration system*

System allows check accuracy of red and infrared rotating lasers and their stationary beams, in real time, live and precise digital accuracy indication on the screen making manual adjustment of the laser beam. Procedure could be fully automated using the CalMaster software, which contributes to the minimalization of operator influence to the measuring results. One more advance is automatic generation of calibration reports according to ISO 17123-6 standard for evaluating the repeated accuracy of rotating lasers. The Leica CalMaster offers a modern and portable calibration set-up that is unique in the industry, complying with the highest accuracy and repeatability standard ISO 17123-6 for rotating lasers, taking into account the highest productivity, calibration and certification through a fully automatic process. The main component is very accurate level, Leica Sprinter, where the height of the level defines the height of the whole system.

It is important to know, when determining the height of the CalMaster, the height of the different rotation lasers must be taken into consideration. Once the CalMaster is setup at a height, it shouldn't be adjusted. The only time it is allowed to move the CalMaster is when setting or checking the focus. The height of the laser can be adjusted as needed. The minimum distance between CalMaster and the currently used rotation laser must be at least min 0.8m - max 1m. The laser emitted from the rotation laser has to be aligned with the CalMaster horizontally. This horizontal alignment insures that the laser beam goes through the middle of the CalMaster. The Figure10 shows the mentioned alignment. The rotating laser beam has to be centered on the front of the CalMaster. The upper housing of the CalMaster can be used as a reference to find the middle of the instrument. In addition a Laser Receiver can be aligned with the CalMaster this then can be used to align rotation lasers with the CalMaster. The gun sights of the CalMaster and the rotation laser also have to be aligned. This also is a rough aligment, the fine adjustment will be done inside the CalMaster software.

Figure 10. *Horizontal alignment between rotating laser and CalMaster*

3.3. Post processing

With 12 observations and four unknown parameters, *h*, *a*, b_1, b_2, there is an over-determined system, which leads to a parametric adjustment. As the observation formulae are already linear, Table 2 can easily be transferred in matrix notation:

$$r = A\tilde{y} - x, \qquad (2)$$

were:

r is residual vector (12x1),

$x = x_B - x_A$ is the (12 × 1) quasi-observation vector of the height differences, with

x_A (12x1) reading vector xAj, j = 1, …, 12 of the levelling staff A and

x_B (12x1) reading vector xBj, j = 1, …, 12 of the levelling staff B;

$\tilde{y}$ (4x1) is the vector of the unknown parameters

With the design matrix A:

$$A^T = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ -1 & 0 & 1 & 0 & -1 & 0 & 1 & 0 & -1 & 0 & 1 & 0 \\ 0 & 1 & 0 & -1 & 0 & 1 & 0 & -1 & 0 & 1 & 0 & -1 \end{bmatrix} \qquad (3)$$

the solution vector of the unknown parameters is:

$$\tilde{y} = \begin{pmatrix} h \\ a \\ b_1 \\ b_2 \end{pmatrix} = (A^T P A)^T P x = N^{-1} A^T P x, \qquad (4)$$

The weight matrix p:

$$p = \begin{pmatrix} p1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & p12 \end{pmatrix}, \qquad (5)$$

is given by diag (p_j) =(1.7, 1.7, 1.7, 1.7, 0.6, 0.6, 0.6, 0.6, 0.6, 0.6, 0.6, 0.6,)

the experimental standard deviation for a sighting distance of 40 m is given by:

$$s = \sqrt{\frac{r^T P r}{v}}, \qquad (6)$$

with v, $v = 12 - 4 = 8$,

From all series i = 1, …, 4 of observations we can derive the mean values of the parameters

$$\tilde{y} = \frac{1}{4}\sum_{i=1}^{4} \tilde{y}_i = \frac{1}{4}\sum_{i=1}^{4} \begin{pmatrix} h \\ a \\ b_1 \\ b_2 \end{pmatrix} \qquad (7)$$

Finally we get the total deviation of the rotating axis from the true vertical of the rotating laser, referenced to a sighting distance of 40 m:

$$b = \sqrt{b_1^2 + b_2^2}, \quad (8)$$

the overall experimental standard deviation of all series i = 1, …, 4 yields:

$$s = \sqrt{\frac{\sum_{i=1}^{4} s_i^2}{4}} = \sqrt{\frac{\sum_{i=1}^{4} \frac{r_i^T Pri}{v}}{4}} \quad (9)$$

Herewith we can state the standard uncertainty (Type A) of a height difference, h, between the instrument level and a levelling staff (reading at the levelling staff) referenced to a sighting distance of 40 m:

$$s_{ISO\_ROLAS} = s \quad (10)$$

The experimental standard deviation for the parameters of all series can be calculated by

$$s(\tilde{y}) = s\sqrt{\frac{1}{4}\text{dijag}(Q)}, \text{ where } Q = \begin{bmatrix} \frac{1}{12} & 0 & 0 & 0 \\ 0 & \frac{1}{4} & 0 & 0 \\ 0 & 0 & \frac{1}{6} & 0 \\ 0 & 0 & 0 & \frac{1}{6} \end{bmatrix} \quad (11)$$

Thus the standard deviations and the standard uncertainties (Type A), respectively, of the parameters are given by:

$$sh = u(h) = 0.14s \quad (12)$$

$$sa = u(a) = 0.25s \quad (13)$$

$$sb1 = sb2 = sb12 = 0.20s \quad (14)$$

Applying the law of variance covariance propagation, the experimental standard deviation of the parameter b can be written as:

$$sb = \frac{1}{b}\sqrt{b_1^2 s_{b1}^2 + b_2^2 s_{b2}^2} = \frac{1}{b}\sqrt{(b_1^2 + b_2^2) s_{b12}^2} = s_{b_{12}}, \quad (15)$$

$$sb = u(b) = 0{,}20s. \quad (16)$$

4. MEASURING RESULTS

In aim to perform all steps, verification, calibration and conformity assessment of the rotating laser level, it was performed one test procedure using laboratory reference system CalMaster, as well as two field test procedures by two different operators, described as full test method in ISO 17123-6. The results are presented in tables (Table 4, Table 5, Table 6, Table 7, Table 8, Table 9 and Table 10):

Table 4. *Verification and calibration rotating laser level using the CalMaster system*

Sample specification	Self-leveling accuracy, maximum deviation from horizon: -/+ 10”, 1,6 mm per 30 m.
Test results for grade from horizon:	Maximum deviation from horizon -/+ 6”, 1 mm per 30 m
Standard deviation:	-/+ 3”, 0,5 mm per 30 m
Test procedure	The measurement are determined with a test tool specifically to develop and designed for testing rotation lasers under laboratory conditions. Test Equipment: Leica CalMaster for rotation lasers, Cal Master Focus Check,
Temperature	20 degrees C
Pressure	1018 hPa
Humidity	35%

Measured values	X1 arcsec	X2 arsec	Y1 arcsec	Y2 arcsec
Set 1 1/1	-4,3	-5,8	-6,7	-5,3
Set 2 1/1	-5,4	-6,7	-6,1	-6,3
Set 3 1/1	-6,0	-5,9	-5,8	-5,7
Result plane X_1	Calibration value 0,5”		standard deviation +/- 0.7	
Result plane X_2	Calibration value - 0,2”		standard deviation +/- 0.5	
Cone:	-5,8”			
Traceability	The test equipment used is traceable to national standards or recognized procedure.			
Compliance:	The test results are within the specification of the product			

Verification and calibration rotating laser level using ISO 17123-6 full method ISO 17123-6 is given below.

Table 5. *Measuring data from the first operator*

SET 1					SET 2			SET 3			SET 4		
Position	j	x_{Aj}	x_{Bj}	x_j	x_{Aj}	x_{Bj}	x_j	x_{Aj}	x_{Bj}	x_j	x_{Aj}	x_{Bj}	x_j
		m	m	m	m	m	m	m	m	m	m	m	m
1	1	1.241	1.516	0.275	1.766	2.043	0.277	1.915	2.193	0.278	2.279	2.555	0.276
	2	1.241	1.518	0.277	1.766	2.043	0.277	1.915	2.192	0.277	2.278	2.555	0.277
	3	1.239	1.517	0.278	1.765	2.043	0.278	1.915	2.192	0.277	2.280	2.556	0.276
	4	1.239	1.512	0.273	1.765	2.043	0.278	1.915	2.192	0.277	2.280	2.556	0.276
2	5	1.886	2.161	0.275	2.415	2.693	0.278	2.756	3.033	0.277	2.898	3.178	0.280
	6	1.885	2.161	0.276	2.415	2.693	0.278	2.756	3.033	0.277	2.899	3.178	0.279
	7	1.885	2.160	0.275	2.415	2.692	0.277	2.756	3.033	0.277	2.898	3.178	0.280
	8	1.885	2.160	0.275	2.414	2.691	0.277	2.756	3.034	0.278	2.899	3.177	0.278
3	9	2.194	2.468	0.274	2.455	2.733	0.278	2.886	3.163	0.277	3.228	3.505	0.277
	10	2.194	2.467	0.273	2.455	2.733	0.278	2.886	3.162	0.276	3.229	3.505	0.276
	11	2.194	2.469	0.275	2.455	2.733	0.278	2.886	3.163	0.277	3.230	3.505	0.275
	12	2.194	2.467	0.273	2.456	2.733	0.277	2.886	3.163	0.277	3.229	3.505	0.276
∑		21.277	24.576	3.299	26.542	29.873	3.331	30.228	33.553	3.325	33.627	36.953	3.326

Table 6. *Measuring data from the second operator*

SET 1					SET 2			SET 3			SET 4		
Position	j	x_{Aj}	x_{Bj}	x_j	x_{Aj}	x_{Bj}	x_j	x_{Aj}	x_{Bj}	x_j	x_{Aj}	x_{Bj}	x_j
		m	m	m	m	m	m	m	m	m	m	m	m
1	1	1.759	2.035	0.276	1.767	2.043	0.276	1.916	2.193	0.277	2.279	2.554	0.276
	2	1.758	2.034	0.276	1.767	2.043	0.276	1.916	2.192	0.276	2.278	2.554	0.277
	3	1.758	2.034	0.276	1.766	2.043	0.277	1.916	2.192	0.276	2.280	2.555	0.276
	4	1.758	2.034	0.276	1.766	2.043	0.277	1.916	2.192	0.276	2.280	2.555	0.276
2	5	2.599	2.875	0.276	2.416	2.693	0.277	2.758	3.033	0.275	2.897	3.177	0.280
	6	2.599	2.875	0.276	2.416	2.693	0.277	2.758	3.033	0.275	2.898	3.177	0.279
	7	2.599	2.875	0.276	2.416	2.692	0.276	2.758	3.033	0.275	2.897	3.177	0.280
	8	2.599	2.876	0.277	2.415	2.691	0.276	2.758	3.034	0.276	2.898	3.176	0.278
3	9	2.728	3.005	0.277	2.456	2.733	0.277	2.888	3.163	0.275	3.227	3.504	0.277
	10	2.728	3.004	0.276	2.456	2.733	0.277	2.888	3.162	0.274	3.228	3.504	0.276
	11	2.729	3.005	0.276	2.456	2.733	0.277	2.888	3.163	0.275	3.229	3.504	0.275
	12	2.729	3.005	0.276	2.457	2.733	0.276	2.888	3.163	0.275	3.228	3.504	0.276
∑		28.343	31.660	3.317	26.553	29.873	3.320	30.246	33.553	3.307	33.620	36.946	3.325

Table 7. *First operator – results of measuring*

	set_1	**set_2**	**set_3**	**set_4**	**S_{ISO_ROLAS} =**	**0,71**	**mm**
h=	0,276362	0,276725	0,275728	0,276836	U_{ISO_ROLAS} =	1,43	mm
a=	-6,5E-06	-0,00012	0,000289	0,001625	h=	0,28	m
b_1	-0,00012	0,00015	-0,00027	-0,00023	a=	0,000448	m
b_2	-0,00012	-3,3E-05	-0,00023	0,000383	b_1=	-0,00012	m
s	0,394	0,585875	0,650189	1,058286	b_2=	-5,2E-08	m
					b=	0,000117	m

Table 8. *Second operator – result of measuring*

	set1	set2	set3	set4	S_{ISO_ROLAS} =	0,67	**mm**
h=	0,276117	0,277558	0,277133	0,276892	U_{ISO_ROLAS} =	1,34	mm
a=	2,36E-16	-0,00013	0,00025	0,001625	h=	0,28	m
b1	-0,00012	0,00015	-0,00027	-0,00023	a=	0,000437	m
b2	-0,00012	-3,3E-05	-0,00023	0,000383	b1=	-0,00012	m
s	0,366288	0,584166	0,458712	1,058497	b2=	5,9E-17	m
					b=	0,000117	m

Table 9. *Conformity assessment tests*

No	Null hypothesis	Test statistic	Question
1	$s = \sigma$	$s \leq \sigma \cdot \sqrt{\frac{X^2_{1-\alpha}(v)}{v}}$	The null hypothesis stating that the experimental standard deviation, s, is smaller than or equal to a theoretical or a predetermined value, σ ,
2	$\sigma = \tilde{\sigma}$	$\frac{1}{F_{1-\alpha/2(v,v)}} \leq \frac{s_1^2}{s_2^2} \leq F_{1-\alpha/2(v,v)}$	In the case of two different samples, a test indicates whether the experimental standard deviations, s and $\tilde{s}$, belong to the same population.

Table 10. *Conformity assessment results*

s_1=	1,43	Measurement uncertainty				
s_2=	1,34					
v_1=	8					
v_2=	8					
$F_{1\text{-alfa}/2,v,v}$=	4,43					
s_1^2/s_2^2=	1,14					
Test statistic	0.23	≤	1,14	≤	4,43	
s_1=	0,276	High difference				
s_2=	0,277					
v_1=	8					
v_2=	8					
$F_{1\text{-alfa}/2,v,v}$=	4,43					
s_1^2/s_2^2=	0,996					

Test statistic	0,23	≤	0,996	≤	4,43
σ=	**1,6**				
S_{ISO_LEV}	1,42				
v	8		Measurement uncertainty		
$\chi^2_{1-alfa,\ v}$	15,51				
Test statistic	2,228				
	1,42	≤	2,23	TRUE	
σ=	**1,6**				
S_{ISO_LEV}	1,34				
v	8		Measurement uncertainty		
$\chi^2_{1-alfa,\ v}$	15,51				
Test statistic	2,23				
	1,34	≤	2,23	TRUE	

Traceability: The results of the calibration are traceable to the national standard of the Frequently Stabilized Helium-Neon Laser (DMDM, Serbia).

5. CONCLUSION

Quality is an important factor when it comes to any product or service. With the high market competition, quality has become the market differentiator for almost all products and services. There are many methods followed by organizations to achieve and maintain required level of quality for different types of products, equipment and services.

The most important characteristics of measuring instruments and measuring equipment are changing over the time. These changes are caused by environmental effects, mishandling, wear of measurement surface, etc. It is very important to check, review and follow the long term of equipment quality check, in the aim to assure that the equipment intended to be used meets the requirements of the project.

Building projects first have to give save products, as well as they are very expensive, so securing quality in all phases of project is crucial. Since one phase consist from different process and procedures, and further from recourses and methods, all single part of project management must be quality assured. When it comes from building equipment, rotating lasers are very useful for securing really horizontal and vertical levels during the building process. Very often, project by self insists on special range of accuracy and precision, so criteria with respect to technical specifications is given in advance.

There are different types of rotating lasers, with different technical specification. It is important to secure that the rotating laser has ability to respond to project requirements, so there are officially recognized norms recommended for verification, testing and calibrating it.

In this paper has shown interpretation of international norm ISO 17123-6 from two different approaches. First one is laboratory reference systems as automatized systems for rotating lasers verification, and second one is field method for uncertainty measurement assessment type A.

Laboratory reference system show that the rotating laser has standard deviation confirmed within declared values by manufacturer. Field method is performed by two operators, with many repeated measurements, giving the assessment of results for high difference, deviation of laser beam in horizontal and vertical sense, as well as experimental standard deviation of high difference.

Using the recommended statistic test it is shown that results of measurement obtained by two different operators belong to the same population, as well as results are confirmed within range values given by manufacturer.

It is important to say, the ISO 17123-6 qualified calibration certificate is necessary to large contractors bidding for governmental projects, as well as small to medium size contractors bidding for projects from regional authorities, including rental companies upgrading their services and expanding client basket and potentially any laser owner needing written confirmation for his quality process.

LITERATURE

[1] James P.Dux, Handbook of Quality Assurance for the Analytical Chemistry Laboratory, Springer Science & Business Media, 06.12.2012. - 204 page.

[2] BIPM, IEC, IFCC, ILAC, ISO, IUPAC, IUPAP and OIML. „International Vocabulary of Metrology – Basic and General Concepts and Associated Terms (VIM 3rd edition) JCGM 200:2012“, 2012.

[3] Universitas Tartuensis. „The concept of measurement uncertaint“, Internet: https://sisu.ut.ee/measurement/introduction-concept-measurement-uncertainty

[4] Tom Lish. „What is Measurement Traceability“, Internet: https://www.setra.com/blog/what-is-measurement-traceability, September 05, 2016.

[5] 2010 Johnson Level & Tool Mfg. Co., Inc. „Spirit Level, Laser Levels & Construction Measuring Tool Leader”, internet http://www.johnsonlevel.com/News/RotaryLaserLevels

[6] International Organization for Standardization, „ISO 10012:2003 Measurement management systems — Requirements for measurement processes and measuring equipment“, Genève 2003.

[7] International Organization for Standardization, „ISO 17123-6:2012 Optics and optical instruments — Field procedures for testing geodetic and surveying instruments — Part 6: Rotating lasers“, Genève 2012.

[8] Zrinjski, Mladen & Barković, Đuro & Gudelj, Marina, „Testing and Analysis of the Measurement Quality of the Rotating Laser System“ Geodetski List. Vol. 73 (96). pp 109-128. year 2019.

[9] Leica Geosystems AG, “Leica CalMaster 100 - Grow and bond your distribution through unique service offering”, Heerbrugg 2014.

[10] Google images, “Accuracy and precision” https://i.pinimg.com/originals/ea/2e/ae/ea2eae9ca6992d2ff76deffa8f470d28.jpg

13 | Research paper I Оригинални научни рад
ISSN 2566-4484 I Doi 10.7251/STP2014127P
pages 127-141

Bojan Popović, bojanpop94@uns.ac.rs, Faculty of Technical Sciences, University of Novi Sad
Igor Ruskovski, rus_igor@uns.ac.rs, Faculty of Technical Sciences, University of Novi Sad
Stevan Milovanov, s.milovanov@uns.ac.rs, Faculty of Technical Sciences, University of Novi Sad
Miro Govedarica, miro@uns.ac.rs, Faculty of Technical Sciences, University of Novi Sad
Dušan Jovanović, dusanbuk@uns.ac.rs, Faculty of Technical Sciences, University of Novi Sad

ANALYSIS OF THE INFLUENCE OF CLIMATE FACTORS ON DIFFERENT CROPS USING MULTIVARIABLE ANALYSIS AND REMOTELY SENSED DATA

Abstract:

Phenology modeling of the most common agricultural cultures based on time series of high spatial resolution satellite imagery and vegetation indices was conducted for several crop types. This data was used as an indicator of crops state in the multivariable correlation model as dependent variables. The influence of climate factors (temperature, air pressure, precipitation, insolation, cloudiness and humidity) on crops state was determined using multivariable correlation. This model allows prediction of delayed influence of climate factors on plant health and state through the values of NDVI.

Keywords: remote sensing, multivariable analysis, NDVI, climate factors

АНАЛИЗА УТИЦАЈА КЛИМАТСКИХ ФАКТОРА НА РАЗЛИЧИТЕ УСЕВЕ ПОМОЋУ МУЛТИВАРИЈАБИЛНЕ АНАЛИЗЕ И ДАЉИНСКИ ДЕТЕКТОВАНИХ ПОДАТАКА

Сажетак:

У овом раду је извршено моделовање најзаступљенијих пољопривредних култура на основу временских серија сателитских снимака високе резолуције и вегетационих индекса. Ови подаци су коришћени као показатељи стања усева у моделу мултиваријабилне корелације као зависне променљиве. Утицај климатских фактора (температура, притисак, падавине, инсолација, облачност и влажност ваздуха) на стање усева је утврђен помоћу мултиваријабилне анализе. Овај модел омогућује предвиђање одложеног утицаја климатских фактора на стање усева помоћу вредности NDVI.

Кључне ријечи:даљинска детекција, мултиваријабилна анализа, NDVI, климатски фактори

1. INTRODUCTION

Vegetation indices and climate parameters-based crop phenology analysis have been the subject of many scientific papers and many methodologies have been established in order to extract the most information about current plants state. That information is further used to plan corrective actions and neutralize hazards (diseases, pests, drought) through agro technical measures. The problem in this approach is in the chronological order: the damage happens and, although prompt, is detected later.

Recently, the tendency in the area of remote sensing is to use available datasets to develop models that will take input parameters and predict vegetation state and alarm if there is a harmful influence that needs to be prevented. Similarly, it is possible to develop models that would predict the yield in the early stages of crop development (these models require historical data about crop development and a large number of dependent variables).

Authors van Wart and others [1] concluded that crop simulation models can be used to estimate the influence of current and future climate on crop yield and food safety but demand long-term historical data about daily climate in order to get robust simulation. Many regions that grow crops do not have daily climate data. Alternatively, there are connected databases about climate data with overall coverage of the Earth that usually come from computer models with global flow, interpolated data from meteorological stations and remote sensing data. The aim of this study is to estimate the abilities of computer models with global flow to simulate crop yield potential that can serve as a measuring stick to estimate the influence of climate change on crop productivity. The conclusion is that the study results that rest on computer models with global flow are very uncertain. [1]

Based on the analysis of financial losses, author Nedacelov M. [2] concluded that in the time period from 2007 until 2012 the fluctuation of climate changes intensity induced great yield loss in the past few decades. The results show that emphasized manifestation of climate changes in the past years have added to the decline of the harvest of winter wheat compared to the harvest expected in 2020 calculated by the most drastic Special Report on Emissions Scenarios (SRES) B2A scenario. They concluded that the urgent prevention measures are needed. The climate changes adaptation measures have been taken in Moldova. [2]

Authors Ceglar and others [3] have estimated the influence of inter-season climate variability on inter-annual differences in yield of winter wheat and corn in 92 French administrative areas. Observed monthly time series of temperatures, precipitation and insolation during the vegetation season are analyzed alongside recorded yearly yield with the statistical approach based on partial least squares regression. The results show significant spatial differences in the contribution of main meteorological initiators in the variability of crop yield and time domain of maximal influence. Temperature and strong insolation are identified as the most important variables that influence corn yield in the south, east and north part of France, while precipitation is the most important in central and north-west parts of the country. Positive anomalies of precipitation during summer months lead to corn yield increase, while positive temperature and radiation anomalies have the opposite effect. Extensive irrigation in drought years reduces rain signal. Temperature differences in eastern France mostly influence the yield of winter wheat and precipitation differences influence north, north-west and south-east France. [3]

The aim of this paper was to produce a robust model for crop state prediction based on the current climate parameters. One of the critical steps for model development was to determine the time period of delayed impact of climate factors to the state of crops, quantified through the values of Normalized Difference Vegetation Index (NDVI). Based on the built model it is possible to predict the values of the NDVI for different crops if the current climate parameters are known. In this way, it is possible to roughly determine if there is a need for corrective actions in order to neutralize harmful influence of the weather on the plant health.

2. METHODOLOGY

The area of statistics deals with the acquisition, representation, analysis and application of data used in decision making, problem solving and product and process designing [4]. Statistical methods are used to improve variability description and understanding. Variability is presented by successive observations or phenomena that do not produce the same results. Two methods have been used in this paper: Z-score method and multivariable regression.

2.1. Z-score method

Outlier is a term in statistics that represents an observation significantly different from other observations [4]. This definition suggests that the outlier is something separated or different from the rest. Every data science project begins with the data acquisition and in that phase, there is no knowledge about the outliers. Outliers can be the result of data acquisition errors or the sign of the differences in data. There are several methods in statistics that can be used to detect the outliers [5]. Z-score method was used in this paper. Z-score method is a statistical test used to determine if the two mean values within a population differ when their variances are known and the sample sizes are large. This is performed under the assumption that the data is normally distributed and the standard deviation is known. The point of Z-score method is to detect and eliminate the outliers from the dataset [6].

2.2. Multivariable analysis

In the process of scientific explanation of the nature of some phenomenon, starting points consist of the data about one or more objects [7]. These objects can be: individuals, communities, different physical objects but also natural phenomena or a result of human activities. Sometimes it is not possible to look at the nature of the object as a whole. However, it is possible to observe one multidimensional phenomena that consists of several characteristics. Those characteristics are the subjects of the observation, and are usually called variables. Multivariable analysis represents an aggregate of statistical methods that simultaneously analyse multidimensional observations acquired for each unit of observation of examined objects. Assuming that the data about *j* characteristics about *i* objects was acquired and that this data was presented as a matrix (rows represent objects, columns represent variables), the table of data has the following structure:

$$\begin{array}{cccccc} & Variable\ 1 & Variable\ 1 & \dots & Variable\ j & \dots & Variable\ p \\ Feature\ 1: & X_{11} & X_{12} & \dots & X_{1j} & \dots & X_{1p} \\ Feature\ 2: & X_{21} & X_{22} & \dots & X_{2j} & \dots & X_{2p} \\ \vdots & \vdots & \vdots & & \vdots & & \vdots \\ Feature\ i: & X_{i1} & X_{i2} & \dots & X_{ij} & \dots & X_{ip} \\ \vdots & \vdots & \vdots & & \vdots & & \vdots \\ Feature\ n: & X_{n1} & X_{n2} & \dots & X_{nj} & \dots & X_{np} \end{array} \tag{1}$$

where (i, j) element of the matrix represents the value of *j* variable measured on *i* object. In matrix notation, this matrix is noted as X, or X_{ij}, i=1,2,...,n; j=1,2,...,p.

Methods for data matrix analysis are categorized into two categories: methods of dependence and methods of interdependence. If the goal is to examine dependence between two groups of variables, where one group represents dependent and the other group are independent variables, a former group of methods is used. Later group is used when there's no apriori, theoretical base to divide all the variables into two groups. With the methods of dependence, one or more dependent variables have to be predicted based on the group of independent variables. In the other case this is not mandatory.

2.2.1. Multivariable regression

The main objective of a regression is to discover as many factors (independent variables) that influence a dependent variable. First assumption is that if there are more variables included in the model, latent variables (standard errors) will have less impact [8]. It is very important to decide which variables will be included in the model. Basic multivariable regression model is defined with the following:

$$\hat{x_i} = a_1 + b_2 x_{i2} + b_3 x_{i3} + \cdots + b_m x_{im} + \varepsilon_i, \quad i = 1, 2, \dots n \tag{2}$$

where:

a_1 – free term

$\hat{x_i}$, *i = 1,2,...,n* – single value of regression

x_{ij}, *i = 1,2,...,n, j = 1,2,...,m* – values of independent variables

b_j, *j= 1,2,...,m* – regression coefficient

ε_i, *i + 1,2,...,n* – latent variable

m – number of independent variables

n – sample size

This model offers best possible prediction of dependent variable values based on the values of independent variables, if all of the assumptions are met. It is possible to conclude the relative impact or importance of each of the independent variables based on the regression coefficients if those coefficients are converted into beta coefficients. These coefficients are a result of variable values standardization. One of the assumptions is that in order to use regression analysis, there has to be linear dependence between the variables. It is a mandatory assumption because the analysis begins with the calculation of simple correlation coefficients for all tuples of variables, and all these calculations require linear relationship between the tuple members.

2.2.2. Multicollinearity

Multicollinearity shows the interdependence between independent variables. The bigger the multicollinearity, the more it reflects on beta coefficients and they can't further be used to show relative impact of each independent variable. The reason behind this is that regression coefficients, b and beta are always calculated so that they give the best possible prediction of dependent variable Y, and not to show relative importance of each independent variable X. When the multicollinearity is low or doesn't exist, then regression coefficients are proportional to simple correlation coefficients and both of those give similar ideas about relative importance of independent variables. If there is a significant multicollinearity, then the most important independent variable gets the real value of beta coefficient, while the rest get lower values so that interdependence and mutual impact of the independent variables is avoided [9].

2.2.3. Variance inflation factor (VIF)

Variance inflation factor quantifies the level of correlation between one independent variable (predictor) and other independent variables in the model. It is used to determine collinearity and multicollinearity. Larger values show that it is difficult or impossible to determine the contribution to the model. Multicollinearity produces the problem in multivariable regression because the input factors have mutual impact, they are not independent which makes it hard to test how many combinations of independent variables influence dependent variables. Multicollinearity reduces the power and legitimacy of the model. The extent to which the predictor is correlated to other predictors can be quantified as R^2 statistics of the regression, where the predictor is predicted through all the other predictors' values [10]. VIF is then calculated as:

$$VIF = \frac{1}{1 - R^2} \tag{3}$$

VIF can be calculated for each predictor in the model. Value of 1 means that the specified predictor is not correlated to any other variables. If the value is larger, it means that there is more correlation between the observer variable and other variables in the model. Values larger than 5 are classified as medium and high values, and values larger than 10 are classified as very high values. This classification should be taken with a caution, because sometimes the value of 2 can cause issues. If one variable has a high VIF, it means that there is at least one more variable with a high VIF (two highly correlated values).

2.2.4. R-Squared

Multiple regression also shows how strong the interdependence is between dependent variable and all independent variables through the R index. R^2 index shows what the percentage of variability of dependent variables is explained through variability of independent variables. Since the correlation index and determination index are calculated based off the acquired data, there is no methods to improve them. Still, it is advised that a pilot research should be conducted in order to identify all the variable with the most impact, and only after that the whole research should be done. Multicollinearity can be determined through a specific indicators such as level of tolerance. Level of tolerance is a proportion of variable variance that is not connected to other variables in the regression model. High level of tolerance, above 0.8 means that those variables are relatively not correlated with other variables. Low level of tolerance, under 0.2 means that there is a high multicollinearity and that that variable doesn't contribute a lot to the explanation of dependent variable in the model. Their statistical significance should be tested when the results are explained. If R, b and beta are not statistically significant, the conclusion is that no independent variable has any real connection to the dependent variable. If all of the regression coefficients b are significant, then the index of correlation R will be significant.

2.2.5. Heteroscedasticity

Heteroscedascity refers to the situation where variability of dependent variable is not equal in the range of values of independent variables that predicts it. Scatterplot of these variables is often conic shaped, where dependent variable expands or narrows when independent variable grows [11]. The opposite case is homoscedasticity, which shows that the variability of dependent variable is the same within the scope of values of independent variable.

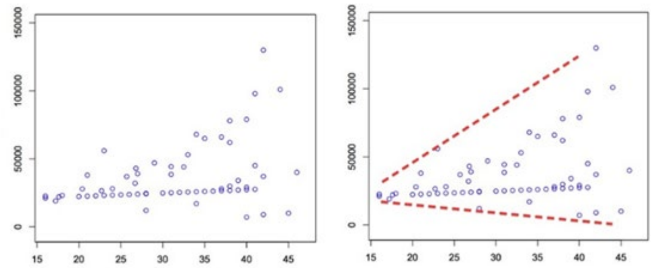


Figure 1. *Heteroscedasticity in the data (notable differences in the values of standard deviation alongside horizontal axis)*

Heteroscedascity influences the analysis results in the following ways:

- Although it does not provoke bias in the coefficients estimation, it makes them less precise. Lower precision means that it's probable that estimated coefficients are further away from the correct value
- Heteroscedasticity tends to produce p-values lower than they should be. This effect happens because heteroscedasticity increases coefficient estimates, and OLS is not able to detect this increase. This problem can cause the conclusion that the model is statistically significant when in fact it is not.

2.2.6. Autocorrelation

Autocorrelation refers to the extent of correlation between the values of one variable in different moments of observation [12]. The concept is usually considered in time series where observations happen in a different time domains (temperature during one month). If two values that are close to each other in time domain were more similar to each other in comparison to other values that were observed later during the month, it could mean that the data is autocorrelated. This can cause problems in conventional analyses that assume independence of observations.

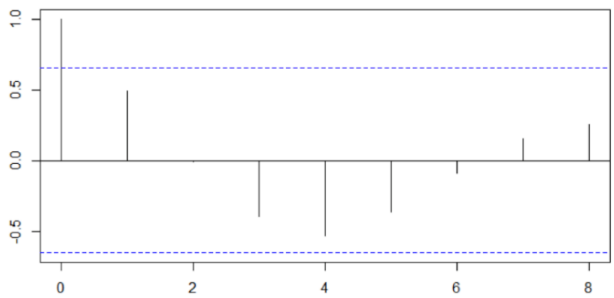


Figure 2. *Correlogram for demo data. Lag is connected to the order of correlation. Correlation has the value of 1 when there is no lag. With the lag present, the value of the correlation changes and it can be within or outside of the limits*

Autocorrelation can be seen in any dataset if it is observed based on the error sampling. That is the reason why statistical tests should be performed in order to avoid the situation of sampling causing autocorrelation. Standard test for this is Durbin-Watson. This test explicitly tests for correlation of first order. Problems that arise due to autocorrelation are OLS coefficient estimates that are not good enough as well as the estimates performed off those estimates, data overfitting, low values of standard errors, high t-statistics values.

2.2.7. Error measurements

Mean absolute error measures the average value of error in the prediction set, without the consideration of their directions. It is the average value for the sample of absolute differences between predicted and true values of observation where all the differences have the same weights.

$$MAE = \frac{1}{n}\sum_{j=1}^{n}\left|y_j - \hat{y}_j\right| \quad (4)$$

If the absolute value is omitted, mean absolute error becomes mean bias error and it's usually meant for measuring model bias. This error can provide a lot of information, but has to be carefully analyzed because there is a chance of positive and negative errors undoing each other.

$$RMSE = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(y_j - \hat{y}_j\right)^2} \quad (5)$$

Given the fact that RMSE errors are first squared before the average value is calculated, RMSE gives relatively higher weights to larger errors. This means that RMSE is more useful when the goal is to eliminate larger errors [13].

2.3. NDVI

Green plants absorb sunlight and use it as an energy source in the process of photosynthesis. Chlorophyll, the plant leaves pigment, absorbs visible part of the spectrum (0.4-0.7 nm) and reflects near infrared spectrum (0.7-1.1nm). The absorption at these wavelengths would make plant overheat and the tissue would be damaged. That is why green plants look relatively dark in the visible spectrum (RGB) and relatively bright in the NIR band [14].

It's well known that the combination of near infrared and red bands can be used as an indicator of plant's health and give more useful information than separate bands can discover. NDVI is a quantitative measure of a plant's health based on the way that the plants reflect lights at different frequencies. The equation for NDV was developed several decades ago in order to use satellite images in agriculture. The structure of the equation makes it insensitive to the total brightness of the scene. Basically, the relation between NIR and red band was described through the equation and that relation doesn't change with the total scene brightness.

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (6)$$

Today, NDVI is often used in many different analyses. Agricultural producers use NDVI to measure biomass, while in forestry it is used to quantify forest farms. Its most important application is that NDVI allows detection of changes in plants up to two weeks before human eye could see. That way it is possible to discover diseases, pests, fungi on time and react properly [15].

3. RESULTS

Proposed methodology has been tested on the study area shown in Figure 3. Data that was used is consisted of 10 parcels located in the vicinity of Bečej, Republic of Serbia. 20 sample points were generated for each parcel (200 in total) and NDVI was calculated for each sample point based on the satellite images available for this area for the year of 2017. Over 15 Sentinel-2 satellite images were used in the sampling process.

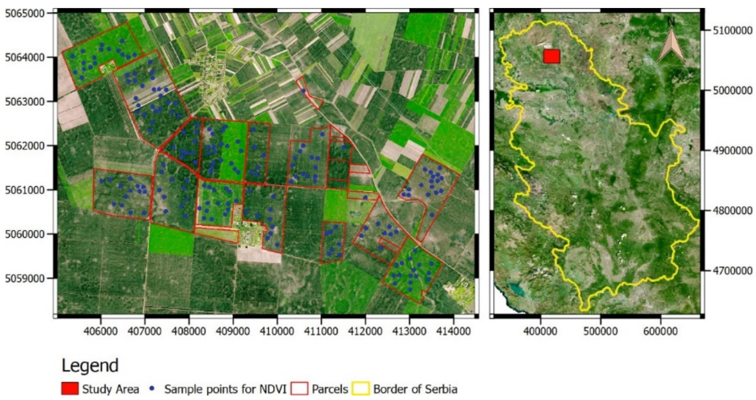


Figure 3. *Parcels, located in the vicinity of Bečej, Republic of Serbia, which were used for development and testing of regression model*

Data visualization plays a very important role in statistical analysis. Certain rules and exceptions in the data can be seen this way that can serve as a starting point for future decisions in the analysis. One of the visualization methods is BoxPlot. This method displays 5 parameters that describe the data: minimal value, first quartile, median, third quartile and maximum value. The data that fall under the minimal value and above the maximum value are called outliers. Based on the box plot (Figure 5) it is visible that each culture has observations that are significantly different than others within the same culture and the conclusion is that they are the outliers that need to be excluded from the future analysis in order not to skew the results.

Box plot of wheat (Figure 4) gives insight into a large range of values throughout the year which leads to a deeper analysis of this culture. The result of this research shows that there are two types of wheat in the Republic of Serbia: one that is sowed in the spring and one that is sowed in the autumn.

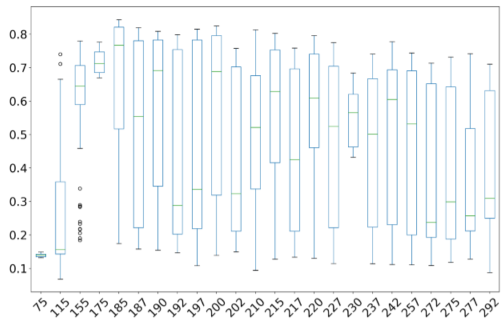


Figure 4. *BoxPlot of wheat data with a notable wide range of values*

The data has been filtered based on the calendar of agricultural actions, two types of wheat were separated and analysed separately.

Even though the negative buffer eliminated the possibility of sample points falling out of the specified culture, the additional test for outliers was performed. The possibility of outliers existence can be explained by the following situations: sample points fell on weed, cloud, passage in the field, excess water etc. The value of the vegetation index can be significantly different and this is why the Z-score test was performed. All the values that were declared an outlier were removed from the dataset, which can be seen on the example of winter wheat (Figure 5).

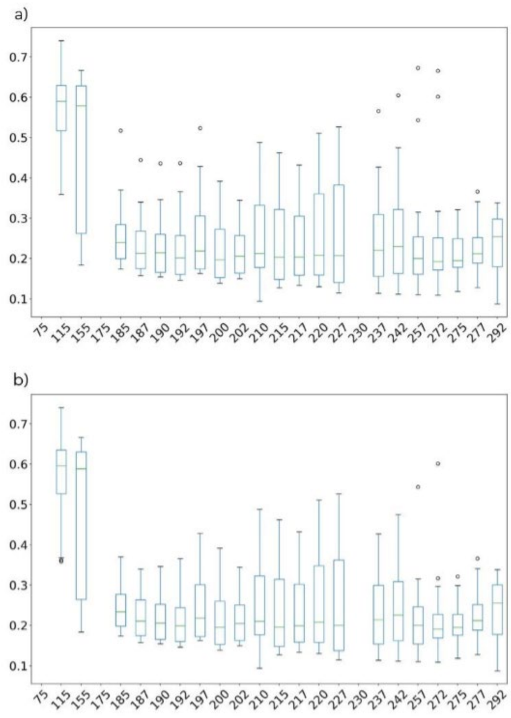


Figure 5. *BoxPlot for winter wheat before and after Z-score test for outliers*

When all the data is within the limits of Z-score and all the outliers are eliminated, the mean value of the index is calculated for each culture and each date. This results in a value that corresponds to each date (Figure 6).

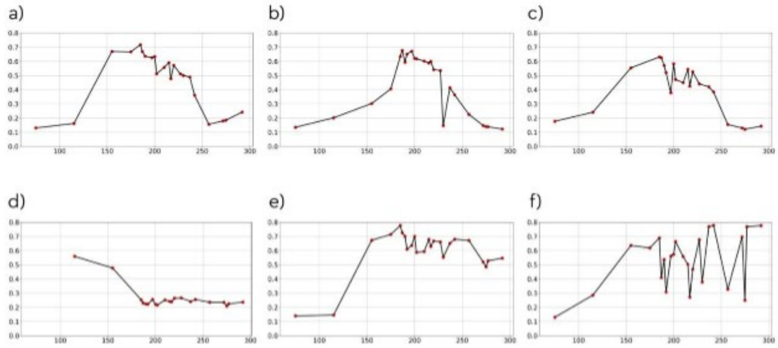


Figure 6. *Mean values of the vegetation index (NDVI) for: corn (a), sugar beet (b), barley (c), winter wheat (d), spring wheat (e) and clover (f) during the year of 2017*

In order to get a mathematical model of crop phenology during the whole period of observation, approximation with a polynomial function of 4^{th} degree was done through nonlinear regression.

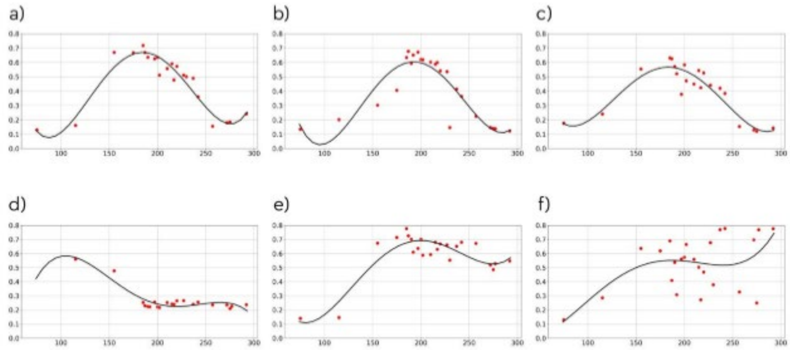


Figure 7. *Mean values and regression curve for: corn (a), sugar beet (b), barley (c), winter wheat (d), spring wheat (e) and clover (f) during the year of 2017*

Meteorological data was taken from the archive of the Republic Hydrometeorological Service of Serbia for the year of 2017 [16]. The data included in this research are air pressure, temperature, precipitation, insolation, humidity and cloudiness and refer to the geographical area in the vicinity of Novi Bečej. After the data has been loaded and checked for completeness, the dates of interest were picked. Meteorological data were taken for the time period from 31. of March until 2nd of October in 2017. This time domain was determined in the accordance of crop development.

The first step in the meteorological data analysis was the test for multicollinearity. From a mathematical standpoint, the problem with multicollinearity is that it produces unreliable coefficient estimates. In addition to that, standard errors of the coefficients become artificially enlarged. Since standard error is used to calculate p-values, this leads to a bigger probability that a variable will be declared statistically insignificant when in fact the truth is the opposite. A correlation matrix was generated and the values are presented in Table 1.

Table 1. *Correlation coefficient values for the meteorological data*

	air pressure	temperature	humidity	insolation	cloudiness	precipitation
air pressure	1	-0.297766	-0.015235	0.084048	-0.197213	-0.126089
temperature	-0.297766	1	-0.701491	0.61549	-0.493282	-0.219265
humidity	-0.015235	-0.701491	1	-0.780406	0.731885	0.381271
insolation	0.084048	0.61549	-0.780406	1	-0.838166	-0.248826
cloudiness	-0.197213	-0.493282	0.731885	-0.838166	1	0.270916
precipitation	-0.126089	-0.219265	0.381271	-0.248826	0.270916	1

Correlation heatmap (Figure 8) is often used when there are several variables. This offers a great insight into variables that have a high correlation coefficient (darker colors). By looking at this heatmap, it is possible to determine several highly correlated variables. For example, insolation and cloudiness are highly correlated. This is expected, since the amount of sunlight is directly tied to the cloudiness.

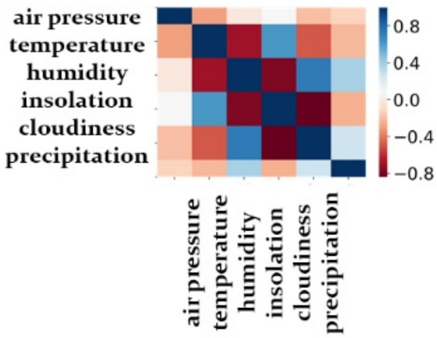


Figure 8. *Graphical representation of meteorological parameter correlation. Darker colours represent strong positive (blue) and negative (red) correlation*

Still, systematic search and removal of the variables with a high degree of correlation is a must. One of the methods used in this process is Variance Inflation Filter – VIF which measures how much the variable contributes to the amount of standard error in the regression model. When there is a significant multicollinearity, VIF will have a high value for the variable used in the model. General advice is that if any variable has a VIF factor 5 or higher, it should be excluded from the model. In this case, since no factor has a value higher than 5, all the variables will be kept in the model (Table 2).

Table 2. *VIF values for meteorological data. Value of VIF for insolation is close to the limit value of 5, but this factor was kept in the analysis.*

air pressure	1.359661
temperature	2.565814
humidity	3.790195
insolation	4.484016
cloudiness	3.820751
precipitation	1.202791

For the better insight into data, all standard statistical parameters (mean, standard deviation, minimum and maximum etc) were calculated and are shown in Table 3.

Table 3. *Standard statistical parameters for meteorological data*

	air pressure	temperature	humidity	insolation	cloudiness	precipitation
count	186	186	186	186	186	186
mean	1005.640323	19.625806	63.892473	9.35	4.098925	1.701613
std	4.325417	6.095375	13.057844	4.32494	2.883729	5.630424
min	994.7	2.7	37	0	0	0
25%	1002.725	15.475	54	6.8	1.7	0
50%	1005.65	20.1	62.5	10.5	4	0
75%	1008.1	24.075	72	12.675	6.6	0.275
max	1018.5	31.8	97	14.9	10	48.6
+3_std	1018.616573	37.911933	103.066006	22.324821	12.750111	18.592885
-3_std	992.664072	1.33968	24.718941	-3.624821	-4.552261	-15.189659

After the data has been cleared of errors, the next step is the model development. The first step is the definition of dependent and independent variables, and then the data needs to be divided into training and test sets. Independent variables are meteorological data, and dependent variable is the NDVI value. Good ratio of test and train data division is 20% to test and 80% to train the model.

When the data is fitted in the model, results are analysed. First part consists of the intercept model analysis. Intercept value is the value of dependent variable when all of the independent variables are zero. For each slope coefficient, it is the estimated difference of dependent variable for single unit change of specific independent variable. Intercept model variables are shown in Table 4.

Table 4. *Intercept values of the model. If all of the variables except temperature are zero, single unit change in temperature would contribute to a change of 2.9% to NDVI*

air pressure	0.0055
temperature	0.029
humidity	0.0046
insolation	0.023
cloudiness	0.027
precipitation	0.00064

The second part of the analysis consisted of tests for normal distribution of regression residuals, residual homoscedasticity and lack of multicollinearity (this has already been tested). Using various statistical tests all of the assumptions were confirmed: the residuals are homoscedastic with normal distribution. To get a better feel of model fitting, several indicators were calculated: mean average error, mean square error and root mean square error. The values of these errors are shown in Table 5.

Table 5. *Values of mean average error, mean square error and root mean square error*

MSE	0.0166
MAE	0.108
RMSE	0.129

R^2 provides a way to measure goodness of fit. Larger R^2 means better fitting. One of the limitations is that this value gets larger if there are more variables, which leads to larger R^2 value when new variables are added even though they are not necessarily good choice. R^2 value in the case of corn is 0.56 which is a low value, but it was expected in a way. It is normal that the climate changes affect the crops only after several days, not instantly. Keeping this in mind, NDVI will not show results in real time. For example, if day 100 is observed and the value of NDVI is 0.45 and it rains, an increase of NDVI value is expected in 7 to 10 days. In order to identify the time domain when the climate change impact is the strongest, the same above-explained process was repeated for time ranges from 1 to 14 days, and R^2 indicates the impact that has happened.

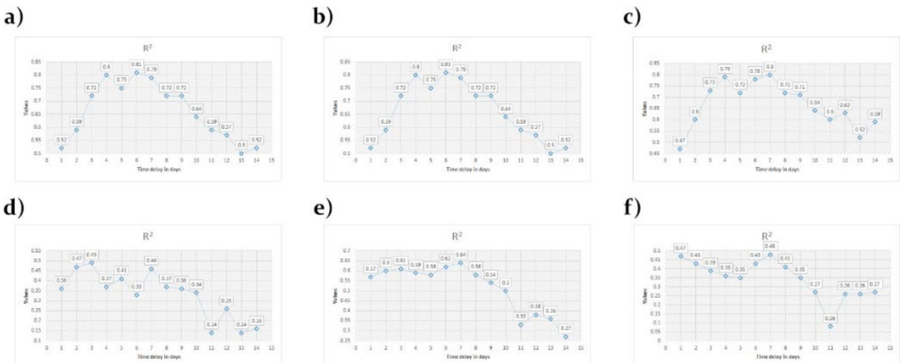


Figure 9. *Values of R2 with time delay taken into consideration for: corn (a), sugar beet (b), barley (c), winter wheat (d), spring wheat (e) and clover (f)*

The conclusion of the step above is that the climate parameters will have the strongest impact after 6 days. The analysis parameters have changed and the values for the new model are given below:

Table 6. *New values for model intercept*

air pressure	0.0035
temperature	0.029
humidity	0.0037
insolation	0.016
cloudiness	0.014
precipitation	0.0025

Table 7. *New model values for MSE, MAE and RMSE*

MSE	0.00736
MAE	0.0714
RMSE	0.0858

Table 8 shows the values of the 95% confidence interval for each meteorological parameter. Hypothesis tests were performed after this with the goal of determining statistical significance of coefficients estimates. Null hypothesis was that there is no connection between independent and dependent variables, while the alternative hypothesis claimed the opposite.

Table 8. *95% Confidence intervals for each of the meteorological parameters*

	0	1
air pressure	-0.001155	0.007161
temperature	0.024506	0.032801
humidity	0.001054	0.005723
air pressure	0.006921	0.022144
temperature	0.004110	0.025483
humidity	-0.001301	0.004720

Table 9 presents the p-values for each parameter, and Table 10 gives the summary of p-values for meteorological parameters before and after the removal of excess variables.

Table 9. *Estimated p-values for meteorological parameters*

air pressure	1.56e-01
temperature	1.74e-29
humidity	4.68e-03
air pressure	2.23e-04
temperature	6.92e-03
humidity	2.64e-01

Table 10. *P-values report for meteorological parameters before (above) and after (below) removal of insignificant independent variables*

OLS Regression Results						
Dep. Variable:	NDVI_corn		R-squared:			0.698
Model:	OLS		Adj. R-squared:			0.688
Method:	Least Squares		F-statistic:			68.97
Date:	Fri, 27 Sep 2019		Prob (f-statistic):			5.77E-44
Time:	17:18:12		Log-Likelihood:			155.83
No. Observations:	186		AIC:			-297.7
Df Residuals:	179		BIC:			-275.1
Df Model:	6					
Covariance Type:	nonrobust					
	coef	std. err	t	P>|t|	[0.025	0.975]
const	-3.5804	2.147	-1.667	0.097	-7.818	0.657
air pressure	0.0038	0.002	1.425	0.156	-0.001	0.007
temperature	0.0287	0.002	13.633	0.000	0.025	0.033
humidity	0.0034	0.001	2.864	0.005	0.001	0.006
insolation	0.0145	0.004	3.768	0.000	0.007	0.22
cloudiness	0.0148	0.005	2.732	0.007	0.004	0.25
percipitation	0.0017	0.002	1.12	0.264	-0.001	0.005
Omnibus:	7.84		Durbin-Watson:		0.602	
Prob(Omnibus):	0.02		Jarque-Bera(JB):		8.213	
Skew:	0.582		Prob(JB)		0.0165	
Kurtosis:	2.769		Cond. No.		2.77E+05	
OLS Regression Results						
Dep. Variable:	NDVI_corn		R-squared:			0.698
Model:	OLS		Adj. R-squared:			0.688
Method:	Least Squares		F-statistic:			68.97
Date:	Fri, 27 Sep 2019		Prob (f-statistic):			5.77E-44
Time:	17:18:12		Log-Likelihood:			155.83
No. Observations:	186		AIC:			-297.7
Df Residuals:	179		BIC:			-275.1
Df Model:	6					
Covariance Type:	nonrobust					
	coef	std. err	t	P>|t|	[0.025	0.975]

const	-0.5474	0.11	-4.974	0.000	-0.765	-0.33
temperature	0.0275	0.002	14.492	0.000	0.024	0.031
humidity	0.0036	0.001	3.193	0.002	0.001	0.006
insolation	0.015	0.004	3.902	0.000	0.007	0.023
cloudiness	0.0133	0.005	2.51	0.013	0.003	0.024
Omnibus:	6.424		Durbin-Watson:		0.578	
Prob(Omnibus):	0.04		Jarque-Bera(JB):		6.5	
Skew:	0.427		Prob(JB)		0.0388	
Kurtosis:	2.672		Cond. No.		9.65E+02	

Table 11. *True and estimated values of NDVI for test dataset*

Day	True	Estimated	Residual	143	0.4739	0.4705	0.0035	198	0.6486	0.6183	0.0302
94	0.0866	0.2648	-0.1782	144	0.4824	0.5122	-0.0299	207	0.6113	0.6429	-0.0316
101	0.1172	0.0453	0.0719	146	0.4989	0.5567	-0.0579	208	0.6062	0.6585	-0.0523
104	0.1351	0.0079	0.1272	149	0.5226	0.5637	-0.0411	212	0.5836	0.6759	-0.0922
106	0.1484	0.0837	0.0647	156	0.5725	0.5139	0.0586	217	0.5516	0.6629	-0.1112
109	0.1701	0.2887	-0.1186	168	0.6361	0.6088	0.0272	220	0.5306	0.5487	-0.0181
119	0.2540	0.2825	-0.0285	171	0.6470	0.5804	0.0667	252	0.2744	0.2632	0.0111
121	0.2721	0.3041	-0.0320	172	0.6502	0.6217	0.0285	255	0.2532	0.3500	-0.0968
125	0.3092	0.4110	-0.1018	183	0.6695	0.6227	0.0468	257	0.2400	0.2914	-0.0514
130	0.3562	0.4582	-0.1020	187	0.6692	0.5988	0.0704	260	0.2218	0.3302	-0.1084
132	0.3749	0.4149	-0.0400	192	0.6634	0.4786	0.1848	268	0.1854	0.1578	0.0275
137	0.4211	0.2805	0.1405	195	0.6570	0.6144	0.0426	270	0.1795	0.3542	-0.1747
138	0.4301	0.5177	-0.0876	196	0.6544	0.6262	0.0282	271	0.1772	0.3055	-0.1283

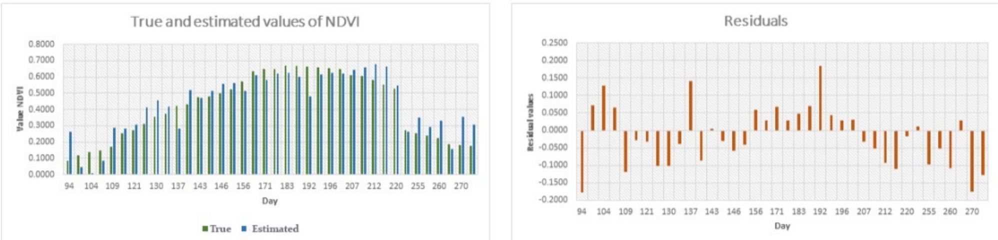


Figure 10. *True and estimated values of NDVI (left) and residual values (right)*

4. DISCUSSION

After initial acquisition of NDVI values, based on BoxPlots it was concluded that the data contain large amount of outliers that come from different sources and all of them were eliminated with Z-score method. Based on the ScatterPlot of mean values by culture, large oscillations were noticed throughout the year. This can be justified by the fact that climate conditions change during the year and they have an impact on plant development: drought, precipitation and agro-technical measures such as watering and fertilization after which the values of NDVI can improve or deteriorate (Figure 26). This fact was also confirmed by looking at the ScatterPlot of residuals. After the elimination of the outliers, a mathematical model was defined in order to get the values of the index for each date in the time period of plant development. Due to the nonlinearity of the data, a polynomial function of 4th order was chosen as it was the one that fit the data in the most adequate way. Resulting data was further used as dependent variables in the multivariable regression.

Meteorological data (temperature, air pressure, humidity, insolation, cloudiness and precipitation) were taken from the website of Republic Hydrometeorological Service of Serbia for the area of interest. A test for multicollinearity was performed before the model development in order to check if any factors have the same impact. Result of this test showed that insolation impacts the model in the same way as cloudiness, which was expected since the two phenomena are directly connected, although VIF factor was less than the limit which resulted in keeping it in the analysis.

The data was split in 80% for training and 20% for verification of the multivariable regression model. Model analysis showed that the impact of coefficients of single climate parameters are very low, which is expected since the values of index are between 0.2 and 0.8. Heteroscedascity and autocorrelation tests confirmed that the data is homoscedastic with high autocorrelation. Again, this result was expected since there is a well-known trend in the meteorological data, where it is possible to predict future values based on past ones. Mean value of the residuals was zero, and residuals are normally distributed. Initial value of R^2 test gave a very low value (0.56 for corn) since the observed climate parameters have no impact on the index in real time. By observing the R^2 values for different time domains, it was determined that the changes in climate parameters will be noticed after 6 days in the case of corn (it varies from 3 to 7 days for other crops). Analysis of residuals also confirms that the model predicts the values of NDVI on a very satisfactory level. If the more detailed data about agro technical measures was available (crop yield for past years), this model could be used to predict yield in the early stages of planting the crops.

5. CONCLUSION

Cloud platforms for data processing allow fast processing of large amounts of data which makes it easy to perform certain analysis and discover trends in data. Time series of satellite images would be almost impossible to process with classic methods. Statistical methods used in this paper could be used as steps of preprocessing this data. One of the biggest sources of errors in the process of image classifications is the input data (known locations of classes that are identified and contain outliers). Input data (true data) is usually blindly taken as correct when in fact this paper shows that sometimes outliers can be found within.

Multivariable regression offers methods to determine the impact of independent variables on a dependent variable as well as to generate a model that can estimate the values of dependent variable based on the independent variable values. This paper tests the impact of climate parameters (temperature, air pressure, humidity, cloudiness, insolation and precipitation) on several crops during its development in 2017. Based on the model, there are several conclusions: the impact of climate parameters, examined in this paper, will be best noticed after 3 to 6 days; climate factors precipitation and air pressure do not have a significant impact on changes of crops plant state; if model gets real time data, it will estimate NDVI values for the culture in 3 to 7 days from the day of observation, depending on the crop type.

Future work requires the expansion of independent parameters that are determined by the application of agricultural measures (fertilization, watering, usage of herbicide and pesticide etc.) as well as the values of yield for several years back in order to predict yield for the current year in the early stages of plant development.

LITERATURE

[1] J. Van Wart, P. Grassini, K. G. Cassman, “Impact of derived global weather data on simulated crop yields”, Global change biology, vol. 19, pp. 3822–3834, Sep. 2013.

[2] M. Nedealcov, “The Impact of Weather and Climate Risks on Cereal Crops Productivity”, Present Environment and Sustainable Development, vol. 8, pp. 195-208, Aug. 2014.

[3] A. Ceglar, A. Toreti, R. Lecerf, M. Van der Velde, F. Dentener, “Impact of meteorological drivers on regional inter-annual crop yield variability in France”, Agricultural and Forest Meteorology, vol. 216, pp. 58–67, Jan. 2016.

[4] Douglas C. Montgomery and George C. Runger, “Applied Statistics and Probability for Engineers, Third edition, United States of America, Publisher: John Wiley & Sons, Inc., ISBN 0-471-20454-4, 2003.

[5] Towards Data Science, Ways to Detect and Remove the Outliers, Available: https://towardsdatascience.com/ways-to-detect-and-remove-the-outliers-404d16608dba, [25.08.2019].

[6] Investopedia, Z-test, Available: https://www.investopedia.com/terms/z/z-test.asp, [25.08.2019].

[7] Das Panchanan, “Econometrics in Theory and Practice”. 10.1007/978-981-32-9019-8_8, pp.207-243, 2019.

[8] W. Yoo, R. Mayberry, S. Bae, K. Singh, Q. Peter He, JW Jr. Lillard, “A Study of Effects of MultiCollinearity in the Multivariable Analysis”, Int J Appl Sci Technol, vol. 4. pp. 9–19, Oct. 2014.

[9] Investopedia, Multicollinearity, Available: https://www.investopedia.com/terms/m/multicollinearity.asp [25.08.2019.].

[10] Cecil Robinson, Randall E. Schumacker, “Interaction Effects: Centering, Variance Inflation Factor, and Interpretation Issues”, Multiple Linear Regression Viewpoints, Vol. 35, Jan. 2009.

[11] E. Peksova-Szolgayova, Z. Lukac, P. Roncak, J. Szolgay, “Considering heteroscedastic in the modelling and forecasting of time series of mean daily discharges of the Hron river at station Brehy in Slovakia”, 18th International Multidisciplinary Scientific GeoConference SGEM 2018, vol.18, pp. 151-158, July. 2018.

[12] G. E. P. Box, G. Jenkins, Time Series Analysis: Forecasting and Control, USA: Holden-Day, Inc. 1976.

[13] T. Chai, R. Draxler, “Root mean square error (RMSE) or mean absolute error (MAE)? –

[14] Arguments against avoiding RMSE in the literature”., Geoscientific Model Development, vol. 7, pp. 1247–1250 , Jun. 2014.

[15] NDVI – normalized difference vegetation index, Available: https://gisgeography.com/ndvi-normalized-difference-vegetation-index/ [26.08.2019.].

[16] NDVI Available: https://eos.com/ndvi/ [26.08.2019.].

[17] Republic Hydrometeorological Service of Serbia, Available: http://www.hidmet.gov.rs/index.php [26.08.2019.].

14 | Research paper I Оригинални научни рад
ISSN 2566-4484 I Doi 10.7251/STP2014142T
pages 142-158

Igor Tucaković, tucakovicigor93@gmail.com, University College of Civil Engineering and Geodesy, Belgrade

Marina Nikolić Topalović, marinatopnik@gmail.com, University College of Civil Engineering and Geodesy, Belgrade

Tanja Trkulja, tanja.trkulja@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

CASE STUDY OF THE IMPACT OF THE STRUCTURE AND THICKNESS OF THE THERMAL ENVELOPE ON THE ENERGY CLASS OF THE INDIVIDUAL SINGLE-FAMILY HOUSING

Abstract:

The aim of the research is to obtain optimal ranges of thermal envelope for the desired energy classes, which will contribute to a more economical and rational approach to the design of buildings, as well as to prove that with the increase of thermal envelope there is an increase of the energy class. The model on which the research was formed and applied is a typical semi-detached house in Belgrade. By comparing the results of the reference family house, the framework parameters for the satisfaction of a certain energy class have been formed, based on the fulfillment of the energy efficiency requirements established by national regulations.

Keywords: improvement of energy properties, thermal insulation sheath, energy class of building, single family housing

СТУДИЈА СЛУЧАЈА УТИЦАЈА СТРУКТУРЕ И ДЕБЉИНЕ ТЕРМИЧКОГ ОМОТАЧА НА ЕНЕРГЕТСКИ РАЗРЕД ЗГРАДЕ ИНДИВИДУАЛНОГ ПОРОДИЧНОГ СТАНОВАЊА

Сажетак:

Циљ истраживања је добијање оптималних распона термичког омотача за жељене енергетске разреде, што ће допринети економичнијем и рационалнијем приступу пројектовању објеката, као и доказ да са повећањем термичког омотача долази до пораста енергетског разреда. Модел на којем је формирано и примењено истраживање је типична двојна кућа у Београду. Упоређивањем резултата референтне породичне куће формирани су оквирни параметри за задовољавање одређеног енергетског разреда, а на основу испуњености услова о енергетској ефикасности утврђених националном регулативом.

Кључне ријечи: унапређење енергетских својстава, термоизолациони омотач, енергетски разред зград, зграде индивидуалног становања

1. INTRODUCTION

In 2011, the European Commission adopts the Roadmap for Resource Efficient Europe, outlining the actions to be taken [1] to mitigate the effects of climate change. At a global level, construction is, along with traffic, the largest sector in terms of consumption of resources and consequently of environmental impact [2]. In an effort to reduce these impacts, the European Commission [1] calls for action at a global level in terms of progress in saving energy and resources in general, in the production of construction materials and in the use of facilities. Energy consumption is directly related to the production of greenhouse gases (GHG). In Serbia, the construction sector in 2008 participated with 38.50%, and in 2011. 49.16% in final energy consumption [3]. In 2009, Serbia had the highest per capita energy consumption, higher than Croatia and BiH [4]. With the adoption of the Planning and Construction of Buildings Act in 2009 [5], energy efficiency and the rational use of materials are being recognized as a sustainable building model. By the adoption of the legislation on the energy efficiency of buildings in 2011 [6-7] and its mandatory implementation some progress has been made. Per capita energy consumption indicators for Serbia in 2013 show that it is declining but still is the highest in the region [8]. More than 50% of Serbia's environmental footprint comes from CO2 production [9]. A part of Serbia's environmental footprint comes from the use of energy to heat buildings [10]. By introducing the obligation to energy-rank and rehabilitate buildings, an effort has been made to reduce the energy used to heat the buildings. Research on energy consumption in buildings has shown that much of the environmental impact of a buildings (about 80%) is due to the use of the buildings [11 - 12]. Energy efficiency is also discussed by many local authors who analyze buildings in Serbia [13-14].

However, recent research in this area points to the fact that the application rate for the thermo-insulation of buildings increases the amount of materials built into the buildings [15-16], and thus the embodied energy, i.e. the impact on the environment through the built-in materials, according to research of some authors [19-22]. The "embodied carbon" part of the carbon footprint has been left unjustly neglected when analyzing the impact of buildings over the life cycle, which is an observation made in new research into the environmental impact of buildings [21 - 24].

According to the National Typology of Residential Buildings of Serbia, single-family dwellings are represented by 96.3% compared to 3.7% of multi-family dwelling.[25] This relation between family and multi-family housing is the reason why research is being conducted on the project of family housing.

This paper will present the results of the research from the defended Master's Thesis at the College of Civil Engineering and Geodesy in the subject of Energy efficiency and certification of buildings. For the purpose of research and calculation of energy class, a model [26] of a new individual residential building in Belgrade was designed with conventional building materials which are used for the construction of buildings of this type. For the purpose of the research, three models of the same design have been formed, and for each of the models polystyrene sheets or hard mineral wool boards, in different thicknesses, are used as additional thermal insulation of thermal envelope, which will show what energy class can be achieved, and what differences in energy needs to heat the facility can be expected. In this sense, the energy required per m2 of the building was calculated for each of the project models formed and energy classification was performed according to the current legislation in the Republic of Serbia. [6-7]. Therefore, it is possible, even at the stage of conceptual design, to propose the thickness and structure of thermal envelope so that the energy class of the buildings can be planned in the design phase. Also it is possible to propose a thermal envelope assembly with less environmental impact and optimize the selection and use of thermal insulation materials as part of the thermal envelope project.

In addition to the thickness and structure of the thermal envelope, the thermal conductivity characteristics (λ) of the building materials used will be calculated for each model by the heat transfer coefficients (U) of the characteristic assemblies. This research aims at comparing the preliminary design of a new individual single-family housing to the extent on which progress in energy ranking can be achieved by adding a thermal insulation layer in different thicknesses from the outside of the thermal envelope. The second goal set in this research is to compare the two most commonly used thermal insulation materials, Polystyrene and Mineral wool, and their contribution to the energy ranking of the analyzed project of a newly designed individual single-family housing. The research also has the third objective of comparing three common systems of construction of individual residential buildings in Serbia, from the aspect of energy ranking.

Other criteria: the financial or life expectancy of the materials used in this paper will not be considered and evaluated.

This information is important because at the design stage, measures can be proposed to optimize the energy class of the buildings and the materials used in the thermal envelope structure. The goals of the research are to quantify the relation between the thickness and the structure of the thermal envelope with the reduction of the required energy for heating the building according to the current regulations in Serbia, and the calculation of the energy class of the building [6-7]. The analysis of different variants of the model of the house should indicate the relation of thickness and type of thermal insulation with the influence on the energy class, as well as the results obtained to explain and give indicative parameters when forming a knowledge base for the design of architectural projects in the conceptual design phase.

2. DESCRIPTION OF THE RESEARCH

The subject of this research covers measures for improving the energy efficiency and energy class of individual residential buildings in Serbia, as well as improving the thermal envelope in order to reduce energy loss during the operational phase. Efforts are made to calculate the approximate values of the required energy for heating an object by comparing different circuits and thicknesses of the thermal envelope, in accordance with the current regulations in the Republic of Serbia [6-7], for the construction of new facilities. According to the current regulation [6-7], the minimum acceptable energy class for new buildings is C. [6-7].

The aim of this research is to form framework parameters in terms of thickness and type of thermal insulation that is necessary when determining the input data related to the thermal envelope calculation as part of the energy efficiency study.

It is necessary to make accurate calculations for each facility when designing an energy efficiency study, and this research should provide basic guidelines in terms of the thermal insulation thickness to be added within the thermal envelope to achieve the desired energy class.

The research uses the usual materials for the construction of family houses in Serbia to form models. The two most commonly used thermal insulation materials, Polystyrene and Mineral wool, in different thicknesses are used as additional thermal insulation materials to determine how much difference in the achieved energy class can be achieved by increasing the thickness of the thermal insulation layer, or by selecting the type of thermal insulation, or by selecting construction material as the basic structure in the thermal envelope.

The study analyzed the thermal envelope of a new semi-detached family house, in order to compare the most commonly used thermal envelope assemblies that are used both in the design of new buildings and in the energy rehabilitation of existing facilities to improve energy performance. For the purposes of the research, the Ursa Building Physics 2 software package [27] was used, which is one of the software packages in accordance with national regulations in the field of energy efficiency in Serbia [6-7].

The study is conducted under the assumption that the facility is in the city of Belgrade and all data will be used accordingly to the parameters in national legislations [6] for this territory of the Republic of Serbia.

2.1. Model

The building on which the study was conducted is a project of new semi-detached family house in the city of Belgrade in Zvezdara municipality, in Hajduk Stankova street. The semi-detached house is designed as a newly built freestanding building on a plot with surrounding low-growing and high-growing greenery. The facility consists of two symmetrical houses designed for individual housing for two five-member families. The base of the object is shown in Fig. 1 and the floor in Fig. 2. The adjacent plots contain freestanding facilities, which do not obscure the analyzed object in terms of forming a cut or additional reflection that would affect the analyzed object. The ground floor is intended for daily activities of the family and consists of hallway, staircase, guest toilet, living room, dining room, kitchen and terrace. The floor is designed as a bedroom block consisting of a hallway, one single and one double room, parent room, master bathroom, children's bathroom, office and balcony. The attic is an attic space below the roof and does not have a housing function, which means that the thermal envelope borders the attic space.

The structure of the building is skeletal with supporting reinforced concrete columns measuring 25x25 cm, at distances of 4 to 6 m, with a fill formed by façade walls, rusted bricks, solid bricks or Ytong blocks.

For three types of plastered facade walls: hollow bricks d = 25 cm, (densities ρ = 1400 kg / m3), solid bricks d = 25 cm, (densities ρ = 1200 kg / m3) and Ytong block d = 25 cm (density ρ = 350 kg / m3). Three models of the same design were formed in that way, and the thickness of the facade wall varies depending on the thickness of the thermal insulation, which is added to the basic structure of the facade wall in the model. The form factor of all the models analyzed, is the ratio between the surface of the thermal envelope of the building (exterior dimensions) and the gross volume covered by it, is fo = 0,436.

The thermal characteristics of thermal conductivity (λ) of the building materials used for each of the formed models, and according to the current legislation in the Republic of Serbia [6] are shown in Table 1.

Table 1. *Thermal conductivity of materials used in submodes (colored boxes indicate the presence of material in the assembly)*

Facade wall materials used in submodels		Submodels used in case study						λ [W/mK]
		M1S	**M1V**	**M2S**	**M2V**	**M3S**	**M3V**	
1.	Hollow brick	■	■					0,610
2.	Solid brick			■	■			0,470
3.	Ytong block					■	■	0,100
4.	Polystyrene	■		■		■		0,041
5.	Mineral wool		■		■		■	0,036
6.	Cement mortar	■	■	■	■	■	■	1,400
7.	Pigment fasade plaster	■	■	■	■	■	■	0,700
8.	PVC foil	■	■	■	■	■	■	0,190

For the formed models it should be emphasized that in the layer of floor construction according to the external terrain, the same thickness of thermal insulation is planned as in the model intended for the walls. For the floor-to-ceiling structure, for solid and hollow brick models, the calculation is done with the TM ceiling, and the thickness and type of thermal insulation is the same as that provided for in the walls.

For a model built from the Ytong block, it is calculated with the Ytong type ceiling and the thermal insulation applied in the wall structure.

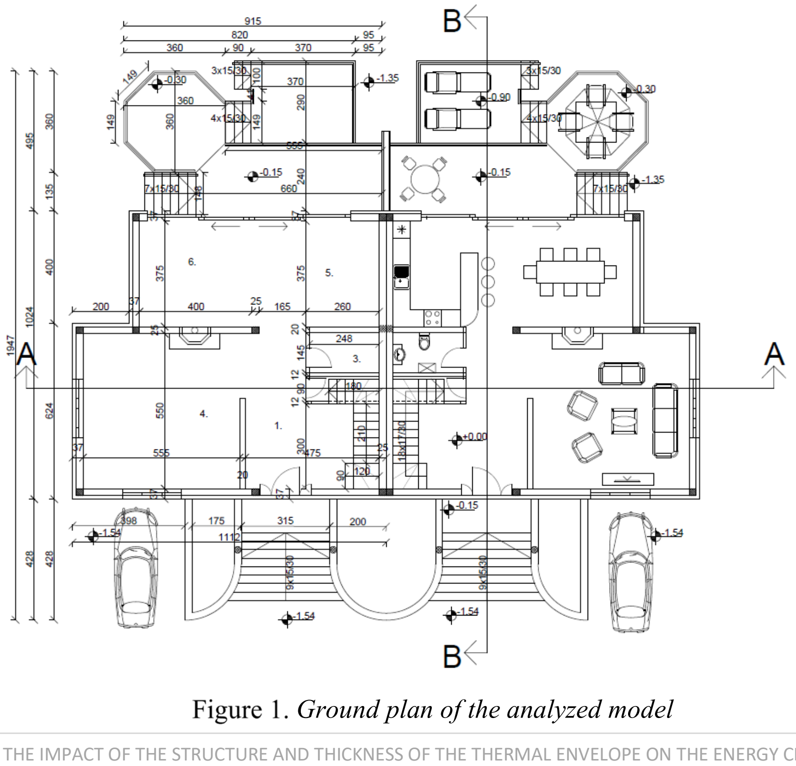


Figure 1. *Ground plan of the analyzed model*

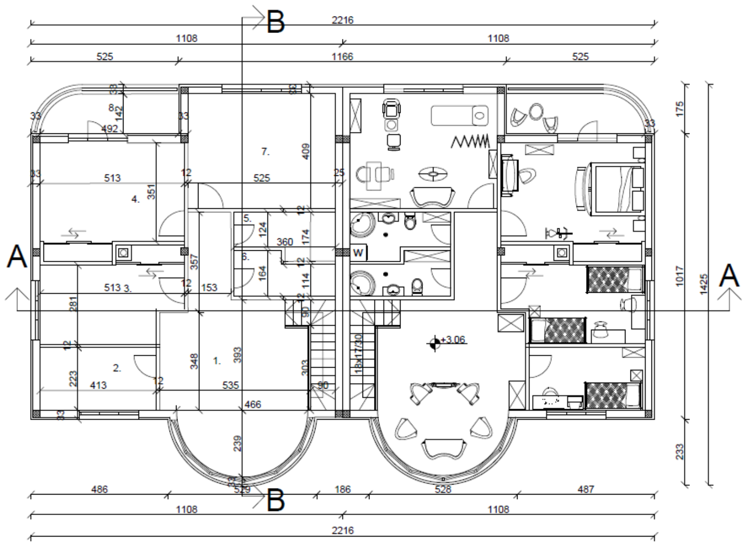


Figure 2. *Floor plan of the analyzed model*

For the purpose of research, three models of facade walls were formed, M1 (hollow brick facade wall d = 25 cm), model M2 (solid brick wall d = 25 cm) and model M3 (Ytong block facade wall d = 25 cm). Each of the analyzed walls is plastered on both sides, which is a common way of finishing the facade walls in Serbia. For each of the three facade wall models analyzed, it is planned to use two types of thermal insulation materials, polystyrene sheets in one variant and hard mineral wool plates in the other variant. Thus, a total of six submodels are obtained: M1S (hollow brick + polystyrene), M1V (hollow brick + mineral wool), M2S (solid brick + polystyrene), M2V (solid brick + mineral wool), M3S (Ytong block + polystyrene) and M3V (Ytong block + mineral wool).

Each model group first calculates the energy class of the building, which does not have a layer of thermal insulation material in the thermal envelope structure, and determines the energy class, that is, the energy consumption for heating the object per m^2 of useful floor space in accordance with the Building Energy Efficiency Regulations [6]. Then, in further research, using different thicknesses of thermal insulation of polystyrene sheets or mineral wool in the thickness of 2, 5, 10, 12, and 15 cm, the energy requirements of the building per m^2 of heated surface are calculated and the energy class is calculated. The thickness of the facade wall directly influences the relationship between the net and the gross surface of the building, so the thickness of the façade walls will be presented in further research. In this way, the thickness of the façade wall, the required thermal insulation and the energy required to heat the object per m^2 can be compared, that is, the energy class of each sub-model analyzed. It should be emphasized that the same thickness of thermal insulation is planned both in the floor towards the ground and in the ceiling towards the unheated space.

3. THE RESULTS OF THE RESEARCH

By investigating three models: M1 (hollow brick facade wall), M2 (solid brick facade wall) and M3 (Ytong block facade wall) with the addition of polystyrene or hard mineral wool thermal insulation, six submodels were formed for which research was carried out: M1S (hollow brick + polystyrene), M1V (hollow brick + hard mineral wool boards), M2S (solid brick + polystyrene), M2V (solid brick + hard mineral wool boards), M3S (Ytong block + polystyrene), M3V (Ytong block + hard mineral wool boards).

By adding thermal insulation materials to the thermal envelope structure (facade walls, ground floors and attic to unheated space), 36 output results for the specific annual energy required for heating were formed and calculated per m^2 of heated space. Based on this calculation and according to the Regulation on Energy Efficiency of Buildings [6] the energy class for each variant is shown in the following tables. In addition to these important data, the tables also show the thickness of the facade walls, that is, the structure of the wall with a clearly shown type and thickness of the thermal insulation layer, which is in the structure of the thermal envelope for the energy classes from the lowest F to the highest B, which could be achieved in the analyzed models by adding thermal insulation in thermal envelope structure.

Table 2. shows the values for the M1S sub-model (hollow brick + polystyrene), the structure of the thermal wall sheath, the thickness of the polystyrene in the model structure, the energy class achieved, and the numerical value of the specific annual energy required for heating per m^2 of heated space.

The M1S submodel, in which the thermal envelope is without thermal insulation layer, has a hollow brick d = 25 cm mutually plastered in the facade wall structure. The sub-model without thermal insulation is in energy class F, with the values of specific annual energy required for heating Qn, an = 205 [kWh / m^2]. The wall heat transfer coefficient for this model has a value of U = 1.603 [W / m^2K]. These values are well above the permissible national legislation [6] for new buildings. By adding 2 cm thick polystyrene thermal insulation over a hollow brick in the facade wall structure, the values of the specific annual energy required for heating Qn, an = 105 [kWh / m^2], corresponding to energy class D are obtained. The wall heat transfer coefficient for this model has a value of U = 0.900 [W / m^2K] which is higher than the prescribed values for new objects [6]. By adding 5 cm thick thermal insulation of polystyrene over a hollow brick in the structure of the facade wall, the values of the specific annual energy required for heating Qn, an = 74 [kWh / m^2] corresponding to the energy class C are obtained, which is required by national legislation [6] for new objects. The wall heat transfer coefficient for this model has a value of U = 0.543 [W / m2K] which is higher than the prescribed values for new buildings [6].

By adding thermal insulation of 10 cm thick polystyrene over a hollow brick in the facade wall structure gives the values of the specific annual energy required for heating Qn, an = 56 [kWh / m^2] corresponding to energy class C [6]. The wall heat transfer coefficient for this model has a value of U = 0.327 [W / m^2K] which is higher than the prescribed values for new objects [6]. With the addition of 12 cm thick polystyrene thermal insulation over a hollow brick in the facade wall structure, the values of the specific annual energy required for heating Qn, an = 52 [kWh / m^2], corresponding to energy class C, are aquired, which is required by national legislation [6]. The wall heat transfer coefficient for this model has a value of U = 0.282 [W / m^2K], which is the satisfactory value for new objects [6]. In this model, both conditions required for energy class C for new facilities are met [6]. With 15 cm thick polystyrene thermal insulation added over a hollow brick in the facade wall structure, the values of the specific annual energy required for heating Qn, an = 48 [kWh / m^2], corresponding to energy class B, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.234 [W / m^2K], which is in accordance with national legislation [6]. In this model, both conditions required for energy class B for new objects are met [6].

Table 2. *Energy classes for thermal envelope structures and thicknesses for the M1S submodel*

M1S submodel						
The composition of the thermal envelope		The total thickness of the facade wall	Thickness of thermal insulation	Energy class	U [W/m^2K]	Q_H,an [kWh/m^2]
1.	Hollow brick without thermal insulation	29,00 cm	0,00 cm	**F**	1,603	205
2.	Hollow brick + 2 cm polystyrene	31,00 cm	2,00 cm	**D**	0,900	105
3.	Hollow brick + 5 cm polystyrene	34,00 cm	5,00 cm	**C**	0,543	74
4.	Hollow brick + 10 cm polystyrene	39,00 cm	10,00 cm	**C**	0,327	56
5.	Hollow brick + 12 cm polystyrene	41,00 cm	12,00 cm	**C**	0,282	52
6.	Hollow brick + 15 cm polystyrene	44,00 cm	15,00 cm	**B**	0,234	48

Table 3. shows the values for submodel M1V (hollow brick + mineral wool), thermal wall sheath structure, thickness of polystyrene in model structure, achieved energy class and numerical value of specific annual energy required for heating per m^2 of heated space.

The M1V submodel, in which the thermal envelope is without thermal insulation layer, has a hollow brick d = 25 cm mutually plastered in the facade wall structure. The sub-model without thermal insulation is in energy class F, with the values of specific annual energy required for heating Qn, an = 205 [kWh / m^2].

Table 3. *Energy classes of thermal envelope structures and thicknesses for M1V submodel*

M1V submodel						
The composition of the thermal envelope		The total thickness of the facade wall	Thickness of thermal insulation	Energy class	U [W/m^2K]	$Q_{H,an}$ [kWh/m^2]
1.	Hollow brick without thermal insulation	29,00 cm	0,00 cm	**F**	1,603	205
2.	Hollow brick + 2 cm mineral wool	31,00 cm	2,00 cm	**D**	0,848	102
3.	Hollow brick + 5 cm mineral wool	34,00 cm	5,00 cm	**C**	0,497	71
4.	Hollow brick + 10 cm mineral wool	39,00 cm	10,00 cm	**C**	0,294	54
5.	Hollow brick + 12 cm mineral wool	41,00 cm	12,00 cm	**B**	0,253	50
6.	Hollow brick + 15 cm mineral wool	44,00 cm	15,00 cm	**B**	0,209	47

The wall heat transfer coefficient for this model has a value of U = 1.603 [W / m^2K]. These values are well above the permissible national legislation [6] for new objects. By adding 2 cm thick thermal insulation of mineral wool over a hollow brick in the structure of the facade wall, the values of the specific annual energy required for heating Qn, an = 102 [kWh / m^2] corresponding to energy class D are obtained. The wall heat transfer coefficient for this model has a value of U = 0.848 [W / m^2K] which is higher than the prescribed values for new objects [6]. By adding 5 cm thick thermal insulation of mineral wool over a hollow brick in the structure of the facade wall, the values of specific annual energy required for heating Qn, an = 71 [kWh / m^2] corresponding to energy class C are obtained, which is required by national legislation [6] for new objects. However, the wall heat transfer coefficient for this model has a value of U = 0.497 [W / m^2K] which is higher than the prescribed values for new buildings [6]. By adding thermal insulation of 10 cm thick mineral wool over a hollow brick in the facade wall structure, the values of specific annual energy required for heating Qn, an = 54 [kWh / m^2], corresponding to energy class C, are obtained for new objects [6]. The wall heat transfer coefficient for this model has a value of U = 0.294 [W / m^2K], which is a satisfactory value for new objects [6]. In this model, both conditions required for energy class C for new objects are met [6]. With 12 cm thick thermal insulation of mineral wool added over a hollow brick in the structure of the facade wall, the values of the specific annual energy required for heating Qn, an = 50 [kWh / m^2], corresponding to energy class B, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.253 [W / m^2K], which is a satisfactory value for new objects [6]. And this model has both the energy class B requirements for new objects fulfilled [6]. With 15 cm thick thermal insulation of mineral wool over a hollow brick in the structure of the facade wall, the values of the specific annual energy required for heating Qn, an = 47 [kWh / m^2], corresponding to energy class B, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.209 [W / m^2K], which is a satisfactory value for new objects [6]. And this model has both the energy class B requirements for new objects fulfilled [6].

Table 4. shows the values for the M2S sub-model (solid brick + polystyrene), the thermal wall sheath structure, the thickness of the polystyrene in the model structure, the energy class achieved, and the

numerical value of the specific annual energy required for heating per m^2 of heated space. The M2S submodel, in which the thermal envelope is without a thermal insulation layer, has a hollow brick d = 25 cm mutually plastered in the structure of the façade wall. Submodel without thermal insulation is in energy class E, with the values of specific annual energy required for heating Qn, an = 154 [kWh / m^2]. The wall heat transfer coefficient for this model has a value of U = 1,341 [W / m^{2}K]. These values are well above the permissible national legislation [6] for new objects. By adding 2 cm thick polystyrene thermal insulation over solid brick in the façade wall structure, the values of the specific annual energy required for heating Qn, an = 101 [kWh / m^2] corresponding to energy class D are obtained. The wall heat transfer coefficient for this model has a value of U = 0.811 [W / m^{2}K] which is higher than the prescribed values for new objects [6].

Table 4. *Energy classes by thermal sheath structures and thicknesses for the M2S submodel*

M2S submodel						
The composition of the thermal envelope		The total thickness of the facade wall	Thickness of thermal insulation	Energy class	U [W/m^{2}K]	Q_H,an [kWh/m^2]
1.	Solid brick without thermal insulation	29,00 cm	0,00 cm	**E**	1,341	154
2.	Solid brick + 2 cm polystyrene	31,00 cm	2,00 cm	**D**	0,811	101
3.	Solid brick + 5 cm polystyrene	34,00 cm	5,00 cm	**C**	0,509	72
4.	Solid brick + 10 cm polystyrene	39,00 cm	10,00 cm	**C**	0,314	55
5.	Solid brick + 12 cm polystyrene	41,00 cm	12,00 cm	**C**	0,272	52
6.	Solid brick + 15 cm polystyrene	44,00 cm	15,00 cm	**B**	0,227	48

By adding 5 cm thick thermal insulation of polystyrene over a hollow brick in the structure of the facade wall, the values of the specific annual required energy for heating Qn, an = 72 [kWh / m^2] corresponding to the energy class C are obtained, which is required by national legislation [6] for new objects. The wall heat transfer coefficient for this model has a value of U = 0.509 [W / m^{2}K] which is higher than the prescribed values for new objects [6]. With 10 cm thick polystyrene thermal insulation over solid brick in the facade wall structure, values of the specific annual energy required for heating Qn, an = 55 [kWh / m^2] corresponding to energy class B, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.314 [W / m^{2}K] which is higher than the prescribed values for new objects [6]. With 12 cm thick polystyrene thermal insulation over solid brick in the facade wall structure, values of the specific annual energy required for heating Qn, an = 52 [kWh / m^2], corresponding to energy class C, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.272 [W / m^{2}K], which is a satisfactory value for new objects [6]. This model has both energy class C requirements for new objects fulfilled [6]. With 15 cm thick polystyrene thermal insulation added over solid brick in the façade wall structure, the values of the specific annual energy required for heating Qn, an = 48 [kWh / m^2], corresponding to energy class B, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.227 [W / m^{2}K], which is a satisfactory value for new objects [6]. This model has both energy class B requirements for new objects fulfilled [6].

Table 5. shows the values for the M2V submodel (solid brick + mineral wool), the thermal wall sheath structure, the mineral wool thickness in the model structure, the energy class achieved, and the numerical value of the specific annual energy required for heating per m^2 of heated space.

The M2V submodel, in which the thermal envelope is without a thermal insulation layer, has a hollow brick d = 25 cm mutually plastered in the structure of the façade wall. Submedel without thermal insulation is in energy class E, with the values of specific annual energy required for heating Qn, an = 154 [kWh / m^2]. These values are well above the permissible national legislation [6] for new objects. The wall heat transfer coefficient for this model has a value of U = 1.34 [W / m^2K] which is higher than the prescribed values for new objects [6]. By adding 2 cm thick thermal insulation of mineral wool over solid brick in the facade wall structure, the values of specific annual energy required for heating Qn, an = 97 [kWh / m^2] corresponding to energy class C are obtained, which is an acceptable energy class for new objects [6]. The wall heat transfer coefficient for this model has a value of U = 0.768 [W / m^2K] which is higher than the prescribed values for new objects [6]. By adding 5 cm thick thermal insulation of mineral wool over the hollow brick in the structure of the facade wall, the values of specific annual energy required for heating Qn, an = 69 [kWh / m^2] corresponding to the energy class C are obtained. The wall heat transfer coefficient for this model has a value of U = 0.468 [W / m2K] which is higher than the prescribed values for new objects [6]. By adding thermal insulation of 10 cm thick mineral wool over a hollow brick in the facade wall structure, the values of the specific annual energy required for heating Qn, an = 53 [kWh / m^2], corresponding to the energy class C, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.284 [W / m^2K], which is a satisfactory value for new objects [6]. This model has both energy class C requirements for new objects fulfilled [6].

Table 5. *Energy classes by thermal envelope structures and thicknesses for the M2V submodel*

M2V submodel						
The composition of the thermal envelope		The total thickness of the facade wall	Thickness of thermal insulation	Energy class	U [W/m^2K]	Q_H,an [kWh/m^2]
1.	Solid brick without thermal insulation	29,00 cm	0,00 cm	**E**	1,341	154
2.	Solid brick + 2 cm mineral wool	31,00 cm	2,00 cm	**C**	0,768	97
3.	Solid brick + 5 cm mineral wool	34,00 cm	5,00 cm	**C**	0,468	69
4.	Solid brick + 10 cm mineral wool	39,00 cm	10,00 cm	**C**	0,284	53
5.	Solid brick + 12 cm mineral wool	41,00 cm	12,00 cm	**C**	0,246	50
6.	Solid brick + 15 cm mineral wool	44,00 cm	15,00 cm	**B**	0,204	46

Adding thermal insulation of 12 cm thick mineral wool over a hollow brick in the façade wall structure gives the values of the specific annual energy required for heating Qn, an = 50 [kWh / m^2], corresponding to the energy class C. The wall heat transfer coefficient for this model has a value of U = 0.246 [W / m^2K], which is a satisfactory value for new objects [6]. And this model has both requirements for energy class C for new objects fulfilled [6]. With 15 cm thick thermal insulation of mineral wool added over solid brick in the facade wall structure, the values of the specific annual energy required for heating Qn, an = 46 [kWh / m^2], corresponding to energy class B, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.204 [W / m^2K], which is a satisfactory value for new objects [6]. This model has both energy class B requirements for new objects fulfilled [6].

Table 6. shows the values for the M3S sub-model (Ytong + polystyrene), the structure of the thermal wall sheath, the thickness of the polystyrene in the model structure, the energy class achieved, and the numerical value of the specific annual energy required for heating per m^2 of heated space.

The M3S submodel, in which the thermal envelope is devoid of a thermal insulation layer, has Ytong d = 25 cm mutually plastered in the facade wall structure. The sub-model without thermal insulation is in energy class C, with the values of specific annual energy required for heating Qn, an = 78 [kWh / m^2]. These values are permitted according to new legislation [6] for new objects. But the wall heat transfer coefficient for this model has a value of U = 0.368 [W / m^2K] which is higher than the prescribed values for new objects [6]. By adding 2 cm thick polystyrene thermal insulation over

Yitong in the façade wall structure, the values of the specific annual energy required for heating Qn, an = 65 [kWh / m^2] corresponding to the energy class C are obtained. The wall heat transfer coefficient for this model has a value of U = 0.312 [W / m^{2}K] which is higher than the prescribed values for new objects [6]. By adding thermal insulation of 5 cm thick polystyrene over Yitong in the facade wall structure, the values of the specific annual energy required for heating Qn, an = 55 [kWh / m^2], which are in the energy class C are obtained. The wall heat transfer coefficient for this model has a value of U = 0.254 [W / m2K], which is a satisfactory value for new objects [6]. This model has both energy class C requirements for new objects fulfilled [6]. With 10 cm thick polystyrene thermal insulation added over Yitong in the facade wall structure, the values of the specific annual energy required for heating Qn, an = 46 [kWh / m^2], corresponding to energy class B, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.194 [W / m^{2}K], which is a satisfactory value for new objects [6]. This model has both energy class B requirements for new objects fulfilled [6]. With 12 cm thick polystyrene thermal insulation across the Yitong in the facade wall structure, values of the specific annual energy required for heating Qn, an = 46 [kWh / m^2], corresponding to energy class B, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.177 [W / m^{2}K], which is a satisfactory value for new objects [6]. This model has both energy class B requirements for new objects fulfilled [6]. With 15 cm of polystyrene added over Yitong in the facade wall structure, the values of the specific annual energy required for heating Qn, an = 44 [kWh / m^2], corresponding to energy class B, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.157 [W / m^{2}K], which is a satisfactory value for new objects [6]. And this model has both the energy class B requirements for new objects fulfilled [6].

Table 6. *Energy classes by thermal structures and thicknesses for the M3S submodel*

M3S submodel						
The composition of the thermal envelope		The total thickness of the facade wall	Thickness of thermal insulation	Energy class	U [W/m^{2}K]	Q_H,an [kWh/m^2]
1.	Ytong block without thermal insulation	29,00 cm	0,00 cm	**C**	0,368	78
2.	Ytong block + 2 cm polystyrene	31,00 cm	2,00 cm	**C**	0,312	65
3.	Ytong block + 5 cm polystyrene	34,00 cm	5,00 cm	**C**	0,254	55
4.	Ytong block + 10 cm polystyrene	39,00 cm	10,00 cm	**B**	0,194	48
5.	Ytong block + 12 cm polystyrene	41,00 cm	12,00 cm	**B**	0,177	46
6.	Ytong block + 15 cm polystyrene	44,00 cm	15,00 cm	**B**	0,157	44

Table 7. shows the values for the M3V submodel (Ytong + mineral wool), the structure of the thermal wall sheath, the thickness of the polystyrene in the model structure, the achieved energy class, and the numerical value of the specific annual energy required for heating per m^2 of heated space.

The M3V submodel, in which the thermal envelope is without a thermal insulation layer, has Ytong d = 25 cm mutually plastered in the facade wall structure. The sub-model without thermal insulation is in energy class C, with the values of specific annual energy required for heating Qn, an = 78 [kWh / m^2]. These values are permitted according to new legislation [6] for new buildings. But the wall heat transfer coefficient for this model has a value of U = 0.368 [W / m^{2}K] which is higher than the prescribed values for new objects [6].

Table 7. *Energy classes by thermal envelope structures and thicknesses for the M3V submodel*

M3V submodel						
The composition of the thermal envelope		The total thickness of the facade wall	Thickness of thermal insulation	Energy class	U [W/m²K]	$Q_{H,an}$ [kWh/m²]
1.	Ytong block without thermal insulation	29,00 cm	0,00 cm	**C**	0,368	78
2.	Ytong block + 2 cm mineral wool	31,00 cm	2,00 cm	**C**	0,306	64
3.	Ytong block + 5 cm mineral wool	34,00 cm	5,00 cm	**C**	0,244	54
4.	Ytong block + 10 cm mineral wool	39,00 cm	10,00 cm	**B**	0,182	47
5.	Ytong block + 12 cm mineral wool	41,00 cm	12,00 cm	**B**	0,165	45
6.	Ytong block + 15 cm mineral wool	44,00 cm	15,00 cm	**B**	0,145	43

By adding thermal insulation of 2 cm thick polystyrene over Yitong in the façade wall structure, the values of the specific annual energy required for heating Qn, an = 64 [kWh / m^2] corresponding to the energy class C are obtained. But the wall heat transfer coefficient for this model has a value of U = 0.306 [W / m^2K] which is higher than the prescribed values for new objects [6]. By adding thermal insulation of 5 cm thick polystyrene over Yitong in the facade wall structure, the values of the specific annual energy required for heating Qn, an = 54 [kWh / m^2], which are in the energy class C are obtained. The wall heat transfer coefficient for this model has a value of U = 0.244 [W / m^2K], which is a satisfactory value for new objects [6]. This model has both energy class C requirements for new objects fulfilled [6]. With 10 cm thick polystyrene thermal insulation added over Yitong in the façade wall structure, the values of the specific annual energy required for heating Qn, an = 45 [kWh / m^2], corresponding to energy class B, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.182 [W / m^2K], which is a satisfactory value for new objects [6]. This model has both energy class B requirements for new objects fulfilled [6]. With polystyrene thermal insulation 12 cm thick over Yitong in the facade wall structure, values of the specific annual energy required for heating Qn, an = 45 [kWh / m^2], corresponding to energy class B, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.165 [W / m^2K], which is a satisfactory value for new objects [6]. And this model has both the energy class B requirements for new objects fulfilled [6]. With 15 cm of polystyrene added over Yitong in the façade wall structure, the values of the specific annual energy required for heating Qn, an = 43 [kWh / m^2], corresponding to energy class B, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.145 [W / m^2K], which is a satisfactory value for new objects [6]. And this model has both the energy class B requirements for new objects fulfilled [6].

From the Tables showing the thermal envelope thicknesses for energy classes F to B, we can see the movement of the thermal envelope thickness ratio depending on the thickness of the thermal insulation layer within the façade wall and the type of thermal insulation material. A detailed overview of the results and values of the studies is given in Table 8.

Table 8. *Optimal ranges of thermal envelope for energy classes F to B for the observed model of individual housing in Belgrade*

Sub-models / Energy class	M1S	M1V	M2S	M2V	M3S	M3V
F	without thermal insulation	without thermal insulation	/	/	/	/
E	up to 2 cm	up to 2 cm	without thermal insulation	without thermal insulation	/	/
D	from 2 cm to 5 cm	from 2 cm to 5 cm	from 2 cm to 5 cm	up to 2 cm	/	/
C	from 5 cm to 12 cm	from 5 cm to 10 cm	from 5 cm to 12 cm	from 5 cm to 12 cm	up to 10 cm	up to 10 cm
B	more than 12 cm	more than 10 cm	15 cm and above	15 cm and above	more than 10 cm	more than 10 cm

A graphical representation of the results obtained for the analyzed models using polystyrene as the insulating material for the facade walls is shown in Diagram 1. for submodels: M1S (hollow brick + polystyrene), M2S (solid brick + polystyrene) and M3S (Ytong block + polystyrene).

From Diagram 1. it can be seen that the difference that exists in submodels in which there is no thermal insulation layer, diagrams of submodels M1S, M2S and M3S initially has significant deviations. Sub-model M1S has the values of specific annual energy required for heating in energy class F. Sub-model M2S has the values of specific annual energy required for heating in energy class E. The M3S submodel has the values of specific annual energy required for heating in energy class C. With the application of only 2 cm thick polystyrene, the M1S (hollow brick + polystyrene) and M2S (solid brick + polystyrene) submodels almost coincide and have the values of specific annual energy required for heating in energy class D and approaching significantly energy class C. With 5 cm of polystyrene thermal insulation, the M1S and M2S submodels reach the values which are sufficient for the energy class C in the middle zone. Further increases in the thickness of polystyrene at 10 and 12 cm in the thermal envelope of the submodels M1S and M2S, obtain the values of the specific annual energy required for heating which are still in the energy class C, slightly approaching the energy class B.

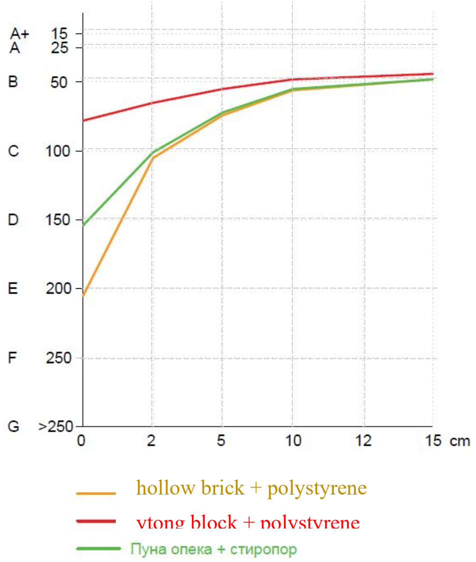


Figure 3. *Comparative analysis of the increase of the energy class and the thickness of the thermal insulation layer (polystyren) for the models M1S, M2S and M3S*

Only with a thickness of 15 cm of polystyrene in the thermal envelope of the submodels M1S and M2S, the values required for the energy class B in the lower zone are obtained, which carries a certain risk that it can easily slip into the lower energy class.

Diagram showing the increase of energy class for M3S sub-model (Ytong block + polystyrene) from the very beginning, even without polystyrene thermal insulation, has values that are sufficient for energy class C. With the addition of 2 and 5 cm polystyrene in the thermal envelope of the M3S submodel, the values are still in the energy class C, still slightly approaching the energy class B. Only with 10 cm, energy class B is achieved, and with polystyrene thickness of 12 and 15 cm, but all in the energy class B zone. For M1S, M2S and M3S submodels, from Diagram 1 it can be seen that with 10 cm of polystyrene in the thermal envelope all three models have a very small difference in the value of the specific annual energy required for heating. This means that by increasing the thickness of the polystyrene layer, it is possible to achieve small savings in energy consumption if the polystyrene of 12 and 15 cm is planned as an additional layer in the thermal envelope of the M1S, M2S and M3S submodels. From this it can be concluded that it is also necessary to analyze the financial effects that appear with higher costs for obtaining thermal insulation of larger thicknesses.

A graphical representation of the results achieved for the analyzed models using hard pressed mineral wool as insulation material for the facade walls is shown in Diagram 2 for sub-models M1V (hollow brick + hard pressed mineral wool), M2V (solid brick + hard pressed mineral wool) and M3V (Ytong block + hard pressed mineral wool).

From Diagram 2. it can be seen that the difference that exists in submodels in which there is no thermal insulation diagrams of submodels M1V, M2V and M3V initially also has significant deviations. The M1V submodel has the values of specific annual energy required for heating in energy class F. The M2V submodel has the values of specific annual energy required for heating in energy class E. The M3V submodel has the values of specific annual energy required for heating in energy class C. The M1V submodel of the initial energy class F manages to achieve the energy class D values, approaching the energy class C significantly, with the application of a thermal insulation layer of 2 cm hard-pressed mineral wool in the thermal envelope structure. The M2V submodel with the application of a 2 cm thick thermal insulation layer of hard pressed mineral wool in the thermal envelope structure changes from the initial energy class E to the values sufficient for the energy class C. With the application of 5 cm thick thermal insulation of hard pressed mineral wool, the M1V and M2V submodels almost coincide to reach the energy class C values in the middle zone, which is very significant. By further increasing the thickness of hard pressed mineral wool to 10 cm in the thermal envelope of submodels M1V and M2V, the specific annual energy requirements for heating are still in energy class C, approaching both each other and the values of the M3V diagram and the values to be achieved for energy class B. Only with a thickness of 12 cm of hard-pressed mineral wool in the thermal envelope of submodel M1V, it is possible to achieve the values required for energy class B. With the same thickness of hard pressed 12 cm thick stone wool, the M2V submodel has the values of specific annual energy required for energy class C, in the upper zone, approaching energy class B. With a thickness of 15 cm of hard pressed mineral wool in the thermal envelope of submodel M1V, and M2V, they have the values required for energy class B, and approach the values of submodel M3V.

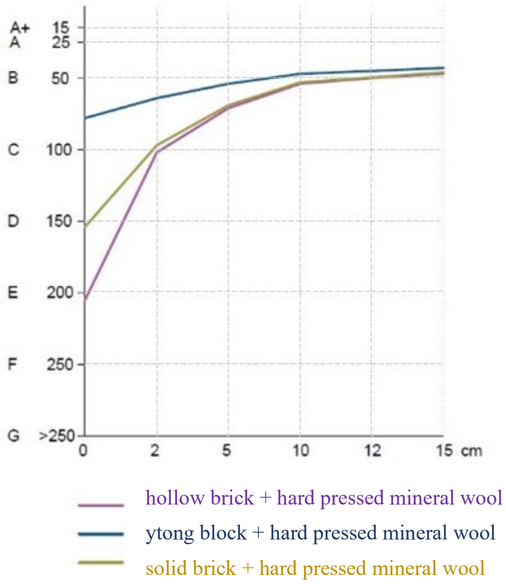


Figure 4. *Comparative analysis of the increase of the energy class and the thickness of the thermal insulation layer (mineral wool) for the models M1V, M2V and M3V*

A diagram showing the increase of the energy class for the M3V (Ytong block) submodel from the very beginning, even without thermal insulation, has the values sufficient for the energy class C. With the addition of 2 and 5 cm hard pressed mineral wool in the thermal envelope of the M3V submodel, the values are in the energy class C. It is only with 10 cm thickness that energy class B is achieved, and with a thickness of hard pressed mineral wool of 12 and 15 cm, they are still found in the energy class B zone.

For the M1V, M2V and M3V submodels, it can be seen from Diagram 2. that with only 10 cm of hard-pressed rock wool in the thermal envelope, all three models have a very small difference in the value of the specific annual energy required for heating. This means that with the increase in the thickness of the layer of hard-pressed mineral wool, it is possible to achieve small savings in energy consumption if 12 and 15 cm are planned as an additional layer in the thermal envelope of submodels M1V, M2V and M3V. In this case, the financial aspect needs to be further analyzed, which was not foreseen in this research.

From Diagrams 1 and 2, we can see that with the increase of the thickness of the layer of thermal insulation material in the structure of the thermal envelope there is an increase of the energy class.What can be further noted in the diagrams is that with increasing the thickness of the thermal envelope, the effect of the thermal envelope on the energy class is also dramatically reduced, but at the same time the thickness of the thermal insulation layer is significantly increased.

From Diagrams 1 and 2, we can see that the starting points of the curves (when there is no thermal insulation layer in the thermal envelope) show significant differences in the energy class. With the addition of 2-5 cm thick thermal insulation, the curves show a tendency to fade. With thermal insulation thickness of 10-12-15 cm, all the curves tend to meet in one line,therefore, the approximate value of the specific annual energy required for heating, on the same energy class B.

We can observe that the curves represented by the M3S and M3V submodels (Ytong block + thermal insulation) have better starting energy classes and a milder curve in both diagrams, indicating better initial ytong block characteristics compared to the M1S and M1V submodels (hollow brick + thermal insulation) and M2S and M2V submodels (full brick + thermal insulation). However, this initial lack of a thermal envelope in which hollow or solid bricks are used with the addition of 5-10 cm of thermal insulation reaches the values of the specific annual required energy for heating and energy class, as a model in which the Ytong block was used in thermal envelope.

The energy class diagrams for polystyrene (Diagram 1) and hard pressed mineral wool (Diagram 2) , as can be seen, do not show significant deviations from the wall elements, and therefore some parameters need to be introduced for the selection of materials, which may be further investigated.

4. CONCLUSION OF THE RESEARCH

For the purpose of the conducted research, models M1, M2, and M3 were formed, which represent common ways of constructing family housing in Serbia. Each of the analyzed models, in the further course of the research applied in the structure of thermal envelope two commonly used thermal insulation materials in the construction industry of Serbia, polystyrene and pressed mineral wool, thus forming the submodels M1S, M1V, M2S, M2V, M3S and M3V. Added layer of thermal insulation material to the basic structure of the thermal envelope of the building is polystyrene or pressed mineral wool in thicknesses of: 2, 5, 10, 12, 15 cm. Thus, as a result of computer simulations done in URSA software Building Physics 2, 36 output results and energy class results, were obtained for the same project, but with a different thermal envelope assembly. The results of the research have led to certain conclusions that are directly related to the set goals of the research.

The research conducted through this paper aimed to obtain approximate thermal envelope thicknesses for energy classes from the lowest F to the highest B. The research should provide support and assistance in selecting the thickness and structure of the thermal envelope when designing new objects of this type during the conceptual design phase to achieve a certain energy class, and for new buildings, this is energy class C in accordance with applicable regulation [6]. The exact thickness and structure of the thermal envelope are determined at the stage of preparation of the project for construction of the object, when in order to obtain a building permit it is necessary to make an Energy Efficiency Study in accordance with the applicable regulations of the Republic of Serbia [6]. In order to achieve the energy class C, the M1S submodel should have 5-10-12 cm in the thermal envelope. The M1V submodel with 5-10 cm of thermal insulation have energy class C values. With higher thermal insulation thicknesses, the M1S submodel with 15 cm and M1V with 12-15 cm reach the energy class B.

In order to achieve the energy class C, the M2S submodel should have 5-10-12 cm in the thermal envelope. The M2V submodel with 5-10-12 cm of thermal insulation have energy class C values. With higher thermal insulation thicknesses, the M2S submodel with 15 cm and the M2V with 15 cm reach energy class B. In order to achieve the energy class C, the M3S submodel without thermal insulation or with 5-10 cm in thermal envelope is in the energy class C zone. The M3V submodel without thermal insulation or with 5-10 cm thermal insulation is in the energy class C values. With higher thermal insulation thicknesses, the M3S submodel with 10-12-15 cm and M3V with 10-12-15 cm reach energy class B.

The results of the research can be useful information for designers and civil engineers when designing new buildings or redeveloping existing ones. Based on the research, it can be concluded that the structure and thickness of the thermal envelope influence the increase of the energy class, which could be expected as a result of the research.

However, it is observed that with the increase of the thickness of the thermal insulation layer in the structure of the thermal envelope, from 10 cm to 12-15 cm, there are no significant shifts in the energy class, that is, there is no major contribution in terms of savings in the consumption of specific annual required energy for heating calculated in m2. A significant increase in the thickness of the thermal envelope with the addition of thermal insulation materials of 12-15 cm does not result in significant savings in energy consumption for heating.

However, since the permitted value of the Umax wall heat transfer coefficient [W / m^2K] is by the Regulations on Building Energy Efficiency [6], some models do not satisfy both conditions, in addition to the fulfilled condition for energy class C.

One of the results of the research, which is not expected, is that in the results obtained by the application of polystyrene or hard-pressed mineral wool there are no large deviations in the consumption of specific annual energy required for heating, or the achieved energy class. The difference in the price of these two insulation materials is an important factor for investors to decide which material to apply, so new research with such an objective would be very useful. In some future research, several different individual housing projects could be compared. This was not foreseen by this research, but it would certainly be useful to do some further research. In some future research, the results obtained can also be compared in terms of finances and life expectancy, which would be of multiple use. In this large-scale research this was not foreseen.

These research findings suggest that rational and reasonable consideration should be given to selecting the type and thickness of thermal insulation material when designing buildings in an effort to achieve the desired energy class.

The research raises new questions and topics for some future professional work in this field, such as: cost comparison in the construction and exploitation phase for these analyzed models, comparison of the life of the assemblies used, comparison of the results obtained using other software packages with the results obtained in this research , as well as many other topics raised by the profession, when it comes to energy efficiency, but also the impact of buildings on the built and natural environment.

LITERATURE

[1] European Commission, „Analysis associated with the Roadmap to a Resource-Efficient Europe Part II“, Commission Staff Working Paper. Brussels; 20.9.2011. SEC (2011) 1067 final.

[2] European Construction Tehnology Platform, „MATERIALS“, Vision 2030 & Strategic Resarsh Agenda, Focus Area Materials. Version 1, http://www.ectp.org.20.1.2013. Brussels; 2005.

[3] Drugi akcioni plana za energetsku efikasnost Republike Srbije za period od 2013-2015, „Sl. glasnik RS“, br. 98/2013 Available at: https://mre.gov.rs/doc/efikasnost-izvori/efikasnost/B_01_Drugi_akcioni_plan_za_energetsku_efikasnost_za_Republiku_Srbiju_za_period_od_2013_do_2015_godine.pdf [accessed: 25. 4. 2020.]

[4] IEA. International Energy Agency, „Final Report 2009“, Commission of the European Communities, 2009.

[5] Zakon o planiranju i izgradnji objekata „Sl. glasnik RS“ br. 72/2009, Available at:<http://www.mgsi.gov.rs>

[6] Pravilnik o energetskoj efikasnosti zgrada „Sl. glasnik RS“ br. 61/2011, [On-line] Available at:<http://www.mgsi.gov.rs>

[7] Pravilnik o uslovima, sadržini i načinu izdavanja sertifikata o energetskim svojstvima zgrada, Službeni glasnik RS, No. 69/2012.[On-line]Available:<http://www.mgsi.gov.rs> [accessed: 25. 10. 2016].

[8] IEA, International Energy Agency, Final Report 2013, Commission of the European Communities, 2013.

[9] Energy balance of the Republic of Serbia, [On-line]Available: <www.mre.gov.rs/.../EN%20BILANS%20ZA%2014>[accessed: 20. 12. 2017].

[10] Global Footprint Network today at an event at Oxford University. Availableat:<https://www.footprintnetwork.org/2018/04/09/has_humanitys_ecological_footprint_reached_its_peak/> [accessed: 14. 3. 2018.]

[11] Asdrubali, F., D'Alessandro, F., Baldinelli, G., Bianchi, F.“Case Study- Evaluating in situ thermal transmittance of green buildings masonries A – case study“, Univerzitet Perugia, Italija/Case Studies in Construction Materials1. (pp. 53-59). 2014.

[12] Adalberth, K.; „Energy use during the Life Cycle of Buildings: A Method“, Building and Environment. 32. pp. 317-320, 1997.

[13] Šumarac, D. M., et al, „Energy Efficiency of Residencial Buildings in Serbia“, Thermal Science, 14 (2010), Suppl, pp.S97-S113.

[14] Krstić-Furundzic, A., Kosic, T., „Assessment of Enegy and Environmental Performance of Building Models“,A Case Study, Energy and Buildings, 115 (2016), Mar., pp 11-22.

[15] Ibn-Mohammed, T., Greenough, R., Taylor, S., Ozawa-Meida, L. & Acquaye, A., „Operational vs. Embodied emissions in Buildings – A Review of Current Trends“, Energy and Buildings, (2013). No.66, pp.232-245.[On-line]Available:< https://doi.org/10.1016/j.enbuild.2013.07.026(10.08.2018)>[accessed: 6. 6. 2018].

[16] Ramersh, T., Prakash, R., Shukla. K.K., „Life cycle energy analysis of buildings: An overview“, Energy and Buildings, (2010) No. 42. pp. 1592-1600.[On-line]Available:< https://doi.org/10.1016/j.enbuild.2010.05.07>[accessed: 10. 8. 2018].

[17] Slavković, K., Radivojević. A., „Evaluation of energy embodied in the external wall of the single-family buildings in the process of energy optimization“, Energy Efficiency. (2014) Published online: 03

[18] Nikolić Topalović, M., Stanković, M. „A Case study of the increase of Carbon dioxide due to the Application of energy efficiency regulations in Serbia“, Contemporary materials, UDK 616.314-089.87(497.11), IX-2, 2018. pp. 159-164, doi 10.7251/COMEN1802159N.

[19] Nikolić Topalović, M., Momčilović, A., Stefanović, G., Case Study: „The Effects the Improvements in Energy Rating Band C to Band B has on the Flow of Necessary Materials and Embodied“, ANNALS, ISSN 1584-2665(printed version); ISSN-L 1584-2665(online); ISSN 2601- ANNALS OF FACULTY ENGINEERING HUNEDOARA – INTERNATIONAL JOURNAL OF ENGINEERING Faculty of Engineering, Hunedoara, www.fih.upt.ro 2. Avgust 2018.

[20] Nikolić Topalović M., Stanković M. „A Case study of the increase of Carbon dioxide due to the Application of energy efficiency regulations in Serbia“, Banja Luka, 2018. Contemporary Materials, IX-2 (2018) nn 159-167, UDK 616.314-089.87(497.11) DOI 10.7251-COMEN1802159N, ANURS of the Republic of Srpska, Banja Luka, [www.savremeni materijali.info].

[21] Nikolić Topalović M., Ćirović G., „Embodirani ugljenik kao kriterijum za vrednovanje projekta individualnog stambenog objekta sa aspekta uticaja na životnu sredinu“, ″Embodied Carbon as a Criteria for Evaluation of a Family Dwelling Project from the Aspect of the Environmental Impact“, XLVI Symposiuom of Operational Research, Međunarodna konferencija. SIMOPIS 2019, 15-18 Septembra, Kladovo, Srbija, Međunarodna konferencija

[22] Zhang, X., Shen, L., Zhang, L., „Life cycle assessment of the air emissions during building construction process - A case study in Hong Kong. Renew. Sustain. Energy“ Rev. 17, pp. 160-169. 2013.

[23] Battle, G., Chair, J. (2014) „Embodied Carbon Industry Task Force Recommendations – Proposals for Standardised Measurement Method and Recommendations for Zero Carbon Building Regulations and Allowable Solutions“. https://asbp.org.uk/wp-content/uploads/2016/01/Embodied-Carbon-Industry-Task-Force-Proposals_June-2014_Final.pdf.

[24] Sturgis, S. (2017), „Targeting Zero, Embodied and Whole Life Carbon Explained“, RIBA Publishing.http://sturgiscarbonprofiling.com/news/targeting-zero-embodied-and-whole-life-carbon-explained/>.

[25] Jovanović Popović, M., Ignjatović, D., Radivijević, A., Rajčić, A., Đukanović, LJ., Žuković Ignjatović, N., Nedić, M. (2013), „Nacionalna tipologija stambenih zgrada Srbije“,Arhitektonski fakultet Univerziteta u Beogradu, GIZ - Deutsche Gesellschaft für internationale Zusamemenarbeit, Beograd.

[26] Al-Esaifer E. „Project of individual residential house in Belgrade“,University College of Civil Engineering and Geodesy Belgrade, Belgrade, 2017

[27] URSA construction physics 2, Available: <https://www.ursa.rs/softver> [On-line] [accessed: 10. 3. 2019].

15 | Research paper I Оригинални научни рад
ISSN 2566-4484 I Doi 10.7251/STP2014159D
pages 159-174

Milena Dinić Branković, milena.dinic@gaf.ni.ac.rs, Faculty of Civil Engineering and Architecture, Univerisity of Niš

Milica Igić, milica.igic@gaf.ni.ac.rs, Faculty of Civil Engineering and Architecture, Univerisity of Niš

Petar Mitković, petar.mitkovic@gaf.ni.ac.rs, Faculty of Civil Engineering and Architecture, Univerisity of Niš

Jelena Đekić, jelena.djuric@gaf.ni.ac.rs, Faculty of Civil Engineering and Architecture, Univerisity of Niš

Ivana Bogdanović Protić, ivana.bogdanovic@gaf.ni.ac.rs, Faculty of Civil Engineering and Architecture, Univerisity of Niš

EXPLORING THE POTENTIALS OF SMALL URBAN STREAMS IN CREATING BLUE-GREEN INFRASTRUCTURE IN THE CITY OF NIŠ, SERBIA

Abstract:

"Blue-Green Infrastructure" (BGI) is a simple and cost-effective natural resource that enhances the appeal, resilience and sustainability of urban areas. Small urban streams are an important BGI component that is often underused, especially regarding stormwater management. The aim of this research is to explore small urban streams and their integration into BGI in the urban area of Niš, and to point out the benefits that their restoration would bring in functional, social and environmental terms. Results of this study show that Niš urban area has significant "Blue" natural capital in small streams, and that standing planning documents support the creation of BGI to some extent. These are good grounds for the implementation of BGI in urban planning practice.

Keywords: stormwater management, stream restoration, urban area resilience, planning measures

ИСПИТИВАЊЕ ПОТЕНЦИЈАЛА МАЛИХ УРБАНИХ ВОДОТОКОВА У КРЕИРАЊУ ПЛАВО-ЗЕЛЕНЕ ИНФРАСТРУКТУРЕ У ГРАДУ НИШУ, СРБИЈА

Сажетак:

„Плаво-зелена инфраструктура" (ПЗИ) је једноставан и ефикасан природни ресурс који повећава привлачност, отпорност и одрживост урбаних подручја. Мали градски водотокови су важна ПЗИ компонента која је често недовољно искоришћена, посебно у погледу управљања атмосферским отицајем. Циљ овог рада је да истражи мале урбане водотокове и њихову интеграцију у ПЗИ у урбаном подручју Ниша, и да укаже на користи које би њихова обнова донела у функционалном, социјалном и околишном смислу. Резултати ове студије показују да урбано подручје Ниша има значајан „Плави" природни капитал у малим потоцима и да важећи плански документи у одређеној мери подржавају стварање ПЗИ-ја. Ово су добри темељи за имплементацију ПЗИ у урбанистичку праксу.

Кључне ријечи: управање атмосферским отицајем, обнова потока, отпорност, планске мере

1. INTRODUCTION

Increasing urbanization and especially urban densification have resulted in the increase of paved surfaces in urban areas, which are usually impervious [1]. Impervious land cover alters both the quantity and quality of surface runoff water. In terms of the hydrologic cycle, less water is infiltrated and more runs off at the surface. Also, most of the water runoff nowadays contains pollutants caused by human activities (hard metals from roads, roofs and paved surfaces, lawn chemicals from fertilization). This runoff is conventionally conveyed into pipe-based drainage systems (so-called "grey infrastructure"[1]) and then transported further, directly into waterways, instead of being filtered through soil. Therefore, it can be stated that impervious surface affects the physical structure of streams and rivers, as well as biodiversity and abundance of wildlife. In urbanized areas, large volumes of excess stormwater runoff in a short amount of time can cause flash flooding, water pollution and destroyed habitat. All of these points significantly contribute to the importance of adequate stormwater management.

It is becoming more and more evident that the traditional "gray" approach to infrastructure, which discharges stormwater into pipes, is unable to respond to the challenges of intense urbanization and stresses associated with climate change. New strategies and approaches have been developed in the last couple of decades to mitigate the impact of stormwater runoff and pollutant loading. The role of "Blue-Green Infrastructure" (BGI) in stormwater management in highly urbanized areas is becoming increasingly important as an alternative to conventional pipe-based stormwater management in cities [2]. BGI offers a feasible and valuable solution for urban areas facing the challenges of climate change, by complementing or even replacing the need for grey infrastructure [3].

Blue-Green Infrastructure grid is created by interconnecting various natural open spaces in urban areas, with green or blue linear pathways for walking, cycling, kayaking, rowing and other recreation. Blue-green infrastructure connects: (1) the *blue component*, which refers to urban hydrological functions, such as watercourses (rivers, streams) and still waters (lakes, ponds), and (2) the *green component*, which entails vegetated areas in urban environment, such as urban forests and meadows, parks and protective greenery. As many urban areas already possess some natural capital (blue and green), implementing the BGI grid is not a technologically demanding or expensive task. Various authors [4][5][6][7] state that BGI has multiple benefits:

- Mitigation of the "heat island" effect[2],
- Improved stormwater management and reduced flooding and erosion in urban areas,
- Improved adaptation of urban areas to climate change,
- Establishment of new recreational areas and sport fields,
- Preservation of biodiversity and restoration of the ecosystem,
- Improved water quality,
- Improved health of urban residents,
- Creation of high quality urban areas with added aesthetic value,
- Socio-economic benefits.

Small urban streams are a very important BGI element. Often, small urban streams seem to be neglected, devastated and forgotten, and their potential stays hidden. It is only with a flood event that they return to the focus of people's attention [8]. Restoration of small urban streams and creeks and re-profiling existing urban water edges can help build capacity for stormwater through retention and detention [6]. Many cities around the world are exploring the possibilities to use small urban streams as a BGI element to reduce the city's risk of flooding from intense rainfall and strengthen the ecosystem, and thus improve the resilience of urban areas. Cities such as Graz (The Streams of Graz program, 2006) and Oslo (Oslo Reopening Waterways Project, 2002) are already implementing programs for restoration of small watercourse in order to help address the climate change challenges (Figure 1).

---

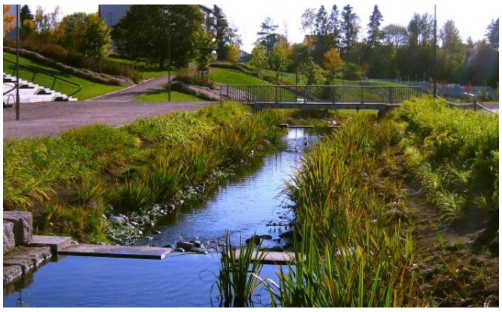
[1] "Grey infrastructure" is called that way because of the massive amounts of concrete and metal typically involved [9].

[2] "Heat island" is a phenomenon that occurs in urban environments with temperatures that are much higher than in natural environment, due to intensive urbanization and the increase of paved surfaces.

a

(a) Flood protection and renaturation of the Gabriachbaches River, Graz. Ecological upgrading of the river by removing the former concrete half-shells and creating a meandering low-water channel with wooden pilots.

Source: http://www.wasserwirtschaft.steiermark.at/cms/beitrag/10006871/4579632/



b

(b) Reopening of approximately 650 m of the Hovinbekken stream, Oslo, with a natural filtration system to create a clean habitat to native species and a popular recreation zone. Until the 1980's, the stream was considered problematic and it was put in underground pipes and culverts.

Source: https://www.klimatilpasning.no/eksempler/blagronne-losninger/hovin-bekken/

Figure 1. *Restoration of small urban streams in Graz and Oslo.*

Aside from the watercourse itself (blue component), green areas in the riverfront zone that are designed to retain, filter and absorb stormwater can significantly reduce flooding in urban areas. Riverfront projects that are planned and developed as natural cleaning systems, with sedimentation basins, water rapids and shallow waters with dense vegetation, also help to control pollution and improve water quality for the urban citizens and wildlife. From the aspect of sustainability, it is of crucial importance to filter pollutants before they enter the drinking water system. Vegetation slows the runoff water, filters it and then allows it to infiltrate into the ground or into a storm drain, thereby improving water quality.

There are additional benefits of vegetated areas next to the watercourses. Green space accessibility is associated with increased physical activity [10][11]. By implementing greenery in the flood plain of river or stream, new public open spaces are created and accessibility of sport-recreational amenities is improved. In this manner, healthier lifestyle for the denizens is promoted, and the overall improvement of population health may be expected.

Floodable public open spaces are an excellent opportunity for modern stormwater management within urban areas because they can have large retention capacity. They are particularly convenient and easy to use in watercourse-adjacent areas, where they can be implemented as floodable parks and recreation spaces or floodable public space, such as wet plazas and squares [6]. Floodable parks and recreation areas throughout the watershed receive stormwater outflow and can also provide retention, cleansing and infiltration of stormwater by using technical elements such as bioswales, rain gardens, bioretentions, infiltration trenches etc. Floodable public spaces are typically hardscapes with some potential vegetation [6]. In addition to using formerly mentioned technical elements in vegetated areas, they can implement porous pavement in order to absorb more quickly large amounts of stormwater and therefore reduce flooding. Additionally, floodable open spaces can convey stormwater to drainage systems or rainwater tanks, in order to allow the spaces to return to normal use quickly and to reuse stormwater runoff.

Finally, by reviving small urban watercourses, socio-economic benefits are achieved. The overall design can restore not only the ecosystem, but also create new neighborhood character and spaces for social interaction. Even though the investment might initially be higher than standard waterfront design, in the long run it will be cheaper than total costs associated with repair of erosion and flood damages.

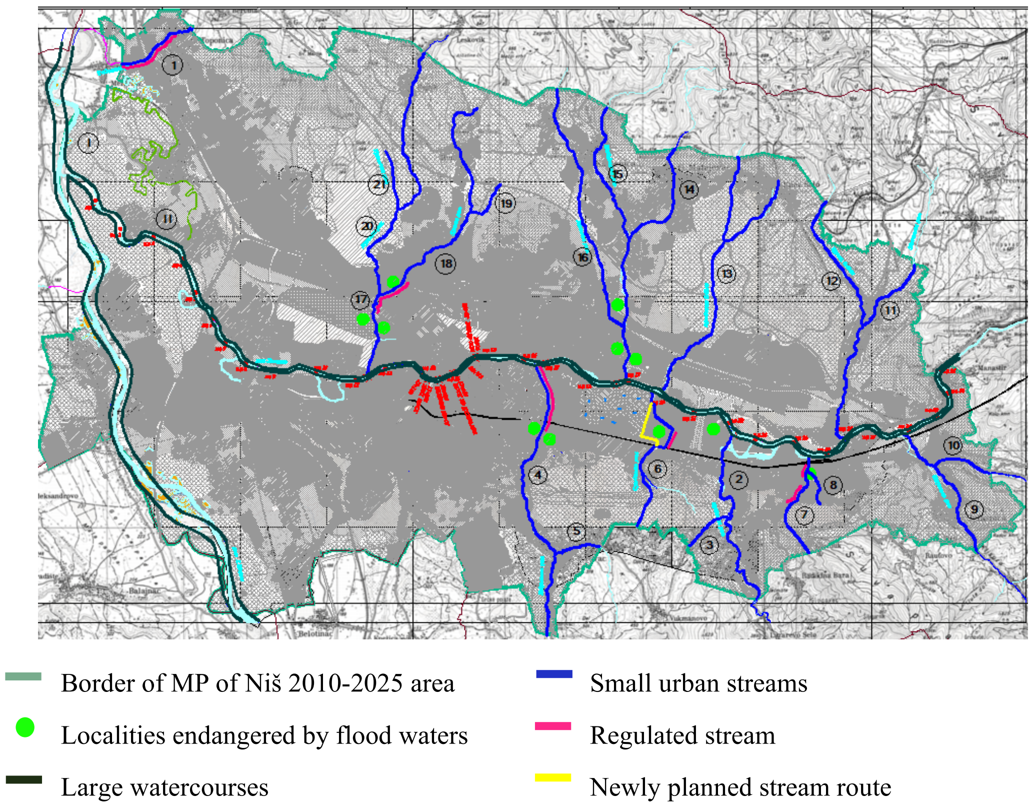
This research explores the impact of small urban streams within the concept of Blue-Green Infrastructure, and considers their potential use in shaping the post-socialist urban landscape in the City of Niš, Serbia. With a population of approximately 260.000 inhabitants (2011 Census), Niš is the third largest city in Serbia and a typical post-socialist city of medium-size. Post-socialist development period had significant implications upon the urban landscape of Niš, with urban densification and loss of public open space/green areas being the most remarkable features of transition [12]. The increase of paved surfaces had significant environmental impacts. Traditional stormwater system is often unable to absorb and process all of the excess water runoff, resulting in flooding of various parts of urban area. In Niš territory there is a multitude of small watercourses, which have torrential character and are completely underused from the BGI perspective. Unfortunately, the BGI approach has not been yet been considered in urban planning policy and culture.

It is the standpoint of this research that the creation of the Blue-Green Infrastructure grid, that would involve small urban streams as the blue component, could significantly improve not only stormwater management in Niš, but also provide new recreational spaces, restore the ecosystem and improve the overall quality of life of urban residents. Therefore, this paper investigates small watercourses in Niš territory, evaluates their current state, explores proposed planning solutions and examines the possibilities of their integration into the Blue-Green grid in the City of Niš.

2. MATERIALS AND METHODS

There are twenty-three significant watercourses in the territory of the City of Niš, which is the area covered by the Master Plan (MP) of Niš 2010-2025 (Figure 2). Four of them are waters of the first order and the rest are waters of the second order[3]. Two major watercourses of the first order in the analyzed area are rivers Nišava and Južna Morava. All remaining watercourses are smaller and can be classified as urban streams.

This research explores the potential of small watercourses of the City of Niš in creating a BGI grid, by using a review of relevant literature, analysis of standing planning documents and field observation. Small urban streams represent the focus of this research, with their impact on urban and suburban area of the City of Niš. The effect of these watercourses on rural settlements, beyond urban border, is not evaluated in this study. A total of 21 small streams located within the administrative area of the City of Niš are analyzed, and their main characteristics are presented in Table 1. In the defined urban area, these watercourses have a total length of about 90 kilometers.



[3] According to the Water Law [13], in line with their importance for water management, surface waters in Serbian territory are divided into waters of the first and second order.

I Južna Morava, II Nišava, 1. Toponička River, 2. Kutinska River, 3. Vukmanovski Creek, 4. Gabrovačka River, 5. Vukmanovska River, 6. Suvodolski Creek, 7. Kovanlučki Creek, 8. Suvobanjski Creek, 9. Jelašnička River, 10. Kunovička River, 11. Malčanska River, 12. Crveni Creek, 13. Knezselski Creek, 14. Matejevačka River, 15. Kamenička River, 16. Brenička River, 17. Rujnička River, 18. Humski Creek, 19. Brenički Creek, 20. Rujnički Creek, 21. Grkovački Creek. Source: Authors' drawings on the MP of Niš 2010-2025: Infrastructure – Plan of regulation of watercourses

Figure 2. *Watercourses in the urban area of the City of Niš.*

Table 1. *Watercourses in the City of Niš territory*

No.	Name	Category	Tributary of	Floods (year of critical event)	Riverbed regulation	Length in MP area
1.	Toponička River	I	Južna Morava	Yes (2012, 2018.)	Partly regulated	2,1 km
2.	Kutinska River	I	Nišava	Yes (2004, 2012, 2014, 2018.)	Partly regulated	8,0 km
3.	Vukmanovski Creek	II	Kutinska River	No	Unregulated	1,3 km
4.	Gabrovačka River	II	Nišava	Yes (1926, 1948.)	Partly regulated	5,5 km
5.	Vukmanovska River	II	Gabrovačka River	No	Unregulated	1,1 km
6.	Suvodolski Creek	II	Nišava	Yes (2014.)	Mostly unregulated	4,5 km
7.	Kovanlučki Creek	II	Nišava	Yes	Partly regulated, insufficient existing regulation	3,0 km
8.	Suvobanjski Creek	II	Kovanlučki Creek	Yes	Unregulated	1,0 km
9.	Jelašnička River (Studena)	II	Nišava	Yes (2014.)	Partly regulated	2,7 km
10.	Kunovička River	II	Jelašnička River	Yes (2014.)	Unregulated	1,5 km
11.	Malčanska River	II	Nišava	Yes	Unregulated	5,2 km
12.	Crveni Creek	II	Malčanska River	No	Unregulated	3,7 km
13.	Knezselski (Suvodolski) Creek	II	Nišava	Yes	Unregulated	9,0 km
14.	Matejevačka River	II	Nišava	Yes	Unregulated	7,0 km
15.	Kamenička River	II	Matejevačka River	No	Unregulated	7,5 km
16.	Brenička River	II	Matejevačka River	Yes	Unregulated	7,0 km
17.	Rujnička River	II	Nišava	Yes	Partly regulated, insufficient existing regulation	2,2 km
18.	Humski Creek	II	Rujnička River	Yes	Partly regulated	8,2 km
19.	Brenički Creek	II	Humski Creek	No	Unregulated	1,2 km

20.	Rujnički Creek	II	Rujnička River	Yes	Unregulated	7,0 km
21.	Grkovački Creek	II	Rujnički Creek	No	Unregulated	1,6 km
Sources of data: MP of Niš 2010-2025; Operational plan for flood defense in the City of Niš territory for watercourses of the II order for 2018; Own research						

The planning database involves 16 standing documents: the MP of Niš 2010-2025 and 15 Plans of General Regulation (PGRs) [14-30], which cover entire municipalities or parts of municipalities of the City of Niš:

- Crveni Krst (CK) - Phases I, II, III, IV west (IVw), IV south (IVs),
- Pantelej (PN) - Phases II, III east (IIIe), IV north (IVn), IV northeast (IVne), IV northwest (IVnw),
- Niška Banja (NB) - Phases I, II, III,
- Palilula (PL) - Phase II,
- Medijana (ME).

Planning documents that are considering each of the watercourses are given in Table 2.
Current characteristics of small urban streams, their regulation, arrangement and related flooding issues, as well as traditional habits in using the space in waterfront zones, are determined on the basis of field investigations, the use of various legislation, satellite photo images and available data from internet sources. Review of standing planning documents involves the analysis of planned land uses adjacent to the watercourses in order to determine their potential for BGI. The results of this research should help to provide a better insight into the "blue" natural capital of the city of Niš regarding its current state and proposed planning solutions, and to establish a quality database for the creation of BGI grid in Niš urban area.

3. WATERFCOURSES IN THE CITY OF NIŠ

Erosion processes and torrential floods are some of the most significant natural hazards in Niš area. Small urban streams in Niš city territory all have torrential character. After heavy rains or snow melting, their flow volume increases and a large amount of debris is carried with the flow. In summer months there is very little water flow, so sometimes the streams dry out. Current state regarding riverbed regulation and main issues for each of the analyzed small urban stream is discussed in more detail in this chapter. Regarding flood protection from the outflows of small streams in the territory of the City of Niš, some planning measures are provided in the MP of Niš and in PGRs of various city municipalities, and these are also further discussed here.

The role of urban planning in protecting buildings from flooding is extremely important, in terms of determining the permitted use of each zone according to flood risk [31]. Therefore, this research investigates land uses that are planned by current planning documents along the analyzed watercourses, and the results are presented in Table 2.

Toponička River. Toponička River is the right tributary of Južna Morava, and it's only tributary in Niš territory. Part of its riverbed, located in the area covered by the MP, is regulated on the course downstream of the bridge in the settlement Gornja Toponica. Riverbed is not regulated upstream of the bridge. Therefore, in the section with natural riverbed, the course is variable and does not have sufficient throughput. After heavy rainfall, stormwater is retained at the parterre level due to rising levels of groundwater, which poses a threat for residential structures and agricultural facilities in this part of the settlement.

Planning documents suggest regulating the unregulated part of the riverbed in order to ensure better transport of suspended sediment and debris, consolidation of riverbeds and shores, protection of settlements against flooding, and receiving stormwaters from catchment areas along the watercourse. Protective green belt along Toponička River is also envisioned.

Kutinska River. Kutinska River is the fourth largest tributary of Nišava River, and flows into it near the settlement Nikola Tesla. It is about 40 kilometers long in total, has a large and indented river basin with a large number of small tributaries, the majority of which are outside the MP. Kutinska River has a considerable longitudinal fall in the upper section and part of the midstream, while the remaining part of the midstream, as well as lower watercourse have a small longitudinal fall. The middle and upper parts of the river have almost linear riverbeds, while numerous meanders are formed in the lower section of the watercourse (which is in the scope of this research). The large amount of sediment downstream of Prva Kutina settlement is an indicator of torrential character of Kutinska River. Torrential floods in this basin are frequent and directly affect the hydrological regime of Nišava River, as well as flooding of suburban settlements.

Kutinska River is largely unregulated. Regulation works on Kutinska River were carried out in the length of 300 m from the confluence with Nišava River towards the railway bridge. The section upstream of the railway bridge is unregulated with a low flow profile, so that arrival of large waters leads to overflow and flooding of adjacent surfaces, especially residential and industrial buildings in the settlement of Nikola Tesla. In the analyzed section of Kutinska River, along the right bank, there are single family houses with gardens, which often infiltrate into the designated waterfront area. Riverbed is neglected, filled with waste and dense weeds. The issue of unresolved land rights is a major impediment for the regulation of this watercourse. Along the left bank of Kutinska River there is also a large stretch of agricultural land.

Planning documents suggest further regulation of Kutinska River in order to protect against flood waters by widening and deepening the riverbed. Regulatory work would primarily prevent the overflow of water from the riverbed in cases of large waters. The width of the planned area intended for regulation of Kutinska River is 32 m. A trapezoidal profile is recommended but not binding. Further construction on the watercourse route is prohibited and it is mandatory to clean and maintain the riverbed regularly.

Vukmanovski Creek. This small urban steam with unregulated riverbed is a left tributary of Kutinska River, and it flows through agricultural land only.

Gabrovačka River. Regulation of the riverbed is only partly completed. Complete regulation is performed in the section from the confluence with Nišava River to the railway line in the length of 1660 m. Riverbed is designed as a two-level trapezoidal profile. Bottom width of the riverbed is 4.0 m. Minor trough is sized according to fifty years of large water, and major trough according to 100 years of large water, with an elevation of 20cm. Unregulated riverbed is located in the segment upstream from the railway line. The 1400 m section from the railroad to the road bridge in the south is partially profiled and cleared of debris. The rest of the riverbed is 5.500 m long and totally unregulated. Due to low throughput of the profile, when reaching high waters, flooding of adjacent areas occurs in the section of unregulated riverbed.

Proposed planning actions involve increasing the throughput capacity under the railway bridge by opening new culverts, and implementing a two-level profile riverbed in the 1400 m unregulated segment from the railway to the southern road bridge.

Vukmanovska River. As its largest right tributary, Vukmanovska River flows into Gabrovačka River in the center of Gabrovac village. It does not have a regulated riverbed.

Suvodolski Creek. Natural riverbed of Suvodolski Creek does not have a clearly defined profile on certain sections of its course. Regulatory works were done only in the segment length of 400 m, from the center of Brzi Brod settlement upstream to the railway. Problems are particularly manifested in the lower part of the stream, throughout the settlement of Brzi Brod. After every heavy rain or melting snow, water overflows from the shallow natural trough and floods the surrounding residential buildings. Tubular culvert at the Niš-Niška Banja road, which is located in the upper zone of the river profile, represents a barrier even for small and medium waters. Therefore, increased sediment deposition and a decrease in watercourse profile occur in the upstream section.

The need to regulate this torrential watercourse is evident. Therefore, a completely new route for the regulation of Suvodolski Creek is planned, displacing a part of the stream's natural course. For this purpose, the urban project was made, but it has not been implemented yet. Regulation works are also planned in the urbanized area, in the settlement Suvi Do. In the segment of the watercourse that passes through agricultural land, the MP suggests an expansion of the natural riverbed according to the principle of field regulation.

Kovanlučki Creek. This urban stream has prominent torrential characteristics. Kovanlučki Creek is regulated throughout Niška Banja settlement to the Niš–Jelašnica road, and in one more segment further downstream until the railway. Existing riverbed regulation through the settlement of Niška Banja was built partly with open canals and partly with closed canals. Trough is lined with stone in cement mortar and it is partly filled with sediment and deposits. Therefore, due to the decrease of flow profile, after emergence of large waters, flooding of surrounding fields occurs.

Planning measures suggest thorough cleaning of the Kovanlučki Creek riverbed from debris, deposits and other material.

Suvobanjski Creek. Suvobanjski Creek flows as a right tributary into the regulated bed of Kovanlučki Creek just before the confluence with Nišava River. Suvobanjski Creek has a low flow profile and upon reaching large waters an outflow occurs as well as flooding of surrounding area.

Planning documents propose the regulation of this stream. Regulation should ensure that the settlement is protected from floods, and improve the elements of natural riverbed, in order to achieve more favorable conditions of water flow and sediment as well as the safety of existing facilities. A trapezoidal profile is recommended but not binding. Along the watercourse, a 3 m wide area is planned on one side for maintenance, and on the other a 1,2 m wide footpath.

Jelašnička River (also called Studena River). This urban stream is made up of two major constituents who merge in the village Donja Studena. Jelašnička River is of torrential character with a considerable longitudinal fall, and consequently has a large amount of drawn sediment. Parts of the watercourse of Jelašnička River were regulated, mainly in the areas passing through settlements. However, in certain sections in the villages of Jelašnica and Čukljenik, the riverbed is narrowed, partly covered with sediment and debris, and overgrown with trees, thus increasing the risk of torrential flooding. Deposits are particularly evident through the village Jelašnica itself, where the longitudinal fall is smaller. In 2015, regulatory work began on Jelašnička River in the area of planned development, on watercourse section that intersects with the highway. Regulation of the riverbeds should prevent water outflow from the troughs at the occurrence of high waters, and thus secure endangered objects and adjacent surfaces.

It is planned to regulate Jelašnička River from Kunovačka River to Nišava River. The upstream section of Jelašnička River, through the densely populated village of Jelašnica, is proposed for further consideration in Plan of Detailed Regulation (PDR). In the area defined for PDR, in addition to Jelašnička River, an integrative tourist zone is also planned, and some basic guidelines for the arrangement of this zone are proposed by the PGR. The following uses are suggested along the upstream route of Jelašnička River: (1) landscaped protective greenery and (2) smaller residential areas adjacent to the river, that are endangered by the river outflow. Parts of protective greenery along the river should be designed with the following characteristics: (1) park features, especially in residential areas, (2) landscaping as a buffer area towards the intact nature of the southern part of the stream, (3) water wells with multiple structures of former water mills should retain their function of draining excess water, while reconstructing water mills, and (4) forming bicycle and pedestrian paths along the river and connecting them to the immediate environment.

Kunovička River. Kunovička River is the largest tributary that flows into Jelašnička River just before the confluence into Nišava. Its riverbed is not regulated. When reaching high waters, the most endangered area is the one upstream and downstream of the bridge on the road Niš-Jelašnica-Studena, especially when bridge opening gets blocked by trees, deposits and debris.

Regulation of Kunovička River on watercourse section that intersects with the highway also began in 2015. Planning documents suggest regulating Kunovička River along the entire route covered by the PGR.

For both Jelašnička and Kunovička Rivers the PGR prescribes leaving a minimum of 3 m corridor of open area along regulated watercourses, and a minimum of 5 m of open area along unregulated watercourses, for the case of flood protection. It is also mandatory to prohibit further construction on the watercourse route as well as to regularly clean and maintain the riverbeds.

Malčanska River. The riverbed of Malčanska River is not regulated. This river is of torrential character, with a large longitudinal fall and, consequently, a large amount of drawn sediment, whose deposits are particularly evident zones of bridges. In the village of Malča itself, the river flow profile is deep, so that there is no flooding of adjacent surfaces. Flooding occurs in the zone near the highway bridge (road to Svrljig) and directly downstream. When the level of Mačanska River reaches large waters, tubular culvert on the highway bridge gets blocked by debris and waste materials, and causes flooding of the bypass road as well as of the agricultural fields. Downstream of the culvert, riverbed profile is partially covered and overgrown with trees. Therefore, the river endangers the banks, bridge and areas downstream of bridge on the left bank.

As Malčanska River flows downstream through uninhabited area, and according to the planned land uses, following planning actions are proposed by the MP: (1) expansion of the natural riverbed according to the principle of field regulation on the segment of the watercourse through agricultural land, and (2) regulation and arrangement of the flow profile with a two-level trough on the watercourse segment throughout building area. However, there is no project documentation for the regulation of Malčanska River. Further urban consideration through the Plan of Detailed Regulation is suggested by the PGRs in order to regulate the riverbed. For the watercourse segment downstream of the highway, the PGR prescribes a mandatory corridor of open area for flood protection - minimum of 3 m along regulated watercourses and 5 m along unregulated watercourses. It is also mandatory to prohibit further construction on the watercourse route as well as to regularly clean and maintain the riverbeds. Creation of a protective green belt is also suggested.

Crveni Creek. This small stream is the right tributary of Malčanska River and flows into it in the area of Malča settlement.

Further urban consideration through the Plan of Detailed Regulation is suggested by the PGR in order to regulate part of the riverbed. General planning guidelines suggest a creation of the protective green belt.

Knezselski Creek. Riverbed of Knezselski Creek is not regulated and is mostly overgrown with weeds and bushes. From the settlement Knez Selo to the confluence, this stream flows through the uninhabited area in the length of 6 km. Therefore, the outflow of the watercourse causes damage to agricultural land. The biggest issue concerns the bridge on the Niš-Svrljig highway, which gets clogged in times of large waters due to deposits, trees and debris. This causes flooding of the upstream section of about 300 m, and also endangers the downstream section of about 300 m whose riverbed profile is overgrown with trees and covered with deposit.

Therefore, two sets of planning measures are proposed in line with future land use: (1) expansion of the natural riverbed according to the principle of field regulation in the zone of agricultural land, and (2) regulation and arrangement of the flow profile with a two-level trough in the building area. Further urban consideration through the Plan of Detailed Regulation is suggested by the PGRs in order to properly regulate the riverbed. It is also mandatory to prohibit further construction on the watercourse route as well as to regularly clean and maintain the riverbeds. Formation of a protective green belt is suggested.

Matejevačka River. The basin of Matejevačka River is elongated and surface erosion is present throughout most of the basin. In the middle and lower parts of the basin, the stream carries large amounts of torrential sediment and has a variable and unstable trough. Matejevačka River receives Kamenička River just downstream from the village of Donji Matejevac, and Brenička River in the zone of the highway. No regulatory works were carried out on Matejevačka River. Main issues concern flow profiles on almost all bridges, which are partially enclosed by deposits, debris, shrubs and trees. In terms of flood protection, the greatest problem is the section of Matejevačka River downstream from the confluence with Brenička River to the confluence with Nišava, where the flow of large waters is increased by approximately 75%. Thus, the unregulated and narrowed flow profile of Matejevačka River through the village of Donja Vrežina cannot convey such large waters. The situation in Donja Vrežina is further exacerbated by illegal residential development along the shoreline of the minor (lower) trough.

In order to control fooling, the following planning actions are suggested by the MP: (1) the priority is implementation of flood protection regulatory works through Donja Vrežina settlement, (2) regulation of Matejevačka River till the conjuction with Brenička River with a two-level riverbed profile, (3) deepening of the riverbed downstream from the highway bridge, (4) deepening of the existing trough in the zones of bridges, and (5) realization of retarding embankments to the confluence with Nišava River. The PGR suggests a more detailed elaboration of Matejevačka River in the settlement Gornji Matejevac by designing a Plan of Detailed Regulation. For this purpose, a corridor of total width of 30 m is reserved. Until PDR is completed, the PGR provides some general guidelines for land use along the watercourse in Gornji Matejevac. PGR also suggests performing watercourse regulation with a "natural" design, using natural materials such as earth and stone, as well as the formation of a protective green belt.

Kamenička River. Regulatory works in the riverbed of the Kamenička River were not performed, only works on the anti-erosion control of its basin. Narrowing trough at intersections of watercourse and roads represent an issue in the settlements.

For the area of Donji Matejevac settlement, PGR suggest watercourse regulation by using "natural" design, with natural materials such as earth and stone, and the creation of a protective green belt. Through the area of Kamenica settlement, PGR prescribes the elaborationof the Plan of Detailed Regulation for river regulation.

Brenička River. This urban stream was a right tributary of Nišava River that flowed into Nišava downstream of the settlement Donja Vrežina. With the construction of Niš-Pirot highway, the natural riverbed of Brenička River was interrupted and partially displaced, and the waters of this watercourse were conveyed into the flow of Matejevačka River. There is insufficient throughput of this newly formed riverbed section of Brenička River. Regulation of this section is necessary so that the flow profile could fit the required one. In Brenica village, the culvert under the road is partially filled, and the trough downstream of this culvert is narrowed, covered with sediment and occasionally overgrown with trees. The section in the area of Kamenica bridge is also overgrown with shrubs and trees, and the profile is partially filled with deposits.

PGRs prescribe the elaboration of a Plan of Detailed Regulation for the regulation of Brenička River. Formation of a protective green belt is also suggested.

Rujnička River. It is formed by two tributaries: Rujnički and Humski Creek, which merge in the settlement Ratko Jović in the urban area of Niš. The basin of Rujnička River has a lenticular shape, while the tributary basins have an elongated shape. Due to high level of groundwater in the settlement Šljaka, large waters often appear as an issue in the settlement. Regulation works on Rujnička River have not yet been completed. Works were performed in stages and in the following sections: (1) from the composition of Rujnički and Humski Creek, near the boulevard road, the regulated section of the trough starts with a cascade, and is lined with stone in cement mortar up until the industrial railway track, (2) from the industrial railway track to the bridge on the Belgrade-Niš railway line, works were performed according to the projected profile of the trough. Regulated section of Rujnička River downstream of the boulevard road does not have sufficient throughput capacity.

The MP envisages to innovate hydrological bases and calculations and to harmonize project documentation with them, and to perform regulation works until the confluence with Nišava River. PGRs suggest the elaboration of a Plan of Detailed Regulation for the section of Rujnička River from the railway to the confluence with Nišava River. Defined river corridor width for the PDR is 40m. Further construction on the watercourse route is strictly prohibited, while cleaning and maintaining the riverbed is mandatory.

Humski Creek. Humski Creek is a stream of torrential character. From the joining with Rujnički Creek, this urban stream is regulated upstream only 900 m. The unregulated section passes through settlements Donji and Gornji Komren in the length of 2.2 km. Here the route of the natural riverbed is variable and lacks sufficient throughput. The regulated section through Ratko Jović settlement upstream of the joining with Rujnički Creek also has insufficient throughput. After heavy rainfall or snow melting, water flows out of the shallow natural bed and floods the surrounding residential buildings. Unresolved land ownership issues represent a major challenge for the regulation, landscaping and arrangement of Humski Creek.

MP suggests thorough cleaning of the riverbed of Humski Creek from sediment and other material, both along the regulated and the unregulated section of the watercourse in the settlement. Regulation and arrangement of the entire watercourse is also planned, in order to protect this area from flooding. Creation of park areas and protective green belt upstream of the highway are suggested by the PGR. In the section of Humski Creek in the zone of the center of Donji-Gornji Komren, on the right bank, a 1 km long promenade is planned. Further construction on the watercourse route is prohibited and regular cleaning and maintaining the riverbed are mandatory. The section of Humski Creek from the composition with Brenički Creek up to the village of Hum is intended for further urban consideration by Plan of Detailed Regulation.

Brenički Creek. This small urban stream is a left tributary of Humski Creek.

PGR prescribes the elaboration of the Plan of Detailed Regulation for the regulation of the section of Brenički Creek covered by the Plan. Formation of a protective green belt is also suggested.

Rujnički Creek. This urban stream is of torrential character and no regulation works have been carried out on it. Watercourse section from the joining with Humski Creek to the highway (length of 1 km) has a narrow flow profile, which represents a major problem in overcoming flood waters. Riverbed section adjacent to the primary school is particularly problematic, because the concrete culvert profile is insufficient for large waters. The section upstream of the highway is filled with sediment and overgrown with vegetation.

PGRs suggest absolute priority of regulation works on this natural and unregulated riverbed. Trapezoidal riverbed profile is recommended but not obligatory. The section of the stream that starts 400 m upstream of the highway is intended for further urban consideration through the Plan of Detailed Regulation. Regulatory work will prevent the outflow from the trough when the level reaches high waters, ensure unobstructed and safe flow of small and large waters, protect settlements from flooding and enable reception of stormwaters from areas adjacent to the stream. Smaller landscaped areas are planned next to the regulated part of Rujnički Creek in Donji Komren. Formation of a protective green belt is also suggested along the watercourse.

Grkovački Creek. This small unregulated stream flows through agricultural land into Rujnički Creek as its right tributary.

Table 2. *Planned land uses along smal urban strams in the City of Niš territory*

No	Name	Standing planning documents	Adjacent land use													
			E	K	H	S	CI	T	OG	SP	R	B	CT	C	F	A
1.	Toponička River	MP of Niš PGR CK III PGR CK IVw	b						a		b	a b				
2.	Kutinska River	MP of Niš PGR NB II					a		a		b c e	a b c				
3.	Vukmanovski Creek	MP of Niš PGR NB II														
4.	Gabrovačka River	MP of Niš PGR PL II PGR ME	a b		a				b c		a b c d e	a				
5.	Vukmanovska River	MP of Niš									b					
6.	Suvodolski Creek	MP of Niš PGR PL II PGR ME	a						a b		b	a b				
7.	Kovanlučki Creek	MP of Niš PGR NB I			c				b		b	a				
8.	Suvobanjski Creek	MP of Niš PGR NB I									b					
9.	Jelašnička River	MP of Niš PGR NB III							a b		b e	a				
10.	Kunovička River	MP of Niš PGR NB III							a		a b	a				
11.	Malčanska River	MP of Niš PGR PN IIIe PGR PN IVne							a c		b	a b				
12.	Crveni Creek	MP of Niš PGR PN IVne							a b		a b	a				
13.	Knezselski (Suvodolski) Creek	MP of Niš PGR PN II PGR PN IVne							a		a b	a b				
14.	Matejevačka River	MP of Niš PGR PN II PGR PN IVn							a c		a b	a b				
15.	Kamenička River	MP of Niš PGR PN IVn PGR PN IVnw							a c		a b	a				
16.	Brenička River	MP of Niš PGR PN II PGR PN IVnw							a c		a b	a b				
17.	Rujnička River	MP of Niš PGR CK I PGR CK IVj					b		a b		b e	a b				
18.	Humski Creek	MP of Niš PGR CK I PGR CK II	a		a		b		a b d		a b e	a b				
19.	Brenički Creek	MP of Niš PGR CK II					b		a							

20.	Rujnički Creek	MP of Niš PGR CK I PGR CK II	a						a b c		b e	a b				
21.	Grkovački Creek	MP of Niš														

Legend

Land use present

Land use not present

Within building area. E_Education: a-Primary, b-Higher; K_ Kindergarten; H_Healthcare: a-Primary, b-Specialized center, c-Health-Spa complex; S_Sport; CI_Communal Infrastructure: a-Market place, b-Cemetery; T_Traffic areas; OG_Public Open/Green spaces: a-Protective greenery, b-Park/Landscape greenery, c-Recreation, d-Public square; SP_ Special purpose; R_Residential: a-Low density-suburban, b-Moderate density-urban/suburban, c-Medium density, d-High density, e-Business-residential; B_Business zones: a-Business and Shopping, b-Business-Production-Trading, c-Industry; CT_ Catering/Tourism; C_ Church.

Outside of building area. F_ Forest; A_ Agriculture.

4. REVIEW OF EXISTING CONDITION AND PLANNING MEASURES, AND POTENTIAL FOR IMPLEMENTING BGI

Nowadays, riverbeds of small urban streams in Niš territory are a mix of: (1) natural unregulated sections and (2) regulated sections that are either lined with stone in cement mortar or designed as concrete channels. One stream is even partly concealed in pipes (Kovanlučki Creek). This research has identified that in their current state, small streams in the city of Niš territory:

- Are often neglected because of illegal waste disposal and poor maintenance,
- Are often polluted and have an endangered ecological capacity,
- Represent a flooding hazard in all unregulated and in some of the regulated watercourses,
- Do not offer any recreational areas, or offer a very limited extent of recreation,
- Have a reduced aesthetic value,
- Have some landscaping and designing constraints due to illegal developments.

When it comes to the outflow of small streams, pollution and large amounts of sediment and debris are major risks. A very important issue concerns the low level of social and environmental awareness of the residents of nearby areas, since small urban streams often represent a site for illegal waste disposal, thus contributing to flooding and erosion of adjacent land. Pollution and poor maintenance of greenery is a big concern not only for stream outflows from their regular course, but also for habitat and the ecosystem in waterfront areas. Spontaneous and unplanned development represents an additional challenge. Namely, as the city grew in time, illegal development approached the banks of streams and creeks, thus increasing the risk of flooding. Retaining floodwater in the adjacent areas is therefore made difficult or impossible, which is a case with Kutinska River, Matejevačka River and Humski Creek. It can be concluded that small urban streams in Niš are quite underused and that a series of actions need to be performed in order to fulfill their potential and integrate them into a Blue-Green Infrastructure grid.

When reviewing future development of small urban streams in Niš, certain positive guidelines can be observed in standing planning legislation regarding flood protection. The most important planning action for all small watercourses is the suggested riverbed regulation as a flood protection measure for the endangered zones, both in building areas and in agricultural land. Plans also suggest widening and deepening the riverbeds in order to prevent flooding, where land rights enable such actions. For a multitude of urban streams, the problems of both poor maintenance and adjacent illegal development are addressed in planning documents. Prohibiting further construction on the watercourse route and performing regular cleaning and maintaining of the riverbeds is suggested for Kutinska River, Jelašnička River, Kunovička River, Malčanska River, Knezselski Creek, Rujnička River and Humski Creek. All of these actions favor the creation of the BGI grid.

Even though the plans themselves do not recognize the term “Blue-Green Infrastructure”, some of the issues are well addressed in planning regulations. Protective greenery along the watercourse is envisioned in the majority of planning documents, for 15 small streams. In the case of settlement Pantelej, even some networking of green and blue areas can be observed, which makes a great potential for the BGI - linear protective green belts along Knezselski Creek, Brenička River and Matejevačka River represents a segment of the green system which is connected to the river bank of Nišava. Together with other suggested types of green open spaces, protective greenery provides a good land reserve for retaining floodwaters in areas adjacent to the stream, as well as the opportunity for interconnecting the green components by blue pathways.

Newly planned paths along some of the streams (pedestrian path along Humski Creek, Suvobanjski Creek and Jelašnička River, and bicycle path along Jelašnička River) enable recreational areas for the population, but could also represent a significant linkage potential of the BGI grid. Plans prescribe the provision of open space in the flood plain of watercourses for Jelašnička River, Kunovička River and Malčanska River (3 m along regulated watercourses, and 5 m along unregulated watercourses). Sport fields and sport areas are envisioned adjacent to ten small watercourses, thus enhancing the potential for the green component of BGI. Public open spaces (squares) adjacent to Humski Creek in centers of villages Hum and Donji-Gornji Komren are an additional potential for the implementation of modern stormwater management techniques. Some plans indirectly favor the restoration of the stream's ecosystem by recommending watercourse regulation with a "natural" design, by using earth and stone as natural materials, i.e. for Matejevačka River and Kamenička River.

It is important to point out that the Plan of General Regulation of Niška Banja - phase III suits modern stormwater management approaches and BGI creation to a considerable extent. In addition to providing a bicycle path and various open spaces along Jelašnička River, a particular quality of this Plan is that it prescribes open green areas with park features in residential plots that are endangered by the river outflow. Also, the Plan recognizes the potential of water wells of former water mills on Jelašnička River for stormwater management and suggests maintaining their original function of draining excess water for flood protection. The suggested landscaped buffer zone towards the southern part of the stream, with the purpose of preserving natural environment along the stream, is also a planned characteristic that favors BGI.

As welcomed as these planning actions are in particular sites, they seem to be insufficient for general planning of urban watercourses in the whole of Niš area when it comes to new planning paradigms and techniques. In light of the proclaimed tendencies of "living with water" rather than defending from it, creating Blue-Green Infrastructure is advised in the entire Niš territory, as well as using the vast potential of small urban streams as a significant "Blue" element. Aside from planning measures, a wider social action and a shift in paradigm are necessary, in order to revive small urban streams and utilize their full potential within sustainable development practices. Therefore, a series of following actions is proposed with the goal of implementing the BGI concept in the city of Niš:

- *Restore ecological quality of the streams*, by: (1) firmly preventing pollution through stricter institutional and field control and increased penalties for pollutants, and (2) raising awareness of local population and city administrations on the significance of nature preservation, through educating, training, local municipality campaigns, workshops and bottom-up approach in urban planning,
- *Restore biodiversity of the streams*, by promoting "natural" design with rocks and earth, as well as planting trees and shrubs in the waterfront zone, thus creating new habitats for fish, insects and birds. Re-opening the closed canals of riverbed regulation is mandatory in the case of Kovanlučki Creek,
- *Implement floodable parks and sport-recreation areas*, by applying modern stormwater management techniques in open green spaces adjacent to the streams, for retaining and cleansing the outflow (bioswales, rain gardens, infiltration trenches, bioretentions). This can be achieved by providing additional open green spaces, children's playgrounds, sport fields and recreation spaces (i.e. in the spaces where stream's bed has been widened), but also by using water-sensitive design for the already planned open green areas or for redesigning existing ones,
- *Implement floodable public open spaces – squares and plazas,* by using porous pavement in defined public open spaces adjacent to watercourses, and other technical elements of modern stormwater management in vegetated zones of the square/plaza. This is possible by implementing water-sensitive design for two newly envisioned public squares adjacent to Humski Creek, but also by prescribing such design for all those public and commercial

facilities adjacent to watercourses that involve vast paved areas (schools, market places, business and shopping zones, catering and tourism zones, etc.),

- *Implement flood retention tanks* for possible rainwater reuse, in order to quickly drain open spaces and enable their normal use, but also to provide water reserve for irrigation of greenery in arid summer months,
- *Resolve land rights* in a manner that would also enable BGI implementation, since two crucial issues for the regulation of watercourses (land rights and illegal developments) are addressed in plans and legislation but still remain a big concern in actual situation in the field,
- *Improve building codes for developments in flood plains with wet and dry flood proofing techniques and insurance premiums*. For new developments that are at risk of flooding, it is necessary to elevate the groundfloor level to a safe pre-defined height, as well as elevate all electrical components and inventory, and thus enable water to enter the basement premises. For objects that are already built in flood plains (mostly residential and mostly illegal developments), it is suggested to elevate all electrical components and inventory to the upper floors, to provide additional dry flood proofing (embankments, etc.), and to require mandatory premiums for the insurance of such structures against flood damage. It is also necessary to prescribe the minimum coverage of open green areas with stormwater management elements, both in existing and newly planned plots.

Suggested improvements regarding small urban streams that are necessary for the creation of BGI in Niš city territory, can be implemented through Plans of Detailed Regulation or Urban Projects (UP). Most of the analyzed PGRs suggest a more detailed elaboration of small watercourses in PDRs, which makes a good baseline for the BGI vision in Niš. Plans of Detailed Regulation are envisioned for Jelašnička River, Malčanska River, Crveni Creek, Knezselski Creek, Matejevačka River, Kamenička River, Brenička River, Rujnička River, Humski Creek, Brenički Creek and Rujnički Creek. For Suvodolski Creek, Urban Project was envisioned, because of the displacement of a significant part of its natural route. For remaining small urban streams, the procedure for developing a PDR or a UP may be initiated at any time.

5. CONCLUSION

It can be concluded that Blue-Green Infrastructure is a very topical issue in contemporary planning theory and practice. A multitude of examples at the global level confirm that the implementation of BGI can significantly improve the resilience of urban areas to challenges of climate change and contribute to their sustainability. BGI is also a highly valuable and cost-effective resource to make urban areas more appealing.

Small urban streams are a crucial element of the “Blue component”. This paper made an attempt to point out the unused potential of small urban streams in urban landscape of the city of Niš and to guide future development in waterfront areas. Urban area of Niš is quite rich in water, which makes a good starting point for implementing BGI grid. Aside from flood protection, restoring small urban streams would bring additional benefits. In highly urbanized areas of the city, a restored watercourse would have a great effect in improving the microclimate. Parks and landscaped areas along the streams would provide rest and recreation areas for local population. This is a particularly important point in unplanned suburban settlements, that lack organized public open spaces and green areas. Such landscaped zones could become an important focus of social life for local residents. Small urban streams as elements of the BGI can significantly help in improving stormwater treatment, as well as in upgrading the design of various urban spaces.

Current planning documents support the creation of the BGI to some extent, which is another favorable pre-condition for the implementation in Niš. However, it is the conclusion of this research that small urban streams require more attention in both planning documents and in planning practice of the City of Niš. Given the fact that a majority of small watercourses still await regulation works, as well as more detailed plans or project documentation, it can be concluded that a window of opportunity exists for the implementation of BGI. A more detailed examination is necessary to determine the exact sites along watercourses that have potential for retaining the stream outflow, and to explore their size, use and design. Further studies should also explore the “Green component” urban baseline and its potential for the creation of BGI grid.

Finally, since the city of Niš area already possesses significant “Blue” natural capital, it seems that implementing the proposed measures would be quite simple and cost-effective - it is rather a matter of shifting our planning policies and design perspectives. By restoring urban watercourses and interconnecting them with vegetation systems within an attractive urban landscape, the city would achieve long-term viability for its residents and the entire urban ecosystem.

ACKNOWLEDGEMENT

This paper is the result of the project "Improving energy characteristics and quality of inner space in buildings of educational institutions in Serbia with the influence on health" (No. III 42008), financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

LITERATURE

[1] Dinic Brankovic, M., Mitkovic,P., Bogdanovic Protic, I., Igic, M. and Djekic, J., "Bioswales as elements of green infrastructure – foreign practice and possibilities of use in the district of the City of Nis, Serbia," in Proceedings of the 2nd International Conference on Urban Planning, 2018, pp. 347-356.

[2] Liu, L., Fryd, O. and Zhang, S., "Blue-Green Infrastructure for Sustainable Urban Stormwater Management – Lessons from Six Municipality-Led Pilot Projects in Beijing and Copenhagen," Water, vol. 11, no. 10, Oct. 2019, doi:10.3390/w11102024

[3] Ramboll, "Strengthening Blue-Green Infrastructure in Our Cities: Enhancing Blue–Green Infrastructure & Social Performance in High Density Urban Environments," 2016, https://www.zu.de/lehrstuehle/soziooekonomik/assets/pdf/Ramboll_Woerlen-et-al_BGI_Final-Report_small-1.pdf, accessed 06.01.2020.

[4] Ristić, R., Radić, B., Miljanović, V., Trivan, G., Ljujić, M. Letić, Lj. and Savić, R., "'Blue-green' corridors as a tool for mitigation of natural hazards and restoration of urbanized areas: A case study of Belgrade city", Spatium International Review, no. 30, pp. 18-22, Dec. 2013.

[5] Kazmierczak, A. and Carter, J., "Adaptation to climate change using green and blue infrastructure. A a database of case studies," for the Interreg IVC Green and blue space adaptation for urban areas and eco towns (GRaBS) project, 2010, https://www.researchgate.net/publication/228720496_Adaptation_to_climate_change_using_green_and_blue_infrastructure_A_database_of_case_studies, accessed 27.01.2020.

[6] Department of Energy and Environment (DOEE) - Governement of District of Columbia, "Blue green infrastructure: cloudburst management strategies for the District of Columbia," 2011, https://doee.dc.gov/sites/default/files/dc/sites/ddoe/service_content/attachments/BGI_Workshop_Final.pdf, accessed 27.01.2020.

[7] European Comission (EC), "Oslo Reopening Waterways," for the European Green Capital project, 2018, https://ec.europa.eu/environment/europeangreencapital/wp-content/uploads/2018/05/Oslo_Reopening_Waterways.pdf, accessed 02.02.2020.

[8] Schwaberger, C., the TCPA and the GRaBS Project Partners, for the Interreg IVC Green and blue space adaptation for urban areas and eco towns (GRaBS) project, "Green and Blue Infrastructure Exemplars from the City of Graz," 2011, https://circabc.europa.eu/webdav/circabc/env/green_infra_wg/Library/general_information/background_documents/General%20information%20on%20green%20infrastructure%20principles/Green%20Infrastructure%20-%20Best%20practice%20examples/Austria/Expert_Paper_Green_and_Blue_Infrastructure_Exemplars_CityofGraz_FINAL_VERSION.pdf, accessed 06.01.2020.

[9] Ramboll, "Strengthening Blue-Green Infrastructure in Our Cities: Enhancing Blue–Green Infrastructure & Social Performance in High Density Urban Environments," 2016, https://www.zu.de/lehrstuehle/soziooekonomik/assets/pdf/Ramboll_Woerlen-et-al_BGI_Final-Report_small-1.pdf, accessed 06.01.2020.

[10] Cohen, D.A., McKenzie, T.L., Sehgal, A., Williamson, S., Golinelli, D. and Lurie, N., "Contribution of public parks to physical activity," American Journal of Public Health 97, no. 3, pp. 509-514, Mar. 2007.

[11] Roemmich, J.N., L.H. Epstein, S. Raja, L. Yin, J. Robinson and D., Winiewicz, "Association of access to parks and recreational facilities with the physical activity of young children," Preventive Medicine, vol. 43, no. 6, pp. 437-441, Dec. 2006.

[12] Dinić Branković, M., Bogdanović Protić, I., Mitković M. and Đekić, J., “Urban densification of the post-socialist city and its implications upon urban structure: a study of Nis, Serbia,” in Proceedings of the 5th International Academic Conference on Places and Technologies, 2018, pp. 25-34.

[13] Republic of Serbia, “Water Law,” Official Gazette of RS, no. 30/2010, 93/2012, 101/2016, 95/2018 and 95/2018-other law, Serbia, 2018.

[14] City of Niš, “Operational plan for flood defense in the City of Niš territory for watercourses of the II order for 2018,” Official Gazette of the City of Niš, no. 29/2018, Serbia, 2018.

[15] Urban Planning Institute of Niš, “Master Plan of Niš 2010-2025”, Official Gazette of the City of Niš, no. 43/11, Serbia, 2011.

[16] Urban Planning Institute of Niš, “Plan of General Regulation of the Municipality of Medijana,” Official Gazette of the City of Niš, no. 72/12, Serbia, 2012.

[17] Urban Planning Institute of Niš, “Plan of General Regulation of the Municipality of Palilula – Phase II,” Official Gazette of the City of Niš, no. 73/13, Serbia, 2013.

[18] Urban Planning Institute of Niš, “Plan of General Regulation of the Municipality of Niška Banja – Phase I,” Official Gazette of the City of Niš, no. 102/12, Serbia, 2012.

[19] Urban Planning Institute of Niš, “Plan of General Regulation of the Municipality of Niška Banja – Phase II”, Official Gazette of the City of Niš, no. 44/15, Serbia, 2015.

[20] Urban Planning Institute of Niš, “Plan of General Regulation of the Municipality of Niška Banja – Phase III,” Official Gazette of the City of Niš, no. 17/16, Serbia, 2016.

[21] Urban Planning Institute of Niš, “Plan of General Regulation of the Municipality of Crveni Krst – Phase I,” Official Gazette of the City of Niš, no. 102/12, Serbia, 2012.

[22] Urban Planning Institute of Niš, “Plan of General Regulation of the Municipality of Crveni Krst – Phase II,” Official Gazette of the City of Niš, no. 96/13, Serbia, 2013.

[23] Urban Planning Institute of Niš, “Plan of General Regulation of the Municipality of Crveni Krst – Phase III,” Official Gazette of the City of Niš, no. 17/16, Serbia, 2016.

[24] Urban Planning Institute of Niš, “Plan of General Regulation of the Municipality of Crveni Krst – Phase IV west,” Official Gazette of the City of Niš, no. 66/18, Serbia, 2018.

[25] Urban Planning Institute of Niš, “Plan of General Regulation of the Municipality of Crveni Krst – Phase IV south,” Official Gazette of the City of Niš, no. 26/18, Serbia, 2018.

[26] Urban Planning Institute of Niš, “Plan of General Regulation of the Municipality of Pantelej – Phase II,” Official Gazette of the City of Niš, no. 44/15, Serbia, 2015.

[27] Urban Planning Institute of Niš, “Plan of General Regulation of the Municipality of Pantelej – Phase III east,” Official Gazette of the City of Niš no. 44/15, Serbia, 2015.

[28] Urban Planning Institute of Niš, “Plan of General Regulation of the Municipality of Pantelej – Phase IV northeast,” Official Gazette of the City of Niš, no. 66/18, Serbia, 2018.

[29] Urban Planning Institute of Niš, “Plan of General Regulation of the Municipality of Pantelej – Phase IV northwest,” Official Gazette of the City of Niš, no. 126/18, Serbia, 2018.

[30] Urban Planning Institute of Niš, “Plan of General Regulation of the Municipality of Pantelej – Phase IV north,” Official Gazette of the City of Niš, no. 44/19, Serbia, 2019.

[31] Babić Mladenović, M., Uređenje vodotoka, Beograd: Institut za vodoprivredu “Jaroslav Černi,” 2018.

16 | Research paper I Оригинални научни рад
ISSN 2566-4484 I Doi 10.7251/STP2014175K
pages 175-183

Dragana DK Kocić, draganadkocic23@gmail.com, Faculty of Technical Sciences, University of Novi Sad

Violeta Stefanović, violeta.stefanovic@live.com, Faculty of Technical Sciences, University of Novi Sad

THE NATIONAL ASSEMBLY HOUSE OF THE REPUBLIC OF SERBIA AND THE SPACE IN FRONT OF IT AS A SYMBOL OF THE VISUAL REPRESENTATION OF POWER

Abstract:

The National Assembly House of the Republic of Serbia, in Belgrade, is a monumental public building, which has, from the very beginning of its existence, represented basic political and cultural interests and preferences. It has remained the visual paradigm of Serbia's national course and sovereignty to this day. It has had great importance throughout its history. This paper deals with the use of the premises of the National Assembly and the image of the Assembly being developed in the state repository. In the service of various ideological determinants, the House of the National Assembly has been recognized as an architectural symbol that has often been conquered by the authorities. The aim of the paper is to show how the architectural symbol of the city becomes a visual indicator of power,i.e., a concrete indicator of the structure of gaining and losing power.

Keywords: National Assembly, ideology, space, spectacle, power, symbol

ДОМ НАРОДНЕ СКУПШТИНЕ РЕПУБЛИКЕ СРБИЈЕ И ПРОСТОР ИСПРЕД ЊЕ КАО СИМБОЛ ВИЗУЕЛНЕ РЕПРЕЗЕНТАЦИЈЕ МОЋИ

Сажетак:

Дом Народне скупштине Републике Србије, у Београду, представља монументални јавни објекат, који је схваћен од почетка свог постојања као репрезент темељних политичких и културних опредељења. Остао је визуелна парадигма националног курса и суверенитета Србије до данас. Поседује велики значај у читавој својој историји. Рад се бави употребом простора Народне скупштине и слике скупштине која се развија у државном репозиторијуму. У служби различитих идеолошких одредница, Дом Народне скупшине је препознат као архитектонски симбол који је често освајан од стране власти. Циљ рада је да покаже како архитектонски симбол града постаје визуелни показатељ власти, односно конкретан показатељ структуре добијања и губљења моћи.

Кључне ријечи: Народна скупштина, идеологија, простор, спектакл, моћ, симбол

1. INTRODUCTORY CONSIDERATIONS

The House of the National Assembly is a space permanently engraved with identity, a visual representative of different party systems, an architectural symbol that was originally allocated to the aristocracy, a symbol intended for the city, street, stage, and people.

Conceptualizing the Parliament building represented the most significant architectural task in the 19th century. It was set with the aim to have a dominant position in Belgrade's urban tissue, in a significant location in the city center. It is situated on a very vivid public space, bounded by Kosovska Street, Takovska, Nikola Pasic Square and Vlajkovic Street, in the immediate vicinity of the Old and New Courts and the Palace Garden (today known as Pioneer Park), with which it forms a unique architectural and functional unit. It was built between 1907 and 1936. The history of its construction, with numerous interruptions and changes to the project and with the participation of the most important local architects of the first half of the 20th century, symbolically reflects the turbulent history of Serbia, the former Yugoslavian state and its parliamentary life. From the beginning of its existence, it was conceived as a symbol of parliamentarism and democracy, but it was much more accompanied by the shadow of the communist rule and then by the events that followed in the period of post-socialism and transition.

The National Assembly House is, above all, a representative of monumental architecture. The very course of construction of this magnificent representative of Serbian and Yugoslav culture reflected the time and events in the spheres of political, historical, cultural and artistic life. It was rightly proclaimed a cultural monument in 1984 and as such represents the pride of the city of Belgrade. In addition to its cultural and artistic role, it also has the ideological connotations of a society that was decisive in changing its ideology, and of today's society that emerged as a product of the changes that have taken place.

The physical form of a building can be interpreted as a symbol of the conflict of different ideological messages. Often, due to frequent changes in political frameworks, the silhouette of a building is difficult to relate to an event, and therefore events that have marked its history will be analyzed.

We can take its form as a mainstream of buildings used for political purposes. In its existence, it has changed various symbols of ideologies, becoming itself a symbol embedded in the layers of the collective memory of the people. Thus, the architectural form of the building can be remembered as a concrete indicator of power. This paper deals with the analysis of the structure of power, that is, the analysis of political events and the analysis of the symbols of the house.

2. THE HISTORY OF THE HOUSE OF THE NATIONAL ASSEMBLY – THE SPACE IN WHICH POWER IS ESTABLISHED

The Assembly House is one of the most monumental buildings in Belgrade, built in the style of 20th century academicism. The idea of building a National Assembly House came into existence in the 19th century. The Ministry of Construction announced a call for the first project of the National Representative in 1892, created by the architect Konstantin A. Jovanovic, however that project was not realized, presumably due to a lack of funds. The formation of a large state (The Kingdom of Serbs Croats and Slovenes) also required a new project. The new project was created by the architect Jovan Ilkic. The foundation stone for the building was laid by King Peter I on August 27, 1907. The construction was interrupted by the First World War, and the works were resumed only in the third decade of the 20th century by Pavle Ilkic, an architect who worked according to the memory of his father's old plans [1:85]. The assembly was built until 1926 when construction works were stopped due to insufficient funds, and the next phase in construction began after the assassination of King Alexander I Karadjordjevic in 1934. At that time, the architect of the Russian imperial court and the academic Nikolai Krasnov was appointed the chief designer. According to his project, the interior of the Assembly was completed along with all the details. The whole building was completed and consecrated on October 18, 1936, and the first session in the new building was held on October 20 of the same year. (Fig. 1) At that time it already existed as the National Assembly of the Kingdom of Yugoslavia [2]. As for the content of the symbol of the National Assembly, Gordić states that the decoration of the building, the interior, the facade and the main entrance remains the largest artistic endeavor in our country. A large number of works of art were obtained through three open competitions. They accentuated the Yugoslav character, bringing national history and folklore through various artistic forms. He further states that there is great historical value in their joint work and the artistic achievement of the newly created state of Serbs, Croats and Slovenes, with the assistance of Russian emigrants. The newly created works of art had the idea of unity in style, and were imbued with political character [3].

The building was used for three years, from the date of the first session until 1939, when it was dismissed. At the beginning of World War II, the building was used by the occupying German Military Command. The end of World War II brought about a change in political circumstances. Thus, the heraldic symbols and features of the Kingdom of Yugoslavia were removed and replaced with symbols of socialism [4:90].

Figure 1. *The Assembly House 1936. (Source: https://sr.m.wikipedia.org)*

3. A SYMBOL IN SPACE

The House of Commons, as we have already said, frequently changed its features, various symbols of ideology, such as "a dynamic palimpsest on which historical events and personalities are always re-written in their struggle for power, recognition and legitimacy [5:379]." It was this need to gain legitimacy that was critical to recognizing the building as a symbol in space. Each newly formed government sought to erase the past, or at least the memory of it, changing its adherents, emblems of power, dates of public holidays, street names – "in the same way crossing the paths of its power and the avenues of its authority,"[6:379] reflecting them on an architectural object, which no longer represents a mere blend of art, architecture, history, but rather hints at feelings. As described by the authors of "The Forgotten Symbolism of Architectural Form" – "Just as Liechtenstein borrowed comic book techniques and characters to convey satire, sadness and irony rather than fierce adventure, so too can the language of architecture suggest sadness, irony, love, the state of humanity, happiness, or simply inner intent rather than the need to buy soap or the possibility of an orgy. [7:177]". Interpreting and evaluating the symbolic content of this space, the National Assembly House and its plateau is a very challenging process. Its physical structure directed the flows of various manifestations, with its straight square and the plateau on which it was erected. The plateau in front of it has a vacant surface, which was later called the plateau because it lacks peripheral structures and serves as a base for the building for a more monumental approach. Part of the ambiance decoration of the building was a decorative fence with stylish candelabras, which was erected in 1937. (Fig. 2) The project, as well as the whole interior, was done by architect Nikolai Krasnov. The fence was located here until 1956, but it was removed during the construction of Marks and Engels Square (today Nikola Pasic Square). We can interpret the fence as unambiguous symbolism. In fact, it wasn't easy to approach the building until the mid-20th century. Next to the monumental staircase, in 1939, the sculptural group "Playing the Black Horse", by sculptor Toma Rosandić [8:5], was set up. The fence was actually a visual barrier between the authorities and the people.

The disposition of the building forms an orientation in space, form - creates a perceptual representation, ornaments and symbols its identity. Its spatial form shows an articulation of knowledge and skill.

The Assembly was closely involved with the street in every event in which it participated. The street is in Lefebvre's vision, the factor that represents everyday life, the microcosm of the contemporary world. “The street? It is a meeting place, without which there are no other possible meetings in certain places (in cafes, theaters, various halls), [9:28]” here we become a scene, a spectator and sometimes an actor. Such theatricalization of the street as a space of spectacle stems from the fact that “all street events, celebrations, manifestations, demonstrations, create an extraordinary sense of community, stimulate people with an even greater engagement, participation. At the same time, these spectacles support a certain view of the city, its identity, its essence, which wants to impose itself as general and on the citizens themselves - participants of the event, but also those who live outside it”[10:175]. From this we can conclude that the Assembly space, as a scene space, allows one to adjust their own level and strength of personal experience and participation in events.

Figure 2. *Part of the building was a decorative fence*
(Source:http://beogradskonasledje.rs/kd/zavod/stari_grad/zgrada_narodne_skupstine.html)

4. SPACE - SEEING IS BELIEVING

In order to fully understand the role this house plays, in the representation of political power in the city, in addition to interpreting its form, it is necessary to analyze the causes as well as the events, that is, the links between it in the urban core of the city and the events.

It is the place where the Kingdom was abolished in favor of Marshal Josip Broz Tito, thus becoming a symbol of the state ideology of the new regime. From Tito, as the great demiurge of its people and the emanation of the state, until 2000, the space of the building was frequently changed. It had been appropriated by the regime for directing public events for the sake of its glorification, but also used by citizens, who created special kinds of spectacles in front of it. Whether it was a gathering, a protest, which contained the necessary dose of subversion and resistance, as a sign of distinct dissatisfaction of citizens. Creating a spectacle, often triggered by the regime's systematic efforts to bring the masses closer, the Assembly was the stage from which great acts of ideology were displayed.

Todorović sees these great works as “the principle of seeing is believing, in this case believing in the greatness, strength (and sometimes untouchability) of the authorities and the messages that the spectacle shows” [11:190]. In this way, the government encourages the liking and acceptance of political messages.

After Tito's death in 1980, the collective memory was linked to the image of the National Assembly with the cult of the communist rule, while later that image was replaced by numerous images of public protests that took place during the breakup of the state.

State incompleteness and frequent political storms in Serbia in the 1990s, showed that new circumstances could now completely change the function of these territories, and that which was once in the service of the government could become an instrument of the opposition [12:1]. That came true a couple of years later. Belgrade was at that time synonymous with the political stage, where events were often miserable and dramatic.

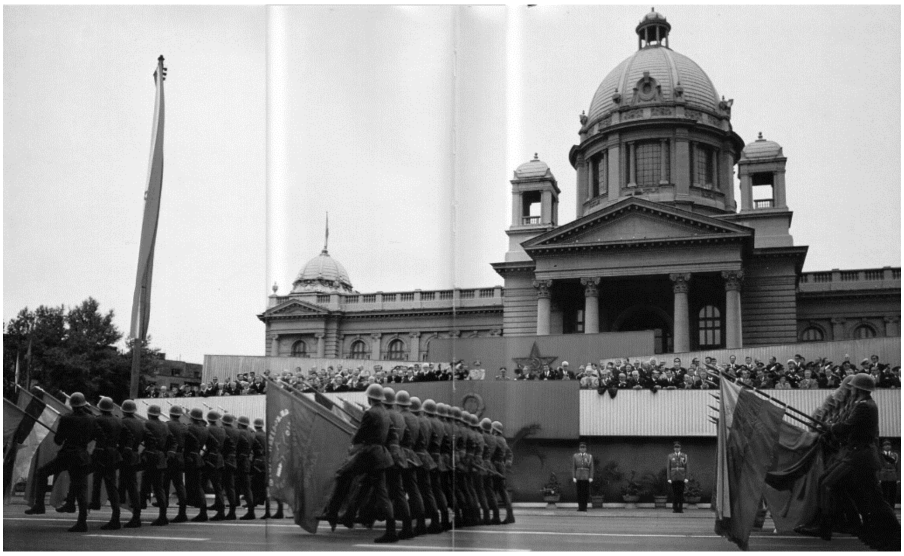
Events such as Tito's military parades, Tito's funeral, are events that seek to assert power in their representations. Another type of events are those where the social role involves open resistance, mockery of authority, and general dissatisfaction. The best example of such an event is October 5, 2000. These two periods best depict the National Assembly as a pars pro toto, which is why its space was the most desirable scenery in the political events and lives of statesmen and citizens.

4.1. The premises of the National Assembly, the time of socialism - verification of power

The National Assembly became the main architectural symbol to support Tito's personal cult and the validity of the new regime. Its monumentality was accentuated by the dome, which rises above the central staircase, creating symbolism between the sacred and the secular-imperial. This symbolism of the dome was related to the centers of power in the world (St. Peter in Rome, St. Paul in London) until the creation of American state houses, which made a radical transformation, especially of the Washington Capitol, where the reading between terrestrial and celestial gains explicit affirmation of the secular rule[13:68]. The exterior of the building has become widely known throughout the country thanks to daily media coverage. On the other hand, the meetings held in it were never broadcast live, so it remained partly mysterious to the public, and its secret quarters hid the mechanisms of the communist rule. Undoubtedly, the image of the National Assembly remains etched in the collective memory of Tito's era for state spectacles, primarily military parades, held in front of the building that took place from 1950 to 1980. (Fig. 3) The major controversy of Tito's rule was his extraordinary ability to conduct complex international relations with countries on both sides of the Iron Curtain and in Third World countries. His ability and acceptance of his personality culminates, in addition to holding military parades, in two other historic events held in the assembly. One is the first session of the Non-Aligned Movement in 1961 and Tito's funeral in 1980 [14:70]. Thus, the building became the main stage in the most significant urban spectacle, which fully fitted into the image of Marshal Tito and his way of life. He did not like modernism. Tito did not like Central Committee building (The CC) because of the ideology he supported and the opposite ideology that the building presented. Tito reportedly entered CC only once, on the occasion of its grand opening. He made all the important decisions elsewhere. The CC itself is a controversial, tall, modernist tower, symbolizing power, and in fact we see a total absence of power in it. The building that represented the Communist Party, modeled on the architecture of the ideologically opposed capitalist system [15:274]. Therefore, Tito chose the Assembly for the visual verification of his rule in space, which was reminiscent of the urban setting of the Reichstag in Berlin. In both cases, the entrance area is dominated by a monumental staircase with a ramp, which stands out on the plateau.

In the parades in front of the monumental main façade of the Assembly, the military and civilians participated, all mixed together making a festival on the plateau. The parades were always organized on May 1st, the International Labor Day, to maintain the populist spirit of the Yugoslav army. The elegantly designed stage, with communist symbols, was set up at the entrance to the Assembly. The monumental stage setting was reinforced by the Assembly silhouette, where the stairs and the dome had a special emphasis. There were also leading figures in the political regime and the military establishment. A key figure in the space and in this spectacle was Marshal Tito, who always stood at the center of the composition, as conductor and owner, who welcomed the impeccably coordinated columns of the participants [16:72]. This would mean that each space had its owner, with property being viewed here as "a relationship ... as an ethical and political relationship in which one person, or group of persons, has the power to change the behavior (roles) of other persons, or the group in the desired direction." [17:13] Therefore, Tito managed a *mise-en-scène* that was well known to everyone. All participants as well as the audience were known, everyone knew their place and everyone knew what to do, everyone was well trained for their roles. Tito was also inspired by the Vienna Parliament, above all in terms of urban aesthetics, a space where various military honors and performances were held. Yet, among all communist countries, only the Yugoslavian First of May Parades were very similar to the Soviet military processions, although the background of these events was reminiscent of the Ringstrasse in Vienna [18:74]. All of those stairs, ramps, stages, walls and other elements of urban street mobiles around the National Assembly, including the Old Palace (Belgrade City Hall) and Pioneer Park, became a kind of attitudes, theatrical boxes and gallery space of a monumental city auditorium, and at the same time, stages for simultaneous representations of power [19:12].

These performances took place in the space of the House of Assembly and were an indication of the new energy and power created by the state. This was also evident on the occasion of the First Non-Aligned Conference in Belgrade, in 1961. In those days, from September 1 to September 6, not only the Assembly, but the whole city was a big stage. The main hall of the Federal Assembly, where plenary sessions were held, was remodeled and adapted for the conference. The United Nations headquarters in New York was completed at that time and it became a model for transforming the interior of the National Assembly Hall to fit the meeting perfectly. In the hall of the Federal Council of the Federal National Assembly, Tito inaugurated a gathering of the highest representatives of non-bloc countries, which by the world public received the qualification of *conscience of humanity* [20:208]



.

Figure 3. *Military parades, in front of the building May 9th 1975.*
(Source:https://sr.wikipedia.org)

During Tito's time, the space of power seemed designed and harmonious. In their own way, each system tried to cover the arena and the hectic relationships with the theatrical spatial gestures, to decorate it into an idyllic urban scene [21:19]. On the other hand, this was not always possible, so the great resistance of the people will mark the period after his death.

4.2. Year 2000 – the space of revolution

Numerous gatherings happened, student protests in late 1996 and early 1997, war and repression in 1999, until October 5, 2000, when this space could be described as a paratheater. The "paratheater" represents every possible behavior, from the more peaceful and ordinary, anti-dramatic behavior (protest walk) to the most intense, dramatic behavior (" hepenning "within protest)" [22:148]. The city became an arena in those days, and on October 5, it was a reality that followed the people and then reached its fullest. The people decided to conquer and take over the center of power, whose identity and symbol were gradually built by the more famous Milosevic's predecessor, Tito.

Scenes of the National Assembly building in flames appeared in all the world media to illustrate the mass protests by the united opposition after Milosevic refused to acknowledge defeat in the elections. Even before the tragic breakup of Tito's socialist country, in the early 1990s, protests became common in many urban areas in Belgrade, including the plateau in front of the assembly. The protest echoed the ambitions of young, educated citizens, not only in Belgrade but throughout the whole country. They did not want to re-map the city in the name of the new order, nor to occupy its streets and mark them with their ideas. Their walk was aimed at key destinations, toward the most significant places of power that needed to be re-established. The National Assembly was not only symbolically but literally recaptured by the masses in the fight against the Belgrade police [23:382]. It is estimated that there were about one million people from across the state in front of the assembly who wanted to take control of their own lives. Then the space of the city became an arena – "the scene of conflicts of different interests and cultures, while fighting for survival and domination. By its very nature, an arena is a place of showdown, matches, feasts or parades, its manifesting stereotypes. The urban arena is a reality - life. It seeks a new chance and a straw of salvation, examining personal abilities and powers [24:16]". It was in this space that the struggle for survival, perhaps prestige, for a better tomorrow, for the right to live and make choices, took place. From the 2nd to 5th of October the energy was booming, more and more each day. The Assembly became the ultimate scene of political spectacle, directed by the people and the opposition.

The plateau was no longer the place where citizens expressed their position and occupied their city, the interior of the Assembly building became that place. A group of people climbed the facade of the building to break in through the window. The building was stoned and set on fire. The crowd looked like a group of violent fans. Perhaps the scenes of the Belgrade events did not fully reflect the tension of the day, the fear and the enormous will, but they created a strong conviction of the great force of the spirit in the fight against power. “In short, and indeed briefly, that performance has replaced the clichéd image of horny nationality - a theater of cockades and uniforms” [25:17].

In the heat of the battle arena the inside of the building was destroyed. The sculptures inside were badly damaged and much of the furniture was stolen. The interior thus changed its appearance, from the royal, replica of the UN, to the ignition and destruction. As Todorovic further states, “spaces of persistence have become spaces of revolution, spaces of acquired power. And like all spaces of revolution, they were inevitably marked by violence; the violence of the police against the people and the people over symbols of power” [26:383]. The conquest of space created an opportunity for an interactive, new energy of the masses, and a new idea of creativity from which a different socio-political community could emerge, which would be more authentic and national. Along the way, the most significant scenography of the city, as the eternal symbol of power that became a symbol of revolution, was the National Assembly. (Fig. 4)

Figure 4. *Bulldozer in front of the building (Source:https://www.politicaexterior.com/articulos/politica-exterior/el-juicio-de-milosevic/)*

Belgrade, in those days, was synonymous with a public political stage outside the country. “We view the year 2000 and the 5th of October events as the beginning of a new time and a new spirit (as much as everyday events relativize this claim), and we consciously deny the conclusion” [27:10].

5. CONCLUSION

The building of the National Assembly House has, in its history, been accompanied by a combination of incredible political events, creating the identity of the Assembly and building its space as one of the most important spaces of power, not only in Belgrade but also in the state of Serbia. Designed as a House to serve the Kingdom, it has changed its emblems of power depending on political circumstances and turmoil that were common in this part of the Balkans.

The first significant period that can be characterized as the period of the establishment of power is 1936 and the date of its inauguration. Then, in very difficult times, from the premises of the National Assembly, the Kingdom sent a message of unification and political aspirations of a newly formed Kingdom.

The second period is certainly the period after the Second World War, when a new ideology occupied a building, not only physically but also scenically, where it showed and assured the people of its power through frequent changes of scenery and defiling of the military, as the most relevant indicator of the power of a country. In addition to the military, it was also the spatial background of a large gathering held in Belgrade, the First Non-Aligned Conference in 1961. This gathering placed the building at the center of the world press, because the organizers of the event, that is, the very top of the country, made sure that it was a true representative of open Yugoslav foreign policy.

The third period is observed as a period of the loss of power. It is actually characterized as a verification of the discontent of the people, when the establishment lost its power and the space of the National Assembly became the space of great revolutions. The plateau in front of the building, which in fact had the greatest power of subversion at that moment, led to the loss of power of the ruling party, that is, the seizure of power by the people. We can conclude that the National Assembly House has successfully served its purpose, display and verification of power. Authority is verified when it is presented visually in the space which is a symbol of the state. Through a series of celebrations, parades and conferences, through its official opening and later through the change from kingdom to socialism, the Assembly has acquired the status of an indispensable symbol whose form, shape, silhouette, secondary plastic and interior show that whoever is on its stage actually possesses power. In the period of post-socialism it continued to be the architectural house of worship of all statesmen. In space, dominant, it always acted neutral, when power was conquered and when power was replaced. Its plateau is often seen as a plateau for the revolution, a plateau on which the mass expresses its affection or dissatisfaction with political circumstances and the state leadership. For the festivities it was decorated, for the revolutions set on fire, in numerous layers of materialization and appellations it carried (crown, star, coat of arms) it became a *pras pro toto* of national events.

As such, it has become, before and after Tito, the polygon of understanding and cognition, that is, the potential for the formation of spatial representations and associations. As a very important city and stage space, as a public presentation of knowledge and events, it continued to showcase events, cultivate, animate and ennoble the city. The National Assembly describes all the aforementioned periods in its own way, through space and through the events that were created there, creating a small theatrical historical vademecum. It does not contain everything, but it contains substance. Its form, monumentality, perseverance and European attitude at the heart of the city are relevant indicators of architectural symbols and their significance for the ideology and the country. From its inception to its existence today, it has changed its protagonists, who have left at least part of the scenery inside it. Participants in these past events have fought against their mythomania, and the space witnessed that fight and speaks of it. The National Assembly is a safe place for new and authentic, highly original stage metaphors about political circumstances in Serbia.

ACKNOWLEDGEMENT

The paper was done within the project “Optimization of Architectural and Urban Planning and Design in Function of Sustainable Development in Serbia” (No. TR36042), funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

LITERATURE

[1] G. Gordić, M. Popović, “Dom Narodne skupštine”, Nasleđe, vol. 3, pp. 85-88, 2001.

[2] V. Pavlović, M. Bujić, Lj. Miljković, „Dom Narodne skupštine – Umetničke vrednosti“. [pdf], Available: https://www.rs.undp.org/content/dam/serbia/Publications%20and%20reports/English/DobraUprava/UNDP_SRB_Umetnicke%20vrednosti.pdf

[3] M. Gordić, „ Ukrašavanje zgrade Narodnog parlementa Kraljevine Jugoslavije od 1936. do 1939. godine“, Nasleđe, vol. 2, pp. 95-104, 1999.

[4] V. Pavlović, M. Bujić, Lj. Miljković, „Dom Narodne skupštine – Umetničke vrednosti“. [pdf], pp. 90. Available: https://www.rs.undp.org/content/dam/serbia/Publications%20and%20reports/English/DobraUprava/UNDP_SRB_Umetnicke%20vrednosti.pdf

[5] J. Todorović, „ O moći I sećanju: ceremonijalni prostori i politički spektakl u Beogradu 2000.-2007,“ in Teatar-politika-grad, 2007, pp. 379-400.

[6] J. Todorović, „ O moći i sećanju: ceremonijalni prostori i politički spektakl u Beogradu 2000.-2007,“ in Teatar-politika-grad, 2007, pp. 379-400.

[7] R. Venturi, S. Braun, S. Ajzenur, Pouke Las Vegasa: zaboravljeni simbolizam arhitektonske forme. Beograd: DIP Građevinska knjiga, 1990, pp. 177.

[8] B. Mišić, „Dom Narodne skupštine," Zavod za zaštitu spomenika kulture grada Beograda, pp. 5, 2010

[9] A. Lefevr, Urbana revolucija. Beograd: Nolit, 1974, pp. 28.

[10] M. Dragićević Šešić, „Stvaranje mita o gradu i politika spektakla" in Javna i kulturna politika, 1st ed., M. Šešić, Ed. Beograd: Magna agenda, 2002, pp. 175.

[11] J. Đorđević, Političke svetkovine i rituali. Beograd: Dosije, 1997, pp. 190.

[12] R. Dinulović, D. Konstantinović, M. Zeković, „Public urban spavce as the stage for a political drama,". [pdf], pp. 1-16. Available: http://www.scen.uns.ac.rs/eng/wp-content/uploads/2013/03/Dinulovic-Konstantinovic-Zekovic-Public-urban-space-as-the-stage-for-a-political-drama.pdf .

[13] T. Damljanovic Conley, „The backdrop of Serbian stateboods: morpbing faces of tbe National Assembly in Belgrade," Nationalities Papers, vol. 41, No. 1, pp. 64-89.

[14] T. Damljanovic Conley, „The backdrop of Serbian stateboods: morpbing faces of tbe National Assembly in Belgrade," Nationalities Papers, vol. 41, No. 1, pp. 64-89.

[15] V. Kulić, „Presvlačenje Zgrade CK: promenljivi identitet najviše beogradske zgrade, " in Teatar-politika-grad, 2007, pp. 267-287.

[16] T. Damljanovic Conley, „The backdrop of Serbian stateboods: morpbing faces of tbe National Assembly in Belgrade," Nationalities Papers, vol. 41, No. 1, pp. 64-89.

[17] S. Prosperov Novak, Planeta Držić. Zagreb: Cekade, 1984, pp. 13

[18] T. Damljanovic Conley, „The backdrop of Serbian stateboods: morpbing faces of tbe National Assembly in Belgrade," Nationalities Papers, vol. 41, No. 1, pp. 64-89.

[19] R. Dinulović, D. Konstantinović, M. Zeković, „Public urban spavce as the stage for a political drama,". [pdf], pp. 1-16. Available: http://www.scen.uns.ac.rs/eng/wp-content/uploads/2013/03/Dinulovic-Konstantinovic-Zekovic-Public-urban-space-as-the-stage-for-a-political-drama.pdf .

[20] I. Vesković, „Park prijateljstva u Novom Beogradu," Nasleđe, vol. 12, pp. 203-216, 2001.

[21] M. Bobić, „Grad između arene i scene," in Urbani spektakl, 1st ed., M. Dragićević-Šešić, I. Šentevska, Ed. Beograd: Clio i YUSTAT, 2000, pp. 19.

[22] A. Jovićević, „Teatar, parateatar i karneval: građanski i studenski protesti u Srbiji 1996-1997," in Urbani spektakl, 1st ed., M. Dragićević-Šešić, I. Šentevska, Ed. Beograd: Clio i YUSTAT, 2000, pp. 148.

[23] J. Todorović, „ O moći i sećanju: ceremonijalni prostori i politički spektakl u Beogradu 2000.-2007," in Teatar-politika-grad, 2007, pp. 379-400.

[24] M. Bobić, „Grad između arene i scene," in Urbani spektakl, 1st ed., M. Dragićević-Šešić, I. Šentevska, Ed. Beograd: Clio i YUSTAT, 2000, pp. 16.

[25] M. Bobić, „Grad između arene i scene," in Urbani spektakl, 1st ed., M. Dragićević-Šešić, I. Šentevska, Ed. Beograd: Clio i YUSTAT, 2000, pp. 17.

[26] J. Todorović, „ O moći i sećanju: ceremonijalni prostori i politički spektakl u Beogradu 2000.-2007," in Teatar-politika-grad, 2007, pp. 379-400.

[27] R. Dinulović, „Teatar-politika-grad" in Teatar-politika-grad, 2007, pp. 9-12.

17 | Review paper I Прегледни научни рад
ISSN 2566-4484 I Doi 10.7251/STP2014184H
pages 184-195

Maximilian Hartmuth, keynote lecturer, maximilian.hartmuth@univie.ac.at, University of Vienna

ORIENTALIZING ARCHITECTURE IN NORTHERN BOSNIA UNDER HABSBURG RULE: EXAGGERATING ALTERITY AS A MEANS OF COHESION?

Abstract:

This paper offers preliminary insights into the phenomenality of Orientalizing styles of architecture in Bosnia-Herzegovina in the period of Austro-Hungarian rule. It examines in some detail three buildings in Banja Luka and Gradiška, with brief detours to Brčko, Dubica, and Šamac, focusing on the problem of decision-making in the planning and design process. This discussion is aided by plan material discovered in the relevant archives as well as contemporary periodicals. The inquiry will conclude with ruminations on this phenomenon's geography: Did Orientalizing architecture in Bosnia's northern region, bordering Croatia-Slavonia, carry different meanings than in Sarajevo and other inland metropolises?

Keywords: Bosnia-Herzegovina, Austria-Hungary, Orientalism, Moorish Style, Banja Luka

ОРИЈЕНТАЛИЗИРАЈУЋА АРХИТЕКТУРА У СЈЕВЕРНОЈ БОСНИ ПОД ХАБСБУРШКОМ ВЛАДАВИНОМ: НАГЛАШАВАЊЕ РАЗНОЛИКОСТИ КАО МЕТОДА КОХЕЗИЈЕ?

Сажетак:

Ова студија представља прелиминарне увиде у феноменалност оријентализујућег стила архитектуре у Босни и Херцеговини за вријеме аустроугарске владавине, те детаљно анализира три зграде на бањалучком кантону с нагласком на проблематику доношења одлука у процесу планирања и дизајна грађевина овог периода. Аргументовању споменуте дискусије помажу извори из савремене периодике, као и ново откривена архивска документација. Закључак ове студије ће ставити фокус на географију овог феномена: Да ли оријентализирајућа архитектура лоцирана у сјеверном дијелу Босне, на граници са Славонијом, 'значи' другачије него у Сарајеву и другим градовима централне Босне?

Кључне ријечи: Босна и Херцеговина, Аустро-Угарска, оријентализам, маварски стил, Бања Лука

1. INTRODUCTION

In 2017, the European Research Council (ERC) provided funding to a five-year project that proposed an in-depth study of the phenomenon of the so-called Moorish style during Habsburg rule in Bosnia-Herzegovina (1878-1918). The project team at the University of Vienna's Department of Art History and its associates in Bosnia set out to shed new light on not only a large number of relevant buildings, but also on the mind-set behind their style's conception and diffusion; instead of 'Moorish', they employ the term 'Orientalizing' as this style drew not upon one but several principal sources within the artistic heritage of the Islamic world. [1][2]

The project also committed to studying lesser-known buildings located outside Sarajevo, Travnik, and Mostar. In these cities are found not only considerable concentrations of such buildings, but also their most monumental examples. Much less studied, while by no means of lesser interest, are numerous buildings in Orientalizing forms in Bosnia's northern and eastern regions. They, too, serve to elucidate the phenomenality and development of an Orientalizing visuality in Habsburg-era Bosnian architecture.

This paper will present preliminary findings related to such buildings. They have been advanced with the assistance of Miroslav Malinović and Ajla Bajramović, who have surveyed on foot cities and towns in Bosnia's northern lowlands for surviving buildings in variations of this style, and have undertaken archival research in Sarajevo, Travnik, and Banja Luka.

Through a deliberate selection of cases, this paper endeavours to name and discuss the broader issues involved. In doing so, it intends to facilitate the step from documentation to critical analysis.

2. CASE STUDIES

2.1. Banja Luka, Gornji Šeher Elementary School, ca. 1896 (44°44'51.4"N 17°09'19.9"E)

Among the many schools erected during Austro-Hungarian rule in Bosnia and Herzegovina, Orientalizing forms tended to be reserved for projects related to the Muslim community.[1] This makes the elementary school in the Banja Luka quarter of Srpske Toplice (formerly Gornji Šeher) an interesting case [Fig. 1]. Archival plans [Figs. 2-3] found in the Arhiv Republike Srpske prove that it was planned as a regular elementary school ("IV klassige Elementarschule"). That is to say, it was not built as an Islamic *mekteb* or *medrese* and later converted to a secular function.

Figure 1. *Banja Luka, elementary school in Srpske Toplice (Gornji Šeher). Architect: Franz (von) Mihanovich, built ca. 1896. Photo: Miroslav Malinović, 2018.*

The same set of project plans helps us securely date this building (or, at any rate, its planning) to 1896 and broadly attribute it to the provincial head engineer (Kreisingenieur) Franz (von)

Michanovich. We also learn that he was aided by an assistant ("Ing.-Adjkt") named Paul Pirckmayer. Just what this can be understood to mean will be debated below.

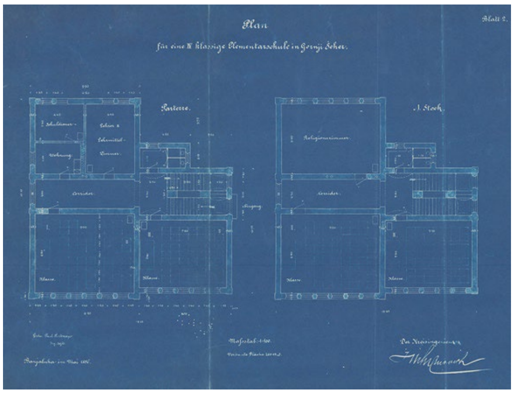
The Gornji Šeher School is, after the Muslim Reading Room (Turkish Kiraethane) perished in the earthquake of 1969, the only surviving building in an Orientalizing style in Bosnia's second-largest city. The polychrome banding and the windows' superimposed horseshoe shapes identify it as belonging to a surge of Habsburg-period Orientalizing public buildings of the 1890s and early 1900s. The widely overhanging eaves, here supported on wooden corbels, are also characteristic for many buildings in this group. The current colouring scheme with alternating pink and yellow is, of course, in disagreement with a more likely original horizontal plaster banding in dark red and beige.

Certain aspects make the Gornji Šeher School diverge from the simplest cases of buildings in this style. Firstly, the generous fenestration; secondly, the asymmetrical façade; and, thirdly, the elaborate roof construction. The latter departs from the economical pitched or hipped standards at the expense of a more varied roof-scape, and closely echoes, as the archival plans reveal, the interior's organization. The decision for, toleration of, or consent to, an asymmetrical appearance may have followed from the design problem caused by differently sized classrooms: the first and second classes were to have 62 pupils/tables, the third and fourth classes only 49.

At the same time, the architect appears to have been determined to orient the buildings so that all classrooms face east. On account of the conspicuously dense fenestration, one wonders if Michanovich was particularly concerned about lighting in this specific project – perhaps due to the school's location in a narrow and deep pass of the Vrbas at the outskirts of the Dinaric Alps.

Yet, a key question remains: Why was an Orientalizing style found appropriate for a secular school in the case of this project and not in others?

One approach could be to relate it to the milieu into which it was built – a predominantly Muslim suburb of Banja Luka. The 1895 population census recorded in Gornji Šeher and neighbouring Novoselija, the quarters this school would likely have served, 506 houses with 2,427 inhabitants. 97% of these adhered to the Muslim faith. The fact that less than half of this demographic depended on income from agricultural work also points to a close connection with Banja Luka's urban economy and a corresponding socio-economic status. In Gornji Šeher, a large number (50) of householders was moreover identified as landowners [3:152-3]. This was to be a 'secular' school, but for pupils who came almost exclusively from a Muslim background.[2]



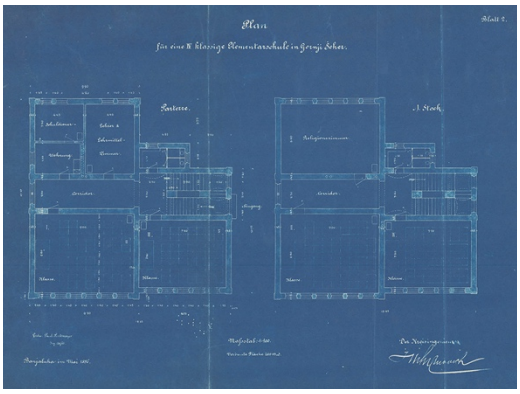


Figure 2. *(Left) Banja Luka, floor plans of the Gornj Šeher school, dated 1896. Source: Arhiv Republike Srpske.*

Figure 3. *(Right) Banja Luka, floor plans of the Gornj Šeher school, dated 1896. Source: Arhiv Republike Srpske.*

Or should the preference for this style be credited to the Kreisingenieur Michanovich, whose name is linked to a large number of projects in this style in Bosnia's northeast?[3] Unfortunately, we still know little about the decision-making power of this group of public servants. They may have mainly executed, if often quite skillfully, what was predetermined by others.

Quite telling in this respect is an unexecuted project for a district authority building (*Bezirksamtsgebäude*) in Bosanska/Kozarska Dubica. Michanovich's signature is found on blueprints that we discovered in the state archives at Sarajevo [Fig. 4]. The design in an Orientalizing style, displaying many similarities with the Gornji Šeher school, is identified there as corresponding to, or deriving from, a template ("Nach einer Type der Landesregierung"). This would suggest that, in such and related cases, stylistic choices were made by upper echelons before orders to plan the details reached the provincial head engineers and their collaborators.

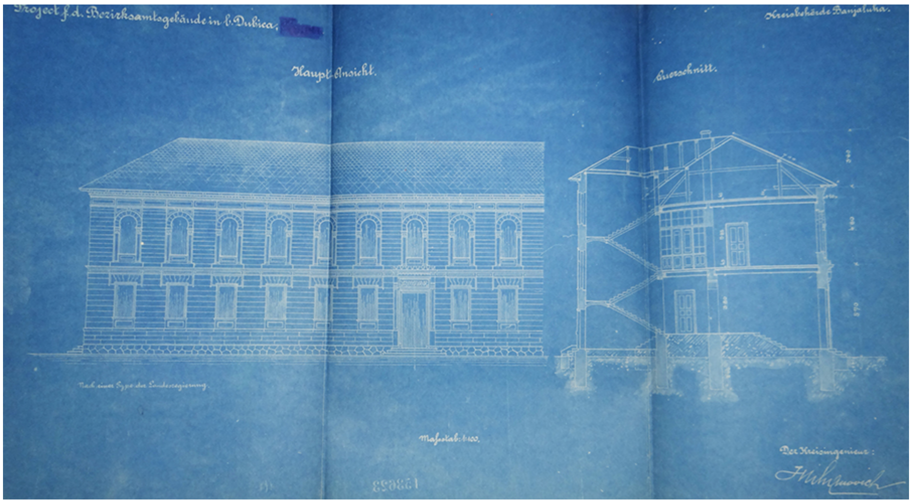


Figure 4. *Dubica, project for an unbuilt district authority building. Architect: Franz (von) Mihanovich, undated. Source: Arhiv Bosne i Hercegovine.*

It may also have been the case that an Orientalizing style was found more appropriate in this situation – by whomever was in the position to make that decision – on account of the asymmetrical scheme apparently necessated by local conditions, notably the sloping terrain and the lighting problem. The school building standard was an axial symmetrical scheme with classicizing ornamentation. This scheme was, for the same topographical and lighting reasons, probably not considered a viable option for this specific plot. The choice for Orientalizing forms thus may also have followed the decision to proceed with an asymmetrical solution, which may have been found unthinkable for, say, a project in Neo-Renaissance forms. The asymmetry and the resulting varied roof-scape may not have looked that out of place in a residential suburb. The free-standing building indeed resembles a villa more than a school. Orientalizing features such as the polychrome banding or the horseshoe shape were evidently foreign insertions into the traditional architectural fabric of Gornji Šeher. However, the same features probably supported the perceptibility of the object as a public building.

Whatever the considerations in the original planning process, it is clear that this school was not a generic project but a surprisingly place-sensitive response, by an almost anonymous public servant, to the challenge of building an elementary school in this particular topographic and cultural setting.

The school is listed (as *Zgrada OŠ "Branislav Nušić"*) as a cultural good of Republika Srpska (NKD025) but not as a National Monument of Bosnia-Herzevovina.

2.2. (Bosanska) Gradiška, Stara Vijećnica, 1890s (?) with extension ca. 1907 (45°08'49.3"N 17°14'59.1"E)

While the former City Hall of Sarajevo (*Vijećnica*) is easily the best-known Orientalizing style building in the whole of Bosnia and Herzegovina, it is less known that a considerable number of administrative buildings drawing upon a related stylistic repertoire exists in smaller towns throughout the country. In towns along the riverine borders with Croatia, no less than five town halls built in this style are preserved – in Brčko, Kostajnica, Gradiška, Novi Grad (Bosanski Novi), and Odžak.

Among these, the *vijećnica* of Brčko is deservedly the best known. This is a free-standing, axial symmetrical building planned on a tripartite, essentially palatial scheme. All other town halls in this part of Bosnia were erected in corner positions and drew upon different formal typologies.

Figure 5. *Gradiška, Stara Vijećnica, 1890s and ca. 1907 (?). Photo: Ajla Bajramović, 2018.*

The former municipal building of Gradiška [Fig. 5] is easily the most remarkable historical building in this border town that once featured an important fortress. Within the typology of Habsburg-Bosnian public buildings this case is unusual in many respects. Its architectural ambition clearly surpasses that of the standard type administrative building. The *vijećnica* of Gradiška is alone among the mentioned examples with a pronounced and centrally positioned single belfry – a mainstay component of European town halls. The extroverted, onion-shaped cupola capping this town hall's belfry probably ensured that it was not mistaken for a church's belfry. This was certainly an unwanted association among the makers of Habsburg policy in Bosnia, who at this point in time sought to avoid alienating Bosnia's Muslims.

The belfry pinpointed the town centre for those arriving by boat. In fact, a situation plan [Fig. 6] reveals that this *vijećnica* was located right where the main street met the street leading to the landing spot for ships ("Save-Überfuhr", "Agentie", and "Save-Wachstube"), opening toward a square ("Platz") with a park. From the upper-storey office beneath the cupola, most central places in Gradiška could be surveyed. In the projected floor plan of 1907 [Fig. 7], this room was taken by the district governor (*Bezirksvorsteher*). However, there is reason to believe that it was previously the mayor's, and located there purposefully.

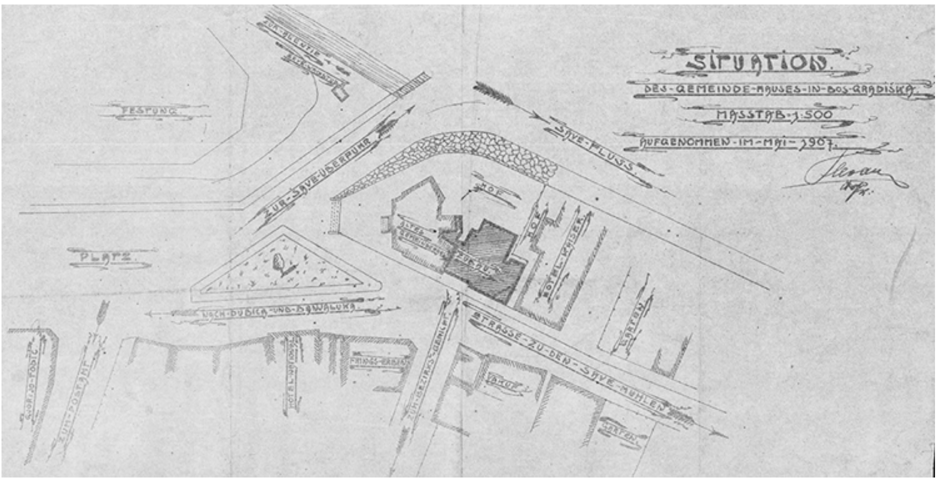


Figure 6. *Gradiška, situation plan of with the extension of the former municipal building highlighted. Source: Arhiv Republike Srpske.*

At this point, it must be noted that the building we see today is actually the product of two building phases. The first, presumably dating to the early 1890s, produced a corner building with arms of approximately the same length hinging from a central tower. This was a municipal building (*općina*), identified on the plan material as "Gemeindehaus," while supra-municipal matters were still handled in another (presumably older) building variously identified on other archival plans in this lot as "Konakgebäude" and "Bezirksamt". It appears that it was then decided to turn that older building into the district court – another (undated) plan in this lot identifies it as "Bezirksgerichtsgebäude" (district-level courthouse) and assigns the rooms to corresponding functions – and move the district administration functions into an enlarged municipal building. This detachment may be related to the separation of district courts (*Bezirksgerichte*) from the district authority offices (*Bezirksämter*) in 1906. [4:171-1]

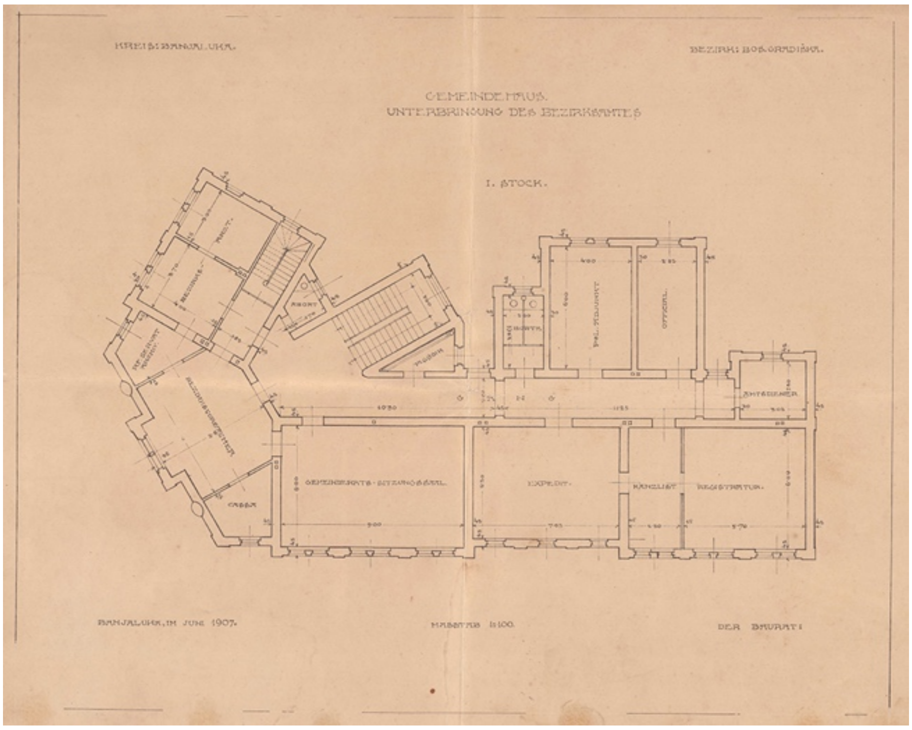


Figure 7. *Gradiška, floor plan of the former municipal building, first floor, dated 1907. Source: Arhiv Republike Srpske.*

For this, around 1907 an annex was built and rooms re-assigned. The *Bezirksvorsteher* moved into the presumably most representative office in the building, affording a good view and located centrally at the end of the flight of stairs on the upper floor. The mayor is found, on plans dated 1909 [Fig. 8], on the lower floor, taking over the veterinarian's office. It is not clearly stated on these plans that the mayor previously occupied the tower office. However, the fact that it is not only located next to the assembly hall but is directly linked with it through a door [Fig. 9] seems to suggest that this was the case.

The extension of ca. 1907 created the additional office space needed for the building to fulfill the tasks of both a municipal and district authority. This was done by expanding the building toward the northeast. This enlargement was undertaken through selective reiteration of the original building's architecture. In fact, no rupture is visually evident. The projection with the assembly hall in the upper floor is repeated after a recessed section with three window axes. However, it appears that the recurring projection in the extension was due to purely formal considerations. For the floor plan reveals that it accommodated not a large assembly room but rather two smaller offices.

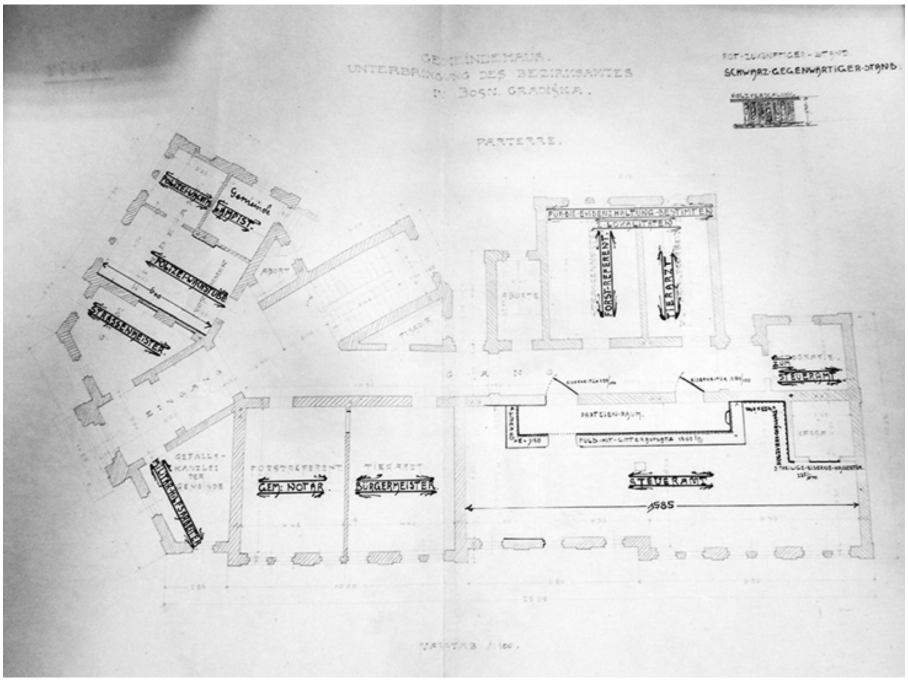


Figure 8. *Gradiška. floor plan of the former municipal building, ground floor, dated 1909. Source: Arhiv Bosne i Hercegovine.*

Additional insight can be gained through comparison with the vijećnica of Brčko, which, if this chronology can be confirmed, must have served as a central reference for the one in Gradiška. This association is perhaps most visible in the towers' design: the cupolas' onion shape and the structuring of surfaces are closely related [Fig. 9]. Another feature that recommends this association is the funnel portal with superimposed horseshoe-shaped arches [Fig. 10]. It is found at Gradiška (with Alhambresque capitals) and at Brčko (with Corinthian capitals) and, to our current knowledge,nowhere else.

Figure 9. *(Left) Brčko, Vijećnica. Architect: Ćiril Iveković, 1891. Details of façade, portal, and ceremonial hall ceiling. Photo: Ajla Bajramović, 2018.*

Figure 10. *(Right and up)Detail*

Figure 11. *(Right and down) Detail*

However, there is one marked difference between the treatment of façades at these two town halls.

At Brčko we find a considerable amount of stucco ornamentation employed so as to enliven the surfaces. At Gradiška we find similar ornamental patterns, yet mostly executed in paint. This suggests that these buildings' architectural morphology and façades were deliberated independently. Was the decision at Gradiška to reduce plastic decoration in favour of painted decoration perhaps due to a smaller budget?

There is another intriguing difference. At Brčko, the ceremonial hall on the first floor ("Gemeinderats-Sitzungssaal"), articulated on the façade as a monumental central section with mullioned windows surmounted by stained-glass rosettes in geometric shapes, is not decorated in a corresponding style in the interior. Surprisingly, a sort of 'Pompeian style' [Fig. 11] was chosen instead. At Gradiška, by contrast, what remains of the ceremonial hall exhibits a pronouncedly Orientalizing style. Thanks to damage visible during site visits in 2018, it can also be discerned that at least some of this decoration [Fig 12], if indeed contemporary to the project and not a later addition, was on wallpaper rather than painted onto the plaster.

More than many other buildings, the old *vijećnica* of Gradiška raises questions about decision-making and design processes in the Austro-Hungarian administrative structure in Bosnia-Herzegovina. It illustrates how the challenge of extending and reorganizing an existing structure was approached. Finally, with regard to the case of Brčko, it illustrates how (presumably) preceding projects informed (presumably) later developments in the same category. In Gradiška's case, the replication was very selective. The model was translated for a different site rather than transposed there.

The building (as part of the disparate ensemble *Vijećnica i Hotel Kaiser*) is listed as both a cultural good of Republika Srpska (NKD770) and a national monument of Bosnia-Herzegovina.

Figure 12. *Gradiška. Stara Vijećnica, ceiling of ceremonial hall. Photo: Ajla Bajramović, 2018.*

2.3. Banja Luka, former Husedžinović house, ca. 1911 (44°45'54.9"N 17°11'14.0"E)

This building's [Fig. 13] importance in the region's architectural history appears to have been greatly underestimated. It represents one of the few truly significant examples outside Sarajevo of the so-called Bosnian Style (*Bosanski slog*), developed in the early 1900s in reaction the damage that imported architecture caused to traditional townscapes. While this 'neo-Bosnian' style's proponents were foreigners themselves, there are clear indications that it had a broader following among Bosnia's different communities than the exoticizing Orientalizing style of buildings like the Sarajevo *Vijećnica*. Even so, this early neo-vernacularist experiment remains largely unknown outside Bosnia.

The Husedžinović house in Banja Luka was the work of the renowned Josef (Josip) Vancaš, one of the 'builders' of Sarajevo. The contemporary significance accorded to this project is evidenced by the publicity it received in the German-language architectural press [Fig. 14-15]. [5] That publicity affords us privileged insight into the design process and considerations during that process. Also exceptional is the preservation of one part of the original interior – some of which remains on site, some of which resides in a local public collection. Together with the fact that the original householder was a relatively well-known person in Banja Luka's more recent history, a fairly comprehensive picture can be drawn.

With regard to the architecture, first, the façade's axial symmetry is noteworthy. It may be considered exceptional in comparison to the picturesque impression buildings in this neo-vernacular style generally sought to achieve, and usually through asymmetrical designs. In that sense, the Husedžinović house seems to exemplify a compromise between the ambition to produce something in line with a tradition and the need to achieve accord with established European schemes of representative monumentality.

Figure 13. *Banja Luka, former Husedžinović house. Architect: Josef (Josip) Vancaš, ca. 1911. Photo: Miroslav Malinović, 2018.*

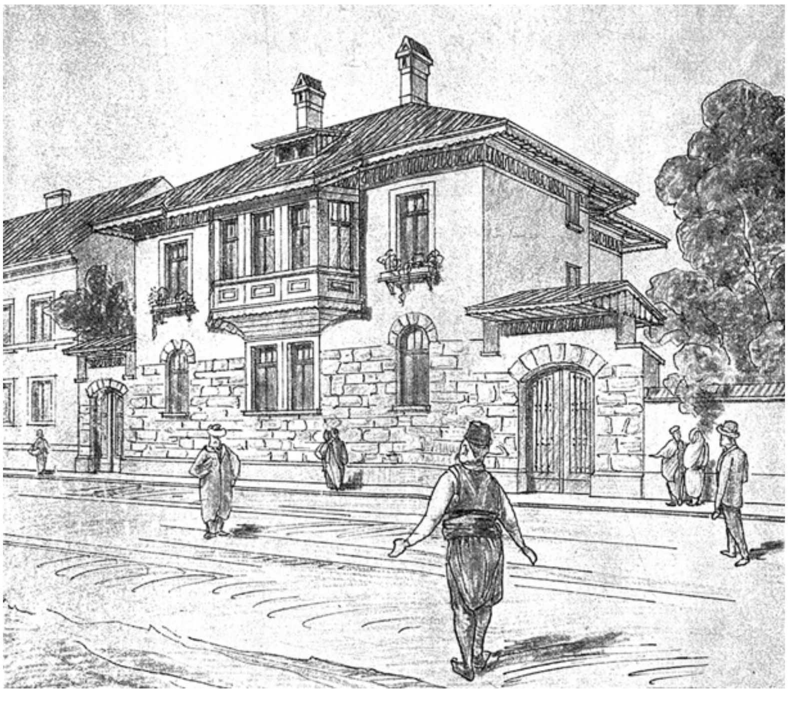


Figure 14. *Banja Luka, former Husedžinović house as depicted in Der Bautechniker in 1915 (XXXV/25, plate 25).*

The façade is divided into three parts. The central section is pronounced by a bay window surmounted by a cat-slide roof and a clustering of windows, echoing a traditional interior seating arrangement. The lateral façade areas are distinguished by semi-circular arches on the lower tier. The (originally irregularly) rusticated plinth adds a romantic touch. The reductionism of the mostly geometric ornament (cornice frieze with vertical lining, rectangle contours on bay window, window compartments) betrays a late secessionist influence.

If we compare the illustrative drawing by Vancaš from a century ago with today's building [Figs. 13 & 14], we notice that some important characteristics of the original appear to have been undone. The green colouration contrasts with the whitewashed façades that are considered defining for this style. Moreover, the plinth's facing with industrially processed stone of uniform shape contributed to a loss of picturesqueness, as have the windows' plastic frames on ground floor level. The original chimneys have also been removed. All this aside, the building's overall character is well preserved.

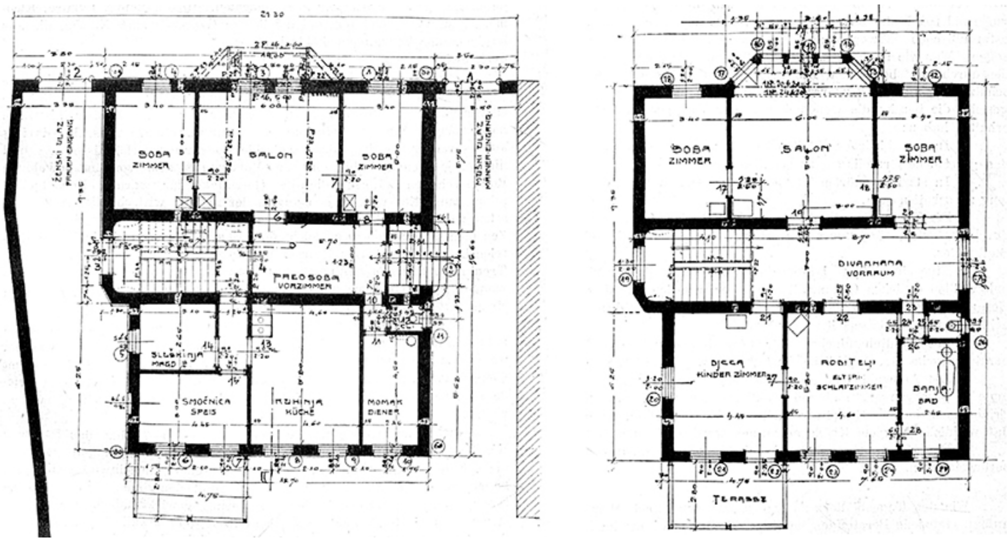


Figure 15. *Banja Luka, former Husedžinović house, floor plans.*
Source: Der Bautechniker XXV/25 (1915), p. 193.

Regarding the interior, the spatial arrangement itself [Fig. 15] is noteworthy from the viewpoint of architectural history. This project by a non-Muslim architect closely echoes the householder's requirements to retain a traditional spatial division of public/male and private/female. This is illustrated and described briefly but tellingly in the journal *Bautechniker*, seemingly by the architect himself.

Two entrances correspond to the different sexes' preferred paths of entry: males to the left, females to the right. The male section leads to a vestibule from which the 'public' rooms of the householder, facing the street, were accessed; the servant's room is immediately to the left. The 'female' entrance provides easy access to the maid's room and the kitchen as well as direct access to the staircase leading to the ('private') upper floor. Noteworthy, too, is that these rooms are not multifunctional anymore, although that would more closely correspond to traditional dwelling practices. On the floor plan we see a parents' bedroom, with an *en-suite* bathroom, next to the children's' room, both facing the Vrbas. The salon (Turkish *divanhane*) of the 'private' upper floor, by contrast, faces the street. In contrast to traditional *konak*-type residences, which often emerge from a courtyard shielded from public view by walls, this representative townhouse also directly faces the street.

What we see here is a quite creative interpretation by Vancaš of a traditional gendering of space. The separation is not twofold but fourfold, and for this purpose engages the building's height as well as depth. The 'private' upper floor is separated into a more public area, articulated on the exterior through a densely fenestrated (and hence more transparent) bay window, and far less public areas facing the garden. This division apparently facilitated the house's later division into two privately-owned flats.

Also interesting is the furnishing programme, to the extent that it can be reconstructed. [6] [7:227,233] The householder's workspace on the ground floor featured wooden furnishings, imported from Cairo via Vienna (!), carpets from Shiraz, Bosnian rugs, and a ceiling painted in Orientalizing forms. It was known as the 'Arab room', probably reflecting a European fashion at the time. In 1958, the movable objects were transferred to the holdings of the Museum of the Bosnian

Krajina in Banja Luka, that is, the present day Muzej Republike Srpske. On the upper floor, the *divanhana* more clearly corresponds to a local, Ottoman tradition, possibly amalgamated with (a contemporary take on) the cultivated simplicity of the Viennese *Biedermeier* aesthetic. Most of the furniture, indeed, was imported from Vienna, as was the tableware and a large wall clock with an engraved inscription, in German, reading “Time is Money”. This probably reflected the householder’s mercantile ethic, for the Husedžinovići were not an old ‘noble’ family but more recent upstarts. The householder Hamzaga owned a profitable brick factory and later served as the city’s mayor.

On the upper floor was also the so-called Pink Room; its furniture arrived from Paris, again via Vienna, and echoed the style of Louis XV. This section of the furniture was sold to a buyer in Dubrovnik and is not preserved in situ.

In the end, one can ponder the reasons for Hamzaga Husedžinović’s choice of this specific architect and style at this point in time. It is likely related to Vancaš’s project for the *Landesbank*’s Banja Luka branch, erected just before. Husedžinović may have taken a liking to this building (destroyed in the earthquake of 1969), which, as a businessperson, he must have visited quite regularly. This may have led him to commission the bank’s architect to plan his residence using a similar formal repertoire. This style contrasts greatly with the villas another Muslim entrepreneur named Ali-aga Kučukalić commissioned from a yet unidentified architect in a more established Orientalizing style in Brčko and Šamac [Fig. 16], presumably only a few years earlier.

The Husedžinović house is not on Bosnia-Herzegovina’s list of national monuments, but has been listed as a cultural good of Republika Srpska (NKD064).

Figure 16. *Šamac, former villa of Ali-aga Kučukalić. Photo: Ajla Bajramović, 2018.*

3. CONCLUSION

The relative briefness of Habsburg rule (1878-1918) stands in great contrast with the extensive architectural imprint it left on Bosnian-Herzegovinian townscapes. Public buildings played an important role as forerunners of a changing aesthetic and models for imitation. However, while the architecture of historicism is often said to have had a homogenizing effect on Central Europe's urban fabric [8], this evidently did not preclude projects, both publicly and privately commissioned, that would clearly have conflicted with an alleged agenda of homogenization.

Just south of the old Sava border between Bosnia and Croatia-Slavonia, we find a large number of buildings designed in Orientalizing forms. In this particular region, which long constituted a threshold between the Habsburg and Ottoman empires, one would have expected efforts to level the differences caused by longstanding separation. Yet, these buildings seem to emphasize rather than downplay the region's liminality. Its historical alterity is stressed rather than silenced.

The three buildings discussed above also allow us to draw significant, if preliminary, conclusions with regard to the process of these buildings' planning and design. They may be exceptional; at the same time, they illustrate how 'case-sensitive' provincial building projects could be, if deemed necessary.

LITERATURE

[1] M. Hartmuth, "Amtssprache Maurisch? Zum Problem der Interpretation des orientalisierenden Baustils im habsburgischen Bosnien-Herzegowina," in Bosnien-Herzegowina und Österreich-Ungarn, 1878–1918: Annäherungen an eine Kolonie. C. Ruthner & T. Scheer, Eds. Tübingen: Narr 2018, pp. 251-268.

[2] M. Hartmuth, "Nach dem Danach: Metamorphosen eines orientalisierenden Schulbaus der Habsburgerzeit in Mostar," kunst und kirche, 3, pp. 10-15, 2019.

[3] Hauptresultate der Volkszählung in Bosnien und der Hercegovina vom 22. April 1895 [etc.]. Sarajevo: Landesdruckerei, 1896.

[4] F. Schmid, Bosnien und die Herzegovina unter der Verwaltung Österreich-Ungarns. Leipzig: Veit & comp., 1914.

[5] [Josef v. Vancaš?] "Familienwohnhaus des Herrn Hamidaga Husedjinović in Banja Luka," Der Bautechniker, XXXV/25, pp. 193-194 and plate 25, 1915.

[6] L. Bušatlić, "Transformacije gradske kuće orijentalnog tipa u postosmanskom periodu na području Bosne i Hercegovine," in Centres and peripheries in Ottoman architecture: rediscovering a Balkan heritage. M. Hartmuth, Ed. Sarajevo: CHwB, 2011, pp. 122-135.

[7] I. Krzović, Arhitektura Bosne i Hercegovine 1878–1918. Sarajevo: Umjetnička Galerija BiH, 1987.

[8] Á. Moravánszky, "Die Sprache der Fassaden: Das Problem des Ausdrucks in der Architektur der Donaumonarchie 1900-1914," in Architektur im 20. Jahrhundert, Österreich. A. Becker, D. Steine, W. Wang, Eds. Munich: Prestel 1995, pp. 12-21.

---

1 The most monumental examples of educational buildings in this style concern cases in which Muslim high schools from the Ottoman period were rebuilt, usually *ex novo*, as was the case with the *medrese* of Elçi İbrahim Paşa at Travnik (*Elči Ibrahim-pašina medresa*, 1895, arch. Ćiril Iveković). A less prominent example in the area of Banja Luka is the *medrese* of Derviş Hanım Smailagić (*Derviš-hanumina medresa*, ca. 1899, arch. unidentified) at Gradiška, reopening in its original function in 2017. By contrast, for supra-confessional schools the choice of an Orientalizing style was uncommon. The Mostar Gymnasium (1898/1902, arch. Franz Blažek) is easily the most prominent exception.

2 In 1895, all but 35 of Banja Luka's 6,042 non-Muslims (45% of a total population of 13,566) lived in the lowland quarters of Donji Šeher (mixed but predominantly Muslim), Varoš (almost entirely non-Muslim), and Petričevac (not yet developed).

3 E.g. Tuzla's *Šarena džamija* and the district authority building (*Bezirksamtsgebäude*, later municipality/*općina*) of Gračanica.

18 | Review paper | Прегледни научни рад
ISSN 2566-4484 | Doi 10.7251/STP2014196V
pages 196-206

Aleksandar C. Videnović, videnovic.a@gmail.com, Faculty of Architecture, University of Belgrade

Miloš Aranđelović, mls.arandjelovic@gmail.com, Faculty of Architecture, University of Belgrade

MULTIFAMILY HOUSING IN THE VILLAGES OF SERBIA: FROM INAPPROPRIATE SPATIAL APPEARANCES TO POSSIBLE ELEMENTS OF URBANITY

Abstract:

Rural housing is directly linked to agricultural work, so the organization of space in the yard is fundamentally different from the functional characteristics of urban housing. In the villages of Serbia, over the years and after the Second World War, multi-storey residential buildings were erected for service to non-agricultural population. By their basic manifestations and visual manifestations, as well as functional characteristics, these objects never fit into the image of the village, and their users do not enter into the habits and customs of life in the environments in which they are built. Semi-agricultural and non-agricultural population in rural areas is predominant today, so the question arises as to the relation of the profession to multi-family housing in villages.

Keywords: multi-family housing, rural context, non-farmers, relationships, adaptation

ВИШЕПОРОДИЧНО СТАНОВАЊЕ У СЕЛИМА СРБИЈЕ: ОД НЕПРИМЕРЕНИХ ПРОСТОРНИХ ПОЈАВА ДО МОГУЋИХ ЕЛЕМЕНАТА УРБАНИТЕТА

Сажетак:

Становање у селима је непосредно повезано са радом у пољопривреди, па је организација простора на дворишту суштински различита од карактеристика урбаног становања. У селима Србије су током времена, а након Другог светског рата, грађени вишеспратни стамбени објекти, намењени услужном непољопривредном становништву. Како основним појавним и визуелним манифестацијама, тако и функционалним карактеристикама, ови се објекти нису никада уклопили у слику села, а њихови корисници у навике и обичаје живота у срединама у којима су грађени. Полуаграрно и неаграрно становништво у селима данас преовлађује, па се поставља питање односа струке према вишепородичном становању у селима.

Кључне ријечи: вишепородично становање, рурални контекст, непољопривредници, релације

1. INTRODUCTION

The main issue discussed in the text is the problem of spatial and social integration of the phenomenon of multi-family housing in collective multi-storey buildings into rural settings in rural areas. Through many years of research in the field of architecture and urbanism in rural areas, especially in the problem of urbanization of rural settlements and the organization of their centers, the authors point to the existence of an inappropriate form of housing in such environments. The text highlights some of the many spatial and sociological problems that the construction of these types of housing has created. The text intends, through the observed spatial - social conflicts, to point out the breadth of problems in the urbanization of such environments, bringing to the same plane of observation other similar cases with regard to the treatment of objects of urban character in rural milieus.

Using theoretical knowledge about the villages and their habitation, previous researches on the genesis, stages and motives of construction of the objects in rural settlements, the method of observing and noting the phenomena, relations and contrasts in the behavior of users in the area, some general conclusions are stated in the text and in principle recommend moves to further treat the artifacts in the surrounding environment. The entire rural space of Serbia, without statistical and factual data, was taken as the framework for the article and its findings, since the paper does not seek to deepen and solve specific named problems, but to its general perception and attempt to point out the need for its careful professional solution.

Given the large number of cases (almost in every village of rural character), the paper tends to offer one possible point of view regarding the direction of further urbanization of rural settlements and their centers, with the aim of making more rational use of the content needed in the rural area, but were not appropriate. A considerable number of these buildings and those of a public character are being abandoned and left to devastation due to the demographic emptying of the village. One of the aims of this text is to recall the possibility of their re - use, in the context of socio - demographic developments, and not infrequently economic - state - political needs. There is no need to lose sight of the constant need for further appropriate urbanization of the village, which should not have the character of disaster and coincidence.

2. HOUSING AND RURAL ENVIRONMENT

Living in villages implies a pronounced individuality and the existence of smaller communities in a (depending on the type of village) sometimes larger and sometimes smaller area. Such a community is usually represented by a close or broader family, or (formerly) a family cooperative, or a gathering by close relatives of relatives, to the broadest extent of gatherings of a diverse and agrarian population. Rural settlements in the predominant centers of agricultural land to which they are referred, and mutually reasonably linked in a hierarchical sense, are the predominant type of organization of life not only in Serbia but in most countries of the world. The main reason for such distribution of the population is its agrarian character, and its tendency to have a direct connection with the area of its basic activity - agricultural land.[1] This connection of life and work in one place, led to the creation of a specific organization of space in the village yard, where clearly interwoven work and other spaces can be clearly observed. As a rule, these relationships are also a generator of the morphological structure of a rural settlement, where, depending on the size, organization and interrelations of the yard, the basic units of the rural settlement, the village and its spatial character are formed.

Due to the connection with work, and as a rule agricultural, the organization of space on the housing of the rural population is very different from the functional characteristics of urban housing. Apart from being spacious and in the image it provides, rural housing in its most general form is clearly grouped into the character of a rural settlement, which over time creates a traditional, inherited attitude towards the ideal and appropriate apartment and garden, the relationship between private and public, feel intimacy and degree of connection with the neighbor, aesthetics and design of objects and their associated usable objects and spaces.[2] Regardless of whether they are in the plain or in the mountains, whether they are compacted or scattered on the slopes of the hills, whether they have more or less begun to take on the character of small towns, urbanize themselves, rural settlements of Serbia (but also other areas) have received in recent times, a discreet atmosphere, which, by the first impression of the observer, has classified them as less prosperous, yet recognizable rural milieus.

By its nature, the village is a closed and conservative environment, mostly a society of like-minded people and acquaintances and neighbors. As such, it is very difficult to adapt to any type of innovation. The established lifestyles practiced by one environment are difficult to change and it takes decades to infiltrate new ideas, customs and ways of thinking into everyday life. In spatial terms, in terms of urbanization of rural areas, the greatest difficulties were encountered in understanding and trusting the villagers, not only in terms of adopting new solutions in landscaping the village, but also in adapting to new architectural forms and objects.[3] The full realization of the advanced visions and plans that the rural areas were to turn into small towns, with recognizable character and peculiarities of specific places did not, as a rule, occur. Instead, the first steps in the design of the village in the form of built public or multi-storey residential buildings are merely attempts, which, as they testify today to the vision of the future, are gloomy to prove the futility and flaws of urban visions of that time.

3. BUILDING CHRONOLOGY AND BUILDING MOTIVES

A radical cut in the construction of facilities in villages was made immediately after World War II, when in rural areas, fueled by a wave of new ways of thinking and new social and productive relationships, buildings began to emerge with the task of symbolizing a new age. Thus, in the economic sense, larger cities and centers are equipped with factories and industry. The construction of industrial plants and factories in the more developed parts of Serbia was not accompanied by adequate construction of workers' flats and dwellings. At least this happened in the villages, which in the post-war period were also an uninteresting space for the development of new social relations. The village, by its agrarian structure and less inclination towards the newly proclaimed social rules, was considered as a backward environment, not to invest, but only to divert resources and drain potential labor for the needs of industry in cities. As poor agricultural districts, the villages provided their needs for new housing in personal management, as before.

After World War II, in many places in Serbia, architecture was built without the obligation to achieve aesthetic reach, or without a visual imperative.[4] Cooperative Homes, Administration Buildings, Workers and Servants Homes and other functions have been built. Known as the socialist realist, this phenomenon tended to rationalize, to completely simplify the form, to clean objects from any decoration, even to the border of the ugly, and not infrequently beyond. In the villages, such architecture was very applied, as it was necessary to quickly break with the tradition in construction, and to impose new relationships through various spatial manifestations. Municipalities were also built in this manner. Although all of this is evidenced by their rational socio-realistic appearance, these buildings are not without a certain aesthetic. What attests to a much greater extent to the social relations of the time is their position in relation to the settlement, where the buildings dominated by squares, are symmetrically placed in the center of the settlement and, by their existence, permanently emit symbols of power.

Figure 1. *Cooperative home in the village Donja Kamenica near Knjazevac, built by type design and Soviet model in the 1940s, after the Second World War.*

The first wave of buildings that came into the village by directive were not residential. Primarily, typified cooperative homes were built, similar to the Soviet ones, intended to unify consciousness and opinion and to bring together villagers around socialist innovations dictated by cities and higher places. These buildings still exist sadly in the rural areas of Serbia, to a lesser extent brought to some rational purpose (shops, warehouses ...), testifying to the unnecessary neglect of objects of solid architecture and condition, in a modern transition time without a rural development strategy.[5]

Figure 2. *Multi-family buildings of the first wave of construction in the years after the Second World War. (Kalna settlement below Stara planina in eastern Serbia)*

In the 1950s, the second wave of construction in the countryside began the practice of building homes for non-agricultural dwellings, which were increasingly growing in anti-agrarian times. These minimal collective residential buildings with a maximum of 4 apartments, usually constructed in displaced locations from village centers, were intended for working families (health, education, culture, administration ...). They were classic apartment buildings and the architecture of social-realist times, with max. two-bedroom apartments sufficient for a small family. The flats are designer-packed in a tract - a panel system of rigorous rectangular building bases, in which storefront or post office and police rarely appeared on the ground floor, rarely ambulance. The model of such construction proved, although forced, to be a long-lasting and poor solution, since, from the point of view of comfort and aesthetics that these buildings now provide to the population and appearance of the settlement, it would be better if they were not built.[6]

Figure 3. *Second wave of residential architecture construction in settlement / litle town Crna Trava in eastern Serbia. Buildings form a row around the central plateau. The buildings were subsequently upgraded. At the bottom of the series and in the middle were the contents later built.*

The housing problem seemed to be seemingly solved for a short period, so after a few years of break, in the late 1950s and early 1960s, the third wave of housing construction in rural areas continued. These buildings were constructed in a socio-realistic manner, but were of slightly larger capacity. Designed for a little more (about ten) families, with spaces for grocery and colonial goods on the ground floor. In general, orientation to the use of social housing could hardly be realized in the villages of Serbia in those years. Many then went on permanent rural living conditions because of the housing problem. Buildings built in the 1960s in rural areas could not satisfy the agrarian-industrial population in the housing-working sense, accustomed to owning a piece of arable land and some little livestock in their daily lives, regardless of the primary work they do. In addition, cramping in a 40-50 square meter apartment and the lack of a garden, porch and yard, contact with the ground, was not the right model for accustoming the population to new housing tendencies. A serious problem was also the threat to privacy, both in the absence of the comfort of a separate entrance and a piece of territory, and with regard to the realization of any investment in the maintenance of the common facility. The disadvantage of these investments is their social character or feature of the common good, instead of private property, which the conservative rural population did not readily accept.

Figure 4. *Facility constructed for the purpose of housing workers in an industrial facility in Vlasina Lake recently. A building was formed in the background for the needs of doctor and teachers much earlier. (Vlasina Okruglica)*

In the 1970s (4th wave), residential buildings were mostly built in the villages of Serbia, mostly in areas where economic or other public facilities appeared, which required accommodation of additional workforce. At the time, it was mostly built in regions that were assisted by the state as underdeveloped areas. The expansion of activities in villages and the increasing need to keep up with the more developed areas, and often to mitigate the migration of the population through the construction of industrial plants, created the need for new housing. In the eighties and early nineties of the 20th century, the buildings of the last 5th wave of collective housing construction were being built in the villages of Serbia. Any subsequent construction was an exception, but not the appearance of a new wave. [7]

These facilities are more contemporary and formatted fully urban-designed facilities, usually taken from urban experiences, which are planned to help urbanization of rural centers. Buildings are of different functional concept. Almost all contain smaller (up to two bedroom) apartments. In addition, the floors are slightly larger (up to four floors). The systems for fitting apartments and concepts are different: three apartments per floor, disposition with a three-sided orientation, the appearance of a half-level, then two apartments per floor, with a separate entrance for each apartment (foreign experience in preserving the intimacy of the entrance), etc.

Figure 5. *The facility for the needs of health and child care workers, built in the 1980s. Urban architecture in a rural landscape. (Crna Trava)*

The right to an apartment, in the conditions of obtaining social property at the time, was of interest to users of rural multi-storey and multi-family buildings in two ways:

- as a first step in furthering their progress and moving to larger centers, or finally evicting rural and, in their view, passive environments, and

- as a definitive solution to the housing problem without further ambition, or as a way of rejecting touch and connection with agrarian work.

Figure 6. *Multi-family residential building where each apartment has a separate entrance. Foreign experiences in the late 1970s in Crna Trava.*

The so-called services - non-agricultural population (administrators, traders, workers, artisans, postal workers, police officers, teachers, doctors, veterinarians, educators, and many more) had to be attracted to the apartment and provided with livelihood (higher pay). so that, in the general trend of satanizing the countryside as an environment, they agree to live in the villages and serve the rural population. Beneficiaries of socially owned apartments received these for use while serving in one of the activities, but this was most often converted into a permanent use practice, with a right of inheritance, thus transforming part of the population into rural residents with urban habits. The temporality of their stay in the countryside and the urban habits they brought with them to these underdeveloped areas was reason enough to offer them as flats facilities and housing unsuitable for the village, with no yard and no working alternative.

Decades before the construction of the objects (until World War II), with more or less success, but always charming and spontaneous, created the character of rural areas and created the spirit of a place in rural areas. In that character, the traditional image of the village, the conservative habits and customs of life in the neighborhoods where they were built, multi-family housing facilities, and especially their immediate occupants, never failed to fit.

Figure 7. *Different types of residential architecture in the center of Zlot, near the town of Bor.*

4. ADJUSTMENT IN THE RURAL MATRIX AND RELATIONS WITH THE ENVIRONMENT

From the point of view of urban regulation, these buildings are, since they are multi-storeyed, dominant in height in terms of ground floor or slightly higher mileage (max. Ground floor, first floor and under the roof). As such, they erroneously accentuate the silhouette of the environment, and unjustifiably assume the role that, at a time of thoughtful space and settlement planning, had a church (religious) or possibly some other object of general importance. In the horizontal sense, these facilities do not, as a rule, respect the existing settlement regulation and the principles of placing the objects in the existing matrix. This happened due to the demanding size of the dimensions of the buildings, and to the village with inappropriate functional characteristics (access surface, entrance, surrounding space, distance from the surrounding physical structure). Satisfying only the needs of a certain part of the population for living space, they in the inherited morphological matrix of space create confusion, and disturb the established rules of spatial behavior, without bringing the essential quality in urbanization of the environment, which as a consequence of such radical visual and physical intervention in the space would have to expect.

Figure 8. *Horizontal and vertical urban confusion at the site of Kraljeve Vode on Zlatibor Mountain. (Western Serbia)*

At the turn of the century, the emergence of the construction of overall inappropriate accommodations in rural areas, occur in locations of investment interest. The law of profit, has found its origins in spas and tourist sites and localities, which still have the visual character of rural agglomerations or quite small towns.[8] This phenomenon finds its reasons in the interest that the tourist accommodation capacities (apartments and studios, belonging to the type of contemporary temporary residence) are located in the immediate centers of the settlement, close to the existing attractions, where there is not enough space for construction, so that the desired capacities are achieved through their development in height. Such tricks, and distorting the spirit of the place, or disregarding the context and traditional image of localities with a predominantly rural character, have negative effects in the experience of a space where users are essentially deluded, leaving urban areas for relaxation in pseudo-urban environments.

A particular problem with such residences is their lack of location in the ground floor. Designed for urban environments, such structures require adequate treatment in surface treatment. Whether a multi-family dwelling is to be found in its natural urban milieu or in landscaped areas depends on the degree of urbanization achieved. The occurrence of incompleteness of the environment in which the object is located is one of the important reasons for its non-alignment within miles. Access to the construction of structures, which is not accompanied by the arrangement of the ground floor areas around it, and to fit with existing landscaping if any, is a common occurrence in rural areas, and not infrequently in cities.[9] However, while in urban areas such deficiencies are resolved over time, planned or spontaneous, in the villages these buildings remain on untreated soil for a long time, giving the impression that the construction is just finished or that the building is not being used, which is often true.

Figure 9. *Contrasts of traditional and urban in the tourist site of Kraljeve Vode on Zlatibor Mountain.*

Quite especially in relation to the urban - architectural and sociological aspect of this problem, there is a psychological moment, both in the tenants and in the environment. Although aware of the specific occupations of the beneficiaries of these housing collectives in a highly individualistic environment, the surrounding agricultural and semi-agricultural population is nevertheless subject to a distorted idea of their way of life and sincere affiliation with the village.

Figure 10. *High-altitude contrasts on the lake at Kraljeve Vode tourist site on Zlatibor mountain. Architecture has elements of traditional construction in hilly and mountainous areas.*

On the other hand, the situation in which the occupants of such buildings are located presents a certain psychological pressure. Constantly exposed to critical judgment by communities in an environment that can hardly be quickly urbanized and thus mitigate the strangeness of their lifestyles, they resort to adapting to rural habits and thus bring the space in which they live and themselves as users of that space to the limit of the absurd.

5. CONTRASTS IN CONSUMER BEHAVIOR AND HOUSING CULTURE

From the point of view of the character of a multi-storey dwelling, where its urban moment could never be related to the rural environment, contrasts can be seen and expressed in the behavior and experience of the premises of the users of these buildings and the objective possibilities that were designed and built in a given place. The population with urban habits tends to adapt to the rural environment and, in many areas of behavior, embraces the habits of rural life. Regardless of the non-agrarian profession, marginally engaging or merely relying on the peasant economy, this part of the population needs additional space and those specific amenities that an apartment in multi-storey buildings is not even designed to satisfy.

Thus, the common space of these buildings (staircases, huts, eaves, storerooms, laundry rooms and council house rooms) will, as a rule, be transformed into improvised facilities, which in the countryside satisfy the space and contents of the yard around the house (firewood, porches and stables, meat-drying facilities, cellars and summer kitchens). The spaces in front of the entrance to the apartments will become an integral part of the private space of the apartment, and not infrequently, the scarce courtyard around the apartment buildings will be used as a small plant, winter heating stock or, in the worst case, for some of the economic buildings (chicken coop, pig building...).

Collectivity in the character of certain functions of multi-storey residential buildings, which implies discipline and a certain degree of urban housing culture, in rural areas is transformed into a set of more or less harmonized individual claims to public space, whereby a high degree of mutual understanding of different users is achieved. In other words, what is almost unimaginable in the usurpation of common spaces is becoming a reality in rural settings and enjoying the tacit mutual consent of users. Housing in buildings of a collective character, in smaller rural areas, has inevitable consequences in terms of radical contradictions in the housing culture and the demands that collectivism places on tenants. The stairways and public spaces in front of these facilities are thus converted into winter pantries, with wood leaning on the stairs next to the front door. A lot of things are kept in front of the door and the rooms in the apartments are inadequately used.

In this way, such objects, spontaneously adapted to the environment by the user, lose their basic designed sense. On the one hand, the function of space is being grotesquely altered, and on the other hand, the new individual comforts achieved are far from the essential and truly comfortable life in the countryside. If, for example, the vast majority of rural residents living in multi-storey buildings are heated by wood (which is logical given the cost and affordability of fuel), the question arises as to the justification of designing and constructing a common heating system from a boiler room or rarely a hot water system.[10] Conversely, if the aforementioned and other elements of collective residential buildings in the villages are not realistically used, then the question of the justification of planning and construction of such housing facilities in them is raised.

The rural behavior of tenants in the private or public spaces of urban buildings is an appropriate topic for deeper sociological analysis. The results of such an analysis would further deepen the doubt about the quality of this approach to urbanization of space.

6. FINDINGS AND RECOMMENDATIONS

There are several general findings regarding the consideration of the issue of multi-family housing in rural areas of Serbia:

- this type of housing in rural areas is resorted to in order to solve the housing problems of servants, workers, in any case non-agricultural population in villages
- the right to inherit an apartment, always looking for housing again, because those who are no longer in service in the settlement stay in the apartment
- in the face of crises and difficult living conditions, the population resorts to their own agriculture; this is where the gap between living in an apartment building and working on a farm property arises
- not always, and not everywhere, but in the vast majority of rural households, the problem of heating is solved solely by supplies and the exploitation of solid fuels (coal, wood), which is completely logical and reasonable; common living spaces inside and outside buildings are a kind of heating storage
- there is and will be a visual, ordinary, sociological, cultural and other disparity between dwelling in collective buildings with multiple dwellings, and living in the countryside along the land and in the yard
- the possibility of effectively incorporating these structures into the rural milieu is observed, especially later constructed structures and necessarily under the expert guidance of urbanization.

The less agricultural the settlement, the smaller the disparity and vice versa. Agrarian practices, especially in the centers of settlements, are becoming less pronounced. Economy functions and auxiliary facilities with livestock have long since disappeared from rural centers. Almost a small amount of arable farming remained, mostly hidden from the public, behind backyard houses and removed from public areas of the village.

For many reasons, the relative possibility of incorporating collective residential buildings into rural settings can be noted, a phenomenon that has long been nothing new in settlements, and which can fit into the image of many places characterized by the beginnings of urbanization. This inclusiveness must now be supported by the actual exploitation of all content created, so that by reviving settlements through affirmation of different approaches to creating new surplus value, many of the resources will be re-appreciated and sought after.[11] It can be assumed, however, that in an attempt to revitalize rural settlements, where undertaken, existing architecture will fit into new concepts.

Figure 11. *The Crna Trava Center aims to reconcile the contrasts and continue urbanization of the premises at the municipal headquarters.*

The fact that mixed (semi-agricultural) population in the villages of Serbia has begun to prevail, and that these processes will continue in the future, indicate an inadequate approach to the construction of housing for the population whose agriculture is secondary, but as a rule always present in supplementary provision of funds for life. Alienation and discouragement, and even dissatisfaction with the way of life, which is created over time by tenants in multi-family housing estates in the countryside, is a good reason to approach the provision of housing for the servant population of the village in a more appropriate way, more appropriate to the rural environment.

The problem of urbanization of villages, which by its characteristics will grow into smaller cities, is the most important framework of action for experts of different profiles, precisely because of the very negative experiences that the rural space of Serbia has in the current practice of urbanization. [12] The current state of multi-family housing in villages is one of the problems that must be addressed with respect to the various disciplines and aspects whose experts are also called upon to deal with the spatial planning of neglected and lay-treated rural areas.

Figure 12. *Arc - a fountain in the center of Crna Trava. In the background is the Municipal Building from the early 1950s. To the left at the end of the residential block is a multi-functional facility (Bus station with accompanying facilities, bakery, restaurant and apartments) as a symbol of the transformation of space in the transition period.*

LITERATURE

[1] B. Kojic, *Seoska arhitektura i rurizam*. Beograd, Srbija: Gradjevinska knjiga. 1973.

[2] А. Виденовић, М. Аранђеловић, *Нови знакови у пределима - реафирмација природних и створених вредности*. Београд: Архитектонски факултет Универзитета у Београду, 2019.

[3] R. Pride, *Destinacija kao brend*, Beograd: Klio, 2015.

[4] М. Аранђеловић, А. Виденовић, ″Друштвени значај задружних домова у постсоцијалистичком контексту,″ *Зборник Матице српске за друштвене науке*, 159-160 (4/2016), pp. 947 - 960, 2016.

[5] М. Аранђеловић, А. Виденовић, ″Традиција као подстицај савременој архитектури у руралним подручјима,″ *Изградња*, 0350-5421, pp. 9 - 14, 2018.

[6] А. Виденовић, *Обнова центара у руралним подручјима.* Београд: Архитектонски факултет Универзитета у Београду, 2017, 351-376.

[7] А. Виденовић, М. Аранђеловић, ″Visitor' centres – new coordinates of Serbian rural areas improvement, ″ *FACTA UNIVERSITATIS,* Series: Architecture and Civil Engineering, FACTA UNIVERSITATIS, 14, 2, pp. 191 - 200, 2016.

[8] M, Maksin, M. Pucar, S. Milijic, & M. Korac, *Odrzivi razvoj turizma u Evropskoj uniji i Srbiji*. Beograd: IAUS, Posebna izdanja, 67, 2011.

[9] A. Videnović, M. Aranđelović, ″Visitor Centres as a Contribution to Improving Urban-Rural Relations: From Primary Needs to Landmarks,″ *Handbook of Research on Urban-Rural Synergy Development Through Housing, Landscape, and Tourism,* , 2326-6139, ed. A. Krstic Furundzic, IGI GLOBAL, 2019, pp. 193-214.

[10] М. Аранђеловић, А. Виденовић, ″Regional factor of sustainable development of rural settlements of Kalna and Minićevo at the foot of the Stara planina mountain,″ *Spatium*, 35, pp. 63 - 70, 2016.

[11] L. Krier, ″Settlements of the future,″ *Beyond Urbanism and the Future of Cities.* Milan, Italia: Rizzoli, ed. T. Haas, 2008, 292-295.

[12] B. Petrovic, I. Raskovic, *Tradicija – tranzicija: upotreba nasleđa u arhitekturi.* Beograd, Srbija: Arhitektonski fakultet, Orion Art, Institut za arhitekturu i urbanizam Srbije, 2011.

19 | Review paper I Прегледни научни рад
ISSN 2566-4484 I Doi 10.7251/STP2014207N
pages 207-214

Nenad J. Nikolić, nenad.nikolic@pr.ac.rs, Faculty of Technical Sciences, Department of Architecture, University of Priština in Kosovska Mitrovica

CHARACTERISTICS OF TRADITIONAL TWO-STOREY RURAL HOUSES IN CENTRAL PART OF KOSOVO AND METOHIJA

Abstract:

This paper deals with the analysis of development and the features of traditional two-story rural houses built in central part of Kosovo and Metohija between the First and the Second World War. The study based on in-situ explorations and literature review has revealed the values of these traditional examples in terms of spatial organization, architectural style, principles of construction, and sustainability-related characteristics. In particular, the study has been deepened on the case of the house of Petković family in Laplje Selo, thus acknowledging the details of this residential type.

Keywords: traditional house, Kosovo and Metohija, principles of design and construction

КАРАКТЕРИСТИКЕ ТРАДИЦИОНАЛНИХ ДВОСПРАТНИХ СЕОСКИХ КУЋА НА ЦЕНТРАЛНОМ КОСОВУ И МЕТОХИЈИ

Сажетак:

Овај рад се бави анализом развоја и карактеристика традиционалних двоспратних сеоских кућа које су изграђене на централном Косову и Метохији између Првог и Другог светског рата. Истраживање, спроведено обиласком локалитета и прегледом литературе, открило је вредности ових традиционалних примера у смислу просторне организације, архитектонског стила, градитељских принципа и одрживих карактеристика. Затим, истраживање је детаљније спроведено кроз анализу студије случаја куће породице Петковић у Лапљем Селу, разоткривајући детаље овог стамбеног типа.

Кључне ријечи: традиционална архитектура, Косово и Метохија, градитељски принципи

1. INTRODUCTION

The area of Kosovo and Metohija is characterized by geographical and cultural diversity. Central part of this territory, known as the Field of Kosovo, features sunny yet windy fertile plateau with emphasized seasonal variations in temperature and precipitation. Thanks to its natural advantages, position in relation to other regions and the connectivity, this territory has been populated since ancient times. In the modern age, both urban and rural settlements have been developing in central Kosovo and Metohija. Sharp spatial differentiation between the "urban" and the "rural" at the very end of the 20th and the beginning of the 21st century, representing an outcome of the overall social transformation, impacted the formation of Gračanica rural zone next to the urban core of the city of Priština. Due to intensive expansion of urban territory and urban functions happening continuously over the last two decades, adjacent rural settlements inevitably became subjected to the transition and its consequences [1] Ongoing pressure of "urban" on "rural" weakens the bond with tradition and shifts the relation towards its most prominent material expression that is the traditional residential architecture.

Although in recent years a lot of effort has been invested to protect major architectural heritage in Kosovo and Metohija, such as churches and monastery complexes, little attention has been paid to traditional rural houses. For that reason, traditional rural house from Kosovo and Metohija nowadays represents a jeopardized yet valuable [2] form of material heritage. In fact, traditional rural houses best illustrate a diversity of living cultures and practices, building methods, and architectural styles. Recording and research of traditional rural houses represent an objective need, in particular in less studied territories [3].

The Field of Kosovo is valuable agrarian landscape and traditional architecture is its significant component. Though a great part of traditional built stock has already disappeared, the objects that still exist put central part of Kosovo and Metohija among areas that are attractive to tourists, researches and architectural practitioners [4]. Rural settlements in the Field of Kosovo were developed at micro locations that were suitable for productive (agricultural) activities [5], often near rivers (such as Gračanka or Sinica) or river streams. Relatively flat terrain on this territory as well as the mixing of local and distanced building practices allowed for the development of different types traditional single-family houses.

The development of residential architecture in this area, especially the spatial component, was influenced by powerful political, economic and cultural factors. Therefore, traditional houses in central Kosovo and Metohija show greater variability in spatial dimensions than in construction methods [6].

The houses built during the 19th and the early 20th century are mostly single-story and simple in concept and construction. There is nothing superfluous about them, nothing that has no purpose. Limited economic opportunities did not allow for dispersion, in either material or space. These modest opportunities also led farmers to alone build their houses, in most cases. The result of such construction tradition was a full-range simplicity of the built structure, which is of great practical importance [2]. Following the end of the First World War, nevertheless, the construction of two-storey houses in this area has been intensified.

2. TRADITIONAL TWO-STOREY HOUSES IN CENTRAL KOSOVO AND METOHIJA

Architecture in conditioned by the following three major components: building materials, climatic conditions and people's lifestyles [7]. A farmhouse in Serbia at the beginning of the 20th century shows remarkable progress [8]. The importance of the house as a space within rural life is the same in all parts of our country. The most important element of the house is the hearth, which becomes the center of formation of the entire living organization of a villager. By the function of space we can recognize: food preparation, living room, laundry, food storage, and sleeping. Considering that all these numerous functions are organized in a small and reduced space, then the folk builder must be honored for the rational and inventive management and solving skills [9].

Both the single- and the two-story house from central Kosovo and Metohija feature elongated rectangular base. If the house is single story, the cattle barn is either built separately or occupies one department within the house itself. In the two-story houses the barn is located on the ground floor. Neither one-story nor two-story houses have basement.

In the internal organization of the space, the connection between the rooms was made only through the porch; the direct connection between the rooms is very rare and was an exception [2]. The kitchen, or food preparation room, is entered from the porch on the ground floor, and is additionally illuminated by a single windows on the side, in which, besides several niche in the walls for storage of kitchen items, there is a large hearth in the wall on the right side. In addition to this room there are other rooms. There was a wooden staircase on the ground floor porch leading upstairs. Upstairs there is a gallery that follows the length of the house, above the porch on the ground floor, from where one can enter several rooms, usually the same size, used for sleeping, with two gallery oriented windows in each room. The interfloor structure, as well as the roof structure, ar made of lumber, while the flooring on the ground floor is made of compacted soil. The houses are built and supplied by the vilagers themselves, assisting one another in the work. The lumber grain was brought from nearby forests, the stone was removed from the Maidan and the bricks were made of soil and baked in the sun. The mortar was also made from the soil by local builders, mixing it with sawdust, while the lime was dissolved at the construction site itself. A large number of houses are left unpainted on the outside, although at one time it was required to paint them white, while in the interior they were mostly unpainted [10].

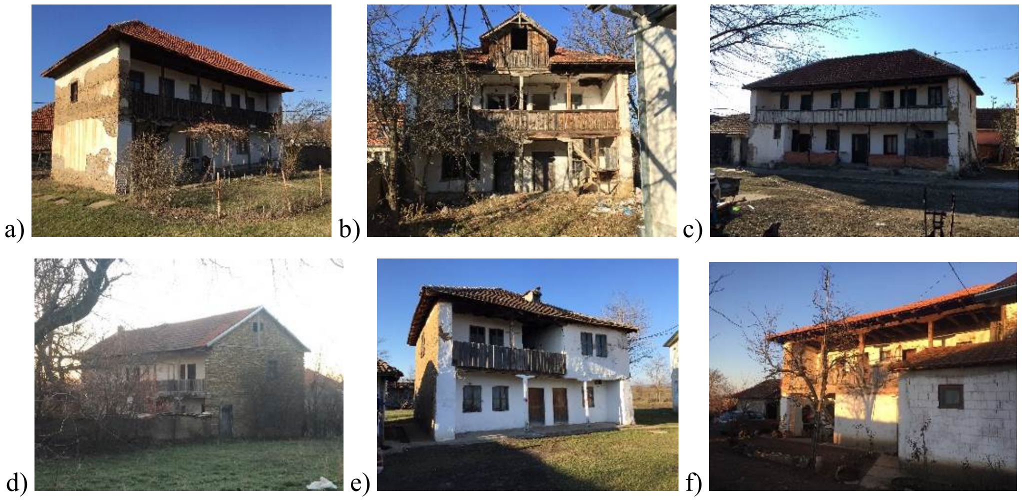


Figure 1. *Photographs of two-storey family houses in central Kosovo and Metohija. a) Popović family house in Gračanica; b)Marković family house in Gračanica; c) Nikolić family house in Gračanica; d) Ćurčić family house Dobrotin; e) Miljković family house in Livadje; f) Maksimović family house in Dobrotin*

Like the ground floor houses, two-story houses in the vicinity of Priština were covered *"ćeramida"* (ceramic roof tile) and have small and narrow windows, often two placed close to each other. The lateral, gable walls are thick and are usually made of broken stone, while the other walls are made of brick. At approximately meter of height, wooden beams are inserted into the wall, which are used for tightening and leveling the layers, functioning as ring beam nowadays. The roof sometimes contains an eyebrow dormer, so called "badža", to illuminate the attic, and a chimney, so called "odžak", to let smoke out of the furnace. The chimney is rectangular in shape in its base, covered with *"ćeramida"* typical of Kosmet, which occurs in the area in the same shape [10].

After the World War I, with increased communication, more frequent migration and, consequently, greater outer influence, the transfer of architectural skills among different parts of Kosovo and Metohija intensified, and beyond, among the different parts of the Balksans. Sometimes, home builders would incorporate their experience from foreign countries, and as a result, for example, some of the two-story houses can even rightly be called palaces [11]. That is why the architectural expression of the two-story houses of central Kosovo and Metohija, although very valuable, is not exclusive to this area, and we find similar form in other parts of Kosmet (for example in the Parish of Sirinic) and in other parts of the Balkans.

The most significant sustainability-related qualities of traditional houses throughout all Kosovo and Metohija and the continental part of the southern Balkans are related to the materials and methods by which these materials are incorporated into the structure [11], [3]. It is hard to determine what a two-story single family home originally looked like in central Kosovo and Metohija, since no houses were preserved in their original condition. All older buildings in this area were modified with various repairs and alterations, and old equipment and hearths were removed [12].

These houses were built from traditional building materials that could be found or produced using resources in the immediate surroundings. Stone, mud, and wood were used to build the structural system: massive stone foundations, walls made of unbaked brick made of mud, so-called "ćerpič", and wood for roof construction and to construct system that supported the precise thinning and stiffening of massive walls to prevent possible demolition. The massive masonry system used was a 50-70 cm thick wall of unbaked mud bricks as a guide material and binder. This construction system has proven to be a very durable structure, and by using natural materials we can conclude that in this way the house is best suited to the climate change conditions during the year. In time houses were developing, becoming bigger, but have always kept its formal simplicity forming regional traditional architecture.

Flexibility and use of natural materials during construction, the use of local, natural, non-toxic and biodegradable materials ensures comfort and quality of life throughout the life cycle of the building. This construction principle is environmentally correct both in the construction phase and in the life span of the building and in the post-construction phase where the structural waste of the entire building is minimized.

Table 1. *Sustainable – "green" features of building materials of Kosovo Field traditional house (criteria based on [13])*

Building Phase	Criteria	Building material				
		Stone	Wood	Clay tiles	Lime plaster	Glass
Pre-building phase: Manufacture	Local material	+	+	+	+	
	Natural material	+	+	+	+	+
	Recycle content				+	
Building phase: Use	Energy efficient					
	Non-toxic	+	+	+	+	+
	Durability	+				
Post-building phase: Disposal	Reusability	+	+	+		
	Recyclability		+	+		+
	Biodegradability		+	+	+	

3. CASE STUDY: PETKOVIĆ FAMILY HOUSE IN LAPLJE SELO

Pristina and its surroundings were predominantly inhabited by Serbs in the period between the two World Wars, therefore this house in Laplje Selo was inhabited by Serbs as well. Its gauge is 11 m length and 7 m width. The house is two-story, with a gallery on the longer side, both on the ground floor and upstairs. The organizational chart of the house indicates a clear division into the day and night zones, which is a general characteristic of the traditional examples, as well as their connection through a semi-open gallery area. The ground floor is in line with the surrounding ground, which creates a direct functional and visual connection between the outer and inner spaces. From the ground floor porch one can enter two separate rooms that are not directly interconnected.

The Petkovic family house is a unique example of two-story houses built during this period where a cattle barn was separated from the house and built in another part of the yard. Two rooms on the ground floor of the Petrovic house don't have the same dimensions and the larger room was used as a living room, for preparing and serving food. This is why this room has additional windows on the east side, aimed to provide natural light in the early morning hours when during this time people were going to a field, church, or preparing for other activities or duties. During summer days in particular, the outside area becomes an extension of the house space, and vice versa. On the right side of the porch is a wooden staircase, only 90 cm narrow, leading upstairs. The stairs have a 70 cm high wooden fence. The upstairs gallery has a view over the courtyard. Two rooms of equal dimensions are located upstairs, and have openings to the gallery and contribute to the formation of the front facade appearance. Front facade is optimally oriented to the south and all rooms have natural lighting, which is why maximum insolation is possible during winter days. 1.6 m wide porch plays a significant role in preventing direct sunlight from entering the rooms on summer days.

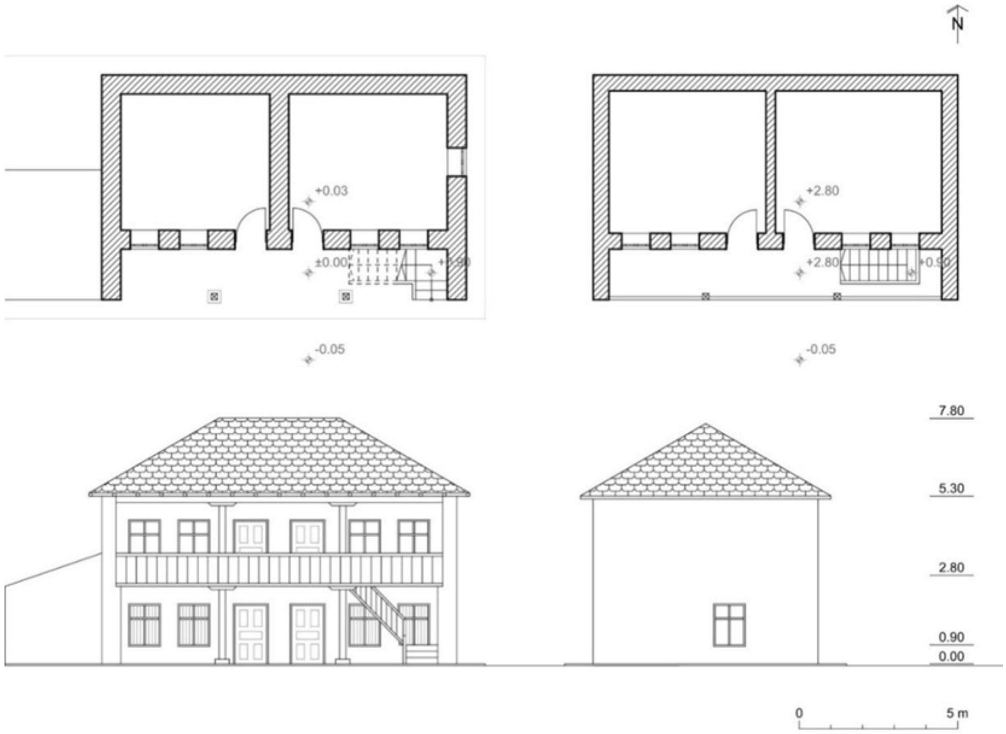


Figure 2. *Floor plan and elevations of Petković family house in Laplje Selo*

By analyzing the materials used during the construction of the family home of the Petković family in Laplje Selo, we can conclude that only local and natural materials that can be found in the immediate area were used. The foundation of the house was built with stone blocks and wooden beams placed above, which represents the structural material that stiffens the construction of the massive walls, which in this case are made of mud blocks. A layer of mud was then applied as a final layer, and then coated with limestone. The floor, interfloor and roof construction is made out of wood. The only material that is not obtained directly from natural materials, and requires additional factory processing is glass, while joinery is completely made of wood.

Wood was used to perform the structural system, straw and fiber was used as a binder and the mortar that was used could be characterized as a new source.

Figure 3. *Photograph of used materials during construction of Petković family house in Laplje Selo*

A massive construction system of unbaked bricks made of mud was used during construction and straw was used as a binder. A 60 cm thick unbaked brick wall rests on 60-80 cm stone foundations, while a 50 cm wall rests on it. The structure that holds the massive walls stiff and prevents them from collapsing is made of wood and extends over the entire length of the wall every 70-80 cm. These beams, in addition to stiffening and constructively supporting the walls, also play a role in the proper leveling of the bricks. The specificity of the construction of structures is reflected in the way the floor was constructed, the interfloor structure and the ceiling structure. Details of floor, interfloor and ceiling structures are shown in Figure 4.

The roof was originaly covered by *"ćeramida"*. The porch downstairs and gallery upstairs is carried on three columns. The walls are made of unbaked brick „ćerpič" and on the ground floor their thickness is 60 cm, while upstairs they are slightly thinner. The interfloor, roof, porch, gallery, staircase and the construction inside the walls are of lumber grain. The floor on the ground floor is of compacted soil and has been boarded in a later period. The walls were also plastered in a later period.

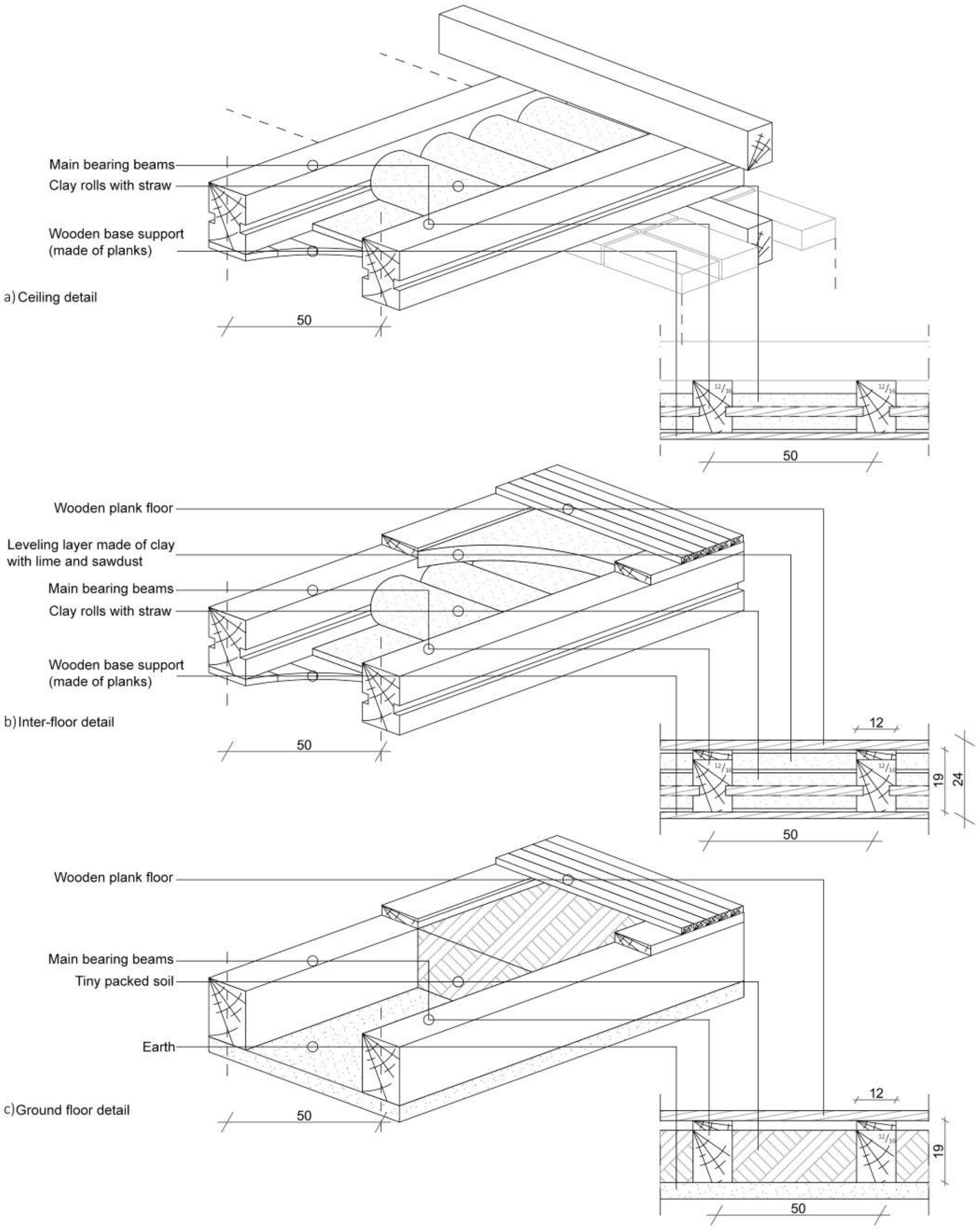


Figure 4. *Construction details of Petrović family house in Laplje Selo, a) ceiling detail, b)interfloor detail and c) ground floor detail*

Figure 5. *Photographs of Petković's family house in Laplje Selo*

4. CONCLUSION

This paper dealt with the analysis of traditional two-story houses built in central part of Kosovo and Metohija in the period between the First and the Second World War. Two-story houses represent the most advanced type of traditional residential architecture in this territory, having regarded that the formation of modern residential typology has been initiated right after the Second World War. Post-war houses demonstrate a sharp interruption of functional, formal and ecological traditions.

The research has shown that traditional two-story houses in central Kosovo and Metohija possess significant values based on which they deserve to be recognized and treated as material cultural heritage. In the first instance, the treatment should encompass protection of their existing architectural and sustainability-related values.

Next to that, the regeneration of traditional two-story single-family houses from Kosovo and Metohija would also refer to their functional reactivation. Bearing in mind that the number of remaining houses of this type is not large, as opposed to their values, a possible regeneration direction could refer to assigning a function of greater public significance to these structures. This means that the regenerated traditional houses from Kosovo and Metohija could become tourist accommodation i.e. additional elements (dependence unit of hotel), educational spots or the museums that witness the cultural wealth of this part of Balkans.

LITERATURE

[1] S. Kosanović, A. Fikfak and S. G. Popović. (2016, June). "AGRARIAN LANDSCAPE BETWEEN TRANSITION AND SUSTAINABILITY - GRACANICA AREA CASE STUDY", The Journal "Agriculture and Forestry", 62(2), pp. 227-241. Available: 10.17707/agricultforest.62.2.20 [23 February 2020].

[2] R. Findrik, "Seoska kuća u Kosovu Polju" in Zbornik zaštite spomenika kulture, 1957, pp. 35-50.

[3] S. Kosanović, B. Folić, S. Kovačević, I. Nikolić and Lj. Folić. (2019, Aug.). "A Study on the Sustainability of the Traditional Sirinić House in the Šar Mountain Region, the South-Western Balkans", Sustainability. [On-line]. 11(17), pp. 4711. Available: http://dx.doi.org/10.3390/su11174711 [23 February 2020].

[4] D. Ćukić, Kosovo, znamenitosti i lepote. Priština: Turistički savez Kosova, 1971.

[5] N. Gadžić. (2016,). "Seoska arhitektura Sirinićke župe". Patrimonium.MK. [On-line]. 9(14), pp. 325-334. Available: 728.6(497.751) [23 February 2020].

[6] B. Kojić. Seoska arhitektura i rurizam. Beograd: Građevinska knjiga, 1958.

[7] A. Deroko, "Stara varoška kuća u Srbiji, Kosmetu i Makedoniji, u poređenju sa kućom u Solunu, Carigradu i Maloj Aziji" in Glasnik Etnografskog instituta Srpske akademije nauka, 1954, pp. 407-417.

[8] Z. Radić, "Pregled osnovnih tipova i načina gradnje seoskih kuća u Srbiji tokom XVIII i XIX veka" in Glasnik Etnografskog muzeja, 1995, pp. 58-59.

[9] Z. Petrović, "Seoska „kuća" i ognjišta na Kosovu i Metohiji" in Glasnik Muzeja Kosova i Metohije, 1964, pp. 369-373.

[10] I. Zdravković, "Seoska kuća u okolini Prištine" in Glasnik Etnografskog instituta Srpske akademije nauka, 1954, pp. 793-803.

[11] N. Gadžić. "Arhitektura Šar planinskih sela sa posebnim osvrtom na stvaralaštvo sredačkih zidara". Ph.D. thesis, Univerzitet u Beogradu, Srbija, 2016.

[12] R. Findrik, "O prostoru stare seoske kuće" in Saopštenja Republičkog zavoda za zaštitu spomenika kulture, 1982, pp. 143-162.

[13] R. Tomovska and A. Radivojević. (2017, Mar.). "Tracing sustainable design strategies in the example of the traditional Ohrid house", Journal of Cleaner Production. [On-line] 147, pp. 10-24. Available: https://doi.org/10.1016/j.jclepro.2017.01.073 [23 February 2020].

20 | Review paper I Прегледни научни рад
ISSN 2566-4484 I Doi 10.7251/STP2014215K
pages 215-223

Saja M. Kosanović, saja.kosanovic@pr.ac.rs, Faculty of Technical Sciences, University of Priština in Kosovska Mitrovica

Martina Zbašnik Senegačnik, martina.zbasnik@fa.uni-lj.si, Faculty of Architecture, University of Ljubljana

Ljubiša Folić, ljufolic@gmail.com, Faculty of Technical Sciences, University of Priština in Kosovska Mitrovica

Branislav Folić, branislav.folic@pr.ac.rs, Faculty of Technical Sciences, University of Priština in Kosovska Mitrovica

Alenka Fikfak, Alenka.Fikfak@fa.uni-lj.si, Faculty of Architecture, University of Ljubljana

A DISCOURSE ON THE APPLICATION OF BIOLOGICAL PRINCIPLES IN BUILDING DESIGN

Abstract:

This paper elaborated on a variety of reasons for the use of biological principles in building context over time. A particular accent was placed on position of biological systems within the contemporary concepts of sustainability, circularity, resilience, and regeneration. Existing design barriers were identified and discussed, and the currently available ways to overcome them were outlined. Conclusively, several general steps towards a more comprehensive future application of biological principles in building design were suggested.

Keywords: biological principles, building design, contemporary concepts, challenges

ДИСКУРС О ПРИМЕНИ БИОЛОШКИХ ПРИНЦИПА У КОНТЕКСТУ ПРОЈЕКТОВАЊА ЗГРАДА

Сажетак:

У овом раду су анализирани разлози примене биолошких принципа у контексту зграда током времена. Нарочито је истражена позиција биолошких система у оквирима савремених концепата одрживости, циркуларности, отпорности и регенерације. Утврђене су и разматране актуелне пројектантске баријере, и предочени тренутно расположиви начини за њихово превазилажење. Закључно је предложено неколико општих корака ка будућој широј примени биолошких принципа у контексту пројектовања зграда.

Кључне ријечи:биолошки принципи, пројектовање зграда, савремени концепти, изазови

1. THE EVOLUTION OF BIOLOGY-DESIGN NEXUS

Humans possess the innate tendency to focus on life and lifelike processes [1]. Complex human relation with life and nature is based on biological, cultural, psychological and ethical bonds [2]. An essential need to worship nature [3] stretches back to the early examples of human creativity. Architectural artifacts of different historical periods repeatedly demonstrate the imitation of natural shapes applied to ornamental surfaces or the three-dimensional elements.

First notable examples involving biological principles in the function of achieving both the innovation and the usefulness [4] belong to the sphere of invention. Pioneering biologically inspired and deliberated design solutions emerged as a result of the research of living species' abilities and their translation to designed objects. Leonardo da Vinci, for example, examined biomechanics of flying animals, muscle forces and the functions of joints, and attempted to apply biological features in his technical inventions. Matthew Baker studied the flow-optimized form of fishes to enhance the performance of his new galleon-type ship [5:4]. The use of biological principles in various fields and in a reasoned way was largely made possible during the 19th century. At that time, natural sciences became more mature, and communicated fund of knowledge from newly emerged disciplines enlarged significantly.

In the 19th century architecture, however, the application of biological principles was rather a topic for debate than a design inspiration or a research subject. While some notable representatives of this period believed that the ultimate beauty of nature should simply continue to be imitated, others, like Eugene Emmanuel Viollet-le-Duc, argued for the architecture that does not copy the nature, but instead emulates its laws [6]. The later design approach was a stimulus for more thoughtful analogies with biological systems that aimed to derive technically usable solutions based on natural abstraction [5:4]. The works of Antonio Gaudi show that such approach also leads to a unique aesthetic result.

Particular scarcity of biology-inspired architectural design concepts in the second half of the 19th century [7] represents a consequence of the emergence of new technical knowledge and technical experimentation. During the first half of the 20th century, technological and industrial progress and the overall societal shifts were used as a base of modern design philosophy, and the ideas of past were neglected together with the relation to nature and its forms, due to "conceptual barrier erected between nature and culture" [8:47]. Nevertheless, some theoretical discourses from this time, such as those written by Honzik or Keisler [9], aimed to draw analogy between technology and nature. By the middle of the past century, alternative theories and concepts started to emerge. In Metabolism, a building was compared to an organism, and, therefore, it had to be adaptive and able to grow. In the 1950ies, Peter Collins discussed the idea of 'Biological Analogies', and Otto Schmitt coined the term 'Biomimetics', referring to the mix of biology and technology. Since its first introduction, different definitions and the contexts of use of biomimetics have been emerging. According to Dollens [10:420], for example, biomimetics represents a "design where properties, elements and systems from nature are viewed, researched and extrapolated from in order to apply natural functions and attributes to architectural structures, materials, systems, spaces and aesthetics." In the 1960ies, Frei Otto and Johann-Gerhard Helmcke together founded the 'Biology and Building' research group that promoted collaboration between architects, engineers and biologists in research and experimentation [11]. In the USSR, architect and researcher Yuri Sergeyevich Lebedev developed 'Architectural Bionics' that aimed to explore analogies „not only between natural and architectural structures and functions but also between their fundamental compositional and forming principles such as architectonics, symmetry, proportions, modularity, rhythm, expression of forms, etc." [12:103]. With that, the connections between golden ratio, Fibonacci sequence and architecture were strengthened, although proportions based on inorganic, geometric rules have been applied since ancient times. Following progress in biological science, geometry of nature and the analogy with art and architecture were explored by Zeising, G.L. Raymond, S. Colman, T.A. Cook, B. Fuller, G. Doczi, I. Ševelev, Z. Pađan, and others.

Over the last decades of the 20th century, experiments on natural models [13] were surpassed by digitization and experimentation with the new design media [14] such as animations of morphological transformations, deformations, or movement through time [15]. Together with parametric modelling and generative techniques for design and manufacture of building products [16], including 3D printing, these tools allowed for the development of very complex design concepts like the pattern design. At the same time, the bond between design and ecology was becoming firmer, and the role of biological systems in building context was again redefined (e.g. the works of Hundertwasser). In 1997, Janine Benyus introduced the term 'biomimicry revolution' to describe new "era based not on what we can extract from nature, but on what we can learn from her" [17:2]. In the 21st century, the application of biological principles in the building context is seen as a contribution to the universally relevant frameworks: sustainability, circularity, resilience and regeneration.

2. BIOLOGICAL PRINCIPLES IN CONTEMPORARY FRAMEWORKS

In 2016, the European Commission has included nature-based solutions among focus areas for research and innovation on environment, and provided the following definition: Nature-based solutions are "solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions" [18]. Nature-based solutions addressing social, economic and environmental challenges have also been promoted in the global policy contexts, by science-based organizations, the World Bank, and the United Nations [19]. So far, however, nature-based solutions at the building scale have not been particularly emphasized in policy frameworks.

In contemporary terms, the application of biological principles in building contexts can refer to a reasoned adoption of biological characteristics, an actual introduction of biological entities into a building, or both, while a simple imitation of natural forms accounts for an obsolete approach from above discussed reasons.

2.1. Sustainability and circularity

Analogies with living organisms, applied to the system of an environmentally sustainable building and possibly connected with intelligence component as well as underlying design concept, aim to support efficient use of natural resources and the reduction of negative environmental impact.

Biological principles may be applied to achieve energy efficiency of a building, i.e. to reduce energy demand (e.g. through the adoption of methods for wise energy use by living organisms) and to generate energy (e.g. by introducing solar panels based on photosynthesis). Some bio-based measures are multi-beneficial: facades with integrated algae, for example, capture carbon, produce oxygen and generate renewable energy [20]. A particular contribution of living systems to water efficiency is recognized in the domains of water harvesting and wastewater recycling (e.g. living machine installations). Similarly, living organisms can contribute to organic waste decomposition in situ. Nevertheless, the greatest progress in the application of biological principles in contemporary building context has so far been achieved in the field of materials.

The experimental and research work of Frei Otto in the field of minimal surfaces and their analogies with natural principles could today be compared with the optimal use of building materials encompassed by sustainability and circularity concepts. Next to that, there is a wide range of bioinspired building materials whose modified features ultimately result in bettered ecological quality, from improved durability (e.g. self-healing materials [21]), to enhanced interaction with surroundings (e.g. color changing surfaces, or intelligent glass that reacts to temperature or light changes), to carbon storing, e.g. [22], etc.

Green movements that were emerging from the 1970ies shed a new light on materials of plant and animal origin, and raised awareness about their ecological advantages, including: abundance, renewability, low embodied energy and CO_2, low ecotoxicity and toxicity, provision of good indoor air quality, biodegradability, recyclability, etc. In the 21st century, the application of bio-based solutions became an integral part of sustainability and circularity schemes, and the matter of biological origin an optimal raw material. Particularly interesting nowadays are the materials made of agricultural waste, such as wheat straw, hemp shiv, flax shiv, or corn pith, and active bio-based materials with integrated living organisms – the 'living materials' – such as bricks, concrete and textiles with living bacteria. State-of-the-art research focuses on optimization of performance of bio-based materials (e.g. increased resistance to molds, and fire, or improved durability), reduction of negative ecological impact of composite materials representing a mix of natural and artificial ingredients (e.g. bio-plastics), and the development of bio-based insulation materials that contribute to both material and energy efficiency.

In addition to material features alone, functional circularity schemes emphasize their bonds within building components and systems, altogether known as design-for-disassembly approach. It is being foreseen that the analogies supporting circularity and sustainability concepts could in future be extended from individual organisms to ecosystems, their cycles of matter and energy transfer [22], [23].

2.2. Climate resilience

One of the basic functions of a building is to protect its users from variable external conditions such as climate. Examples from different historical periods point at the multitude of measures applied for this purpose as well as the shifting character of barrier separating indoor from outdoor space. These variations – ranging from isolation and independence to responsiveness and adjustment – are well observable in the 20th-century building design. The designers who took later approach were in particular interested in exploring the potential for dynamic response to climate patterns, and biological principles were often used as role models. In 1964, Andrija Mutnjaković developed the Homobil – a vision of the house behaving as an organism-machine thanks to its flowerlike form that opens and closes depending on external circumstances [24]. Kinetic buildings based on biological principles were designed by the Archigram group, the Japanese Metabolists, Buckminster Fuller, Yona Friedman and, more recently, Santiago Calatrava.

The key role in building adaptation has been assigned to the envelope, for which reason it is often referred to as ‘adaptive skin’. By changing functions, properties and behavior over time, adaptive building skins are aimed at improving the overall sustainability-related building performance [25]. In spite of increasing number of examples, however, the use of biological principles in design and construction of adaptive building envelopes should be developed further. Possible directions include diversification of applied biological characteristics, accomplishment of multifunctionality [25], development of systemic solutions [26] and, in that regard, development of building skins that perform well under the impact of climate change manifestations.

Climate change is experienced, scientifically proven and widely recognized phenomenon. In addition to mitigation covered by the concept of sustainability, there is an urgent need to find ways to develop resilience to climate change-related manifestations in the built environment. “The pursuit of resilience adds another dimension to design projects, gives additional challenges to architects, and redefines the complexity of the design process and methodology, by requiring transdisciplinary and a systemic approach, as well as the inclusion of various correlating agents that determine the future behavior of a building subjected to climate change” [27:45]. The application of principles of the living world in the context of building resilience is yet to be studied. At the root of current scarcity of building design theories and examples lies the so far modest body of work dealing with the effects of climate change on living organisms and their responses to gradual (long-term) changes and sudden surprises.

According to some authors, the notion of climate resilience in the built environment extends beyond the boundaries of individual buildings. In such a conceptual approach, a building is not only an independent object, but also part of an ecosystem in which diversity and redundancy are present, which results in a greater ability for adaptation [22:177] [23:7]. Therefore, application of biological principles in building resilience refers not only to the characteristics of built objects, but as well to their users, e.g. [28].

2.3. Regeneration

In 1993, Wilson pointed to the obligation of psychologists and other scholars to consider biophilia in more urgent terms, as the natural environment is disappearing. “What, they should ask, will happen to the human psyche when such a defining part of the human evolutionary experience is diminished or erased?” [29:35] It appears that sustainability and circularity measures taken until now can only slow down negative processes in natural capital. From the other hand, advanced regeneration schemes aim to shift the course of negative phenomena by creating net positive effects for the environment.

Like resilience, regenerative design demands an outreaching, systemic approach where buildings represent nodes instead of independent objects, and human systems are indivisible from ecosystems [30]. The role of humans in regenerative framework is active, as the ultimate goal is to bring their needs into a long-lasting synergy with the requirements for natural integrity. Therefore, humans, at the current point of development, need to recognize (again) their positioning within the living systems and to understand the complex patterns of dynamics [31] in which they are embedded. “Bringing humans back to their biological nature ultimately opens a new debate on the relationship to contemporary technologies. In addition, between design that regenerates the environment by involving humans and their activities, and the perspective that looks for ways to intensify positive effects of nature on humans, a new integral framework needs to be defined. The introduction of biological entities into design is believed to represent a significant agent in the integration process”. [32:268]

Hence, the application of biological principles in regenerative building design extends to the point of actual introduction of the living matter, not only during the use and maintenance (e.g. living walls or green roofs), but as well in other life cycle phases (e.g. by embedding seeds and stimulants of growth into biodegradable materials). Nature-based regenerative design concurrently contributes to sustainability – by reversing environmental impact trends, circularity – by stimulating biological cycles, and resilience – by developing ability of a system to adapt and thus overcome experienced stress.

3. CHALLENGES AND CURRENT RESPONSES

In spite of recent progress, the implementation of biological principles in building design is still under development [33]. This state is due to several interconnected key issues that concern building professionals, among them the lack of profound knowledge from the field of biological science and related disciplines, as well as the lack of classifications and characterizations based on which the design solutions could be worked out.

Exceptional complexity of living systems and their possible analogies, variety of baselines from which analogy definitions can be derived, present flexible use of umbrella terms, and, consequently, overlaps in their meaning, jointly impede the accuracy of potential typologies.

Simple systematizations of application of biological principles in the building context can be made according to:

- Type of living organisms;
- Characteristics of individual living organisms or whole ecosystems, e.g. regarding contents, structures, forms, functions, or processes;
- Analogy scope: from mono-characteristics to systemic solutions;
- Analogy type: reasoned transfer of biological characteristics or actual introduction of living organisms into the building context;
- Analogy hierarchy: materials, components, or structures; and other.

Biological studies of living organisms are encompassed by several interrelated biological branches: external morphology or eidonomy that studies external appearance of living beings; anatomy (internal morphology); and physiology. Anatomic studies are divided on microscopic anatomic research of structural units small enough to be seen only with a microscope, and macro-anatomic studies of those body structures (forms) that are large enough to be examined without the help of magnifying devices [34]. Physiology, on the other hand, is the study of functions in living organisms and their constituent parts – tissues and cells. These functions include: metabolism, transport, information transfer, and regulation [35]. Therefore, studies of forms and functions can be carried out at different scales of living organisms. These scales, nevertheless, do not always correspond to building-related scales and the relationship between parts and the whole, for which reason a scale-related parallel between natural entities and man-made artifacts cannot be drawn in all cases.

A building can feature one function (e.g. a kinetic response to external stimuli), one form, or a range of interrelationships, forms and functions that are typical of a single biological species (e.g. the tree). Deliberated transposition of a single biological characteristics into building context accounts for the most commonly applied design strategy throughout the history. The examples range from Egyptian hypostyle halls, to Gothic buildings with shells, to the dome of Brunelleschi's Santa Maria del Fiore cathedral, to Sir Joseph Paxton's glasshouses, to the Eiffel Tower, to the works of renowned 20th- and 21st-century designers: Frei Otto, Felix Candela, Jorn Utzon, Oscar Niemeyer, Eero Saarinen, Luigi Nervi, Santiago Calatrava, Frank Lloyd Wright, and others.

Biological characteristics can be applied at different building scales (e.g. material self-repairing – at micro level, movement of façade parts – at mezzo level, or kinetic action encompassing whole building structure – on macro scale). Furthermore, actual introduction of living organisms can be done at the scale of building materials (e.g. concrete with added bacteria), components (e.g. cladding with integrated algae), or structures (e.g. living plant structures). Processes of cohabitation of different species in a common space and potential for their application in building context are yet to be explored.

Supplementing these considerations with specificities of organisms regarding conditions in the environment in which they live, it is being confirmed that the development of analogies between biological systems and buildings should be treated as case-specific. For that reason, the possibilities for application of biological principles within the building context can only be used with sufficient knowledge and understanding.

Even the very nature of sustainability, resilience, circularity and regeneration frameworks still stretches beyond the boundaries of designer's core knowledge. Although these concepts are understandable in general, the measures to reach their encompassed values must be precise. Therefore, the application of biological principles in contemporary building context requests “a transfer of knowledge from biology and ecology into architectural design in a way that transcends poorly understood and applied analogies or metaphors” [22:172]. The lack of knowledge hinders the development of ideas, solutions and products that are novel and useful [4:349] and generates doubt as to what is the initial question: “What do the biological systems do?” or “What is to be achieved by design?”

In recently published researches, the two possible starting lines were described as: solution-based vs. problem-based; bottom-up vs. top-down; or ‘Biology to Design’ vs. ‘Design to Biology’ approaches [36], [37], [38], [39]. Regardless of the type and the definition, these approaches reflect an effort to bridge knowledge gap and establish effective design methodology and process that will allow for more successful integration of biological principles into a building context. Other compatible/complementary design-related responses to the above-mentioned challenges currently include:

- Dividing building system into parts that can be treated independently in terms of application of biological principles, and developed within separate design domains;
- Application of previously developed biologically inspired building products, mainly materials;
- Development of design guides, e.g. the Biomimicry Toolbox [40], and resource bases such as the Ask Nature [41];
- Introduction of biology-related themes into education, and development of cross-disciplinary educational contents and methodologies, e.g. [32], [39], [42], [43];
- Development of innovative building assessment systems such as the Living Building Challenge [44];
- Development of inclusive theoretical frameworks, e.g. [45], [46]; and
- Establishment of cross-disciplinary design and research teams.

4. DIRECTIONS

Lack of classifications, differing interpretations of key terms, insufficient knowledge from biological science, and scarce evidence concerning sustainability-, circularity-, resilience-, and regeneration-related advantages aggravate the designer’s perception of possibilities for the application of biological principles in building design. Although researches published during the last two decades bear witness to growing interest and progress in the use of biological principles, their integration into building context is yet to be achieved, and systemic solutions yet to be developed and applied.

To further support the application of biological principles in building design, it is necessary to create solid theoretical base by systematizing the body of published works, and to identify scientific knowledge gaps as a basis for future contributing studies. Likewise, there is a need to develop evidence-based databases that could confirm the concrete benefits of applied biology-related measures in building context. When the benefits of biological principles application are justified by sufficient number of realized cases, pre- and post-build assessment systems can be developed, and their criteria and indicators established.

Having on mind the level of specialization involving biology and building science, there is a need to promote the development of cross-disciplinary research units, to enhance experimental work, and to connect these labs both with education and practice. To that end, another raising challenge is the acceptance [47] of currently unconventional solutions by a range of actors, from policy makers, to manufacturers, to investors, to contractors, to end-users of the built space.

In terms of education alone, the introduction of innovative courses and specializing programs could represent an effective response to existing lack of knowledge. However, an extent to which biology-related themes should penetrate into formal designers’ education can be determined only when comprehensive theoretical and evidence bases are established. The content of these bases could assist in shaping the competencies of future building professionals, reveal the depth of necessary knowledge, and inform if educational concepts should opt for architects and engineers with deep knowledge from biology or those equipped with skills for advanced collaboration with biologists, not only in terms of finding an optimal design solution, but as well an optimal methodology to arrive to that solution.

Finally, a designer capable of introducing the biological principles into building context must also consider many other meanings of the buildings. There are aspects of architecture that depend but cannot be explained by natural laws [48], and sole relying on biological principles may bring a radical shift to design ideas, creativity [49] and aesthetics [50].

LITERATURE

[1] E.O. Wilson, *Biophilia: The human bond with other species*. Harvard University Press, 1984.

[2] S.R. Kellert “Introduction” in *The biophilia hypothesis*. S.R. Kellert and E.O. Wilson, Eds. Island Press, 1993, pp. 20-29.

[3] I. Mazzoleni, *Architecture follows nature: biomimetic principles for innovative design*. CRC Press, 2013.

[4] P. Sarkar and A. Chakrabarti, “Assessing design creativity”, *Design studies*, vol. 32(4), pp. 348-383, 2011.

[5] W. Nachtigall and A. Wisser, *Bionics by examples: 250 scenarios from classical to modern times*. Springer, 2015.

[6] M. Zbašnik-Senegačnik and M. Kitek-Kuzman, “Interpretations of organic architecture”, *Prostor*, vol. 22(2), pp. 291-302, 2014.

[7] A. Zakharchuk, “Bionics in Architecture”, *Challenges of Modern Technology*, vol. 3(2), pp. 50-53, 2012.

[8] Rubedo: L.P. Robert and V. Petresin Robert, “Distructuring utopias”. *Architectural Design*, vol. 79(5) (Special Issue: Architectures of the Near Future), pp. 42-49, 2009.

[9] W.W. Braham and J.A. Hale, *Rethinking technology. A reader in architectural theory.* London and New York: Routledge, 2007.

[10] D. Dollens, “Architecture as nature: A Biodigital Hypothesis”, *Leonardo*, vol. 42(5), pp. 412-420, 2009.

[11] P. Steadman, *The evolution of designs. Biological analogy in architecture and the applied arts*. A revised edition. London and New York: Routledge, 2008.

[12] D. Kozlov, “Architectural bionics: From living nature to architecture”, in *Conference Proceedings Kine[SYS]tem From Nature to Architectural Matter, June 19-20, 2017, Lisbon, Portugal*, 2017, pp. 102-110.

[13] Lj. Folić, “Formiranje prostora prirodnim oblicima”, *Gradjevinar*, vol. 9, pp. 355-363, 1986.

[14] A.J. Nocek, “Biomedia and the pragmatics of life in architectural design”, *Inflexions*, vol. 8(7), pp. 8-58, March 2014.

[15] G. Lynn, *Animate Form*. New York: Princeton Architectural Press, 1999.

[16] M. Zbašnik-Senegačnik and Lj. Koprivec, “Biomimetika v arhitekturi prihodnosti”, *Architecture, Research*, vol. 2009(1), pp. 40-49, 2009.

[17] J.M. Benyus, *Biomimicry: Innovation Inspired by Nature*. Harper Perennial, 2002.

[18] European Commission, “Policy topics: Nature-Based Solutions”. Internet: https://ec.europa.eu/research/environment/index.cfm?pg=nbs, 2016 [Jan. 2, 2020].

[19] N. Faivre, M. Fritz, T. Freitas, B. de Boissezon and S. Vandewoestijne, “Nature-Based Solutions in the EU: Innovating with nature to address social, economic and environmental challenges”, *Environmental Research*, vol. 159, pp. 509-518, 2017.

[20] KH. Kim, “A feasibility study of an algae façade system”, in *Conference SB13 Seoul-Sustainable Building Telegram toward Global Society*, 2013, pp. 7-10.

[21] S. van der Zwaag, *Self-Healing Materials. An Alternative Approach to 20 Centuries of Materials Science*. Dordrecht: Springer, 2007.

[22] M. Pedersen Zari, "Biomimetic design for climate change adaptation and mitigation", *Architectural Science Review*, vol 53(2), pp. 172-183, 2010.

[23] C.J. Kibert, J. Sendzimir and G.B. Guy, "Defining an ecology of construction", in *Construction Ecology. Nature as the basis for green buildings*, C.J. Kibert, J. Sendzimir and G.B. Guy, Eds. London and New York: Spon Press, 2002, pp. 7-28.

[24] R. Margaretić Urlić, "Arhitektonski nestašluci u enformelističkom društvu – razgovor s Andrijom Mutnjakovićem", *Život umjetnosti*, vol. 82(1), str. 52-65, 2008.

[25] A. Kuru, P. Oldfield, S. Bonser and F. Fiorito, "Biomimetic adaptive building skins: Energy and environmental regulation in buildings", *Energy and Buildings*, vol. 205, 109554, 2019.

[26] K.M. Al-Obaidi, M.A. Ismail, H. Hussein and A.M.A. Rahman, "Biomimetic building skins: An adaptive approach", *Renewable and Sustainable Energy Reviews*, vol. 79, pp. 1472-1491, 2017.

[27] S. Kosanović, B. Folić and A. Radivojević, "Approach to design for resilience to climate change", in *Sustainable and Resilient Building Design: Approaches, Methods and Tools*. S. Kosanović, T. Klein, T. Konstantinou, A. Radivojević and L. Hildebrand, Eds. Delft: TU Delft Open, 2008, pp. 37-48.

[28] A. Johnson, S. Zheng, A. Nakano, G. Schierle and J-H. Choi, "Adaptive kinetic architecture and collective behavior: A dynamic analysis for emergency evacuation", *Buildings*, vol. 9(2), 44, 2019.

[29] E.O. Wilson, "Biophilia and the conservation ethics" in *The biophilia hypothesis*. S.R. Kellert and E.O. Wilson, Eds. Island Press, 1993, pp. 31-41.

[30] M. Pedersen Zari, *Regenerative Urban Design and Ecosystem Biomimicry*. Oxon and New York: Routledge, 2018.

[31] A. Roetzel, R. Fuller and P. Rajagopalan, "Integral sustainable design - Reflections on the theory and practice from a case study". *Sustainable Cities and Society*, 28, pp. 225-232, 2017.

[32] M. Stamenković, C. Zappulla and S. Kosanović, "Biological entities and regeneration by design", in *Sustainable and Resilient Building Design: Approaches, Methods and Tools*. S. Kosanović, T. Klein, T. Konstantinou, A. Radivojević and L. Hildebrand, Eds. Delft: TU Delft Open, 2008, pp. 249-271.

[33] E. Graeff, N. Maranzana and A. Aoussat, "Biomimetics, where are the biologists?". *Journal of Engineering Design*, vol. 30(8-9), pp. 289-310, 2019.

[34] The Editors of Encyclopaedia Britannica. "Anatomy". Internet: https://www.britannica.com/science/anatomy, [Dec. 5, 2019].

[35] B.T. Scheer. "Physiology". Internet: https://www.britannica.com/science/physiology, [Dec. 5, 2019].

[36] T. Speck, D. L. Harder, M. Milwich, O. Speck, and T. Stegmaier. "Bionik: Die Natur als Innovationsquelle", in *Technische Textilien*. P. Knecht, Ed. Frankfurt: Deutscher Fachverlag, 2006, pp. 83–101.

[37] D. Baumeister, *Biomimicry Resource Handbook: A Seed Bank of Knowledge and Best Practices*. Missoula: Biomimicry 3.8, 2014.

[38] L. Badarnah and U. Kadri, "A methodology for the generation of biomimetic design concepts". *Architectural Science Review*, vol. 58(2), pp. 120–133, 2015.

[39] N. Amer, "Biomimetic Approach in Architectural Education: Case study of 'Biomimicry in Architecture' Course". *Ain Shams Engineering Journal*, vol. 10(3), pp. 499-506, 2019.

[40] Biomimicry Institute. "Biomimicry Toolbox". Internet: https://toolbox.biomimicry.org/, [Dec. 20, 2019]

[41] "Ask Nature". A project of the Biomimicry Institute. Internet: https://asknature.org/, [Dec. 20, 2019]

[42] International Living Future Institute. "Biophilic Design". Internet: https://education.living-future.org/#/catalog/3f42f062-ea71-48f5-985f-c18ba25023b0, [Dec. 22, 2019]

[43] G.M. Yeler, “Creating nature awareness in design education”. *Procedia-Social and Behavioral Sciences,* vol. 174, pp. 406-413, 2015.

[44] International Living Future Institute. “Living Building Challenge”. Internet: https://living-future.org/lbc/, [Dec. 20, 2019]

[45] A. Gamage and R. Hyde, “Can Biomimicry, as an approach, enhance Ecologically Sustainable Design (ESD)?”, presented at *45th Annual Conference of ANZAScAAt: Faculty of Architecture, Design and Planning, The University of Sydney, Australia*, 2011. Available: http://anzasca.net/paper/can-biomimicry-as-an-approach-enhance-ecologically-sustainable-design-esd/, [Jan. 10, 2020]

[46] J.J. Park, *Adaptive biomimetic facades: Compound bio-inspired design strategy for multi-functional stadiums*. Doctoral Dissertation. Australia: University of Melbourne – Faculty of Architecture, Building and Planning, 2016.

[47] D. Jones, “Introduction to the performance of bio-based building materials”, in *Performance of Bio-based Building Materials*. D. Jonnes and C. Brischke, Eds. Woodhead Publishing, 2017, pp. 1-19.

[48] B. Hillier, *Space is the machine. A configurational theory of architecture*. London: Space Syntax, 2007.

[49] P. Trummer, “Engineering Ecologies”. *Architectural Design*, vol. 78(2), Special Issue Versatility and Vicissitude: Performance in Morpho-Ecological Design, pp. 96-101, 2008.

[50] M. Cruz and S. Pike, “Introduction: Neoplasmatic Design. Design Experimentation with Bio-Architectural Composites”. *Architectural Design*, vol. 78(6), pp. 6-15, 2008.

21 | Review paper I Прегледни научни рад
ISSN 2566-4484 I Doi 10.7251/STP2014224G
pages 224-234

Darija Gajić, darija.gajic@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

Anna Sandak, anna.sandak@innorenew.eu, InnoRenewCoE, Isola

Slobodan Peulić, slobodan.peulic@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

Črtomir Tavzes, crtomir.tavzes@innorenew.eu;, InnoRenewCoE, Isola

Tim Mavrič, tim.mavric@innorenew.eu, InnoRenewCoE, Isola

PREFABRICATED TIMBER PANELS APPLICATION POSSIBILITIES FOR THE ENERGY REFURBISHMENT OF RESIDENTIAL BUILDINGS ENVELOPE IN BOSNIA-HERZEGOVINA AND SLOVENIA

Abstract:

System of prefabricated modules installed on the existing building envelope is one alternative solution for deep energy refurbishment of buildings in the European Union. It allows thermal upgrade installation of new parts in the HVAC system. Moreover, some elements of the envelope can be made of renewable materials. This research compares the residential building stock and identifies potential types of buildings for energy refurbishment in Bosnia and Herzegovina and Slovenia. It presents refurbishment possibilities of existing residential building stock in both countries with prefabricated timber panels. It also presents potential obstacles to the wider application of this refurbishment solution.

Keywords: prefabricated timber panels, building envelope, refurbishment, energy saving

МОГУЋНОСТИ ПРИМЈЕНЕ ПРЕФАБРИКОВАНИХ ДРВЕНИХ ПАНЕЛА У ЕНЕРЕТСКОЈ ОБНОВИ ОМОТАЧА ЗГРАДА У БОСНИ И ХЕРЦЕГОВИНИ И СЛОВЕНИЈИ

Сажетак:

Нова рјешења дубоке обнове зграда у Европској унији односе се на постављање префабрикованих модуларних система на постојеће омотаче зграда, који осим топлотног унапређења омотача са грађевинским производима и елементима од обновљивих материјала, такође могу инсталирати и нове дијелове КГХ система. Ово истраживање упоређује градитељски фонд стамбених зграда Босне и Херцеговине и Словеније и идентификује потенцијалне врсте зграда за енергетску обнову. У раду су представљене могућности обнове омотача постојећих стамбених зграда, префабрикованим дрвеним панелима, Босне и Херцеговине и Словеније. Такође, представљене су потенцијале препреке за ширу примјену овог рјешења обнове омотача зграде.

Кључне ријечи: префабриковани дрвени панели, омотач зграде, обнова, уштеде енергије

1. INTRODUCTION

Article 4 of Directive 2012/27/EU on energy efficiency defines the need to develop and adopt a long-term strategy to encourage investment in the reconstruction of housing and commercial, public and private buildings [1]. All EU countries have pledged, including Bosnia and Herzegovina (B&H), which is not yet in the EU, by signing the Energy Community Treaty, to assume the obligations of harmonizing the legal framework with the EU acquits in the energy sector [2]. Accordingly, both countries, Slovenia as an EU member state and B&H as a signatory to that Treaty, adopted the Draft Building Renovation Strategies in 2018 [3] and 2019 [4]. The Strategies do not emphasize the refurbishment of building envelopes by renewable products and materials, but only the use of renewable energy sources. Due to its membership in the EU, Slovenia certifies construction products and materials. Since January 2018, the Environmental Product Declaration – EPD – is recommended, which encourages the use of renewable materials [5]. Green public procurement rules recommend that timber walls contain at least 10% of recycled wood and new buildings contain at least 30% of wood in the total volume of all construction materials used. In addition, high environmental standards for public procurement procedures, including construction of new public buildings and refurbishment of existing ones, are set [6]. This paper presents renovation of buildings with an emphasis on contemporary refurbishment solutions for renewable materials and products, which have been invested in developed countries such as Finland, Norway, Germany, Switzerland and Austria for the last ten years [7] [8]. Although individual materials and elements on the building envelope have a limited economic lifetime (5-25 years), it is estimated that changes to the complete envelope should be made as early as 30 years [9].

Energy refurbishment of the building envelope is considered to be one of the necessary measures to reduce the energy need for heating in B&H and Slovenia (60-70% reduction of the energy need for heating is possible, what will be presented in this paper as well) due to the large amount of building stock built according to the regulative when neither adequate energy performance for buildings nor energy certification was presented. Multiple studies were implemented on this topic and this work tends to present some of which are tackling possibilities of its' implementation in these two countries. B&H and Slovenia had same energy performance for building law legislative up to 1990. However, due to historic circumstances, the changes in law, funds availability, industry capability and international connections enhanced further differences trough time. Still, both countries share exquisite amount of forests capable for providing high quality timber material for envelope refurbishment. Connections between two countries can be established on mutual projects based on ecological approaches in energy refurbishment, thus, this paper aims to present current building stock similarities in both countries and to provide insight of good practice examples from developed countries as well as possibilities of systematic and methodological implementation of those in analysed regions.

The basic strategy for implementing this kind of refurbishment concept should be related to available building stock. Comparative analysis of data on the residential buildings of BiH and SLO was carried out through a methodological framework of the European international project "TABULA". The project investigated typology of residential buildings in accordance with directives 2002/91/EC and 2006/32/EC. The TABULA project, initiated by researchers at the Darmstadt IWU Housing and Ecology Institute, establishes a unique framework for the classification of typology of residential buildings in Europe, with a defined methodology for calculating the energy performance of buildings. Within both projects *Typologies of Residential Buildings in Bosnia and Herzegovina* [10] *and Slovenia* [11] an absolute and specific energy need for heating was calculated for the total of 29 representative residential buildings in B&H and 28 representative residential buildings in Slovenia, which represent six categories of buildings classified into six periods of construction according to the TABULA methodology [12] Figure 1.

In Bosnia and Herzegovina and Slovenia, a building stock that would be adequate for the above-mentioned contemporary method of building renovation has been considered. The overal aim was to expand the offer of building refurbishment methods that can lead to a uniform appearance of buildings and, in general, to the increased use of renewable materials.

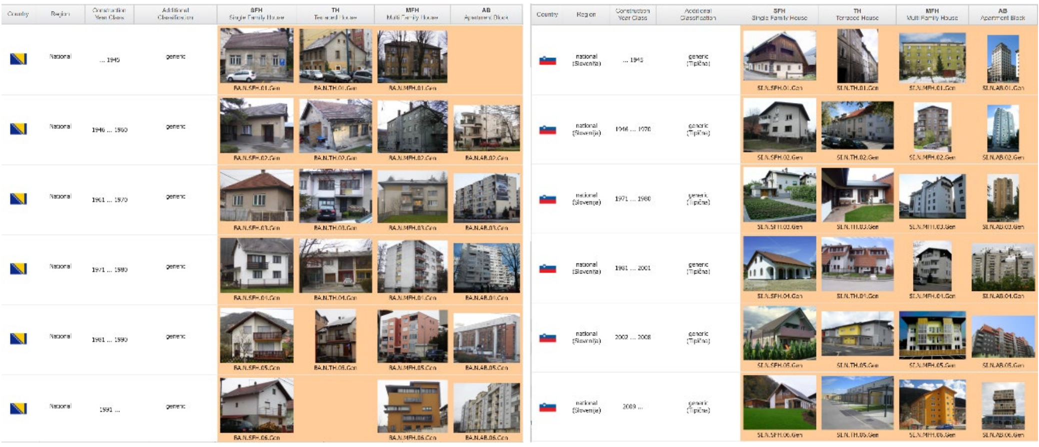


Figure 1. *Typology of residential buildings in Bosnia and Herzegovina and Slovenia [13]*

2. SOLUTION FOR THERMAL REFURBISHMENT OF BUILDING ENVELOPE

Every activity in construction should consume raw materials and energy in a responsible way, therefore causing the least emissions. A possible solution is the adoption of a sustainable and ecological refurbishment method should base preferably on renewable materials, such as timber and other bio-based materials, since they have a positive impact on the carbon performance, considering the whole life cycle of a building. [14, 15]

Today, there are known four ways of refurbishment for buildings envelope presented in Figure 2:

- External composite insulation system (ETICS). The common insulation measure is manually brought up insulation panels, covered with reinforced priming material and a plaster coating, which is colored.
- Ventilated façade system. The insulation is brought up between laths or other substructure, fixed with mounting system, covered by various claddings. Entire assembling procedure is carried out manually.
- Partly prefabricated façade system. Assembly of prefabricated substructure is filled with blown-in insulation. Cladding can be integrated in prefabricated system or manually brought up afterwards.
- Prefabricated module system. Fully prefabricated modules are assembled in fabrication hall, transported on-site and mounted on prepared sub-structure onto façade. Serial production is possible.

The first two, which are common and widespread, have been on market since the 1980s, and the other two have been in use since 2010 and they are environmentally friendly.

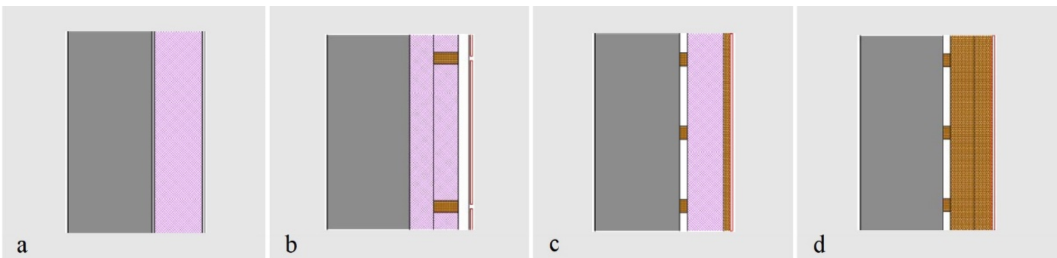


Figure 2. *Solutions of refurbishment façades for existing buildings envelope: a) ETICS, b) Ventilated façade system, c) Partly prefabricated façade system and d) Prefabricated module system [8]*

Although ETICS is currently the most common thermal improvement of building envelopes, it is not future-oriented. The modularity of the prefabricated timber systems, besides significant shortening of renovation time, can be adjusted on-site or in factory conditions. Moreover, it can also be used for various extensions of the building (e.g. upgrades, addition of balconies, corridors) [16]

Prefabricated timber panels are adequate for the deep restoration that is usually required after 45-50 years of use. In this case, apart from interior refurbishment, a new building envelope and building services are required. Prefabricated timber panels can serve in this case to accommodate new distribution pipes for water, sewerage, heating, ventilation and wiring systems [8] (Figure 3). Compared to common insulation solutions, prefabricated panels reduce the disturbance and impact on building users and the neighborhood by faster construction.

The use of prefabricated insulation integrates the building as a whole, ensuring a high-quality execution in a faster time. Prefabricated retrofit systems are standardized in construction layers and joints. They can be combined with each other or with conventional renovation systems. It should be mentioned, however, that during design and development of prefabricated panels, in addition to thermal properties, other aspects such as structural engineering, architecture, building physics, material science, life cycle analysis and life cycle cost should be considered.

Therefore, several parties, such as the thermal specialists which track suitable conditions under environmental changes [17], building physicists which are researching material mutual behavior within complex envelope structures such as moisture control and thermal conductivity, architects capable for managing complex details and detailed designs, HVAC engineers, structural engineers and contractors, shall be involved in the panels' design phase.

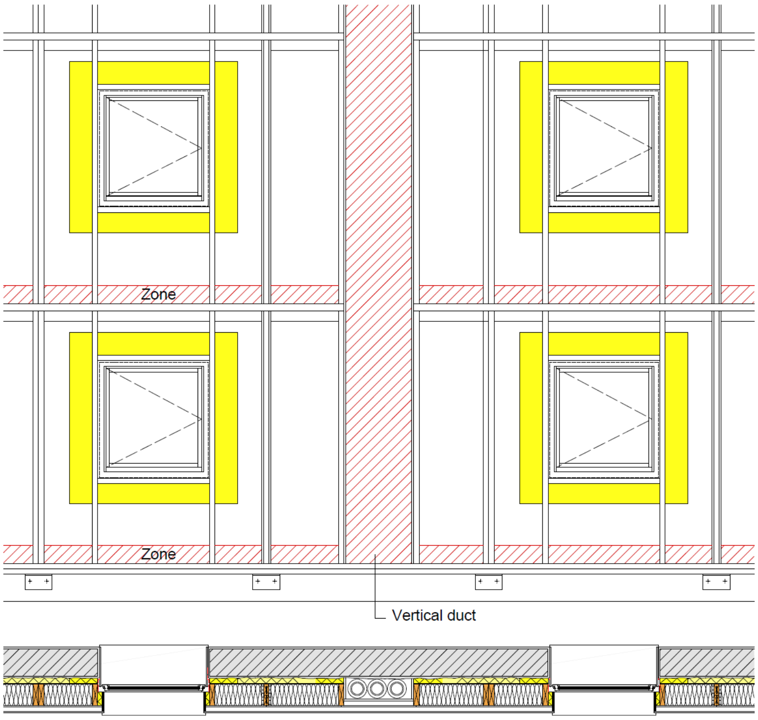


Figure 3. *Scheme of prefabricated system for façade retrofitting [7]*

3. POSSIBILITIES OF REFURBISHMENT IN EXISTING RESIDENTIAL BUILDING STOCK OF BIH AND SLOVENIA WITH PREFABRICATED TIMBER PANELS

During refurbishment of the complete envelope, it is possible to achieve the stated reduction of the energy need for heating, which depends on the building's period of construction (in general, the existence of thermal insulation on the envelope and its thermal characteristics and thickness) and shape factors of the building (the ratio of the area of the envelope and the volume of heated space). The number of buildings with renovation needs is important in order to correctly estimate the number of energy audits. In the case of multifamily houses, the number of apartments within individual buildings and potential number of users are important to correctly calculate economic savings and predict thermal comfort of inhabitants.

3.1. Existing residential building stock

The potential building stock over which the building envelope could be upgraded has been examined through a comparative analysis of data of the housing stock of both countries. In accordance with valid EN ISO 13790 standard, energy requirements of buildings are calculated and expressed in accordance with annual heating energy requirement [16]. Data for Bosnia and Herzegovina were estimated up to 2014 (Table 1) and for Slovenia up to 2011 (Table 2).

Table 1. *Number of residential buildings in Bosnia and Herzegovina [10]*

	SFH	TH	MFH	AB	TOTAL
	Single-family house	Terraced house	Multi-family house	Apartment block	All types
up to 1945	10.773	1.157	450	219	12.599
1946-1960	26.133	1.639	2.462	1.188	31.422
1961-1970	87.596	7.480	3.012	2.164	100.252
1971-1980	194.076	9.257	2.203	2.156	207.692
1981-1991	236.075	5.905	1.116	975	244.071
1992-2014	254.799	6.653	2.725	1.752	265.929
TOTAL	809.452	32.091	11.968	8.454	861.965

Table 2. *Number of residential buildings in Slovenia [11]*

	SFH	TH	MFH	AB	TOTAL
	Single-family house	Terraced house	Multi-family house	Apartment block	All types
up to 1945	140.605	12.974	10.693	930	165.202
1946-1970	91.163	11.383	5.142	885	108.573
1971-1980	82.684	7.505	2.105	1.060	93.354
1981-2001	114.561	8.301	2.248	826	125.936
2002-2008	21.567	2.394	1.152	256	25.369
2009-2011	99	47	14	4	164
TOTAL	450.679	42.604	21.354	3.961	518.598

Bosnia and Herzegovina and Slovenia have a predominantly higher number of buildings / houses intended for individual housing (B&H 97.53%, SLO 95.12%), compared to the number of collective housing buildings. But when looking at the number of housing units within these buildings, the ratio decreases because the number of housing units in individual housing is 66.47% in B&H and 61.78% in SLO, respectively.

In BiH, the total number of individual dwellings is about 841.543, while the number of collective dwellings is around 20.422. When observing the number of dwelling units, 10.764.240 belong to individual dwellings, while 542.945 belong to collective dwellings. In SLO, the total number of individual dwellings is about 493.283, while the number of collective dwellings is about 25.315. When looking at the number of dwelling units, 526.825 belong to individual dwellings, while to collective dwellings the number is 325.868 (Table 3).

Table 3. *Number of residential buildings and apartments in both countries [10] [11]*

	Bosna and Herzegovina		Slovenia	
	number of buildings	number of apartments	number of buildings	number of apartments
SFH and TH	841.543	1.076.240	493.283	526.825
MFH and AB	20.422	542.945	25.315	325.868
Total	861.965	1.619.185	518.598	852.693

B&H has about 39.83% more residential buildings of all types compared to Slovenia, but the number of collective housing buildings in Slovenia is 19.33% higher. The number of housing units in B&H is about 40% higher, which indicates that Slovenia has a larger number of collective housing units of smaller dimensions (MFH). For calculation requirements, it was assumed that the entire building surface used for residential purposes was heated. In countries of the West Balkan region, it was estimated that only 50% of households heated over 50% of the conditioned area [18]; whereas, indicators for EU countries are somewhat better [19]. Therefore, several building categories, especially single-family houses, which according to share in the total surface of the housing stock represent a dominant category, have not met this criteria. This is one of the reasons why the calculated values of energy needs for heating (needed, delivered and primary) deviate from the estimates obtained by the relevant studies and statistical data for Bosnia-Herzegovina and the countries in the region [18]. Basic recommendations for accurate calculations of energy requirements are: use of unified climate data, architectural and construction characteristics of buildings reduced to project values, standardized values that take into account user behavior such as the number of heating hours and internal heat gains and assumed project temperature in the heated space of 20°C.

Energy characteristics of the building envelope and compactness of the structures were determined according to anylysis of representative samples of existing structures type, whose dimensions correspond to the average of the census. Existing condition of the building envelope was determined according to the technical requirements and technological capabilities of a specific construction period, including expert assessment of the building envelope's degradation during service life. The expert estimates for energy need for heating of individual buildings, considering their types and construction periods in B&H and Slovenia, are presented in Table 4.

Table 4. *Energy need for heating representative residential buildings in Bosnia and Herzegovina and Slovenia (kWh/ m²a) [10] [11]*

Residential buildings in Bosnia-Herzegovina						Residential buildings in Slovenia				
	SFH	**TH**	**MFH**	**AB**			**SFH**	**TH**	**MFH**	**AB**
	Single-family house	Terraced house	Multi-family house	Apart-ment block			Single-family house	Terraced house	Multi-family house	Apart-ment block
up to 1945	452.3	183.16	230.7	176.08		up to 1945	516.0	146.80	170.80	226.40
1946-1960	473.9	321.27	219.7	222.30		1946-1970	248.3	183.40	133.50	230.20
1961-1970	464.9	196.42	252.3	194.10		1971-1980	154.0	132.40	147.70	157.50
1971-1980	381.5	199.04	187.0	149.90		1981-2001	148.6	101.10	124.40	125.10
1981-1991	135.9	219.20	189.2	110.87		2002-2008	61.20	80.30	83.90	49.00
1992-2014	127.6	-	65.22	54.81		2009-2011	83.50	78.00	53.30	58.90

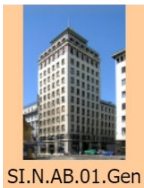
In general, the energy need for heating is decreasing in both countries. Comparing average requirements for all investigated building types, it can be stated that in B&H it decreased by 3.5-3.2 times, while in Slovenia a similar drop was noticed for MFH and AB. The energy need for TH dropped by only 1.6 times, while the highest energy savings can be observed for SFH (over 6 times less comparing investigated timeline).

3.2. Feasibility of prefabricated timber panels application and energy savings

Buildings suitable for the application of prefabricated timber panels are selected according to three criteria: layout, which allows modular division of the façade envelope; period of construction, which requires as a whole the complete thermal improvement of the envelope; and quantity of such buildings within certain typology. Considering the estimate that MFH and AB buildings are suitable for the refurbishment envelope with prefabricated panels in Bosnia and Herzegovina, three construction periods (1945-1960, 1961-1970 and 1971-1980) were selected. The total number of such buildings is about 10.600 MFH and 3.100 AB, while number of residential units are about 179.000 for MFH and 173.500 for AB.

Analyzing the thermal characteristics of buildings in SLO, MFH and AB constructed in three periods (until 1945, 1946-1970 and 1971-1980) are suitable for refurbishment with prefabricated panels. The total number of such buildings is about 17.940 MFH and 2.875 AB, while residential units are about 11.6360 in MFH and 1.295.435 in AB. An estimation of the total envelope area of such buildings is possible by analysis of the typical example for the building presented in Table 5. Each building type has different variations on the shape factor and would require a separate additional analysis of the upgrade envelope.

Table 5. *Representative buildings for refurbishment with prefabricate timber panels from Typology of residential buildings in Bosnia and Herzegovina and Slovenia [13]*

Country	Period	MFH –Multi-family house		AB – Apartment building	
B&H	1946-1960		Reference Floor Area: 489 m^2		Reference Floor Area: 679 m^2
	1961-1970		Reference Floor Area: 585 m^2		Reference Floor Area: 3253 m^2
	1971-1980		Reference Floor AreA: 937 m^2		Reference Floor Area: 2417 m^2
Slovenia	up to 1945		Reference Floor Area: 1160 m^2		Reference Floor Area: 2627 m^2
	1946-1970		Reference Floor Area: 1097 m^2		Reference Floor Area: 2877 m^2
	1971-1980		Reference Floor Area: 2528 m^2		Reference Floor Area: 6774 m^2

Collective residential buildings (MFH and AB), in contrast to individual residential buildings (SFH and TH), have larger envelope areas that need to be renovated. Depending on the type of building (buildings with more of the same slats and floors), structures can be heat-upgraded with the same prefabricated elements of renewable materials, which are also the subject of this analysis.

The annual heat required for heating adequate housing in Bosnia and Herzegovina before and after the implementation of standard renovation measures that reflect legal regulation (achieving U-value for all elements of building envelope) have changed [18, 19]. The measures recently applied are more demanding for the wall and window than prescribed in the FB&H regulation; while in RS, they reach the U-value for windows and do not reach the predicted U-value for walls. Standard improvement measures in typology of residential building defined in accordance with usual measures applied during building reconstruction in the territory of B&H included two actions. The improvement of thermal characteristics of walls and ceilings can be achieved by adding thermal insulation 10 cm thick with λ=0,041W/mK as well as possible replacement of the existing windows with new ones with better characteristics (defined min. U-value 1,60 W/m2K) (Table 6).

Table 6. *Comparative representation of energy required for heating in kWh/m² of representative examples of MFH (multi-family house) and AB (apartment block) buildings, before and after applying standard measures in B&H and Slovenia [13]*

Multi-family house		MFH	MFH	Saving energy
		Before	After	
		measure		
B&H	1946-1960	219.7	85.5	134.2
	1961-1970	252.3	111.6	140.7
	1971-1980	187.0	82.2	104.8
Slovenia	up to 1945	170.8	62.4	108.4
	1946-1970	133.5	53.1	80.4
	1971-1980	147.7	51.4	96.3

Apartment building		AB	AB	Saving energy
		Before	After	
		measure		
B&H	1946-1960	222.3	79.8	142.5
	1961-1970	194.1	85.6	108.5
	1971-1980	149.9	75.3	74.6
Slovenia	up to 1945	226.4	58.1	168.3
	1946-1970	230.2	58.8	171.4
	1971-1980	157.5	50.00	107.5

In Slovenia, the measures implemented are in compliance with the legislation in force since 2010 [23]. Refurbishment measure includes adding of 15 cm of new thermal insulation on the wall in building with no thermal protection and replacement of the existing windows with new ones having better characteristics (defined minimal U-value 1,40 W/m2K) (Table 6). Depending on the type of building and period in B&H, AB buildings from 1946-1960 have the largest reduction in energy demand, by 64%; while in Slovenia, these are also AB buildings from both periods up to 1970 (decrease of 74%). The impact on such results is influenced by the shape factor of the building as type AB has more clustered housing units than type MFH. Higher energy savings in buildings in Slovenia are justified because of the more rigorous regulations, such as setting of allowed U-values.

Data on the total annual heat required for heating residential buildings were obtained on the basis of statistical data on the total number of buildings and projections of energy consumption. The data from the level of typical buildings to the category level was calculated by introducing the ratio of the average gross area of a certain category to the gross area of a typical building and the ratio of the net to gross area ratios of a typical object. For calculation of national energy balance, only two condensed building typologies (single unit buildings – SFH/SUH and multi-unit buildings – MFH/MUH) were used, thus combining SFH + TH into SFH/SUH and MFH + AB into MFH/MUH, respectively. Furthermore, first to age classes were grouped into single-year class (until 1970), resulting in five age classes.

In B&H, it has been taken into account that some buildings have already been heat-upgraded during these periods. About 16% of façade walls and roofs have been further insulated, and more than 30% of windows were replaced. In Slovenia, it has been taken into account that some buildings have already been heat-upgraded in these periods (15% façade walls, 55% of roofs, 20% of intermediate ceilings towards the attic were additionally insulated and more than 50% of windows were exchanged). Possible energy savings after application of above-mentioned standard measures, in both countries, have almost the same effect (3% difference) (Table 7).

Table 7. *Energy need for heating of residential buildings in Bosnia and Herzegovina and Slovenia before and after standard measueres (MWh/a) [13]*

Bosnia and Herzegovina	**MFH – before**	**MFH - after**	**MFH**
	Multi-family	Multi-family	**Saving energy**
before 1970	1.028.840	328.207	700.633
1971-80	886.510	343.815	542.695
TOTAL	**1.915.350**	**672.022**	**1.243.328**

Slovenia	**MUH – before**	**MUH - after**	**MUH**
	Multi-family	Multi-family	**Saving energy**
before 1970	1.262.000	315.500	946.500
1971-80	356.000	99.680	256.320
TOTAL	**1.618.000**	**415.180**	**1.202.820**

5. POTENTIAL BARRIERS FOR REFURBISHMENT OF THE BUILDING ENVELOPE WITH PREFABRICATED TIMBER PANELS

Even if all buildings can be classified to certain typology, refurbishment with prefabricated timber panels should be adjusted to each building individually. The first four steps presented in Figure 4 allows identification of the most suitable retrofitting strategy.

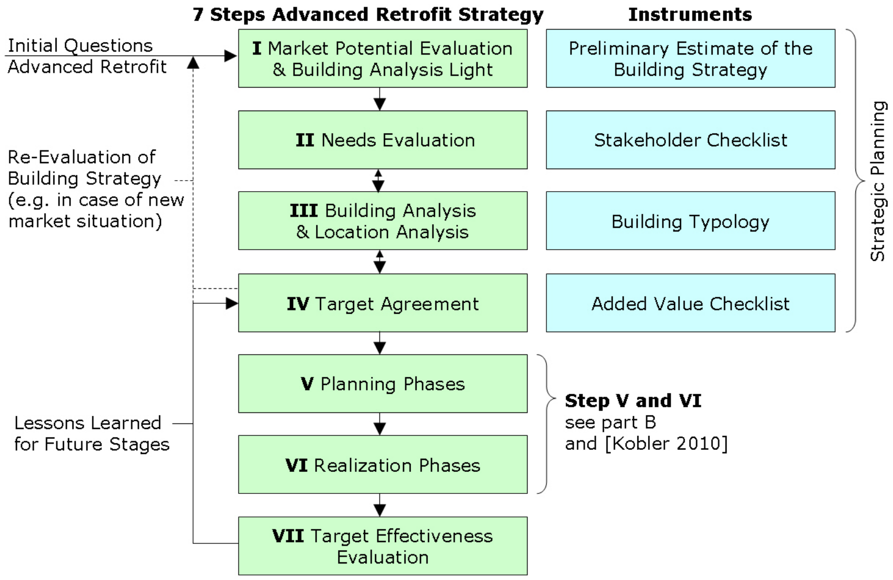


Figure 4. *Strategy of IEA, ECBCS, 2011, for deep refurbishment of building [8]*

In some countries, the use of prefabricated panels with defined dimensions is not a common practice, which cause transportation and installation difficulties. It requires additional training for all people involved in their prefabrication, transportation and installation. Even if execution time and labor are reduced, these systems are still more expensive than common insulation solutions. This represents a challenge because refurbishment costs when using prefabricated timber panels should not be significantly higher than common refurbishment solutions. Even if a lot of research has been carried out in different countries with some successful technological solutions being developed, there has not been a general breakthrough leading to a wider use of such solutions [7]. There are obviously barriers that impede the flow of this know-how toward industry, users and policymakers. Another obstacle might be the higher price of natural renewable materials labelled as “green” or “eco”, commonly perceived products as highly priced. However, this perception may not always reflect reality once a comprehensive cost-benefit analysis is made. The other reason could be the lack of industrial capacity for production of energy refurbishment construction products, elements and systems made from renewable materials. Countries of Eastern and South-eastern Europe frequently limit themselves to the export of raw materials or semi-finished products, due to lack of experience in these regions to run this kind of production in-place. There is a poor exchange of knowledge regarding renewable materials from a cross-border perspective and also between institutions and organizations in the region. Finally, and most importantly, a lack of public awareness about renewable materials for (energy) refurbishments of buildings may also play a role. Very often, only the energy performance of buildings is the focus (also because of its financial consequences for users), and a larger and more holistic view of sustainable refurbishment is missing. In order to overcome above-mentioned obstacles, the following actions are proposed: transfer the knowledge from scientific institutions to industry, implement knowledge at the industrial level to build production capabilities and conduct awareness-raising campaigns aimed at both the public and policy-makers. Only with careful planning and simultaneous execution of these activities, an increase in the use of renewable materials in energy refurbishments might be accomplished.

6. CONCLUSION

In most cases, replacement of the building with a new one can be avoided since deep renovation is more feasible. Every refurbishment project should focus not only on energy optimization of the building but also on increased value for the client: investor, owner and user of the building. The use of prefabricated timber panels in the renovation of buildings might be economically viable if used for deep renovation purposes, due to their multiple roles. Prefabricated elements might serve in addition to thermal retrofitting of the building envelope for building extensions and upgrading. Reducing energy consumption of existing buildings to NZEB (Nearly Zero-Energy Building) is also possible with the use of such systems in the refurbishment of building envelopes.

Bosnia and Herzegovina and Slovenia have almost identical energy savings when comparing refurbishment the entire buildings envelope of the same type (MFH and AB), only for B&H periods from 1945 - 1980 and in Slovenia for all periods until 1980. Respectively, comparing the total energy need for heating condensed buildings in MFH/MUH (MFH+AB), the energy need for heating in B&H is higher than in Slovenia by 15%. The potential energy savings by refurbishment of the envelopes of existing buildings suitable for prefabricated timber panels would be 1.243.328 MWh/a and 1.202.820 MWh/a in Bosnia and Herzegovina and Slovenia, respectively. It is expected that prefabricated timber panels will find their application when sustainable deep refurbishment of buildings using renewable products and materials is required by legislation.

ACKNOWLEDGMENT

This research paper was carried out through bilateral agreement E-REFIT funded by: (i) Government of Republic of Srpska, Ministry for Scientific and Technological Development, Higher Education and Information Society and (ii) ARRS – Slovenian Research Agency. The authors also gratefully acknowledge the European Commission for funding the InnoRenew project (grant agreement #739574 under the Horizon 2020 Widespread-Teaming program) and the Republic of Slovenia (investment funding of the Republic of Slovenia and the European Union European Regional Development Fund).

LITERATURE

[1] E. P. a. t. Council, Directive 2012/27/EU of European Parliament of the Council of 25 October 2012 on Energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC, 2012.

[2] *Ugovor o uspostavi energetske zajednice,* Predsjedništvo Bosne i Hercegovine, 2006.

[3] Ministrstvo za infrastrukturo, "DOLGOROČNA STRATEGIJA ZA SPODBUJANJE NALOŽB ENERGETSKE PRENOVE STAVB," [Online]. Available: https://www.energetika-portal.si/dokumenti/strateski-razvojni-dokumenti/dolgorocna-strategija-za-spodbujanje-nalozb-energetske-prenove-stavb/. [Accessed 18 02 2020].

[4] g. i. e. R. S. Ministarstvo za prostorno uređenje, Nacrt strategije obnove zgrada u Republici Srpskoj do 2050. godine, 2019.

[5] Zavod za Gradbeništvo Slovenije, "Okoljska dekleracija proizvoda," [Online]. Available: https://www.zag.si/si/certifikati-soglasja/sluzba-za-tehnicne-ocene-in-soglasja/okoljska-dekleracija-proizvoda. [Accessed 20 02 2020].

[6] Uredbo o zelenem javnem naročanju, Ministrstvo za javno upravo, 2017.

[7] P. Heikken, H. Kaufmann, S. Winter i Larsen, Energy Façade – prefabricated timber based building system for improving the energy efficiency of the building envelope, Helsiniki, 2009.

[8] P. Schwehr, R. Fischer i S. Geier, Prefabricated systems for Low Energy Renovation of Residential Buildings - Retrofit Strategies, Design Guide, 2011.

[9] *REGULATIONS COMMISSION DELEGATED REGULATION (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU,* European Parliament and Council on the Energy performance of the buildings by establishing comparitive methodology framework for buildings and buildings elements, 2012.

[10] D. Arnautović-Aksić, M. Burazor, N. Delalić, D. Gajić, P. Gvero, D. Kadrić, M. Kotur, E. Salihović, D. Todorović i N. Zagora, Tipologija stambenih zgrada Bosne i Hercegovine, Sarajevo: Arhitektonski fakultet Univerziteta u Sarajevu, 2016.

[11] M. Šijanec Zavrl i A. Rakušček, IEE tabula - Typology approach for building stock energy assessment, Ljubljana: Ljubljana: Gradbeni inštitut ZRMK, 2012.

[12] T. Loga, B. Stein i N. Diefenbach, „TABULA Building Typologies in 20 European Countries - making Energy-related features of resudential buildings stocks comparable," *Energy and Buildings,* 2016.

[13] Institut Wohnen und Umwelt GmbH, "National Building Typologies," [Online]. Available: https://episcope.eu/building-typology/overview/. [Accessed 15 02 2020].

[14] J. Monahan, J.C. Powell, An embodied carbon and energy analysis of modern methods of construction in housing: A case study using a lifecycle assessment framework, Energy and Buildings Vol 43, 179-188, 2011, https://doi.org/10.1016/j.enbuild.2010.09.005

[15] A. Sandak, J. Sandak, M. Brzezicki, A. Kutnar, Bio-based Building Skin. Singapore: Springer Open, 2019, https://doi.org/10.1007/978-981-13-3747-5

[16] C. Cronhjort, V. Riikonen, M. Kolehmainen, K. Nordberg i W. Huß, SmartTES - Innovation in timber construction for the modernisation of the building envelope, T. Samuel Tulamo, Ur., 2014.

[17] S. Jacob, E. Laurent, B. Hageman, B. Romain, J. G. Prunier, D. Legrand, J. Cote, A. S. Chaine, M. Loreau, J. Colbert and N. Schtickzelle, "Habitat choice meets thermal specialization: Competition with specialists may drive suboptimal habitat preferences in generalists," in PNAS - Proceedings of the National Academy of Sciences of the United States of America, 2018. https://doi.org/10.1073/pnas.1805574115 [Online]. Available: https://www.pnas.org/content/115/47/11988. [Accessed 02 05 2020].

[18] EN ISO 13790:2008 Thermal performance of buildings-Calculation of energy use for heating.

[19] T. Csoknyai, S. Hrabovszky-Horváth, Z. Georgiev, M. Jovanovic Popovic, B. Stankovic, O. Villatoro i G. Szendrő, „Building Stock Characteristics and Energy Performance of Residential Buildings in Eastern-European Countries,“ *Energy and Buildings,* 2016.

[20] B. Atanasiu, Alleviating fuel poverty in the EU, Buildings Performance Institute Europe, 2014.

[21] Pravilnik o tehničkim zahtjevima za toplotnu zaštitu objekata i racionalnu upotrebu energije. Službene novine FBiH br. 49/09, Federalno ministarstvo prostornog uređenja, 2009.

[22] Official Government Gazette nr. 30 - Rule book on the minimum building characteristics energy requirements, Banja Luka: Government of the Republic of Srpska, 2015.

[23] Pravilnik o učinkoviti uporabi energije v stavbanh, Ministrstvo za okolje in prostor, 2010.

22 | Review paper I Прегледни научни рад
ISSN 2566-4484 I Doi 10.7251/STP2014235L
pages 235-249

Nevena S. Lukić, nevena.lukic@arh.bg.ac.rs, Faculty of Architecture, University of Belgrade
Ljiljana Đukanovic, djuli@arh.bg.ac.rs, Faculty of Architecture, University of Belgrade
Ana Radivojević, ana@arh.bg.ac.rs, Faculty of Architecture, University of Belgrade

IMPLICATION OF INFILTRATION ON BUILDING ENERGY DEMAND - A REVIEW OF VERIFICATION METHODS

Abstract:

Infiltration has a considerable impact on both, energy efficiency and occupant comfort in buildings. Due to the complexity of the analysis of this phenomenon in buildings, the verification methods are very important for its diagnostics and evaluation. In this paper, the matter of infiltration in buildings is being considered referring to both, calculation models and methods, as well as through current standards and regulations in the EU and Serbia. Different valorization methods are presented and analyzed regarding their characteristics, applicability, and complexity. Finally, preliminary infiltration measurements with a pressurization test, conducted on selected buildings of Belgrade housing stock are presented and compared with values defined by the current regulations in Serbia. Results pointed out current problems and the need for improvements regarding the treatment of infiltration in local regulations and practice.

Keywords: infiltration, building airightness, energy efficiency, verification methods, pressurization test

УТИЦАЈ ИНФИЛТРАЦИЈЕ НА ЕНЕРГЕТСКЕ ПОТРЕБЕ ЗГРАДЕ – ПРЕГЛЕД МЕТОДА ВЕРИФИКАЦИЈЕ

Сажетак:

Инфилтрација има значајан утицај у разматрању питања како енергетске ефикасности тако и комфора у објектима. Због сложености анализе овог феномена, методе верификације показале су се као веома важне приликом дијагностиковања и евалуације инфилтрације. У овом раду се питање инфилтрације разматра у односу на моделе и методе прорачуна, као и тренутне стандарде и прописе у ЕУ и Србији. Разматране су различите методе верификације кроз анализу и поређење њихових карактеристика, примењивост и сложеност. Представљена су и прелиминарна мерења инфилтрације одабраних објеката у склопу стамбеног фонда Београда тестом притиска удувавањем која су упоређена са вредностима дефинисаним важећим прописима у Србији. Резултати су указали на тренутне проблеме и потребу унапређења третмана инфилтрације у локалним прописима и пракси.

Кључне ријечи: инфилтрација, заптивеност објеката, енергетска ефикасност, методе верификације, тест притиска удувавањем

1. INTRODUCTION

Being the largest energy consumer in Europe, buildings use 40% of the total energy and are responsible for around 36% of the CO2 emission. [1] Therefore, European countries are complying with the set of international agreements to increase energy efficiency and reduce energy consumption. Achievement of these goals sets the need to minimize thermal losses through the building envelope. Today, EU strategies support the renovation of the national building stock, emphasizing the need for transformation of a building's stock into nearly zero-energy buildings (nZEB) and highlighting that the calculation of the energy needs beside energy savings must lead to optimized health, indoor air quality, and comfort levels, further defined by the Member States at the national and regional levels. Therefore, it is required that general indoor climate conditions should be taken into account when determining the minimum energy performance requirements of a building. [1]

Nowadays, it is recognized that indoor air quality plays a very important role in the health of the populations. The World Health Organization noted a rising number of illnesses and deaths related to indoor air pollutions in the last years. Consequently, matters of air quality and occupant's health have become one of the major environmental health concerns in Europe. [2] In this context, one of the dominant questions, with a great impact on both energy efficiency and indoor air quality, is the matter of infiltration in buildings. Infiltration, together with ventilation, represents ventilation heat losses, having a significant influence when considering the total energy consumption of buildings. As such, it is one of the main factors considered when calculating heat losses in buildings. It accounts for between 25-50% of the heating load in both residential and commercial buildings. [3] Besides, 1/3 of the heating and cooling load in a building are due to infiltration. [4] Researches show that different building components contribute to a certain percentage to the distribution of infiltration through the building: walls (18-50%, av. 35%), ceiling (3-30%, av.18%), cooling/ heating systems (3-28%, av. 18%), windows and doors (6-22%, av 15% - depending mostly on window/door type), fireplace (0-30%, average 12%), vents in conditioned spaces (2-12%, av. 5%), other 1% or less. [5]

In this paper, the matter of infiltration in buildings is being considered referring to both, calculation models and methods, as well as through current standards and regulations in the EU and Serbia. Valorization methods (pressurization test, tracer gas test, and thermal infrared imaging) are presented and considered from the point of view of applicability, advantages, and disadvantages, as well as the complexity of a method. The analysis of the infiltration of representative examples of the Belgrade housing stock was investigated based on preliminary measurements with the pressurization test, and results are presented and compared with requirements of the current regulations in Serbia.

2. INFILTRATION CALCULATION MODELS AND METHODS

2.1. Infiltration in buildings

Adequate airtightness of a building ensures adequate indoor environmental quality in buildings, lowers the usage of the energy. Both too high and too low infiltration rates may have a negative impact on building energy demand and occupant comfort. Poor airtightness of a building envelope results in impaired internal comfort conditions (thermal, air, and sound comfort), may influence hydrothermal building performances, fire permeability, and can lead to potential building material and structural damages. Air infiltration has a huge impact on the moisture flow across the building envelope possibly causing moisture accumulation and condensation in buildings, that can influence building material properties. [5] In the long term, additional condensation in a building can affect building structural performance and performance of building materials, with the appearance of mould and ice particles inside the materials and construction, changing the properties of materials and interrupting building construction integrity. Poor airtightness can also lead to unexpected heat loss in buildings causing the need for additional usage of heating, ventilation, and air-conditioning systems (HVAC). Although high airtightness prevents energy loss in a building, it may have a negative effect on indoor air quality. The tendency to reduce excessive air changes per hour during the heating period, results in a lack of a minimum amount of fresh air, due to accumulation of internal pollutants that cannot be discharged into the atmosphere by exfiltration, but only by natural and mechanical ventilation.

2.2. Infiltration calculation models and methods

Infiltration calculation models are essential in the building thermal design process - used in calculating the resulting air change rates, energy requirements and costs, and estimating indoor air quality. The output can be used both as a part of the design process (to modify the building characteristics and optimize the design) and during the time of exploitation of a building to check the performance of a building and its components. Air infiltration rate is a very uncertain quality to be measured because of a variety of calculation models and methods available. Also, because of a high variety of available building components and construction techniques, it is hard to define and evaluate the infiltration rate and its characteristics. [6]

Infiltration can be calculated in different methods chosen by the building type and possibility of application. Generally, methods are divided as theoretical (based on previous experience and practice) and empirical (requiring different measurement tools and models). Based on the results of some previous researches, [5,6,7] different models of infiltration calculation are presented and compared in this chapter. They are divided into five categories: air change methods, reduction of pressurization data test, regression techniques, theoretical network methods, and simplified theoretical methods. [5] Empirical models are air change methods, reduction of pressurization test data, and regression techniques, and the remaining two methods are classified as numerical methods with different complexity. Air change methods are considered the least complex and most applicable. Theoretical models can be used as predictive even during the design process and can help during the design decision process, while empirical models require concrete cases and situations on which the verification methods can be applied. The analysis of infiltration calculation models - theoretical and empirical is presented in Table 1.

2.2.1. Theoretical models

All theoretical models are defined on the mass balance - preposition that infiltrating air displaces the equivalent volume of internal air, mantling the balance between masses. [6] The simplest form of theoretical models is a single zone model, that assumes all different zones in a building as a single enclosed space, while more complex multizone models break down building into series of interconnected zones. Single-zone models calculate infiltration considering flow paths and characteristics, building height, internal/external temperature gradient, area

wind speed, local shielding conditions, terrain roughness factors, and mechanical ventilation system properties. [6] Multizone models also require knowledge of flow path details and characteristics, building location, geometry, etc., but multizone calculations in the calculation add the equations representing the airflow/leakage across internal zones and partitions. [6] Simulations are very valuable as control methods during the design process but they cannot be completely accurate. Since there is a large amount of input needed and a lot of values usually based on generic coefficients, these results are generally not precise, and not adapted completely to local conditions and building characteristics. For the results to be accurate, the verification methods should be provided with precise values and input. Multizone models allow simulation of infiltration that can be helpful during the heating/cooling design process and are allowed to predict indoor air conditions and the hygrothermal performance of a building. Usually, these models are based on homogenous indoor air and unformed temperature, neglecting airflow and because of that these assumptions can lead to an error. [8] Because of that, the CFD (computational fluid dynamics) methods are developed capable of reducing the number of assumptions needed for a multizone approach while still providing detailed airflow values, temperatures, and pollutant distribution conditions. Some of these simulations require complex mathematical apparatuses or long-time span, and as such are not adequate for small scale models and general implementation. [5]

2.2.2. Empirical models

Empirical models are a very important tool both for research and understanding of this phenomenon and practical application in different cases, as well as for creating a numerical database of infiltration rate. [5] Empirical models are described as three methods - air change methods, reduction of pressurization test data, and regression techniques. [6] Regression techniques and air change methods are predictive measuring techniques based on adopting values from a database and calculating the infiltration rate based on previous experience and expert estimations, while pressurization test data requires in-situ measurements defining infiltration rate for a special case and current conditions. Air change rates are the simplest tools that require basic building design details but do not provide detailed infiltration predictions. Regressions methods consider infiltration measurement data with parallel records of location climate conditions and may be applied only on existing buildings that were measured by the tracer gas method but also give unreliable results. Tools that can define and measure the infiltration rate *in situ* - are verification methods. The reduction of pressurization test data is the most commonly used verification tool used as a method to measure the airtightness rate. This verification method applies only to existing buildings pressure tested, but it is incapable to define leakage trace and crack location. Therefore, for a complete diagnostic and observation of a problem, an additional tool is needed to define exact problem areas and leakage intensity.

Table 1. *Infiltration calculation models analysis*

<table>
<tr><th>models</th><th>application</th><th colspan="2">type</th><th>disadvantages</th><th>output</th></tr>
<tr><td rowspan="2">THEORETICAL</td><td rowspan="2">- can be used on building models for simulations
-valuable as control methods during the design process;</td><td colspan="2">single-zone models
(different zones in a building as a single enclosed space)</td><td rowspan="2">- require substantial data input
-might be too complex
- unreliable;</td><td rowspan="2">- values based on prediction and generic coefficients</td></tr>
<tr><td colspan="2">multizone models
(break down building into series of interconnected zones)</td></tr>
<tr><td rowspan="3">EMPIRICAL</td><td rowspan="3">-applicable for existing buildings;
- calculating the average infiltration in a building;
-a very important tool for research and understanding of infiltration phenomenon;
-valuable for evaluating creating a numerical database of infiltration rate;</td><td rowspan="2">PREDICTIVE MEASURING</td><td>air change methods
(predictive measuring technique based on previous experience)</td><td>- do not provide detailed infiltration predictions;
- do not reflect buildings specific properties and local conditions</td><td>the numerical value (based on construction airtightness)
q_{inf} =V*(ACH)*C
q_{inf} (W/^{O}C h) infiltration heat loss
V (m^3) space volume
ACH (h^{-1}) air change rate per hour
C (J/m^3 ^{O}C) air heat capacity</td></tr>
<tr><td>regression techniques
(predictive measuring technique based on previous experience)</td><td>- does not consider information about impact of wind, temperature, and local topography and conditions</td><td>numerical value (infiltration data measurements combined with some climatic data)
Qinf =a'+b'DT +C'v2
Qinf infiltration rate per hour,
DT internal/external temperature difference (C),
v (m/s) wind speed,
a', b' and c' regression coefficients</td></tr>
<tr><td>VERIFICATION METHOD</td><td>reduction of pressurization test data
(requires in-situ measurements defining infiltration rate for a special case and current conditions)</td><td>- do not reflect building-specific properties and local conditions</td><td>the numerical value (the average infiltration in a building)
$n=n_{50}$/N
$n_{50}=V_{50}$/V
n50 (h-1) air change rate at 50Pa,
V50 (h-1) air leakage test,
V (m3) building volume,
N correlation factor</td></tr>
</table>

INFILTRATION ACCORDING TO STANDARDS AND REGULATIONS

2.3. Infiltration according to eu standards

The present European building regulatory framework is developed to continuously improve energy efficiency and performance of building stock, reduce CO_2 emission, and ensure good Indoor Air Quality. In previous years sets of regulations related to these problems have been developed and implemented in European countries. European Union continuously sets goals of improving energy efficiency and reducing energy consumption. Goals have been updated and set higher with a set of measurements:

- to reduce primary energy consumption in the EU by 20% by 2020;
- 40% cuts in greenhouse gas emissions (from 1990 levels), 32% share for renewable energy, 32.5% improvement in energy efficiency by 2030;
- to be climate-neutral by 2050 – an economy with net-zero greenhouse gas emissions.

The main legislative instrument affecting energy use and efficiency in both new and existing building stock in the EU is The Directive on Energy Performance in Buildings (EPBD) originally approved in 2002, followed by the recast in 2010 (2010/31/EU) and amending directive in 2018 (2018/844/EU). Consequently, the European Committee for Standardization (CEN) developed a set of standards regarding the energy performance of buildings (EPB standards).

Table 2. *Airtightness requirements in Europe (based on BPIE study[9])*

Country	unit	Air permeability	Pressurization tests
BRUSSELS	h-1	0.6	unknown
DENMARK	l/(sm2)	< = 1.5 when tested @50Pa <1 for low energy building class 0.5 for nZEB buildings	Not mandatory, calculated as the average measurement using overpressure and under pressure
FRANCE	m3/(h*m2)	< = 0.6 individual buildings < = 1 multifamily building	Mandatory for all new dwellings, @4Pa
GERMANY	h-1	< =3 buildings with natural ventilation < =1.5 buildings with mechanical ventilation < = 0.6 passive house standard	airtightness value results from the blower door test @50Pa
ITALY	** only some regions have standards Bolzano - mandatory blower door tests in energy certification of new dwellings (according to EN13829) Trento – requested in energy certification of high-class buildings (for the A+ class)		
POLAND	m3/(m·h)	-9 for low or moderately high buildings (up to 55 m) -3 for high-rise buildings (more than 55 m)	Recommended after the construction phase @100Pa
SWEDEN	l/(s·m2)	< 0.6 (specifically, for single-family homes (<50m2))	unknown
UK	m3/(h·m2)	10 m3/(h·m2) 5 m3/(h·m2) (notional dwelling)	unknown

Buildings Performance Institute Europe (BPIE) did research overviewing the regulatory framework for IAQ, thermal comfort, and daylight in EU countries. It demonstrated that matters of infiltration and ventilation are important factors considering both energy efficiency and indoor air quality. In many energy performance regulations across European countries, it is noted a great difference in the treatment of the matters of infiltration and airtightness in buildings. (Table 2) For some EU members, airtightness can only be defined with measurements (blower-door testing) while some countries allow the use of a quality management approach. [9] The value of airtightness is expressed in different units among countries, varying from litres per second per floor area ($l/s/m^2$) to volume per hour (m^3/h), and the referent value is given in either minimum airtightness requirements or maximum envelope leakage. [9] The default value for building airtightness is different from country to country, respecting differences in building construction types.

In some countries, the Pressurization test (blower-door testing) has become an obligatory part of a building air permeability diagnostics process. In the BPIE research, it is noted that calculation methods vary among countries and measured airtightness data are not fully comparable. [9]

2.4. Infiltration according to standards in serbia

Infiltration in Serbia has been treated through ventilation losses, in addition to transmission losses and heat gains, representing an important aspect of the total energy needs of the building. According to current regulations in the Republic of Serbia, [10] the annual required energy for heating and specific annual energy requirements for the heating of buildings, besides transmission, solar and internal gains include ventilation losses.

The annual energy required to compensate for the heat loss is calculated by the equation:

$$Q_{H,ht}=(H_t + H_v) \cdot 24 \cdot HDD \cdot 10 - 3 \; [kWh/a] \quad (1)$$

H_t (W / K) coefficient of transmission heat loss,

H_v (W / K) coefficient of ventilatory heat loss

HDD degree of the day of heating for a particular location.

Coefficient of ventilation loss is defined as:

$$H_v=\rho_a \cdot c_p \cdot \sum_i V_i \cdot n_i \; [W/K] \quad (2)$$

V (m^3) space volume,

n (h-1) air changes per hour,

$\rho_a * c_p$ = 1200 (J/m^2K).

Following the Building Energy Efficiency Regulation, the infiltration rate is defined by the number of air changes per hour - n [h-1], based on building display, facades exposed to the wind and infiltration rate of the building envelope. The infiltration rate of the envelope is determined according to the standard SRPS EN ISO 13789 Thermal performance of a building – Transmission and ventilation heat transfer coefficients – Calculation methods, [11] that specifies a method and provides conventions for the calculation of the steady-state transmission and ventilation heat transfer coefficients of buildings. The infiltration rate @50Pa is defined relative to the actual measured values of the number of air changes per hour n [h-1] at a pressure difference of 50 Pa.

Table 3. *Air changes per hour regarding building display and infiltration rate of a facility (SRPS EN ISO 13789) - Residential multifamily buildings with natural ventilation [12]*

		ACH (air changes per hour) n (h-1)			ACH (air changes per hour) n (h-1)		
Building display to the wind		More than one facade			Only one facade		
Infiltration rate		high/leaky	median	low/airtight	high/leaky	median	low/airtight
disposition	open	1,2	0,7	0,5	1,0	0,6	0,5
	medium hidden	0,9	0,6	0,5	0,7	0,5	0,5
	very hidden	0,6	0,5	0,5	0,5	0,5	0,5

Table 4. *Air changes per hour regarding building display and infiltration rate of a facility (SRPS EN ISO 13789) - Residential single-family buildings with natural ventilation [12]*

		ACH (air changes per hour) n (h-1)		
Infiltration rate		high/leaky	median	low/airtight
disposition	Open	1,5	0,8	0,5
	Medium hidden	1,1	0,6	0,5
	hidden	0,76	0,5	0,5

In the Republic of Serbia, it is not obligatory to verify the airtightness of the building envelope. The assessment of the infiltration rate is based on the expert assessment of the responsible energy efficiency engineer, and its expertise. The practice demonstrated that the assessment usually comes down to the quality of construction work and craftsmen's precision during the installation of building components. After determining the infiltration rate, the number of facades exposed to the wind and the disposition of the building, tabulated value of the number of air changes per hour - n [h-1] are adopted, separately for single-family and multi-family buildings. The minimal number of air changes per hour in buildings is defined by the Rulebook on the energy efficiency of buildings, and it should be minimally 0,5 (h-1). [10]

3. METHODS FOR VERIFICATION OF INFILTRATION

Evaluation of infiltration can be very complex because of many characteristics regarding building itself and buildings surroundings that should be included in its evaluation. Because of that, verification methods are a very valuable tool for measuring buildings airtightness. Few verification methods can measure a building's airtightness or demonstrate critical points of a building. The most common airtightness verification method is the method of pressurization test, performed with blower door device that can provide a numerical indicator of buildings infiltration rate. Besides the pressurization test, often used is the tracer gas method, that can evaluate and demonstrate air leakage points of a building, and thermal infrared imaging that can show air leakage points and point out problematic spots on a building envelope. The application of these verification methods can be of importance in various situations: for the needs of energy rehabilitation, checking the quality of the building construction and components, checking the technical condition of the building before the exploitation period, for the certification of buildings, before buying real estate.

The infiltration rate is most commonly verified as a part of the evaluation regarding the energy performance of a building of indoor air quality analysis. All verification methods are defined by standards, but as shown in research by BPIE, [9] the standards may vary from one country to another, making the evaluation process hard to compare. Also, during the research of different case studies that evaluate IAQ or EE performance of a building, it is noted that there is no defined methodology for evaluating infiltration in buildings. Measurements are done in different seasons and period over the year, in different weather conditions. Also, infiltration rates calculations are done with a variety of measurement results that vary from one-day measurements to all-year-round measurements that are compared and evaluated. In this chapter, different verification methods will be presented.

3.1. Pressurization test - static method of measuring - blower door

This method is based on the mechanical achievement of compression/decompression in the building and on the measurement of airflow through the building envelope at a certain difference of internal and external static pressure. In practice, the compression/decompression test is a term used to measure the airtightness rate of an individual building component, or whole building envelope. The desired pressure difference from the outside and the inside is achieved by extracting air, creating a pressure difference most commonly of 50 Pa, and then measuring the airflow through the fan unit required to maintain the pressure difference. The obtained values of pressure difference and airflow represent the results of the test. This test determines the amount of air that infiltrates / exfiltrates the object at a given value of pressure difference. A standard regarding the matter of performing and evaluating pressurization test in Serbia is SRPS EN ISO 13829:2008, Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method, (ISO 9972:1996, modified). [12] In the Republic of Serbia, the reference parameter in the calculation of the energy performance of objects is the number of changes in the air per hour n, that is, the variation of the value n50.

Applying compression/decompression tests results in high values of pressure differences, most commonly at 50Pa. Based on a large number of tests, a correlation of results was found, for both residential and non-residential buildings. The number can be converted to air change rates per hour by the equation that divides the measured value with building volume and correlation factors. In different researches, this factor varies from 10-30, and it should be defined regarding local conditions. [13] As described in research by Jankovic et al., [14] the standards that are in use in the region, including Serbia, are based on ISO standard and only roughly defines the infiltration rate. Consequently, partial disagreements between the real and the measured results are possible. The authors point out that for more precise estimation, more factors should be considered taking into account climatic conditions, building height, possible sheltered facades, and physical damage to the façade envelope. [14] The separate evaluation of each parameter would give a more precise evaluation of the infiltration rate. Standard used in Serbia, SRPS EN ISO 13789 [12], estimates the annual infiltration rate as n_{50}/N where N=20, referring to this number for a steady-state calculation method:

$$n_{50}=V_{50}/\mathrm{V} \quad (3)$$

$$n=n_{50}/\mathrm{N} \quad (4)$$

where,

n_{50} (h^{-1}) air change rate at 50Pa,

V_{50} (h^{-1}) air leakage test - measured value,

V (m^3) building volume,

N correlation factor

Results calculated by this equation classify buildings by infiltration rate that varies between low/airtight, median, and high/leaky, and the values for single and multi-family buildings are given in Table 5.

Table 5. *Categorization of infiltration rate of the envelope according to the measured values of the number of changes of air per hour at a pressure difference of 50 Pa - n50 [h-1] SRPS EN ISO 13789 [12]*

ACH (air changes per hour) n50 [h-1]		Infiltration rate
Single-family houses	Multi-family houses	
<4	<2	low/airtight
4-10	2-5	median
>10	>5	high/leaky

3.2. Tracer gas method

This technique consists of introducing a certain quantity of a known gas in the space where the air exchange rate is supposed to be measured. Once the tracer concentration evolution with time is known, it is possible to evaluate the airflow rates through the envelope of the space, with appropriate mathematical analysis. [15] There are three basic tracer gas methods: decay, constant concentration, and constant injection. [16] The decay technique is the most common one. [17] This method is simple and suited for making short term measurements or spot checks at sites, giving the calculation of the infiltration rate to the effective volume. It simplifies the calculating method assuming that the infiltration rate remains constant, and it requires the minimum amount of equipment. This method requires that a trace detector is connected to a single channel chart recorder, or the measurement may be taken by hand. Then the volume of tracer gas to bring the concentration of traces to the full scale of the analyzer is released. This system can stabilize and record data until the concentration drops below its starting value (approx. ½ - 2 hrs.).

To evaluate actual air exchange, gas tracing dilution methods have been developed and standardized. A current standard regarding this matter is SRPS EN ISO 12569:2017 Thermal performance of buildings and materials - Determination of specific airflow rate in buildings - Tracer gas dilution method (ISO 12569:2017) [18]

3.3. Thermal infrared imaging

The use of thermal infrared (IR) imaging is a valuable tool for inspecting and performing nondestructive testing of building elements. Thermography is commonly considered as a qualitative method that is used primarily to indicate variations in thermal resistance on a wall or roof. [19]

The result of a thermal infrared imaging investigation is a recorded visual display (digital picture) - thermograph, usually presented with a regular photograph of an object and a follow-up report. [20]

This method allows easy diagnostics of irregular thermal patterns - thermal anomalies, demonstrated by the temperature difference on an observed surface. These inspections of the building envelope can be used to detect air leakage, targeting specific problem area which helps with easier diagnostics of problem areas. With this method, it is possible to identify air leakage, but it is not possible to see the air or measure the air temperature. [19] Standard defining procedure and conditions for thermal infrared imaging are SRPS EN ISO 6781-3:2016 Performance of buildings - Detection of heat, air and moisture irregularities in buildings by infrared methods - Part 3: Qualifications of equipment operators, data analysts and report writers (ISO 6781-3:2015). [21]

Table 6. *Comparison of infiltration verification methods*

THERMAL INFRARED IMAGING	TRACER GAS METHOD	PRESSURIZATION TEST - STATIC METHOD OF MEASURING - BLOWER DOOR	
existing buildings	existing buildings	existing buildings	APPLICATION
process of measuring is fast and efficient	process of measuring is fast and efficient	installation of device and equipment is required, process of measuring is fast and efficient	COMPLEXITY
yes	yes	yes	TRAINING
camera, computer and additional softer (for data analysis)	the gas tracker can use sophisticated devices but can also be done with simple tools, by hand	blower door device, computer and additional softer (for data analysis)	EQUIPMENT
measuring process is fast	measuring process varies from a method used; localized action; slow; needs to be repeated for results to be more precise	measuring process is fast installation of device and equipment are required	DURATION
temperature scale must be specified	-	baseline pressure test needed	DEVICE INPUT
winter, night or cloud day, the temperature difference between outside and inside, no wind	there are no special conditions needed	winter, the temperature difference between outside and inside, no wind	CONDITIONS
location and a general indication of intensity (demonstrated by temperature difference)	location and a general indication of intensity (indicated by gas movement)	numerical value	OUTPUT
results are visible on the device, but for more complex analysis software is needed	results are visible; reading can be done on the device itself, but for more complex data analysis software is needed	reading can be done on the device itself, but for more complex data analysis software is needed	DATA
does not give numerical values, can be used just as an indicator; does not take in count impact of local climate and topography characteristics; cannot be used on reflective facades (curtain walls)	does not give numerical values, can be used just as an indicator	does not take in count impact of local climate and topography characteristics; for locating the leakage area additional verification methods are required	DISADVANTAGES AND LIMITATIONS

3.4. Infiltration verification methods comparison

Verification methods for measuring infiltration that has been described - pressurization test/blower door, tracer gas method and thermal infrared imaging are tools that can be used for in situ measuring of infiltration rate. The analysis of different verification methods is described in Table 6. It is noted that all methods require expertise and professional training, and are more easily performed with computer software that provides data analysis. For the tracer gas method process of measuring takes a longer time, while the pressurization test requires more preparation and equipment installation. None of the measuring techniques does take into count the impact of local topography and climate. During the blower door method and tracer gas test, results can be detected on the measuring device itself, but for more complex calculations the data analysis software is needed. Traces gas test can be done without computer device, by hand, providing general knowledge of infiltration rate, but for more complex and more accurate measurements, measuring devices should be used.

It is noted that every method has its advantages and disadvantages. Pressurization tests measurement is a method that quickly and efficiently determines the infiltration rate of a building envelope. The main disadvantage of this method is that although it measures the infiltration rate it cannot locate or quantify a specific part of the envelope where airflow occurs. Because of that, it needs additional verification methods for quantification to be more accurate. Tracer gas method and thermal infrared imaging are methods that can define and locate the problematic area but are not capable of giving precise infiltration rate value. Because of that pressurization correlations are, potentially, the superior method for predict infiltration loads and long-term indoor air quality concerns.[4] For a more complete analysis of the infiltration rate and location of a problematic area, the best solution would be to combine pressurization tests with either tracer gas methods or thermal infrared imaging.

4. PRESSURIZATION TEST MEASUREMENTS – CASE STUDY

In order to investigate the real effects of infiltration and to compare them with theoretical assumptions declared in the current regulations, some preliminary measurements of airtightness have been undertaken on the selection of buildings from the Belgrade building stock. The general idea is to investigate the characteristics of the existing housing stock regarding the airtightness and infiltration with respect to the previously defined building typology [22,23]. It has been noticed that in many cases, energy improvement of existing buildings often included partial interventions on the façade that were made individually by the tenants, which refers to the first place window replacement. The original, usually wooden window is usually replaced by a PVC window as a measure of improving the sealing of the building envelope, while in exceptional cases it was replaced by a higher performance - wood-aluminium window. Having this in mind, in the first step of the investigation, three types of windows were selected for the test:

- Wooden windows (since different types of wooden windows have been found as the original window solution on most of the buildings),
- PVC windows (as cheaper and common energy renovation solution) and
- Wood aluminium windows (as more expensive but more energy-efficient renovation solutions).

4.1. Methodology

The windows have been measured in 5 different buildings.

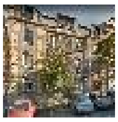
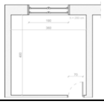
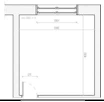
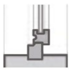
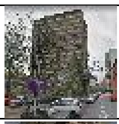
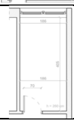
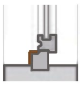
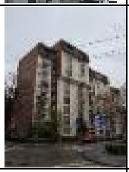
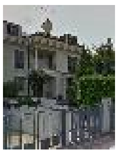
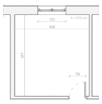
The original, wooden window was measured on a building from the construction period 1919-1945, the PVC window was measured on two different buildings dating from 1961-70, and wood aluminium window has been measured on two buildings, one from the period 1981-90 and one from the following period, 1991-2012.

First, the infiltration rate has been assumed (IR (a)) based on current regulations in Serbia [11] and then based on measured values (n50) the infiltration rate of the windows have been defined (IR(m)) based on the current standard - the correlation factor N has been adopted N=20 based on the current standard in the Republic of Serbia. The results are demonstrated in Table 5. Measurements have been done in six individual rooms, with Blower Door Minneapolis DG700 device, during December 2019 and January 2020. Buildings did not have any additional openings (such as shutters, ventilation, and air conditioning openings) and all windows and doors have been closed providing the preconditions for pressure tests. All measurements have been done according to standard SRPS EN 13879 [12] in optimal conditions (optimal wind, adequate temperature difference, and normal atmospheric pressure). The value of the measured infiltration rate that has been taken into further calculation is a middle value that the device detected during the measuring process @50Pa. So far, this research has been done on a small sample of buildings, therefore, for more precise conclusions the more detailed research should be performed.

4.2. Case study

Based on the National typology of residential buildings in Serbia it is noted that the majority of the buildings have originally installed wooden windows. The rooms with the wooden window have been measured on a building built in period 1919-1945. This building has a wooden window (double frame, double sash (wide box) with single glazing windows) and facade walls without insulation. On both chosen rooms windows were original, maintained by owners only by painting. Chosen rooms are on the ground floor, the building facade is west oriented, sheltered building position. During the diagnostics and measurement, the window in the room one was found to be in slightly worse condition than the window in room two, with few visible damages on the window, and some paint missing. Because of windows' quality and age, they were assumed to have a high infiltration rate.

Table 7. *Results of performed blower door tests*

Window type		Building			room				position and exposure of the room: orientation	floor	exposure	IR (a)	n50	IR (m)
wooden	 Wooden, double framed with a single glass	original	1919-1945		room 1		Area Volume Window area	14.40m2 40.32m3 2.85m2	west	ground	sheltered	high	5.70	high
					room 2		Area Volume Window area	14.40m2 40.32m3 2.85m2	west	ground	sheltered		4.8	median (to high)
PVC	 PVC, double low-E glass unit, inert gas filling	replaced	1961-70		room 1		Area Volume Window area	7.53m2 19.6m3 2.25m2	west	6th	open	low	1.85	low (to median)
		replaced			room 2		Area Volume Window area	19,60m2 49m3 3,08m2	north	3rd	sheltered		2.21	median
wood-aluminium	 Wood aluminium, double glazed low-E glass unit, inert gas filling	replaced	1981-1990		room 1		Area Volume Window area	14,39m2 36,69m3 2,93m2	west	4th	open	low	1.95	low (to median)
		original	1991-2012		room 2		Area Volume Window area	12.2m2 33.4m3 2.59m2	north	1st	sheltered		0.53	low

The rooms with PVC windows have been measured in two different structures built between 1961 and 70. In these buildings, in the last 10 years period, some of the occupants replaced the original windows and installed PVC windows as a measure of energy renovation. The buildings originally had wooden windows and facade walls without insulation. Measurement has been conducted on two rooms, having PVC windows (double low-E glass unit, inert gas filling) that replaced original ones, with no noticeable anomalies regarding window quality and quality of the installation. These windows have been assumed to have a low infiltration rate. Room 1 is on the 6th floor, the building facade is west oriented with open building position, and room 2 is on the 3rd floor, north-oriented facade on building with the sheltered position.

The room with aluminum-wood window was considered on two buildings - one from the construction period 1981-1990 where it was installed after energy rehabilitation, and another on the building built after 1991-2012, where it was originally installed. Both buildings have an insulated external wall. Chosen rooms both have wood aluminum windows (double glazed low-E glass unit, inert gas filling) with no noticeable anomalies regarding window quality and quality of installation, and are assumed to have low infiltration rate. Room 1 is on the 4th floor, the building facade is west oriented with open building position, room 2 is on the 1st floor, facade north-oriented, and sheltered position.

4.3. Results and discussion

The results of the measurement showed disagreements between the predicted and measured results. (Table 7) All of the measured values satisfy minimal requirements defined in the current regulations, some measured values vary slightly from predicted results, indicating potential problems, but for a more accurate investigation, further research should be performed. In the case of a wooden window, due to the age and quality of the window, it was expected for a window to have a high infiltration rate. Measured values did show high infiltration rate, but demonstrated that the quality of the window could significantly affect its performance – the value for room two was high, but almost at the border with the median value of the infiltration rate. PVC windows, as a measure of energy improvement, are considered a solution with a low infiltration rate. The measurement showed that the window in room 1 falls into the predicted category, at the border with the median infiltration rate, while the window in room 2 has worse performance than the predicted ones. Such results may have to do with the quality of the window mounting, but to determine this additional diagnostic is required. Wood aluminium windows, as a more energy-efficient solution, are assumed to perform a low infiltration rate. This assumption has been confirmed by performed measurements. A difference in the infiltration measured has been demonstrated – in room one where the window was installed afterwards as a measure of energy renovation the infiltration rate measured was closer to the median. This result may indicate the poor quality of installation of the opening during the renovation process, but this prediction should be confirmed by other diagnostic methods.

This research pointed out the loosely defined regulations in Serbia, not able to precisely define the infiltration rate and leaving room for mistakes. To prove this further, it is necessary to perform measurements on a much larger sample of objects in combination with additional diagnostic methods

5. CONCLUSION

Although the infiltration is recognized as one of the most important aspects when considering both energy consumption and indoor air quality in buildings, it is noted that there is no uniform methodology for testing infiltration. Case studies presented in the literature, show large variations in the duration of the measuring time, different periods of the year in which the measurement is performed, data processed, etc. However, regulations in Serbia that consider infiltration issues are not sufficiently precise in defining the calculation methods and quite roughly define values leaving a lot of space for assumptions. It is noted that in the Republic of Serbia, it is not obligatory to measure the airtightness of the building envelope - the infiltration rate of the building is based on an expert assessment. Preliminary measurements of airtightness of Belgrade housing stock with pressurization tests demonstrated a certain difference between assumed and measured values of infiltration rate in buildings, indicating potential problems regarding the evaluation of infiltration in practice. It is concluded that for more precise analysis, pressurization tests should be combined with another verification method that diagnostics the location of leaky points on the building. Consideration should also be given to introducing mandatory measurement of infiltration in buildings in Serbian regulations since this parameter is of great importance for energy consumption and both indoor air and environmental quality.

LITERATURE

[1] Directive (EU) 2018/844 of the European Parliament and of the Council amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency, 2018.

[2] Kunkel S., Kontonasiou, E., Arcipowska, A., Mariottini, F. and Atanasiu B. (2015, March). Indoor air quality, thermal comfort and daylight: analysis of residential building regulation in eight EU member states. Available:http://bpie.eu/publication/indoor-air-quality-thermal-comfort-and-daylight-an-analysis-of-residential-building-regulations-in-8-member-states-2015/[Jan. 20, 2020].

[3] Jokisato, j., Kalamees, T. Kurnitski and J., Eskola, L. (2008, July). “A Comparison of Measured and Simulated Air Pressure Conditions of a Detached House in a Cold Climate.” Journal of Building Physics. 32(1), pp. 67-89.

[4] Sherman M.H, Grimsrud, D. T., Condon, P.E. and Smith, B.V. “Air Infiltration Measurement Techniques.”, AHRAE Handbook 1981 Fundamentals. Atlanta, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc, 1980.

[5] Abishdid, C. and Bitsuamlak, G. T. (2012, Jan). “Air infiltration through building envelopes: A review.” Journal of Building Physics. 35. (3), 267-302.

[6] Liddament. M. W. Air Infiltration Calculation Techniques An Applications Guide. University of Warwick Science Park , 1986.

[7] American Society of Heating, Refrigerating and Air-Conditioning Engineers "2009 ASHRAE Handbook – Fundamentals", Atlanta, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2009

[8] Wang L and Chen Q (2006) "Validation of coupled multizone–CFD program for building airflow and contaminant transport simulations." International Journal of HVAC&R Research 13(2): 267–281

[9] Dorizas P.V., De Groote, M. and Volt J. (2018, Oct). The inner value of a building. Linking the indoor environmental quality linking indoor environmental quality and energy performance in building regulation. Available:http://bpie.eu/wp-content/uploads/2018/11/The-Inner-value-of-a-building-Linking-IEQ-and-energy-performance-in-building-regulation_BPIE_FInal.pdf [Jan. 20, 2020].

[10] Rulebook on energy efficiency of buildings. ("RS Official Gazette" no. 61/2011), 2011.

[11] SRPS EN ISO 13789:2017, Thermal performance of a building – Transmission and ventilation heat transfer coefficients – Calculation methods (ISO 13789:2017), 2017.

[12] SRPS EN ISO 13829:2008, Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method, (ISO 9972:1996, modified), 2008.

[13] Guilliem-Lambea, S., Rodrigues, S.B. and Marin, J.M.. (2019, Oct). “Air infiltrations and energy demand for residential low energy buildings in warm climates.” Renewable and Sustainable Energy Reviews. 116, 109469.

[14] Jankovic,A. Gajić,D., Antunovic.B. (2016) "The Significance of Blower Door Test in Determining a Number of Air Changes per Hour", Proceedings / XII International Scientific Conference of Contemporary Theory and Practice in Construction, ed. by B. Antunovic, Banjaluka, University of Banjaluka, Faculty of Architecture, Civil Engeenering and Geodesy, pp. 229-236.

[15] Afonso, C. (2013, May). “Tracer gas technique for measurement of air infiltration and natural ventilation: case studies and new devices for measurement of mechanical air ventilation in ducts .” International Journal of Low-Carbon Technologies. 10(3)

[16] Lagus, P. and Persily A.K. (1985, Jan). “A review of tracer gas techniques for measuring airflows in buildings.” ASHRAE Transactions. 91 (5), 1075-1087

[17] Sherman M.H. “Infiltration in ASHRAE’s Residential Ventilation Standards.” in ASHRAE Transactions 115, 2009.

[18] SRPS EN ISO 12569:2017 Thermal performance of buildings and materials - Determination of specific airflow rate in buildings - Tracer gas dilution method (ISO 12569:2017), 2017.

[19] Grinzato, E., Vavilov, V. and Kauppinen T. (1988, Dec). “Quantitative infrared thermography in buildings.” Energy and buildings. 29(1), pp 1-9.

[20] Balaras, C. and Argiriou, A. (2002, March). “Infrared thermography for building diagnostics.” Energy and buildings. 34. (2), pp. 171-183.

[21] SRPS EN ISO 6781-3:2016 Performance of buildings - Detection of heat, air and moisture irregularities in buildings by infrared methods - Part 3: Qualifications of equipment operators, data analysts and report writers (ISO 6781-3:2015), 2016.

[22] Jovanović Popović, M., Ignjatović, D., Radivojević, A., Rajčić, A., Đukanović, Lj., Ćuković Ignjatović, N., Nedić, M., Stanković, B. Национална типологија стамбених зграда Србије / National Typology of Residential Buildings in Serbia. Belgrade: Faculty of Architecture, University of Belgrade, GIZ - Deutsche Gesellschaft für Internationale Zusammenarbeit, 2013.

[23] Jovanović Popović, M., Ignjatović, D., Đukanović, Lj., Nedić, M., Stanković, B. Национална типологија стамбених зграда Србије грађених од 2013 / National Typology of Residential Buildings in Serbia Constructed since 2013. Belgrade: Faculty of Architecture, University of Belgrade, GIZ - Deutsche Gesellschaft für Internationale Zusammenarbeit, 2016.

23 | Review paper I Прегледни научни рад
ISSN 2566-4484 I Doi 10.7251/STP2014250R
pages 250-262

Marina Rakočević, marinara@ucg.ac.me, Faculty of Civil Engineering, University of Montenegro

Vasilije Bojović, vasilije.b@ucg.ac.me;, Faculty of Civil Engineering, University of Montenegro

Ivan Mrdak, ivanm@ucg.ac.me, Faculty of Civil Engineering, University of Montenegro

ANALYSIS OF THE INFLUENCE OF GROUND TYPES ON SEISMIC RESPONSE OF MULTI-STOREY FRAME STRUCTURE

Abstract:

Experiences from previous earthquakes have shown that level of structural damages depends on ground features where the structure is placed. Also, it is noted that reinforced concrete frame structures collapse due to the appearance of “weak floor”, especially when are founded on grounds with lower characteristics. In this paper, the seismic analysis of structure is presented on example of the six-storey RC frame structure, founded on different ground types. The seismic analysis is performed in accordance with European regulations and still valid ex-Yugoslavian code PIOVSP'81. At the end of the paper, a comparison of the results was made, and corresponding conclusions were reached.

Keywords: ground type, seismic design, capacity design, Eurocode 8

АНАЛИЗА УТИЦАЈА КАТЕГОРИЈЕ ТЛА НА СЕИЗМИЧКИ ОДГОВОР ВИШЕСПРАТНЕ РАМОВСКЕ КОНСТРУКЦИЈЕ

Сажетак:

Искуства стечена из ранијих земљотреса показала су да ниво оштећења конструкција зависи од карактеристика тла на ком се објекат налази. Такође, примијећено је да армиранобетонске конструкције доживљавају лом услијед појаве “слабог спрата“, или усљед колапса цијеле конструкције, посебно онда када је објекат фундиран на тлу лоших карактеристика. У овом раду, приказана је упоредна сеизмичка анализа шестоспратне АБ рамовске конструкције која се налази на различитим типовима тла. Сеизмички прорачун је извршен примјеном Европских прописа и прописа ПИОВСП'81. На крају рада, приказано је упоређење карактеристичних резултата и донијети су одговарајући закључци.

Кључне ријечи: тип тла, сеизмички прорачун, метода програмираног понашања, Еврокод 8

1. INTRODUCTION

The seismic response of structure during an earthquake depends on several factors such as material characteristics which the structure is made of, the type of soil where the structure is founded on, the level of area seismicity which the structure is being built in, the structural system which the structure is made of, on non-structural elements, etc. All these factors influence the dynamic characteristics of the structure, which directly affects the response of the structure to earthquake action.

In this paper, the analysis of the influence of ground types is investigated on the seismic response of a multi-storey frame structure. This is performed on example of the six-storey frame structure founded on different types of ground and analysed in accordance with European regulations and still valid ex-Yugoslavian code PIOVSP'81. The effect of ground types is considered with the corresponding response spectrum and in domestic regulation with the dynamic coefficient.

2. MODELING OF STRUCTURE

The numerical example used for this analysis, is a six-storey frame structure, with a total height of 19m. The storey height of the ground floor is 4m, while the height of the other stores is 3m each. The structure is a square-shaped base, with dimensions of 16.5x16.5m. In both directions, a span of structural elements is 3x5.5m.

The class of concrete is C30/37 according to Eurocode 2 [5], which corresponds to the class strength of concrete MB35 according to code PBAB'87 [6]. The reinforcement type is B500.

Columns have rectangular cross-sections. Dimensions of interior columns are 60x60cm, while dimensions of exterior columns are 50x50cm. A rectangular cross-section is adopted for the beams, with dimensions of 40x60cm. The floor slab has 16cm thickness.

Analysis of structure was performed on a 3D model of the structure by using FEM software Tower – Radimpex (Figure 1). Beside this, a cross-sectional ductility analysis was performed in software XTRACT.

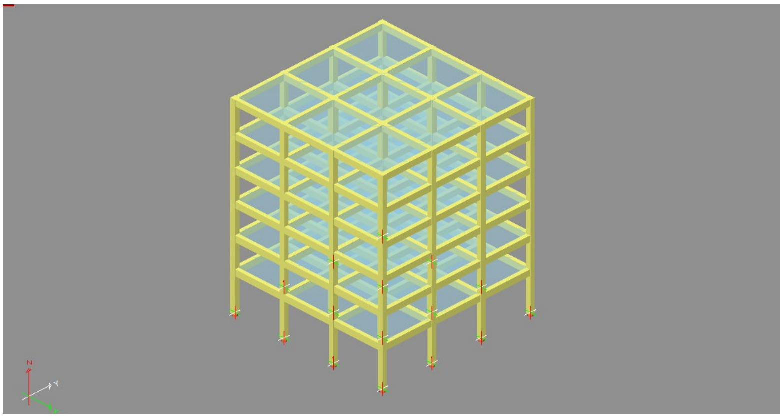


Figure 1. *3D model of analysed structure*

The self-weight load was taken automatically in the software. Additional dead load is uniformly distributed surface unit load, on the floor slabs as well as on the roof. Adopted value of this load is $\Delta g = 2$ kN/m^2. Live load is uniformly distributed surface unit load, on the floor slabs, with the intensity of $p = 2$ kN/m^2.

Considering the location of the structure, the snow load is uniformly distributed surface unit load, with the intensity of $s = 0.75$ kN/m^2.

2.2. Modal periods

According to Eurocode 8 (EC8) [3], the flexural and shear stiffness properties of RC elements should be modeled taking into account the effect of cracking of concrete. The elastic flexural and shear stiffness properties of structural elements are taken to be equal to one half of the corresponding stiffness of the uncracked elements.

In Eurocode 8 [3] the weight of the structure is given by the expression:

$$W=\Sigma G_{kj} + \Sigma \Psi_{ei} Q_{kj} \tag{1}$$

Total weight is calculated as a sum of the dead load, 15% of live load, and 30% of snow load.

The total weight and calculated periods of vibrations for the first 2 modes are given in Table 1.

Table 1. *Characteristics of the structure according to EC8*

Total weight	Period of vibration, the 1. mode	Period of vibration, the 2. mode
17469.4 KN	0.814s	0.814s

It is noted that the European code [3] in seismic design, uses a smaller percent of live load and snow load when compared to code PIOVSP'81 [4]. For seismic design, code POVSP'81 uses total dead load, 50% of live load, and total snow load. PIOVSP'81 [4] does not take into account the effect of cracking by reducing stiffness. According to this code, the greater total weight of the structure, and smaller periods of vibrations are obtained, than in accordance with Eurocode 8 [3], (Table 2).

Table 2. *Characteristics of the structure according to PIOVSP'81*

Total weight	Period of vibration, the 1. mode	Period of vibration, the 2. mode
18586.8 KN	0.588s	0.588s

3. CALCULATION OF SEISMIC EFFECTS ACCORDING TO EUROCODES (EC8) AND NATIONAL REGULATIONS (PIOVSP'81)

3.1. Calculation of seismic forces according to eurocode 8

The analysed building was designed as a high-ductility class structure (DCH), resulting in a greater reduction of seismic forces (higher behaviour factor), higher displacement ductility, and lower bearing capacity.

The structure was located in the IX seismic zone, with the reference peak ground acceleration agR = 0.32g. The analysed building belongs to a group of frame structures. The importance factor of the structure amounts $\gamma 1=1.0$, and the adopted behaviour factor is equal q = 5,85.

According to Eurocode 8 [3], there are 5 ground types: A, B, C, D, and E. They are described by the stratigraphic profiles and parameters given in Table 3. These ground types may be used to account for the influence of local ground conditions on the seismic action. This may also be done by additionally taking into account the influence of deep geology on the seismic action.

Special studies are required for the definition of the seismic effects for sites with ground conditions matching either one of two special ground types S1 or S2. For these types, and particularly for S2, the possibility of soil failure under the seismic action shall be taken into account.

The seismic analysis was performed for the three ground types - ground types B, C, and D.

Table 3. *Ground types according to Eurocode 8*

Ground type	Description of stratigraphic profile	Parameters		
		$v_{s,30}$ (m/s)	N_{SPT} (blows/30cm)	c_u (kPa)
A	Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.	> 800	-	-
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of meters in thickness, characterized by a gradual increase of mechanical properties with depth.	360 – 800	> 50	> 250
C	Deep deposits of dense or medium-dense sand, gravel or stiff clay with thickness from several tens to many hundreds of meters.	180 – 360	15 – 50	70 – 250

D	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.	< 180	< 15	< 70
E	A soil profile consisting of a surface alluvium layer with v_s values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with $v_s > 800$ m/s.			
S_1	Deposits consisting, or containing a layer at least 10 m thick, of soft clays/silts with a high plasticity index (PI > 40) and high water content	< 100 (indicative)	-	10 – 20
S_2	Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types A – E or S_1			

3.1.2. Calculation of seismic forces using the lateral force method of analysis (LFM)

Because of its own simplicity, the lateral force method of analysis (LFM) is the most commonly used in calculating seismic forces. Condition for using this method is defined in a way that the structure must vibrate predominantly in the first mode.

The requirement is deemed to be satisfied in buildings which fulfill both of the two following conditions:

- they have fundamental periods of vibration T1 in the two main directions which are smaller than the following values:

$$T_1 \leq \begin{cases} 4T_c \\ 2.0s \end{cases} \tag{2}$$

- they meet the criteria for regularity in elevation.

The considered structure satisfied both conditions.

The seismic base shear force Fb for each horizontal direction in which the building is analysed, shall be determined using the following expression:

$$F_b = S_d(T_1)m\lambda \tag{3}$$

Distribution of the horizontal seismic forces may be calculated using methods of structural dynamnics or may be approximated by horizontal displacements increasing linearly along the height of the building.

For the anylased building, distribution of the horizontal seismic forces was calculated using methods of structural dynamnics.

$$F_i = F_b \frac{s_i m_i}{\Sigma s_j m_j} \tag{4}$$

3.1.3. Calculation of seismic forces using the modal response spectrum analysis (MMA)

Modal response spectrum analysis (MMA) could be used for all types of structures. It shall be used for buildings that do not satisfy the necessary conditions for using the LFM. It is a reference method for calculating seismic forces according to Eurocode 8 [3].

When using this method, the response of all modes of vibration, contributing significantly to the global response, shall be taken into account. The number of necessary modes is determined by fulfilling one of the following conditions:

- the sum of the effective modal masses for the modes taking into account amounts to at least 90% of the total mass of the structure;
- all modes are taken into account with effective modal masses greater than 5% of the total mass. For each mode of vibrations, it is necessary to calculate seismic force Fbi.

$$F_{bi} = m_{ef,i} S_d T_{(i)},\ i = 1,2,..,n \tag{5}$$

If all relevant modal responses are regarded as independent from each other, the maximum value of a seismic action effect may be taken as SRSS – Square-Root-of-Sum-of-Squares method.

$$E_E = \sqrt{\Sigma E_{Ei}^2} \tag{6}$$

3.2. Calculation of seismic forces according to code piovsp'81

Seismic forces were calculated using the equivalent static load method (ESL method). As defined in the code, the total base shear is equal:

$$S = KG \tag{7}$$

The considered building was located on the Montenegrin coast, in the IX seismic zone, and belongs to the second category of structure.

According to code PIOVSP'81 [4], there are three ground categories. The influence of local ground conditions is taken into account when seismic effects are calculated and is given by a dynamic coefficient, which depends on the ground category.

The first ground category represents rocky and semi - rocky soils (crystalline rocks, calcareous rocks, limestone, marl, well-cemented conglomerates, etc.). The second ground category represents very compacted and hard soil, while the third ground category is characterized by soft-to firm cohesive soil.

The building was founded on different ground categories, on the second and on the third ground category.

Seismic forces, for the structure founded on the second ground category, were equal to seismic forces for the building located on the third ground category. It is noted that the effect of the ground category does not exist if the fundamental period of vibration is lower than 0.5s (lower than 0.7s if the considered structure is founded on the 2. and on the 3. ground category).

In accordance with code PIOVSP'81 [4], the distribution of seismic forces was calculated using the following expression:

$$S_i = S\frac{G_i H_i}{\sum_1^n G_i H_i} \tag{8}$$

Code PIOVSP'81 [4] prescribes that for structures with more than 5 storeys, 85% of total base shear is distributed according to the previous expression, and 15% of the total base shear is added as a concentrated force on the top of the structure.

As well as total shear forces, the distribution of shear forces across the structure, for the building founded on the second and on the third ground category, is equal.

4. DIMENSIONING

For the comparison of the results, characteristic cross-sections of the inner frame on the ground floor were dimensioned. The dimensioned cross-sections are shown in Figure 2.

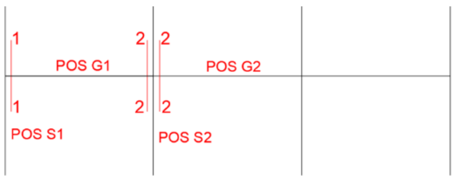


Figure 2. *Characteristic cross-sections of the considered beams and columns*

4.2. Dimensioning according to eurocode 8 (ec8)

Eurocode 8 [3] provides a capacity design procedure for beams and columns, and also defines the rules for the design of critical regions, plastic hinges. By applying the capacity design method defined by Eurocode 8 [3], the aim is to provide such a hierarchy of resistance to different types of fractures and appropriate reinforcement details in critical locations, in order to make the behaviour of RC structure ductile. To achieve the required overall ductility of the structure, the potential regions for plastic hinge formation shall possess high plastic rotational capacities. The non-linear deformations should be the result of bending deformations. In accordance with this, it is necessary to avoid brittle failures and remain in elastic region for the deformations that result in shear and axial force.

In accordance with Eurocode 8 [3], ductile failure shall be provided. For the structure founded on the ground type D, ductile failure could not be provided, but the failure of concrete for beams G1 and G2, so the design conditions were not fulfilled. Increasing the cross-sectional dimensions would be a solution. For the purpose of comparing the final results, dimensioning was continued with the values thus obtained.

Applying the capacity design, the design shear forces of the beams were increased by 55-70%, compared to the shear forces obtained by linear analysis.

The adopted reinforcement of beams G1 and G2, in the considered cross-sections, for the structure on the ground types B, C, and D, is shown in Figure 3.

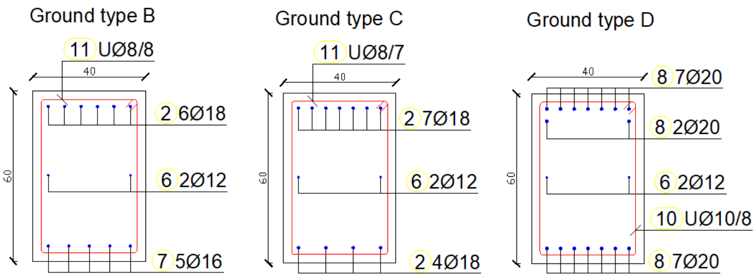


Figure 3. *Adopted reinforcement in beams G_1 and G_2 in considered cross-sections*

For multi-storey RC structures, the basic design objective is to prevent the formation of a "weak floor", i.e. the appearance of plastic hinges at the ends of all columns of one floor. The capacity design is based on providing stronger columns than beams.

Using the capacity design, on average, 50-70% higher values of the bending moments in columns were obtained, compared to the linear analysis.

In order to achieve the required displacement ductility, confining with shear reinforcement is necessary to be applied, due to the negative influence of the axial compressive force on the ductility. Adopted reinforcement in columns S1 and S2 is given in the following figures.

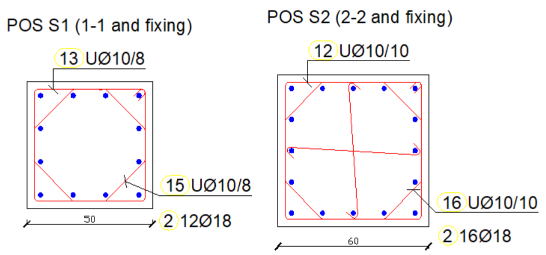


Figure 4. *Adopted reinforcement in columns S_1 and S_2 for the building on the ground type B and C*

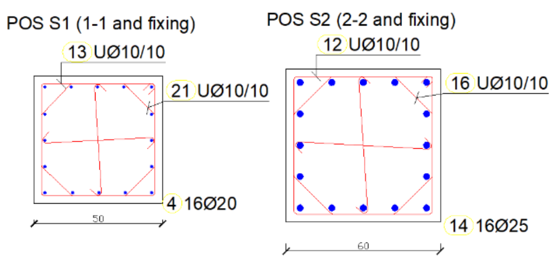


Figure 5. *Adopted reinforcement in columns S_1 and S_2 for structure on ground type D*

4.3. Dimensioning according to codes pbab'87 and piovsp'81

In accordance with the domestic code, the cross-section dimensioning is performed with the effects from the linear analysis.

Adopted reinforcement in considered beams and columns is given in Figure 6.

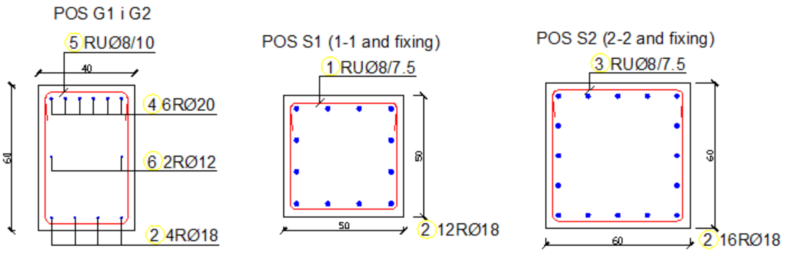


Figure 6. *Adopted reinforcement of beams and columns in considered cross-sections*

5. CROSS-SECTIONAL ANALYSIS OF THE CHARACTERISTIC CROSS-SECTIONS

Analysis of ductility of beams and columns was calculated using the XTRACT (Cross Section Analysis software for Structural Engineers) software package. The XTRACT software is primarily developed for the moment-curvature analysis. The calculation of the moment-curvature relationship is required to determine the nonlinear behavior of the cross-section.

Moment curvature diagrams and interaction diagrams were obtained based on:

- adopted longitudinal and shear reinforcement,
- the stress-strain diagram of unconfined and confined concrete,
- the stress-strain diagram of reinforcement steel B500.

The numerical example of calculation of the moment-curvature diagram and interaction diagram of the column S2, for the structure founded on the ground type B, is presented.

The stress-strain diagram of unconfined concrete C30/37 is shown in Figure 7.

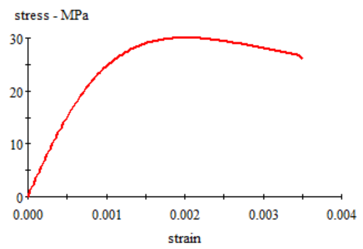


Figure 7. *Stress-strain diagram of unconfined concrete C30/37*

According to Eurocode 2 [5], based on the adopted longitudinal and shear reinforcement of the column, the compressive strength and ultimate strain of confined concrete are given by formulas:

$$f_{ck,c} = \beta \cdot f_c = \min\left(1 + 5\frac{p}{f_c}; 1.125 + 2.5\frac{p}{f_c}\right) f_{ck} \qquad (9)$$

$$\varepsilon_{cu2,c} = 0.0035 + 0.2p/f_{ck} \qquad (10)$$

The stress-strain diagram of the confined concrete is given in Figure 8.

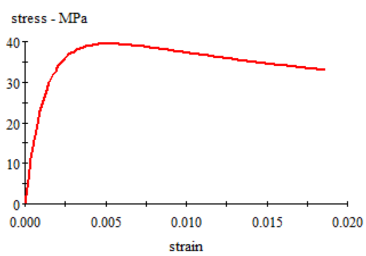


Figure 8. *Stress-strain diagram of confined concrete of column S_2*

The stress-strain diagram for reinforcement steel B500 class C was used for the analysis in accordance with the recommendations of Eurocode 2 [5] and Eurocode 8 [3]. The characteristic yield strength of the reinforcement amounts 500 MPa and the tensile strength is equal 600 MPa. The characteristic strain at maximum force amounts 10%.

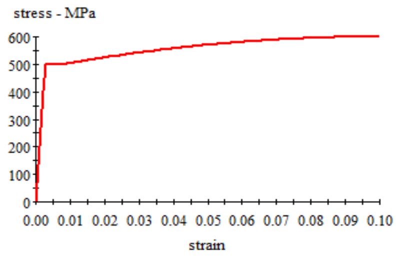


Figure 9. *Stress - strain diagram of steel B500*

Based on these input parameters, the interactions diagram (Figure 10), and the moment-curvature diagram (Figure 11) of the considered column, were formed.

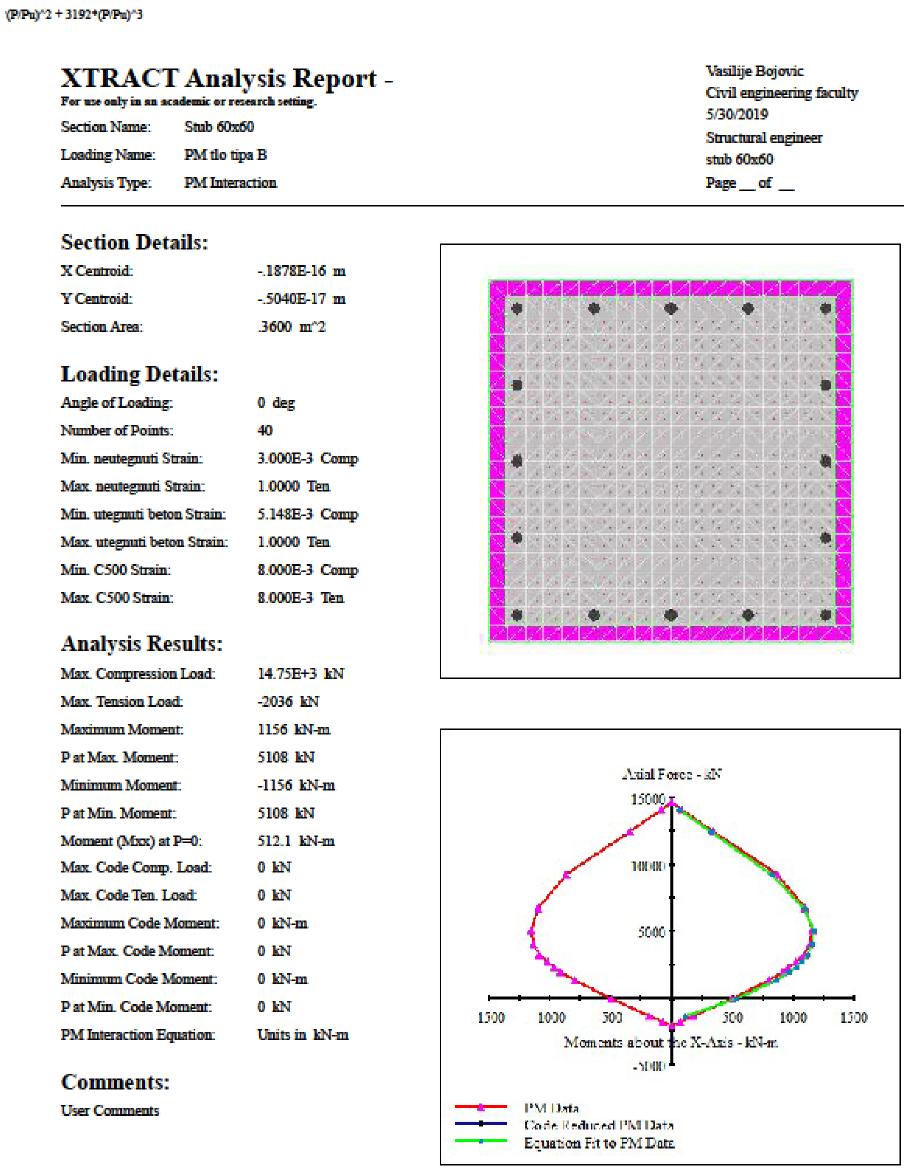


Figure 10. *Interactions diagram of the column* S_2

6. COMPARISON OF THE RESULTS

6.1. Comparison of modal periods

In accordance with Eurocode 8 [3], the calculated fundamental period of vibration for the structure founded on all three ground types, amounts $T_1 = 0.814s$. According to code PIOVSP'81 [4], the fundamental period of vibration is equal $T_1 = 0.588s$.

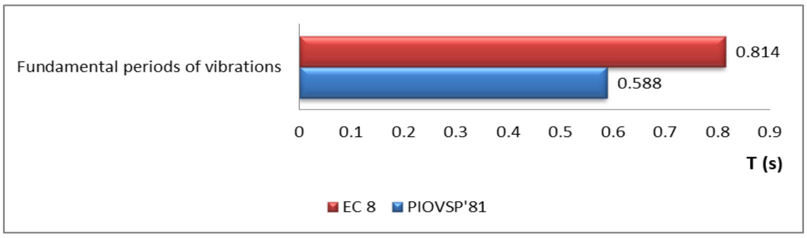


Figure 11. *Comparison of fundamental periods of vibrations according to EC8 and PIOVSP'81*

In Figure 12, a comparison of fundamental periods of vibrations according to codes Eurocode 8 [3] and PIOVSP'81 [4], is shown.

By reducing stiffness in accordance with Eurocode 8 [3], the effect of cracking, during an earthquake was taken into account. The stiffness of the structure was reduced, and the fundamental period of vibration was increased. According to Eurocode 8 [3], the fundamental period of vibrations is higher than according to code PIOVSP'81 [4] for 38.4%.

6.2. Comparison of seismic forces

By comparing the total seismic forces, calculated using the LFM and the MMA, approximately the same values were obtained (Figure 13). It means that the criteria for the regularity of the structure at the base and in elevation are fulfilled, as well as the structure dominantly vibrates in the first mode (the effect of higher modes is insignificant), so the LFM produces satisfactory fluid results.

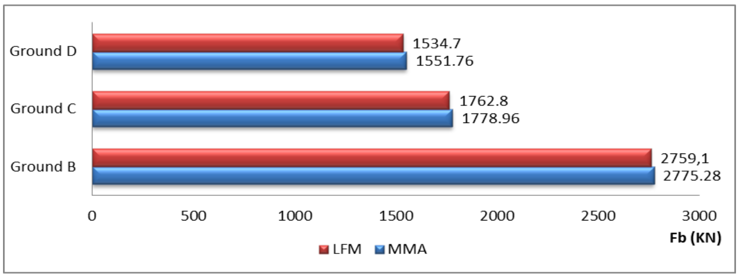


Figure 12. *Comparison of total seismic forces for the structure founded on 3 ground types*

As the total values of seismic forces are approximately equal, their distribution across the structure is approximately equal, so only the LFM was used in the further comparison of the results.

Further charts show a comparison of the total and storey seismic forces. Values of seismic forces, according to code PIOVSP'81 [4] were multiplied with a safety coefficient of 1.3, in order to compare with the seismic forces obtained according to Eurocode 8 [3], by which the coefficient for seismic actions is equal to 1,0.

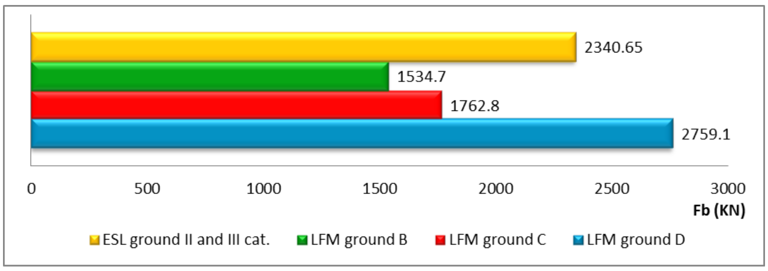


Figure 13. *Comparison of total seismic forces for the structure on 3 ground types*

Depending on the ground category, seismic forces can vary considerably. In analysed case, the seismic forces for the structure founded on the ground type D were higher than seismic forces for the building which was on the ground type B for 79.8%, and 56.5% higher than seismic forces for the structure founded on the ground type C. Using the ESL method, greater seismic forces were obtained than according to Eurocode 8 [3] when the structure was founded on the ground type B and C, and lower seismic forces when the considered building was located on the ground type D.

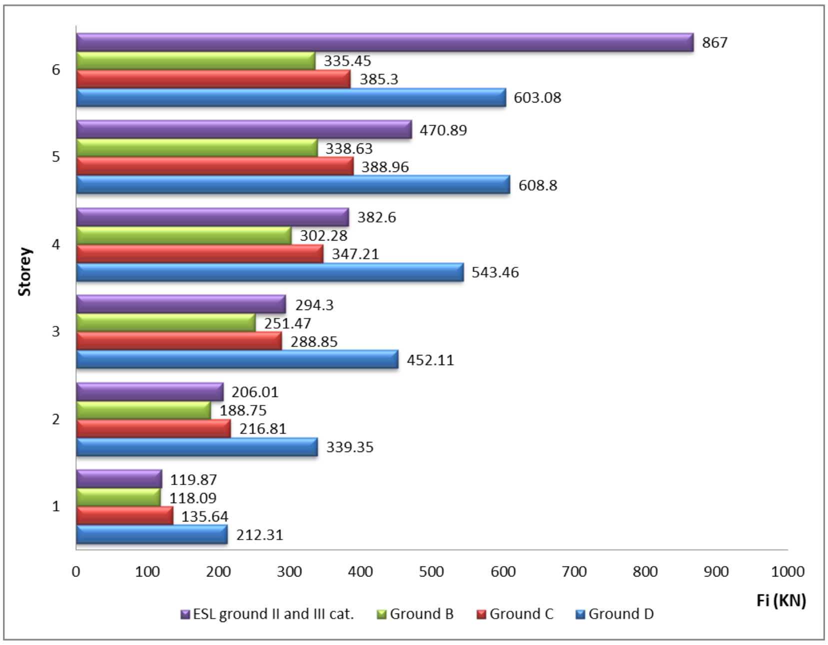


Figure 14. *Comparison of storey seismic forces for the structure on the ground types B, C, and D (LFM and ESL method)*

On the last floor, the seismic force calculated using the ESL method was significantly greater than the seismic force calculated according to LFM, because, according to PIOVSP'81 [4], 15% of the seismic force is added on the top floor for the structures with more than 5 storeys.

6.3. Comparison of total displacements

Figure 16 shows the comparison of total displacements, and Figure 17 presents the comparison of interstorey drifts for the structure founded on the ground types B, C, and D.

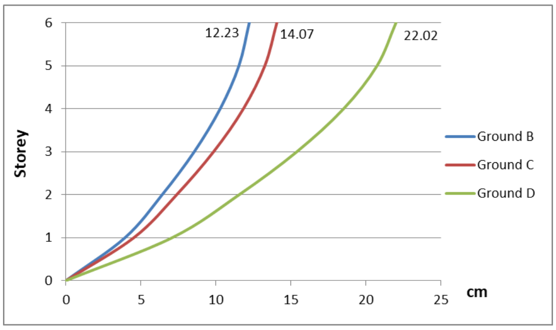


Figure 15. *Comparison of total displacements for the structure on the ground type B, C, D*

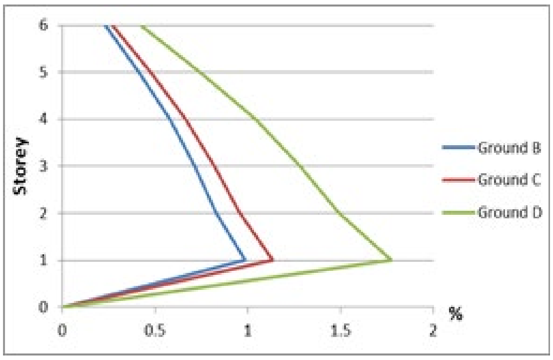


Figure 16. *Comparison of interstorey drifts for the structure on the ground types B, C, D*

Displacement of the top of the structure founded on the ground type D was 80% higher than in case when that building was on the ground type B. Also, the structure founded on the ground type D was displaced 56.5% more than when that building was located on the ground type C.

6.4. Comparison of adopted reinforcement

Comparison of adopted longitudinal and shear reinforcement ratios of the beams is shown in the following figures.

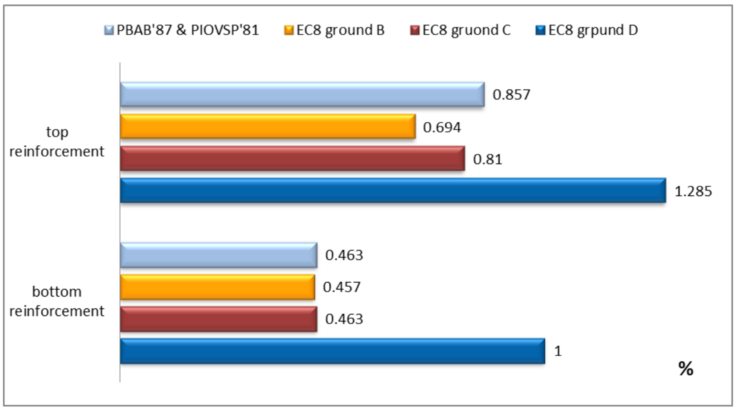


Figure 17. *Comparison of adopted longitudinal reinforcement ratios of beams*

According to PBAB'87 [6] and PIOVSP'81 [4], the reinforcement in the upper zone of the beam is 23% larger than in the corresponding section calculated in accordance with Eurocode 8 [3], for the structure on the ground type B, 5% larger than for a building founded on the ground type C, and 50% lower than for a structure founded on the ground type D.

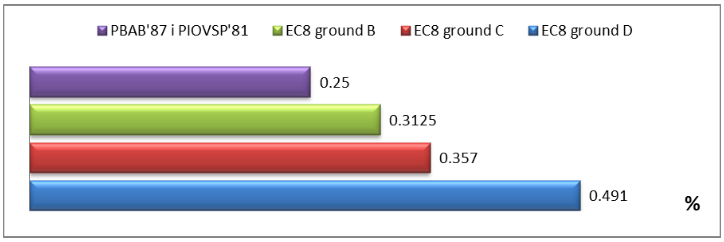


Figure 18. *Comparison of adopted shear reinforcement ratios of beams*

In accordance with Eurocode 8 [3], a larger shear reinforcement, compared to the codes PBAB'87 [6] and PIOVSP'81 [4] was obtained. A 25% larger if the structure was on the ground type B, 42.8% larger if the structure was on the ground C, and 96.3% larger if the building was on the ground type D, then according to codes PBAB’87 [6] and PIOVSP’81 [4].

Comparison of longitudinal and shear reinforcement of the column S2 is shown in the following figures. The longitudinal reinforcement, according to PBAB'87 [6] and PIOVSP'81 [4], and according to Eurocode 8 [3] for the structure on the ground type B and C, was adopted from the condition of the minimum reinforcement ratio.

For the building on the ground type D, 92.7% larger longitudinal reinforcement was calculated when compared to the structure on the other ground types.

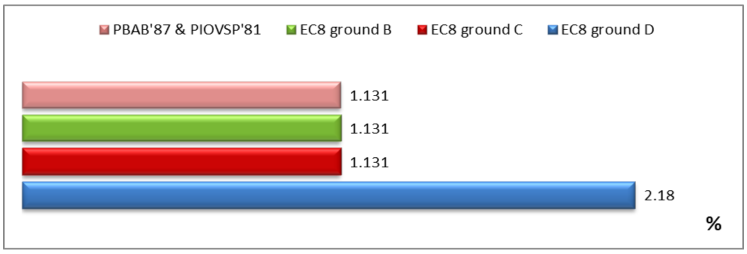


Figure 19. *Comparison of adopted longitudinal reinfocement ratios of the column S_2*

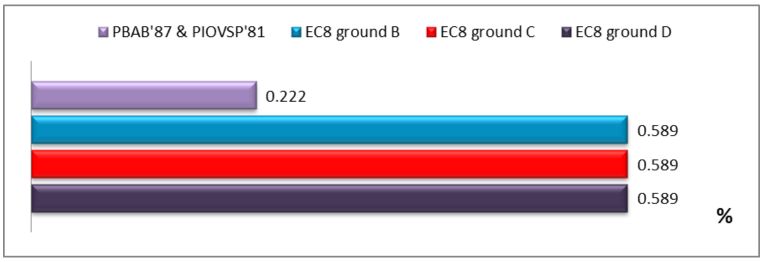


Figure 20. *Comparison of adopted shear reinfocement ratios of the column S_2*

According to Eurocode 8 [3], the stirrups were adopted from the cross-sectional confining conditions, resulting in a 165% larger transverse reinforcement than according to PBAB'87 [6] and PIOVSP'81 [4].

6.5. Comparison of the results calculted using the xtract

The values of the ultimate strain and the curvature ductility of the column S_2 are shown in the following figures.

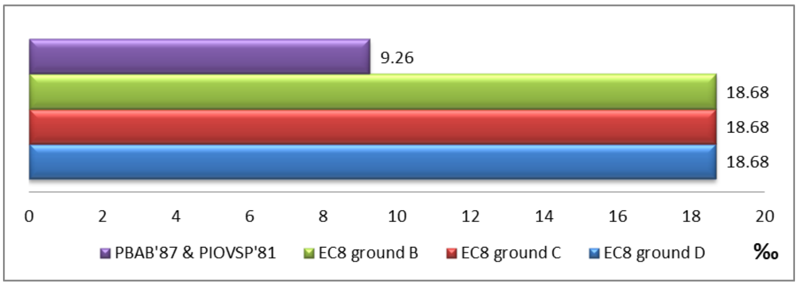


Figure 21. *Comparison of ultimate strains of confined concrete for the column S_2*

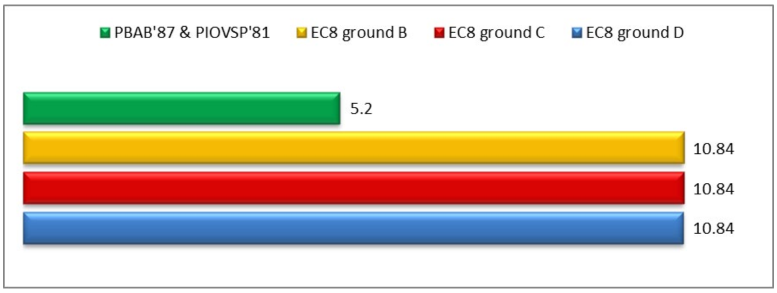


Figure 22. *Comparison of ultimate curvature of the column S_2*

According to Eurocode 8 [3], 102% higher ultimate strain was obtained compared to PBAB'87 [6], and PIOVSP'81 [4].

7. CONCLUSION

Eurocode 8 [3] provides five basic ground types: A, B, C, D, and E, with geological and geophysical parameters that are used in order to select proper parameters. Beside this, it is prescribed that there are two special ground types S1 and S2 where special studies have to be performed for the definition of the seismic actions. In accordance with domestic regulations, there are three ground types and they are given with descriptive geological information.

In accordance with the performed analysis it can be concluded that seismic performance of the structure founded on the ground types B and C, was similar (for the structure on ground type C seismic forces were 15% higher than for the structure on the ground type B). However, when the structure was founded on the ground type D, seismic forces were 80% higher than for the ground type B.

Also, it is concluded that when calculating structure in accordance with Eurocode 8 [3], the effect of changing ground category is better perceived than in accordance with the domestic code. According to code PIOVSP’81 [4], for the structures with fundamental period of vibration lower than 0.5s, there is no effect on the total seismic forces dependent on the selected ground category.

Considering cracked sections, the structure designed according to Eurocode 8 [3], is more flexible than the structure designed according to the code PIOVSP'81 [4].

Designing in accordance with European regulations generally results in slightly smaller longitudinal and much larger shear reinforcement (about 42% for beams and 156% larger for columns) to provide the required ductility of the structure, which is necessary for an adequate seismic performance of the structure.

Based on the analyses performed, it can be concluded that the Eurocode 8 [3] provides good guidelines for taking the ground effects on the performance of the structure and it provides guidelines for detailing for local ductility which is major improvement compared to domestic codes PIOVSP'81 [4] and PBAB'87 [6].

At the end, it can be concluded that type of ground on which the flexible frame structures are founded on, has a great impact on seismic response of the structures during an earthquake. In accordance with this, when designing frame structures in seismic active regions, the additional geotechnical investigations should be performed, local geological conditions should be considered, as well as the effects of deep geology.

LITERATURE

[1] V. Bojović and N. Bjeletić, “The effect of ground category on RC frame structure seismic performance,“ presented on the 7th international conference “Civil engineering science and practice,” Kolašin, Montenegro 2020.

[2] V. Bojović. “Modeling of RC frame structure, calculation and comparison of characteristic results, depending on ground category.” Specialist theses, Faculty of Civil engineering, University of Montenegro, Podgorica, 2019.

[3] EN 1998-1: 2004: Eurocode 8: Design of Structures for Earthquake Resistance, Part 1: General Rules, Seismic Actions and Rules for Buildings. Brussels: CEN, 2004.

[4] The Code of Technical Regulations for the Design and Construction of Buildings in Seismic Regions. Official Gazette of the SFRJ no. 31/1981.

[5] EN 1992-1-1: 2004; Eurocode 2: Design of Concrete Structures-Part 1-1, General Rules and Rules for Buildings. Brussels: CEN, 2004.

[6] The Code of Technical Regulations for Concrete and Reinforced Concrete, PBAB’87, Part 1 and Part 2. Official Gazette of the SFRJ no. 11/1987

24 | Review paper I Прегледни научни рад
ISSN 2566-4484 I Doi 10.7251/STP2014263M
pages 263-276

Ognjen Mijatović, mijatovicognjennada@gmail.com, Faculty of Civil Engineering, University of Belgrade

Rastislav Mandić, rastislav.m@gmail.com, Faculty of Civil Engineering, University of Belgrade

Zoran Mišković, zoran.miskovic@gmail.com, Faculty of Civil Engineering, University of Belgrade

Ratko Salatić, ratko.salatic@gmail.com, Faculty of Civil Engineering, University of Belgrade

Gabriel Relja, gabrielrelja@gmail.com, Elektroprenos BiH a.d. Banja Luka

REVIEW OF BASIC CONCEPTS OF CONTACT MECHANICS OF FRICTIONLESS CONTACT WITH EMPHASIS ON PENALTY METHOD

Abstract:

Problems involving contact are of great importance in industry related to mechanical and civil engineering, but also in biomechanics and other applications. The contact interaction between surfaces and different bodies like in a bolted splice connection joint or area in which a tire interacts with the soil is not known *a priori*, leading to a nonlinear boundary value problem. Due to the rapid improvement of modern computer technology, one can today apply the tools of computational mechanics to analyze contact problems with required accuracy, depending on design requirements. However, even now most of the standard finite element software is not fully capable of solving contact problems, including friction, with robust algorithms. The aim of this paper is to present some basic concepts of Contact Mechanich.

Keywords: Contact Mechanics, penalty method, frictionless contact

ПРЕГЛЕД ОСНОВНИХ КОНЦЕПАТА КОНТАКТНЕ МЕХАНИКЕ ЗА КОНТАКТ БЕЗ ТРЕЊА СА НАГЛАСКОМ НА PENALTY МЕТОД

Сажетак:

Проблеми који укључују контакт од велике су важности у машинској и грађевинској индустрији али такође и у биомеханици, металургији и другим гранамаобластима. Контактна интеракција између различитих тијела и површина, као на примјер вијчане везе монтажног наставка или интеракције аутомобилске гуме и подлоге, нису познате *a priori*, што доводи до нелинеарног граничног проблемаграничнихуслова. Брзим напретком модерне рачунарске технологије, данас је могуће примјенити алате нумеричке механике за анализу контактних проблема у оквиру ограниченетражене тачности, зависно од захтјева пројекта. Међутим, већина стандардних софтвера са коначним елементима још увијек није у могућности да ријеши контактне проблеме укључујући трење. Циљ овог рада јесте представити основне концепте контактне механике.

Кључне ријечи: Контактна механика, пеналту-метода, контакти без трења

1. INTRODUCTION

From mechanical point of view contact is included in all forms of interaction between two bodies which come in touch with one to the other. Contact between solid bodies enables transition of force, temperature and electrical charge from one body to the other therefore we can conclude that describing a contact is one highly demandable and robust mathematical problem that is still far from finished [1]. Contact mechanics is included in wide range of problems that we face, like for an example a vehicle collision with load bearing column, sheet metal forming, car impact with deformable barrier, steel box girders plastic deformation with self-contact and also study of land slides, avalanches and etc. Some of above-mentioned problems are shown in the Fig.1.

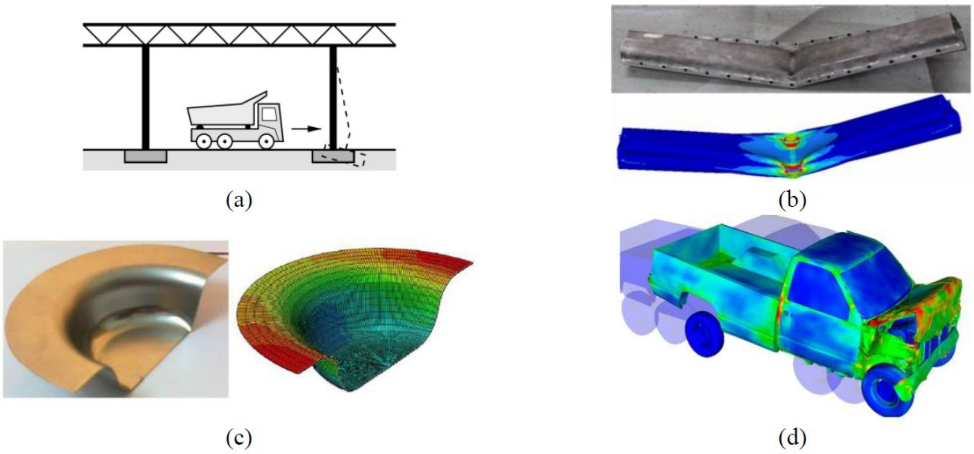


Figure 1. *Vehicle collision with bearing column (a), steel box girder plastic deformation with self-contact (b), sheet metal forming (c), car impact in barrier (d)*

Mechanics of deformable body problems that include contact of two bodies can be seen as a special group of problems, because contact forms as a consequence of two separate continuous surface interface. Limitations that occur on the place of interface cannot be seen and replaced with an usual boundary conditions for both contact surfaces used in mechanic of deformable solid body. At the same time, neither the contact zone could be considered as continual system. By idealization of contact, we can observe area of contact surfaces as: a zero thickness layer that can transfer only the pressure forces which acts perpendicular to the surface of interface Fig. 2a, while the occurrence of tensile forces leads to vanishing the contact interaction of bodies and comes to separation Fig. 2b. In the case of contact with classic Coulomb's friction, in the case without slipping – stick state both surfaces are fixed for each other Fig. 2c [3].

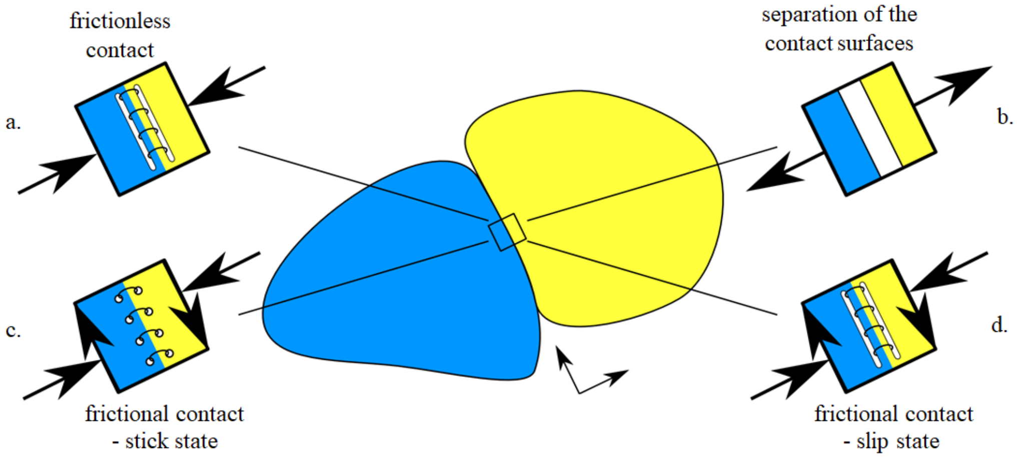


Figure 2. *An analogy for contact interface: a – frictionless contact sustains compressive stress, b – any stretching leads to vanishing of contact interface, c – frictional contact interface can transfer shear stress; d – in Coulomb's friction law in stick state there is no relative sliding up to reaching critical shear stress. experimental and numerical cantilever beam with bolted splice connection joint [3]*

Such contact can be seen as a restraint where the normal and shear stress occur between contact surfaces. Slipping occurs after reaching the critical shear stress between contact surfaces – slip state, Fig. 2d.

For the sake of complexity of describing the contact interaction, in this paper, we will consider a simple numerical example of frictionless normal contact for a linear elastic material. Contacts without friction that only consider normal stress in calculation and are based on Hertz-s theory are defined as normal contacts where friction i.e. tangential force is neglected [4] [5].

We will see that in the case of contact with small deformations, by the linear relationship of the stress-strain curve and in case of frictionless contact, we have a nonlinear response again due to the change of contact boundary conditions. Given the always nonlinear contact behavior and non-smooth contact law for the normal contact pressure, it is necessary to apply some of numerical methods so to overcome this problem. In this paper, Penalty method which represents one of usually applied numerical methods to solve contact problems will be considered.

2. HERTZIAN CONTACT AND BASIC CONCEPTS OF ANALYTICAL CONTACT

As aforementioned in later work, we will deal with normal contact problems that consider two bodies brought in contact by forces perpendicular to their plains. The simplest contact problem is contact between orthogonal parallelepiped and smooth rigid plane without friction Fig. 3.

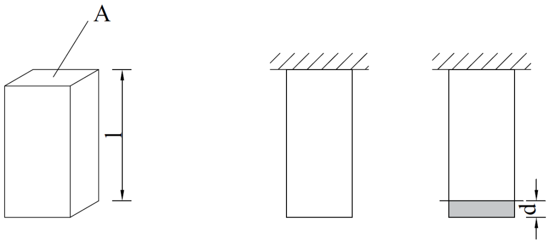


Figure 3. *Contact between an elastic parallelepiped and rigid plane*

When the body is pressed against a plain, deformation occurs, and value d called the "penetration depth" which represents depth of penetration body to plane if plane is not rigid. After the uniaxial stress state is adopted, resulting force of contact surfaces is equal:

$$F = EA\frac{d}{l} \tag{1}$$

From aforementioned example comes the direct connection between penetration depth d and module of elasticity E [4]. Depending on depth of penetration and resulting force, the hardness of material can be determined, which besides the roughness has the crucial part in contacts with friction. Indenting the circular body with constant diameter D in to deformable surface, strength of materials by Brinell is got, from force F_N and area under circular body A ratio, Fig. 4.

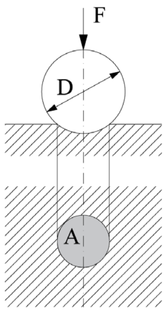


Figure 4. *Brinell hardness test*

$$\sigma_0 = \frac{F_N}{A} \tag{2}$$

Importance of penetration depth comes to expression while describing contact surface discretization, defining and restriction of the finite elements penetration one into other, search and detection of finite elements which will get in contact and defining of normal and tangential gap function.

2.2. Contact between a rigid cylinder and elastic half-space

With further example the basic principles of contact mechanics will be explained. We will observe the contact of rigid cylindrical body and elastic half-space. If it is adopted that stress acts over limited plane with length D Fig. 5, then both the deformation and stress on plane D are the same magnitude in all three directions over volume for length D. To determine the fundamental settings of contact problem we can adopt the presumption that deformation is constant over the aforementioned volume with dimensions D, and that only this volume is deformed. From elastic half-space deformation point of view, this is an approximate presumption of real stress and deformation distribution inside the continuum. Nevertheless, this method can be obtained enough good results and a qualitative connection of contact force and penetration depth, respectively the radius of the contact plane.

We apply the defined rules on the aforementioned example with stiff cylindrical body [4] [5]. When the cylinder radius is equal 2a, then volume in all three directions for length 2a is heavily deformed similar like the deformed volume below indenter from the previous example. If the volume in the place of contact pressure is deformed through depth d independent of overall deformation 2a, deformation can be written as $\varepsilon \approx d/2a$. It follows that the stress is $\varepsilon \approx d/2a$ and the force is $F \approx \sigma(2a)^2 \approx 2Eda$. Contact force is proportional to depth of penetration d and the radius of contact interaction a. By comparing approximate with exact solution, only 10% of difference in result is got. Exact solution is written by expression:

$$F = 2E^{*}da, \quad \text{where} \quad E^{*} = \frac{E}{1-\nu^{2}} \tag{3}$$

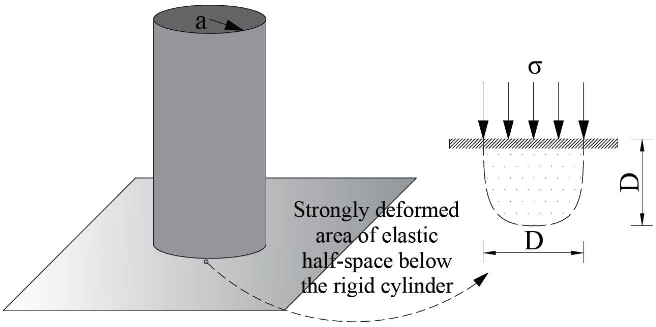


Figure 5. *Contact between a rigid cylindrical indenter and elastic half-space with detail of the strongly deformed area of elastic half-space below of indenter*

Based on described example, approximate method besides qualitative can be used for quantitative evaluation. From the equation (3), it is seen that the penetration depth is proportional to normal force, and $2E^{*}a = k$ represents rigidity of contact plains.

2.3. Hertz - contact theory

Hertz contact belongs to the classical problem of description of normal contact between rigid sphere and elastic half space, which is used as a base for more complex models, Fig. 6 [4].

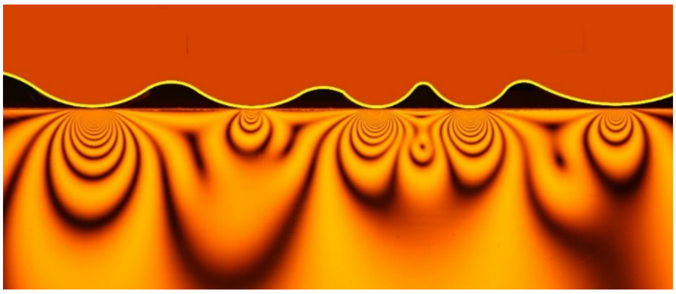


Figure 6. *Visualization of Hertzian distribution of stress for a contact of a spherically rough rigid surface with an elastic plate*

Elastic medium is seen as infinite half space wich only limitation is infinite plane. Under influence of force which acts upon free surface the elastic medium will deform. As was aforementioned only normal contact is considered so we will observe plane xy on the surface of elastic medium upon which acts force F in positive direction Z. In particular, we consider the displacements of the free surface, which means that we have defined as Z = 0 from where follows $r=\sqrt{x^2+y^2}$. The final expressions for displacement are defined as:

$$u_x=-\frac{(1+\nu)(1-2\nu)}{2\pi E}\frac{x}{r^2}F_z \tag{4}$$

$$u_y=-\frac{(1+\nu)(1-2\nu)}{2\pi E}\frac{y}{r^2}F_z \tag{5}$$

$$u_z=\frac{(1-2\nu)}{\pi E}\frac{x}{r}F_z \tag{6}$$

For contact problems without friction, where only normal force is observed, that is, normal pressure $p_{(x,y)}$, only Z component is of interest in approximation of half-space (7). Given that Hertz-s theory is based on contact of spherical peaks, final expression for translation in y direction will be written through cylindrical coordinates (8) in regard of pressure $p(s,\phi)$ with formerly adopted coordinate Z = 0 [5].

$$u_z=\frac{1}{\pi E^*}\iint p(\xi,\eta)\frac{d\xi\, d\eta}{r}, \qquad r=\sqrt{(x-\xi)^2+(y-\eta)^2} \tag{7}$$

$$u_z=\frac{1}{\pi E^*}\iint p(s,\phi)\ ds\, d\phi \tag{8}$$

For vertical displacement of surface points of elastic half-space it is presumed that distribution of pressure according to $p=p_0(1-r^2/a^2)^n$ is applied on circular surface with radius a by which the pressure and contact is exerted with free surface of half space. When $n=1/2$ we get Hertzian pressure distribution.

$$p=p_0\left(1-\frac{r^2}{a^2}\right)^{\frac{1}{2}} \tag{9}$$

The resulting vertical displacement and total force follows as:

$$u_z=\frac{\pi p_0}{4E^*a}\left(2a^2-r^2\right) \tag{10}$$

$$F=\int_0^a p(r)2\pi r dr=\frac{2}{3}p_0\pi a^2 \tag{11}$$

For further defining of Hertz-s problem, contact of rigid sphere with radius R and elastic half space will be observed Fig. 7. The displacement of points on the surface contact area between rigid sphere and flat deformable base is equal:

$$u_z=d-\frac{r^2}{2R} \tag{12}$$

The schematic representation of Hertz-s contact between a rigid sphere and deformable surfaces is reminiscent of the Brinell hardness test previously mentioned [4], where the depth of sphere penetration d into a plane, and later also the radius of contact surface a is found as main parameters.

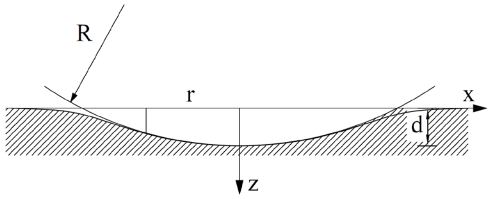


Figure 7. *A rigid sphere in contact with an elastic half-space*

Based on adopted assumptions and obtained expressions, we can write equations that define the Hertz contact of a rigid sphere and a deformable plane.

$$a^2 = Rd \quad \text{contact radius} \tag{13}$$

$$p_0 = \frac{2}{\pi} E^* \left(\frac{d}{R} \right)^{1/2} \quad \text{maximum contact pressure} \tag{14}$$

$$F = \frac{4}{3} E^* R^{1/2} d^{3/2} \quad \text{normal force} \tag{15}$$

2.4. Contact between rough surfaces

Once we have defined the Hertz contact between sphere and plane, we can consider the case of the interaction of rough surfaces without friction, where between the contact surfaces due to roughness, the contact is unevenly spread at several different points. The total contact area (actual) between two rough bodies is much smaller than the (visible) surface that appears to be in contact. The size of the actual contact surface is an important factor, especially in contacts with friction involved, where it significantly affects energy dissipation and damping due to contact interaction. We can say that the cause of friction is actually the breaking, elastic and plastic deformation of the contact micro asperities. In this section, we study the interaction of rough surfaces and rigid plane.

Describing the interaction of rough contact surfaces it gets further complicated when we consider that the roughness of the real surface and thus the actual contact surface are stochastically distributed. The simplest method and most basic model for describing irregular surfaces is the Greenwood model (J. A. Greenwood and J. B. P. Williamson), [4] [5]. Greenwood's model assumes that the roughness or contact points - asperities have the same radius according to Hertz's theory and that the height of the asperities (peaks) is stochastically distributed around some mean value, Fig. 8.

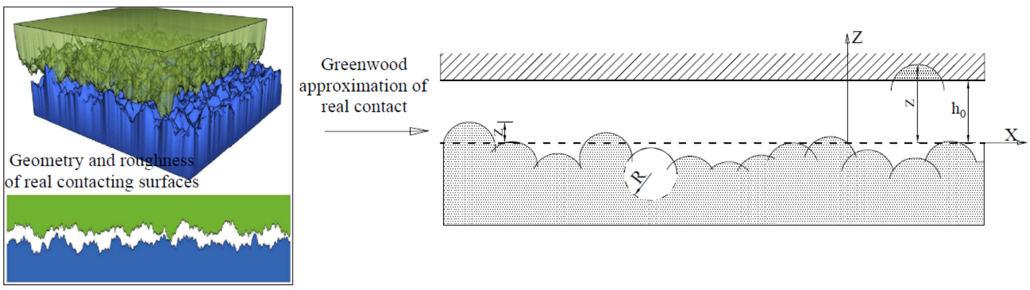


Figure 8. *Greenwood approximation of real contact*

As we can see, the question arises as to whether and when the bodies are in contact and which peak will first touch the body (rigid plane), Fig. 8. If we accept the assumption that the contact peaks are far enough from each other, then the deformation of each peak can be observed separately. Therefore, the position of the contact micro peaks and the configuration of the rough surfaces under the aforementioned assumption are not of great importance. Based on the assumptions we have made so far. We can conclude that if the contact peaks are sufficiently far from each other, then only the high distribution of the peaks is important.

We will define the probability that a given density of asperity has a maximum peak z, as a density function $\Phi(z)$. That means that the probability that the peak has a maximum value at the interval $[z, z+dz]$ is equal to $\Phi(z)dz$. If the total number of peaks in contact is N_0, then the total number of peaks in the interval [z,z+dz] is equal to $N_0\Phi(z)dz$ [4]. For many surfaces depending on the material, it can be assumed normal distribution of the height of the peaks.

$$\Phi(z) = \left(\frac{1}{2\pi l^2}\right)^{1/2} e^{-\frac{z^2}{2l^2}} \tag{16}$$

Where l represents the root mean square (RMS) or contact surface roughness, the peaks height distribution:

$$l = \sqrt{z^2} \tag{17}$$

Based on the aforementioned, from now we consider the contact between a rigid surface and an elastic body with statistically distributed roughness (peaks) at a distance h_0 from the coordinate origin of the z-axis, Fig. 8. The h_0 represents distance of the solid surface to the mean line of rough surface representing the mean value of the heights of all contact peaks. Assuming that there is no elastic interaction of the peaks between each other, all peaks with height $z > h_0$ are in contact with the rigid plate. The penetration depth of the peak with height z is $d = z - h_0$. It is more accurate to say that all peaks exceeding the distance h_0 will be deformed (crushed), and will be in contact with a rigid surface in small circular surfaces of radius a. Each individual contact peak was defined according to the Hertz rule $a^2 = Rd$. Hence based on already defined Hertz contact (13 to 15), we get an expression for the contact surface of one peak:

$$\Delta A = \pi a^2 = \pi dR = \pi(z - h_0)\ R \tag{18}$$

and for the force of the single peak we get:

$$\Delta F = \frac{4}{3}E^* R^{1/2} d^{3/2} = \frac{4}{3}E^* R^{1/2}(z - h_0)^{3/2} \tag{19}$$

By integrating the intervals of all contact peaks, we obtained the total number of points (peaks) that come in contact with the rigid plane N, the total contact area A and the total normal force F_N, which means that the integration must be carried out for all heights from $z = h_0$ to infinity [4] [5]:

$$N = \int_{h_0}^{\infty} N_0 \Phi(z) dz \tag{20}$$

$$A = \int_{h_0}^{\infty} N_0 \Phi(z) \pi R (z - h_0) dz \tag{21}$$

$$F_N = \int_{h_0}^{\infty} N_0 \Phi(z) E^* R^{1/2} (z - h_0)^{3/2} dz \tag{22}$$

The total number, total surface area, and total contact force increase exponentially as the bodies approach each other due to normal pressure (decreasing h_0). The average contact area of one peak can be obtained from the expression

$$\Delta A = \frac{A}{N} = \frac{\int_{h_0}^{\infty} N_0 \Phi(z) \pi R (z - h_0) dz}{\int_{h_0}^{\infty} N_0 \Phi(z) dz} \tag{23}$$

3. COMPUTATIONAL CONTACT MECHANICS CONCEPTS OF NORMAL CONTACT

Particularly demanding nonlinear problems to analyze is the contact between two or more bodies [1-3]. Contact problems can range from simple approximations of frictionless contact with small displacements to frictional contact with large displacements, large rotations and large strains.

3.1. Continuum mechanic formulations of contact

The nonlinearity of the analysis problem from now does not depend only on material and geometrical nonlinearity, which is usually considered for deformable bodies, but from contact conditions which are now included in the equation. Equation of balance in terms of current configuration expressed through Cauchy-s stress tensor is defined as [2]:

$$\int_{{}^{t}V}^{a} {}^{t}\tau_{ij}\delta_{t}e_{ij}\ d^{t}V = \int_{{}^{t}V}^{a} {}^{t}f_{i}^{B}\delta u_{i}\ d^{t}V + \int_{{}^{t}S_{f}}^{a} {}^{t}f_{i}^{S}\delta u_{i}^{S}\ d^{t}S \tag{24}$$

- ${}^{t}\tau_{ij}$: Cauchy stress tensor
- $\delta_{t}e_{ij}$: strain tensor corresponding to virtual displacements
- δu_{i} : components of virtual displacement vector imposed on configuration at time t
- ${}^{t}V$: volume at time t
- ${}^{t}f_{i}^{B}$: components of externally applied force per unit volume at time t
- ${}^{t}f_{i}^{S}$: components of externally applied surface tractions per unit surface area at time t
- ${}^{t}S_{f}$: surface at time t on which external tractions are applied
- $\delta u_{i}^{S} = \delta u_{i}$: components of virtual displacement vector

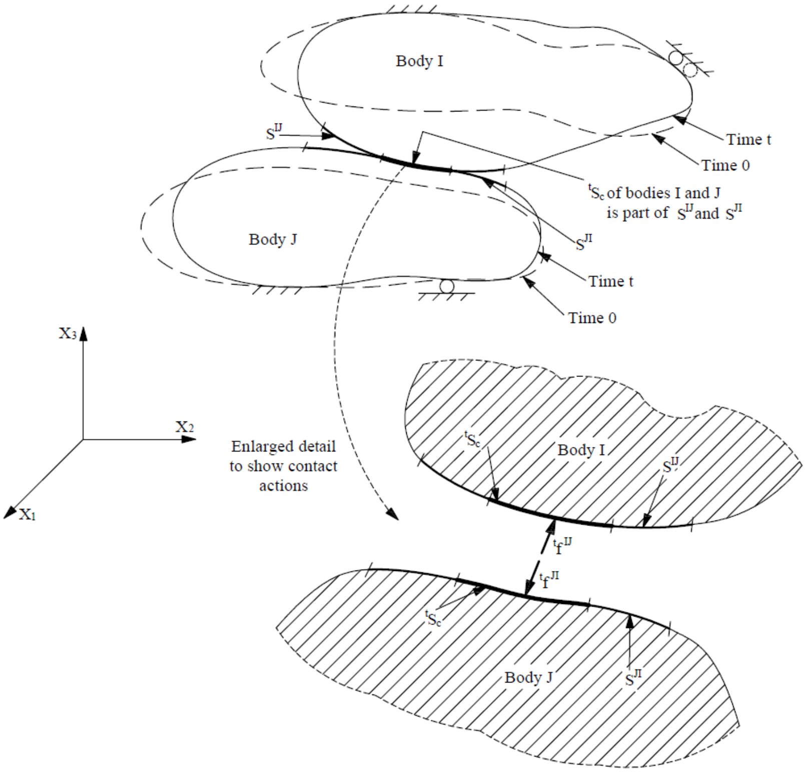


Figure 9. *Bodies in contact at time t*

Considering the contact problem, the equation of equilibrium for the N bodies in the contact on the right-hand side next to the expression of the external virtual work also contains the virtual work of the contact interaction (5). If L bodies are involved in the contacts $L = 1,\dots,N$; where ${}^{t}S_c$ represents the total contact surface of each body, then the principle of virtual work for N number of bodies at time t is defined by the following expression [2]:

$$\sum_{L=1}^{N}\left\{\int_{{}^{t}V} {}^{t}\tau_{ij}\ \delta\, {}_{t}e_{ij}^{T}\ d^{t}V\right\} = \sum_{L=1}^{N}\left\{\int_{{}^{t}V} {}^{t}f_i^{B}\delta u_i\ d^{t}V + \int_{{}^{t}S_f} {}^{t}f_i^{S}\delta u_i^{S}\ d^{t}S\right\} + \sum_{L=1}^{N}\int_{{}^{t}S_c} {}^{t}f_i^{c}\delta u_i^{c}\ d^{t}S \qquad (25)$$

Where part of a braces corresponds to the usual terms (4), while the last summation sign gives the force influence in a contact. As we can see contact force is represented as an exterior force. Components of this force are:

- ${}^{t}S_c$: complete contact area for each body L, L=1,..., Nat the time t
- ${}^{t}f_i^{c}$: component of the contact traction act over the areas ${}^{t}S_c$
- ${}^{t}f_i^{S}$: components of the known externally applied tractions act over the surface ${}^{t}S_f$
- δu_i^{c} : components of the virtual displacement on the contact surface

Figure 9, shows two bodies in contact, which can be generalized to N bodies in contact. Two bodies are shown, the body I and body J, we notice that both bodies are constrained such that without contact no rigid body motions is possible. Let ${}^{t}f^{IJ}$ represent the contact force of body I due to contact with body J, so that from there it follows for body J that ${}^{t}f^{IJ} = -\,{}^{t}f^{JI}$. Now virtual work due to contact interaction can be represented as:

$$\int_{S^{IJ}} {}^{t}f_i^{IJ}\delta u_i^{I}\ dS^{IJ} + \int_{S^{JI}} {}^{t}f_i^{JI}\delta u_i^{J}\ dS^{JI} = \int_{S^{IJ}} {}^{t}f_i^{IJ}\delta u_i^{IJ}\ dS^{IJ} \qquad (26)$$

where δu_i^{I} i δu_i^{J} are components of virtual displacement at the contact surface of bodies I and J.

$$\delta u_i^{IJ} = \delta u_i^{I} - \delta u_i^{J} \qquad (27)$$

The surfaces S^{JI} i S^{IJ} denote the contact surfaces and are not necessarily to be the same size. The actual contact surface ${}^{t}S_c$ is actually a joint of the parts of the surfaces S^{JI} i S^{IJ} that come into contact at time t. Thus, we can represent the right side of equation (26) as a virtual work that produces a contact tract vector by virtual displacement on the contact surface [2].

By further developing of contact virtual work in the expression (25) and by application of Hertz-Signoriny-Morau condition, expression (25) transforms from usual formulation where solution which needs to satisfy equilibrium equation goes into inequality of equilibrium which further complicates defining of contact interaction of two bodies. For a detailed treatment of this subject the reader should consult the literature, e.g. [1-5]

3.2. Frictionless normal contact and defining of hertz-signorini moreau conditions

Consider a frictionless contact problem consisting of a concentrated mass m under a gravitational load supported by a stiffness spring k. The deflection of mass m is restricted by the rigid plane Fig.10. The potential energy of this system is:

$$\Pi_{(u)} = \frac{1}{2}ku^2 - mgu \qquad (28)$$

The first term in the equation is the elastic potential of the spring and the second term represents the potential energy of mass in the gravitational field [1].

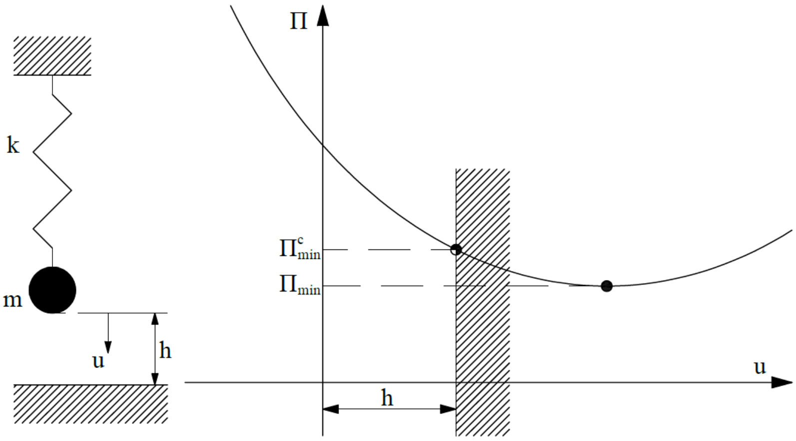


Figure 10. *Point mass supported by spring (a), energy of the mass spring system (b*

In the case that no rigid plane restriction for displacement u, we could define the extremum by the variational principle by introducing the variation of u as δu.

$$
\begin{aligned}
\Pi_{(u+\delta u)} &= \frac{1}{2}k\left(u+\delta u\right)^2 - mg\left(u+\delta u\right) \\
&= \frac{1}{2}ku^2 + ku\delta u + \frac{1}{2}k\delta u^2 - mgu - mg\delta u \\
&= \frac{1}{2}ku^2 - mgu + \delta u\left(ku - mg\right) + \frac{1}{2}k\delta u^2 \\
&= \Pi_{(u)} + \delta\Pi_{(u)} + \delta^2\Pi_{(u)}
\end{aligned}
\tag{29}
$$

Where we get the first variation as:

$$\delta\Pi_{(u)} = \ ku\delta u - mg\delta u \tag{30}$$

Where $\delta\Pi_{(u)} = 0 \ \forall \ \delta u$ represents the stationarity of the potential which is always true for the equilibrium state of the elastic system, from which it follows that the value for the first variation is a simple form of the virtual displacement principle.

The second variation of Π yields to:

$$\delta^2\Pi = k, \tag{31}$$

it follows that the system has a minimum defined by the expression

$$c\left(u\right) = h - u \geq 0 \tag{32}$$

Where penetration is excluded in the inequality of contact boundary condition, the body can only be in contact or separated from another body. For $c\left(u\right) > 0$ one has a gap between point mass m and the rigid plane, in the case that $c\left(u\right) = 0$ then we consider the gap is closed and contact is active [1].

We can observe that now the variation of δu is limited by the contact surface, from which it follows that it must be defined as $\delta u \leq 0$. Which means that the virtual displacement must meet the boundary condition of the contact, so that the variation can only be directed upwards. Based on all of the above, we define the expression for the first variation (30) as variational inequality:

$$ku\delta u - mg\delta u \geq 0 \tag{33}$$

In the inequality, the greater sign follows when the force mg is greater than the force in the spring kh and then the contact between the mass and the rigid surface is realized, which means that the variation is $\delta u < 0$. Due to the above limitations, the minimum in (28) defined as Π_{min} Fig. 10, can no longer be taken as the minimum value of the system. The new minimum value of the system is now limited by the rigid plane or the position of the second contact body Π^{c}_{min} which we call the minimum energy in the allowed solution space Fig. 10.

The variation respectively virtual displacement δu can be represented by the difference between test function $v = \delta u + u$ and displacement u as $\delta u = v - u$.

$$ku(v-h) \geq mg(v-h) \tag{34}$$

The test function should fulfill the condition $v - u \leq 0$ on the contact surface, as well as the solution for u. The expression (30) written with the test function looks like:

$$ku(v-u) - mg(v-u) = 0 \tag{35}$$

When the $mg > ku$ point mass comes into contact with a rigid plate and we have $v - h \leq 0$ the following is the inequality of the boundary condition of the contact:

$$ku(v-h) \geq mg(v-h) \tag{36}$$

In both cases, inequality (32) defines a displacement constraint, which leads to the variational inequality that characterizes the solution of u. The variational inequalities we define cannot be directly applied to solve the contact problem. The most commonly used methods are the Lagrange Multiplier method or the Penalty method, which will be explained in the following sections.

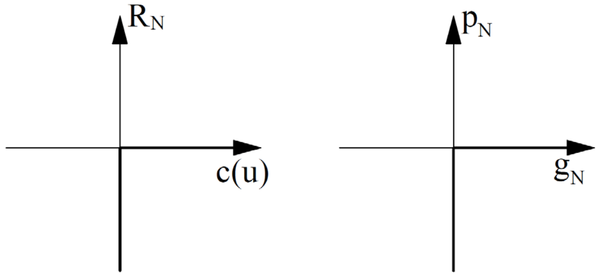


Figure 11. *Reaction force R_N versus gap $c(u)$ and contact force $p(n)$ versus normal gap $g(n)$*

Once the point mass m touches a rigid plane the reaction force R_N appears, we can say that we have an active constraint. We assume that only pressure can occur in contact, and we accept it as negative, while tensile force respectively adhesion is excluded. The reaction force that occurs in contact leads to the following condition:

$$R_N \leq 0 \tag{37}$$

meaning that either we have pressure and an active state in contact interaction $R_N < 0$ or an inactive reaction force which means that contact is not accomplished $R_N = 0$. Based on all of the above, we can define two cases for a contact problem where motion is restricted by condition (32).

1. The spring stiffness is sufficiently large that the mass cannot touch the rigid plane. In this case, the following conditions are valid:

$$c(u) > 0 \quad \text{i} \quad R_N = 0 \tag{38}$$

The ratio of mass to stiffness in the system is such that the mass comes in to contact with the rigid plane. In this case, the following condition applies:

$$c(u) = 0 \quad \text{i} \quad R_N < 0 \tag{39}$$

From the preceding two cases, we can form the Hertz - Signorini - Moreau condition

$$c(u) \geq 0, \quad R_N \leq 0, \quad R_N c(u) = 0 \tag{40}$$

$$g_n \geq 0, \quad p_N \leq 0, \quad p_N g_n = 0 \tag{41}$$

As we can see by comparing the derived basic conditions (40) and the final Hertz - Signorini - Moreau condition [1] of the deformable body (41), the simplified method of determining the contact boundary conditions on the based on example of mass and spring is the basis for the final Hertz - Signorini - Moreau condition for frictionless and no penetration contacts.

The gap function g_n in the simplified model defined as $c(u)$ (32) represents the dependence of spring stiffness, displacement, and mass. The stress vector component of the contact interaction p_N - contact pressure, is represented as the reaction of the active support R_N when the body and the rigid plane come into contact. Finally, if there is a reaction R_n i.e. the pressure p_N the spring stiffness was not exploited, contact is achieved and the gap is closed $c(u) = 0$ i.e. $g_n = 0$. In case the spring stiffness has exploited and the system reached its maximum possible deflection, a gap exists between the contact bodies $c(u) > 0$ i.e. $g_n > 0$, then the reaction R_n respectively pressure p_N are zero. The problem with the application of the contact conditions is that the load-displacement functions are not differentiable Fig. 11, it is necessary to apply one of the numerical methods for solving non-differentiable problems as in the mentioned case. One possible method is the Penalty method, which will be discussed in the following section.

3.3. Penalty method

As a solution of contact problems where motion is defined as inequality (32) often applied method in analysis of contact problem with finite elements is application of Penalty method. In case of active restraint, Penalty member is added to equation of potential and the expression is

$$\Pi(u) = \frac{1}{2}ku^2 - mgu + \frac{1}{2}\epsilon\left[c(u)\right]^2 \quad \text{za} \quad \epsilon > 0 \tag{42}$$

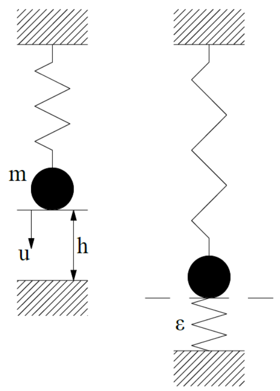


Figure 12. *Point mass supported by a spring and penalty spring due to the penalty term* ϵ

Penalty parameter ϵ can be interpreted as a spring with definite stiffness that connects contact bodies, in this case mass and rigid surface Fig. 12. The presentation of contact by spring simulation is suitable for reason that energy of Penalty parameter has the same structure as the potential energy of simple spring [1]. The variation of (42) yields for the assumption of contact

$$ku\delta u - mg\delta u - \varepsilon c(u)\delta u = 0 \tag{43}$$

from which solution for u can be derived as:

$$u = (mg + \epsilon h)/(k + \epsilon) \tag{44}$$

According to equation (32), the value of the constraint equation is

$$c(u) = h - u = \frac{kh - mg}{k + \varepsilon} \tag{45}$$

When contact is achieved, according to equation (45) there is $mg \geq kh$ and the "penetration" of point mass into the stiff surface has appeared, which is physically equivalent to compression of spring Fig. 12. Equation of restrain is satisfied only in case when $\varepsilon \to \infty \Rightarrow c(u) \to 0$, penetration depends on penalty parameter.

There are two limiting cases in Penalty method

- $\varepsilon \to \infty \Rightarrow u - h \to 0$ from which follows that the exact solution is got only at big values of Penalty parameter, which means that stiffness of contact spring is very high and only small penetrations occur
- $\varepsilon \to 0$ represents inactive contact or unconstrained solution when Penalty parameter is very small, great penetrations are implied, which leads to problems of convergence

The reaction force for penalty method is computed as:

$$R_N = \varepsilon c(u) = \frac{\varepsilon}{k + \varepsilon}(kh - mg) \tag{46}$$

In the practical computations, large values of the penalty parameter are considered. This leads to the acceptable value of penetration and good calculation results [1]. By restraining parameter $\varepsilon \to \infty$ the same result follows as by applying Lagrange-s multiplier. While using penalty method it is important properly to determine penalty parameter ϵ. If too big penalty parameter is adopted price of calculation significantly rises, and in some cases it can reach oversized stiffness of contact interface and which leads to calculation difficulties. On the other hand, if too small a penalty parameter is adopted the accuracy of results is questionable.

Applying the penalty method on the simple system which is built from two bars with geometrically linear and elastic behavior a nonlinear response curve occurs in the case of contact, Fig. 13. This is due to the change of stiffness within the contact process.

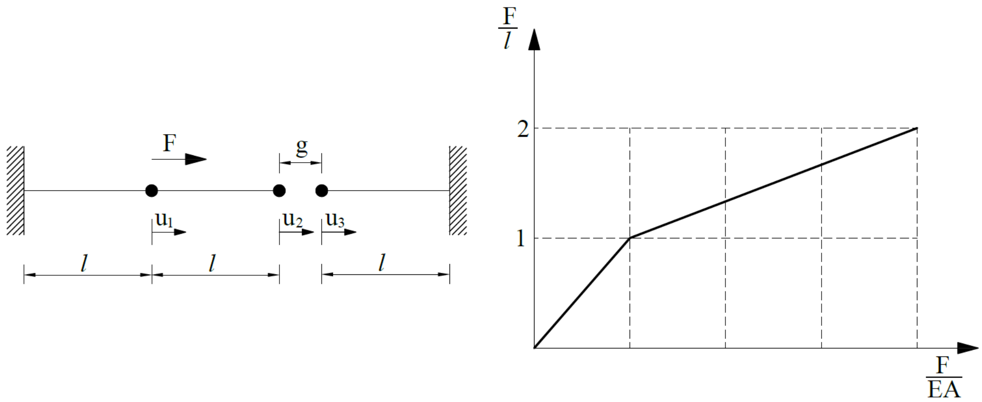


Figure 13. *Finite element discretization of the two separated beams and load-deflection curve*

In general, for a proper definition of penalty parameter, all relevant influences should be considered such as stress level, displacement and nonlinearity in contact interaction. Whether it is a hard or soft contact, is it a mutual contact between two or more bodies or is it a c self-contact, which is the case for large displacements, large rotations and large strains. An example is the deformation of rubber and a polymer under pressure where it is pressed into its own volume or highly deformed steel box profile.

4. CONCLUSION

Although we aimed to present contacts within the framework of small deformations, first we had to define contact problems within the framework of large deformations in order to be able to describe in detail the contact interaction of deformable bodies. Subsequently, certain assumptions were introduced to make the analysis simpler and numerically more acceptable in the first place. Based on the aforementioned we can see how demanding the contact models are and almost always non-linear in nature. From the simple example given in this paper, we saw that even for a system of two simple bars with geometrically linear and elastic behavior a nonlinear response curve is obtained. Finally, we describe the penalty method, which is often used as a basis for other methods. In addition to the penalty method, widely used is the Lagrange multiplier method, which is the basis for the so-called Mortar method of discretization of contact continuous systems within small and large deformations. The Mortar method has been successfully applied and developed for the last 15 to 20 years, we can say that within the mechanics of a deformable body it is still in the development process. In addition to the described methods, for solving the inequality of internal and external virtual works as significant we have: perturbed-Lagrange and augmented-Lagrange method. There are other methods such as the Barrier method and the Nitsche method, but the mentioned methods result in the so-called "ill-conditioning". Due to these drawbacks, the Barrier and Nitsche method are not used very much in computational contact mechanics [1][3].

We can conclude that contact mechanics is a fairly wide range of phenomena to be described and understood, and only for dry friction without the inclusion of adhesion, lubrication, and thermodynamic processes within the contact interaction, which further complicates the analysis and description of contact problem.

LITERATURE

[1] Wriggers P., Computational Contact Mechanics,: Berlin, Springer, 2006

[2] Klaus J.B., “Finite Element Procedures”,: Wtertovn, Prentice Hall, Pearson Education, 2016

[3] Vladislav A. Yastrebov, “Computational Contact Mechanics – geometry, detection and numerical techniques”, Ph.D. dissertation,:Paris, MINES Paris tech, 2011

[4] Valentin L. P., “Contact Mechanics and Friction – Physical Principles and Applications”, Berlin, Springer, 2017

[5] K.L. Johnson, “Contact Mechanics”: Cambridge university press, 1985

25 | Review paper | Прегледни научни рад
ISSN 2566-4484 | Doi 10.7251/STP2014277C
pages 277-287

Goran Ćirović, goran.cirovic@uns.ac.rs, Faculty of Technical Sciences, University of Novi Sad

Dragan Pamučar, dragan.pamucar@va.mod.gov.rs, University of defence in Belgrade, Department of Logistics

Nataša Popović-Miletić, natasa.popovic-miletic@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

MULTI-CRITERIA MODEL BASED ON LINGUISTIC NEUTROSOPHIC NUMBERS: THE SELECTION OF UNMANNED AIRCRAFT

Abstract:

The paper presents a new approach in treating uncertainty and subjectivity in the decision making process based on the modification of Multi Attributive Border Approximation area Comparison (MABAC) and an Objective-Subjective (OS) model by applying linguistic neutrosophic numbers (LNN) instead of traditional numerical values. By integrating these models with linguistic neutrosophic numbers it was shown that it is possible to a significant extent to eliminate subjective qualitative assessments and assumptions by decision makers in complex decision-making conditions. On this basis, a new hybrid LNN OS-MABAC model was formed. This model was tested and validated on a case-study of the selection of optimal unmanned aircraft intended to combat forest fires.

Keywords: Linguistic Neutrosophic Numbers, MABAC, Multicriteria Decision Making

ВИШЕКРИТЕРИЈУМСКИ МОДЕЛ БАЗИРАН НА ПРИМЕНИ ЛИНГВИСТИЧКИХ NEUTROSOPHIC БРОЈЕВА: ИЗБОР БЕСПИЛОТНЕ ЛЕТЕЛИЦЕ

Сажетак:

У раду је приказан нови приступ у третирању неизвесности и субјективности у процесу доношења одлука који је заснован на модификацији MABAC и OS модела применом лингуистиц неутрософхиц бројева (LNN), уместо традиционалних нумеричких вредности. Интеграцијом наведених модела са лингуистиц неутрософхиц бројевима показано је да је могуће у значајној мери отклонити субјективне квалитативне процене и претпоставке експерата у сложеним условима одлучивања. На бази наведених поставки формиран је нови, хибридни LNN OS-MABAC модел у VKO. Наведени модел је тестиран и валидиран на примеру избора оптималне беспилотне летелице намењене за борбу против шумских пожара.

Кључне ријечи: лингвистички неутрософхиц бројеви, MABAC, вишекритеријумско одлучивање

1. INTRODUCTION

Because of the ambiguity of human thinking in complex decision-making conditions, it is difficult to represent the reasoning of experts and their preferences using numerical values. It is much more convenient and realistic to make it possible to present the preferences of experts using linguistic terms, particularly when it comes to qualitative attributes that are used to describe certain phenomena. Therefore, in this paper, linguistic neutrosophic numbers are used to show expert preferences. Since modeling expert preferences in decision-making problems using linguistic terms is an interesting field of research, the authors of this paper present an original multi-criteria model for the evaluation and selection of optimal unmanned aircraft intended for the detection and fight against forest fires which is based on LNN.

The multi-criteria model is based on the modification of the traditional MABAC method [1] by applying the LNN approach. An LNN OS model was used to determine the weights of the evaluation criteria, in which the weights of the criteria are a combination of objective and subjective values of the weighting coefficients of the criteria. The objective values of the criteria weights were obtained by the maximum deviation method, while the subjective values of the weights were obtained based on expert estimates. By integrating the OS-MABAC model with the LNN, it has been demonstrated that uncertainties and uncertainties can be taken into account in qualitative expert judgments that occur in complex decision conditions. The LNN OS-MABAC model has been tested and validated by selecting the optimal unmanned aerial vehicle designed to fight forest fires

2. A MULTI-CRITERIAL MODEL BASED ON LINGUISTIC NEUTROSOPHIC NUMBERS

The following section (Section 3.2) gives the basic framework of the linguistic neutrosophic concept, as well as the basic arithmetic operations with LNN. After this, the OS-MABAC multi-criteria model based on the concept of LNN is presented in sections 3.2 and 3.3.

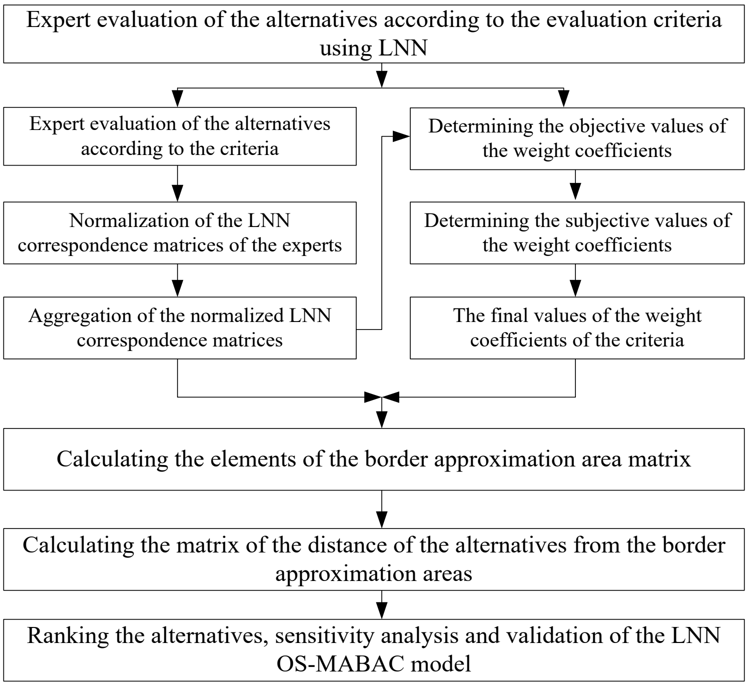


Figure 1. *Framework of the proposed model*

2.2. Some concepts of LNN

Definition 1 [2]. Assume that $S = \{s_0, s_1, ..., s_t\}$ is a linguistic set with odd cardinality $t+1$. If $e = \langle s_p, s_q, s_r \rangle$ is defined for $s_p, s_q, s_r \in S$ and $p, q, r \in [0, t]$, where s_p, s_q and s_r represent linguistic expressions which independently express the degree of truth, indeterminacy and falsity, then e is called the LNN.

Definition 2 [3]. Let $e=\left\langle s_p,s_q,s_r\right\rangle$, $e_1=\left\langle s_{p_1},s_{q_1},s_{r_1}\right\rangle$ and $e_2=\left\langle s_{p_2},s_{q_2},s_{r_2}\right\rangle$ be three LNN in S and $k>0$, then we can define the arithmetic operations for LNN (Liang & Zhao, 2017):

(1) Addition of LNN "+"

$$e_1+e_2=\left\langle s_{p_1},s_{q_1},s_{r_1}\right\rangle+\left\langle s_{p_2},s_{q_2},s_{r_2}\right\rangle=\left\langle s_{p_1+p_2-\frac{p_1p_2}{t}},s_{\frac{q_1q_2}{t}},s_{\frac{r_1r_2}{t}}\right\rangle \tag{1}$$

(2) Multiplication of LNN "×"

$$e_1\times e_2=\left\langle s_{p_1},s_{q_1},s_{r_1}\right\rangle\times\left\langle s_{p_2},s_{q_2},s_{r_2}\right\rangle=\left\langle s_{\frac{p_1p_2}{t}},s_{q_1+q_2-\frac{q_1q_2}{t}},s_{r_1+r_2-\frac{r_1r_2}{t}}\right\rangle \tag{2}$$

(3) Multiplying LNN by a scalar, where $k>0$

$$k\times e=k\left\langle s_p,s_q,s_r\right\rangle=\left\langle s_{t-t\left(1-\frac{p}{t}\right)^k},s_{t\left(\frac{q}{t}\right)^k},s_{t\left(\frac{r}{t}\right)^k}\right\rangle \tag{3}$$

(4) LNN power, where $k>0$

$$e^k=\left\langle s_p,s_q,s_r\right\rangle^k=\left\langle s_{t\left(\frac{p}{t}\right)^k},s_{t-t\left(1-\frac{q}{t}\right)^k},s_{t-t\left(1-\frac{r}{t}\right)^k}\right\rangle \tag{4}$$

2.3. The LNN OS model for determining the weight coefficients of the criteria

In this paper, a new approach for obtaining the weights of the criteria was used when determining the weight coefficients of the evaluation criteria, which includes a combination of subjective and objective elements. Methods that subjectively determine the weight coefficients of the criteria focus on information obtained based on the preferences of the decision makers [4,5] while ignoring objective information. Methods of objectively determining the weight coefficients do not take into account the preferences of the decision makers, namely, these methods do not take into account the subjective attitudes of the decision makers [4]. The advantage of the OS model is that it simultaneously takes into account subjective and objective information. Thus, by combining subjective and objective weights we obtain the final values of the eight coefficients of the evaluation criteria.

The model is implemented through two phases: in the first phase the objective values of the criteria are determined using the method of maximum deviation; (2) in the second phase, experts evaluate the criteria and determine the subjective values of the weight coefficients. After calculating the objective and subjective values of the weight coefficients of the criteria we obtain combined values of the weights that are further used in the multi-criteria model.

Finally, on the basis of the objective and subjective values of the weight coefficients, we obtain the combined values of the weight coefficients

$$w_j=\frac{w_j^*w_j^{'}}{\sum_{j=1}^{n}w_j^*w_j^{'}} \tag{5-23}$$

where w_j^* and $w_j^{'}$ respectively represent the objective and subjective values of the weight coefficients of the criteria. The objective and subjective weights are aggregated by means of a non-linear model in which higher values of the subjective and objective weights give a higher combined value of the weight coefficient and vice versa. The use of equation (5) goes beyond the restrictions of the one-sided application of subjective or objective factors. In addition, equation (5) enables a simultaneous display of the influence of subjective and objective information on the ranking of the alternatives.

2.4. The LNN MABAC model

The MABAC method falls into the category of more recent MCDM methods. It was developed at the Center for Research in the field of Logistics Defence at the University of Defence in Belgrade [1]. Due to its robustness and stability, its results have so far found wide application and modifications, with the purpose of solving numerous problems from the field of multi-criteria decision making: material selection with incomplete weight information, investment problems, manufacturing, military problems; renewable energy, website selection, logistics and so on. In the following section, the algorithm of the modified LNN-MABAC method is presented, which consists of 7 steps:

Step 1. Forming the expert correspondence matrices ($N^{(l)}$). Starting from the assumption that in the process of decision making m experts are involved who evaluate the set of alternatives $A=\{a_1,a_2,...,a_b\}$ (where b denotes the final number of alternatives) in relation to the defined set of evaluation criteria $C=\{c_1,c_2,...c_n\}$ (where n represents the total number of criteria). The experts $\{e_1,e_2,...,e_m\}$ are assigned weight coefficients $\{\delta_1,\delta_2,...,\delta_m\}$, $0\le\delta_l\le 1,\ (l=1,2,...,m)$ and $\sum_{l=1}^{m}\delta_l=1$. The alternatives are evaluated based on a predefined set of linguistic variables $S=\{s_i\mid i\in[0,t]\}$.

In order to achieve the final ranking of the alternatives a_i ($i=1,2,..,b$) from the set of alternatives A, each expert e_l ($l=1,2,...,m$) evaluates the alternatives according to the defined set of criteria $C=\{c_1,c_2,...c_n\}$. So for each expert we construct a correspondence initial decision matrix

$$N^{(l)}=\left[\xi_{ij}^{(l)}\right]_{b\times n}=\begin{bmatrix}\xi_{11}^{(l)} & \xi_{12}^{(l)} & \dots & \xi_{1n}^{(l)}\\ \xi_{21}^{(l)} & \xi_{22}^{(l)} & \dots & \xi_{2n}^{(l)}\\ \vdots & \vdots & \ddots & \vdots\\ \xi_{b1}^{(l)} & \xi_{b2}^{(l)} & \dots & \xi_{bn}^{(l)}\end{bmatrix}=\begin{bmatrix}\left\langle s_{p_{11}}^{(l)},s_{r_{11}}^{(l)},s_{q_{11}}^{(l)}\right\rangle & \left\langle s_{p_{12}}^{(l)},s_{r_{12}}^{(l)},s_{q_{12}}^{(l)}\right\rangle & \dots & \left\langle s_{p_{1n}}^{(l)},s_{r_{1n}}^{(l)},s_{q_{1n}}^{(l)}\right\rangle\\ \left\langle s_{p_{21}}^{(l)},s_{r_{21}}^{(l)},s_{q_{21}}^{(l)}\right\rangle & \left\langle s_{p_{22}}^{(l)},s_{r_{22}}^{(l)},s_{q_{22}}^{(l)}\right\rangle & \dots & \left\langle s_{p_{2n}}^{(l)},s_{r_{2n}}^{(l)},s_{q_{2n}}^{(l)}\right\rangle\\ \vdots & \vdots & \ddots & \vdots\\ \left\langle s_{p_{b1}}^{(l)},s_{r_{b1}}^{(l)},s_{q_{b1}}^{(l)}\right\rangle & \left\langle s_{p_{b2}}^{(l)},s_{r_{b2}}^{(l)},s_{q_{b2}}^{(l)}\right\rangle & \dots & \left\langle s_{p_{bn}}^{(l)},s_{r_{bn}}^{(l)},s_{q_{bn}}^{(l)}\right\rangle\end{bmatrix} \tag{6-24}$$

where the basic elements of matrix $N^{(l)}$ ($\xi_{ij}^{(l)}$) represent the linguistic variables from the sets $S=\{s_i\mid i\in[0,t]\}$, $s_{p_{ij}}^{(l)},s_{q_{ij}}^{(l)},s_{r_{ij}}^{(l)}\in S$ and $p_{ij},q_{ij},r_{ij}\in[0,t]$.

Step 2. Calculating the elements of the normalized expert correspondence matrix ($\tilde{N}^{(l)}$). The elements of normalized matrix $\tilde{N}^{(l)}=\left[\tilde{\xi}_{ij}^{(l)}\right]_{b\times n}$ are calculated using equation (7)

$$\tilde{\xi}_{ij}^{(l)}=\left\langle\tilde{s}_{p_{ij}}^{(l)},\tilde{s}_{q_{ij}}^{(l)},\tilde{s}_{r_{ij}}^{(l)}\right\rangle=\begin{cases}\tilde{s}_{p_{ij}}^{(l)}=s_{t-p_{ij}}^{(l)};\ \tilde{s}_{q_{ij}}^{(l)}=s_{t-q_{ij}}^{(l)};\ \tilde{s}_{r_{ij}}^{(l)}=s_{t-r_{ij}}^{(l)} & if\ \ \tilde{\xi}_{ij}^{(l)}\in C;\\ \tilde{s}_{p_{ij}}^{(l)}=s_{p_{ij}}^{(l)};\ \tilde{s}_{q_{ij}}^{(l)}=s_{q_{ij}}^{(l)};\ \tilde{s}_{r_{ij}}^{(l)}=s_{r_{ij}}^{(l)} & if\ \ \tilde{\xi}_{ij}^{(l)}\in B.\end{cases} \tag{7-25}$$

where B and C respectively represent sets of criteria of the benefit and cost type, and $\tilde{\xi}_{ij}^{(l)}=\left\langle\tilde{s}_{p_{ij}}^{(l)},\tilde{s}_{q_{ij}}^{(l)},\tilde{s}_{r_{ij}}^{(l)}\right\rangle$ represents the elements of the normalized matrix $\tilde{N}^{(l)}$.

Step 3. Calculating the elements of the aggregated normalized matrix. The final aggregated decision matrix N is obtained by averaging the elements $\tilde{\xi}_{ij}^{(l)}=\left\langle\tilde{s}_{p_{ij}}^{(l)},\tilde{s}_{q_{ij}}^{(l)},\tilde{s}_{r_{ij}}^{(l)}\right\rangle$ of matrix $\tilde{N}^{(l)}=\left[\tilde{\xi}_{ij}^{(l)}\right]_{b\times n}$ using equations (9) or (10)

$$\tilde{N}=\left[\tilde{\xi}_{ij}\right]_{b\times n}=\begin{bmatrix}\tilde{\xi}_{11} & \tilde{\xi}_{12} & \dots & \tilde{\xi}_{1n}\\ \tilde{\xi}_{21} & \tilde{\xi}_{22} & \dots & \tilde{\xi}_{2n}\\ \vdots & \vdots & \ddots & \vdots\\ \tilde{\xi}_{b1} & \tilde{\xi}_{b2} & \dots & \tilde{\xi}_{bn}\end{bmatrix}=\begin{bmatrix}\left\langle\tilde{s}_{p_{11}},\tilde{s}_{r_{11}},\tilde{s}_{q_{11}}\right\rangle & \left\langle\tilde{s}_{p_{12}},\tilde{s}_{r_{12}},\tilde{s}_{q_{12}}\right\rangle & \dots & \left\langle\tilde{s}_{p_{1n}},\tilde{s}_{r_{1n}},\tilde{s}_{q_{1n}}\right\rangle\\ \left\langle\tilde{s}_{p_{21}},\tilde{s}_{r_{21}},\tilde{s}_{q_{21}}\right\rangle & \left\langle\tilde{s}_{p_{22}},\tilde{s}_{r_{22}},\tilde{s}_{q_{22}}\right\rangle & \dots & \left\langle\tilde{s}_{p_{2n}},\tilde{s}_{r_{2n}},\tilde{s}_{q_{2n}}\right\rangle\\ \vdots & \vdots & \ddots & \vdots\\ \left\langle\tilde{s}_{p_{b1}},\tilde{s}_{r_{b1}},\tilde{s}_{q_{b1}}\right\rangle & \left\langle\tilde{s}_{p_{b2}},\tilde{s}_{r_{b2}},\tilde{s}_{q_{b2}}\right\rangle & \dots & \left\langle\tilde{s}_{p_{bn}},\tilde{s}_{r_{bn}},\tilde{s}_{q_{bn}}\right\rangle\end{bmatrix} \tag{8-26}$$

where we obtain elements $\tilde{\xi}_{ij}=\left\langle\tilde{s}_{p_{ij}},\tilde{s}_{q_{ij}},\tilde{s}_{r_{ij}}\right\rangle$ using the LNNWAA operator

$$\tilde{\xi}_{ij}=LNNWAA(\tilde{\xi}_{ij}^{(1)},\tilde{\xi}_{ij}^{(2)},...,\tilde{\xi}_{ij}^{(m)})=\sum_{l=1}^{m}\tilde{\xi}_{ij}^{(l)}\delta_l=\left\langle\tilde{s}_{t-t\prod_{l=1}^{m}\left(1-\frac{p_{ij\,l}}{t}\right)^{\delta_l}},\tilde{s}_{t\prod_{l=1}^{m}\left(\frac{q_{ij\,l}}{t}\right)^{\delta_l}},\tilde{s}_{t\prod_{l=1}^{m}\left(\frac{r_{ij\,l}}{t}\right)^{\delta_l}}\right\rangle \tag{9-27}$$

Or using an LNNWGA operator

$$\tilde{s}_{ij} = LNNWGA(\tilde{s}_{ij}^{(1)}, \tilde{s}_{ij}^{(2)}, ..., \tilde{s}_{ij}^{(m)}) = \prod_{l=1}^{m} \tilde{s}_{ij}^{(l)\delta_l} = \left\langle \tilde{s}_{t\prod_{l=1}^{m}\left(\frac{p_{ij\,l}}{t}\right)^{\delta_l}}, \tilde{s}_{t-t\prod_{l=1}^{m}\left(1-\frac{q_{ij\,l}}{t}\right)^{\delta_l}}, \tilde{s}_{t-t\prod_{l=1}^{m}\left(1-\frac{r_{ij\,l}}{t}\right)^{\delta_l}} \right\rangle \quad (10\text{-}28)$$

where elements $\tilde{s}_{ij}^{(l)} = \left\langle \tilde{s}_{p_{ij}}^{(l)}, \tilde{s}_{q_{ij}}^{(l)}, \tilde{s}_{r_{ij}}^{(l)} \right\rangle$ are elements of the expert correspondence matrix (6).

Step4. Calculating the elements of weighted matrix (*D*). We obtain the elements of the weighted matrix $D = \left[d_{ij}\right]_{b\times n} = \left[\left\langle \overset{*}{s}_{p_{ij}}, \overset{*}{s}_{q_{ij}}, \overset{*}{s}_{r_{ij}} \right\rangle\right]_{b\times n}$ using equation (11)

$$d_{ij} = \left\langle s_{p_{ij}}^{*}, s_{q_{ij}}^{*}, s_{r_{ij}}^{*} \right\rangle = w_j \cdot \left\langle \tilde{s}_{p_{ij}}, \tilde{s}_{q_{ij}}, \tilde{s}_{r_{ij}} \right\rangle = \left\langle s^{*}_{t-t\left(1-\frac{p_{ij}}{t}\right)^{w_j}}, s^{*}_{t\left(\frac{q}{t}\right)^{w_j}}, s^{*}_{t\left(\frac{r}{t}\right)^{w_j}} \right\rangle \quad (11\text{-}29)$$

Step5. Calculating the elements of the border approximation area matrix (*G*). We obtain the elements of matrix $G = \left[g_j\right]_{1\times n} = \left[\left\langle s_{p_{ij}}^{\bullet}, s_{q_{ij}}^{\bullet}, s_{r_{ij}}^{\bullet} \right\rangle\right]_{1\times n}$ using equation (12)

$$g_j = \prod_{i=1}^{b}\left(d_{ij}\right)^{1/b} = \left\langle s^{\bullet}_{t\prod_{i=1}^{b}\left(\frac{p_{ij}}{t}\right)^{1/b}}, s^{\bullet}_{t-t\prod_{i=1}^{b}\left(1-\frac{q_{ij}}{t}\right)^{1/b}}, s^{\bullet}_{t-t\prod_{i=1}^{b}\left(1-\frac{r_{ij}}{t}\right)^{1/b}} \right\rangle \quad (12\text{-}30)$$

Step 6. Calculating the matrix of the distance of the alternatives from the border approximation area (*Q*). We obtain the elements of matrix $S = \left[s_{ij}\right]_{b\times n}$ using equation (13)

$$s_{ij} = \begin{cases} d_{Ed}(d_{ij}, g_j), & if \;\; d_{ij} > g_j; \\ 0, & if \;\; d_{ij} = g_j; \\ -d_{Ed}(d_{ij}, g_j), & if \;\; d_{ij} < g_j. \end{cases} \quad (13\text{-}31)$$

where g_j represents the border approximation area for criterion C_j, $d_{ij} = \left\langle \overset{*}{s}_{p_{ij}}, \overset{*}{s}_{q_{ij}}, \overset{*}{s}_{r_{ij}} \right\rangle$ represents the elements of weighted matrix (*D*).

Alternative a_i can belong to the border approximation area (G), to the upper approximation area (G^+) or to the lower approximation area (G^-), that is $a_i \in \left\{G \vee G^+ \vee G^-\right\}$. The upper approximation area (G^+) is the area in which the ideal alternative is located (A^+), while the anti-ideal alternative is found in the lower approximation area (A^-) (Figure 1).

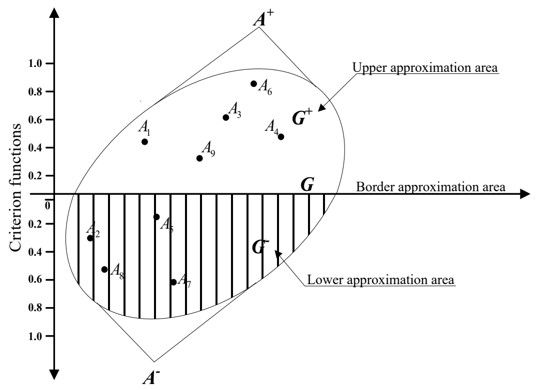


Figure 2. *Figure 1. Upper (G^+), lower (G^-) and border (G) approximation areas*

If the value of $s_{ij} > 0$, that is $s_{ij} \in G^+$, then alternative a_i is close to or equal to the ideal alternative. The value $s_{ij} < 0$, that is $s_{ij} \in G^-$, shows that alternative a_i is close to or equal to the anti-ideal alternative. In order for alternative a_i to be selected as the best from the set it is necessary for as many criteria as possible to belong to the upper approximation area (G^+).

Step 7. Ranking the alternatives. Based on the criterion functions of the alternatives Q_i ($i = 1, 2, ..., b$) the alternatives are ranked. The criterion functions are obtained using equation (14)

$$Q_i = \sum_{j=1}^{n} s_j, \quad i = 1, 2, ..., b; \; j = 1, 2, ..., n. \tag{14-32}$$

Ranking of the alternatives is determined based on the value of Q_i, whereby it is preferable for an alternative to have as high a value as possible of criterion function Q_i.

3. APPLICATION OF THE LNN-OSM-MABAC MODEL

The application of the LNN-OSM-MABAC model was demonstrated on the case-study of selecting unmanned aircraft for the fight against forest fires in Serbia. In the period 2010-2014 in the territory of the Republic of Serbia 428 fires were registered, during which 10 844 hectares of forest area were burned [6]. For the purpose of evaluating the criteria and selecting unmanned fire-fighting aircraft according to the established requirements and the necessary (similar) technical characteristics, the paper considers civil and commercial tactical – short – medium range UAVs [7]. The unmanned aircraft under consideration have the following technical characteristics: short range (to 100 km), maximum take-off weight 200 kg, maximum flight altitude 5000 m, endurance of 6-10 hours, data link range of 30-100 km. The payload of these aircraft allows the installation of fire-fighting equipment for the stages of fire-fighting that are discussed in this paper. On the basis of the above, the criteria and attributes for selecting unmanned fire-fighting aircraft were introduced. The selected criteria are as follows (Table 2): Affordability (C1), Construction and general system (C2), Aerodynamics and ability to process data (C3), Ability to monitor and detect (C4) Ability for diagnosis and Prognosis (C5).

Table 1. *Explanation of the criteria*

Criteria/sub-criteria
Affordability – C1 (*min*)
Maintenance Cost – C11 (*min*)
Acquisition Cost – C12 (*min*)
Operator Training – C13 (*min*)
Operation Cost – C14 (*min*)
Disposal Cost – C15 (*min*)
Construction and General System – C2 (*max*)
Wing Mechanization – C21 (*max*)
Vehicle External Configuration – C22 (*max*)
Remote via Ground Central System – C23 (*max*)
Propulsion system – C24 (*max*)
Aerodynamics and Ability to Process data– C3 (*max*)
Flight Performance – C31 (*max*)
Payload Capacity – C32 (*max*)
Ability of Data – Telemetry and Processing – C33 (*max*)
Ability to Monitor and Detect– C4 (*max*)
Detection Method – C41 (*max*)
Camera Performance – C42 (*max*)

Ability of Detection Object – C43 (*max*)
Fusion of images – C44 (*max*)
Ability for Diagnosis and Prognosis – C5 (*max*)
Ability to Measure Geometrical Features of Fire – C51 (*max*)
Propagation Prediction – C52 (*max*)

3.2. Determining the weight coefficients of the criteria– the LNN OS model

The OS model involves determining the objective values of the criteria using the maximum deviation method and combining the obtained values with the subjective values of the weight coefficients defined by the experts. Since the OS model is carried out in two phases (phase *I* – determining the objective values and phase *II* – determining the subjective values) the following section presents the application of the OS model through the two phases.

Phase I: Determining the objective values of the weight coefficients.

The objective values of the weight coefficients are determined based on the initial decision matrix. Since four experts were involved in the research, each of them evaluated the alternatives according to the criteria (Appendix A, Table A1). Equation (25) was used to calculate the elements of the normalized expert correspondence matrix $\tilde{Y}^{(l)} = \left[\tilde{y}_{ij}^{(l)}\right]_{b\times n}$ ($l = 1,2,..,4$; $b = 1,2,...,7$; $n = 1,2,...,18$).

The normalized expert matrices $\tilde{Y}^{(l)}$ were aggregated using LNNWGA. The aggregated normalized initial decision matrix is shown in Table 2.

Table 2. *Aggregated normalized initial decision matrix*

Crit.	A1	A2	A3	A4	A5	A6	A7
C11	$\langle s_{4.92},s_{1.99},s_{3.00}\rangle$	$\langle s_{1.39},s_{5.23},s_{7.75}\rangle$	$\langle s_{6.00},s_{2.97},s_{3.77}\rangle$	$\langle s_{7.75},s_{4.77},s_{6.89}\rangle$	$\langle s_{3.00},s_{3.9},s_{2.68}\rangle$	$\langle s_{7.26},s_{1.16},s_{4.00}\rangle$	$\langle s_{1.39},s_{6.48},s_{3.22}\rangle$
C12	$\langle s_{3.98},s_{2.20},s_{1.41}\rangle$	$\langle s_{3.91},s_{3.39},s_{5.09}\rangle$	$\langle s_{1.21},s_{1.43},s_{3.44}\rangle$	$\langle s_{3.19},s_{3.77},s_{7.78}\rangle$	$\langle s_{1.51},s_{2.44},s_{1.18}\rangle$	$\langle s_{1.34},s_{2.30},s_{6.00}\rangle$	$\langle s_{1.00},s_{2.33},s_{7.43}\rangle$
C13	$\langle s_{4.98},s_{3.48},s_{5.53}\rangle$	$\langle s_{1.00},s_{1.97},s_{1.00}\rangle$	$\langle s_{4.42},s_{1.22},s_{3.44}\rangle$	$\langle s_{4.45},s_{7.46},s_{2.43}\rangle$	$\langle s_{4.16},s_{1.21},s_{7.78}\rangle$	$\langle s_{4.46},s_{1.22},s_{2.23}\rangle$	$\langle s_{6.48},s_{7.48},s_{1.16}\rangle$
C14	$\langle s_{3.39},s_{1.57},s_{3.20}\rangle$	$\langle s_{4.00},s_{1.00},s_{4.45}\rangle$	$\langle s_{4.00},s_{3.71},s_{6.37}\rangle$	$\langle s_{6.64},s_{4.16},s_{6.92}\rangle$	$\langle s_{1.84},s_{2.18},s_{6.53}\rangle$	$\langle s_{1.16},s_{3.72},s_{4.99}\rangle$	$\langle s_{1.64},s_{4.23},s_{5.51}\rangle$
C15	$\langle s_{4.92},s_{3.75},s_{4.45}\rangle$	$\langle s_{0.00},s_{1.72},s_{1.16}\rangle$	$\langle s_{5.68},s_{1.00},s_{6.00}\rangle$	$\langle s_{5.19},s_{4.45},s_{4.45}\rangle$	$\langle s_{3.22},s_{1.00},s_{5.00}\rangle$	$\langle s_{7.03},s_{1.91},s_{5.00}\rangle$	$\langle s_{0.00},s_{5.7},s_{2}\rangle$
C21	$\langle s_{4.80},s_{5.19},s_{1.22}\rangle$	$\langle s_{2.21},s_{4.70},s_{5.09}\rangle$	$\langle s_{7.17},s_{1.41},s_{1.37}\rangle$	$\langle s_{4.74},s_{5.48},s_{6.49}\rangle$	$\langle s_{4.17},s_{6.23},s_{6.46}\rangle$	$\langle s_{4.1},s_{2.72},s_{5.00}\rangle$	$\langle s_{5.90},s_{0.00},s_{2.43}\rangle$
C22	$\langle s_{1.00},s_{2.37},s_{5.49}\rangle$	$\langle s_{7.78},s_{4.32},s_{7.04}\rangle$	$\langle s_{1.64},s_{2.13},s_{4.00}\rangle$	$\langle s_{1.66},s_{6.51},s_{7.51}\rangle$	$\langle s_{5.19},s_{4.49},s_{2.40}\rangle$	$\langle s_{6.02},s_{7.43},s_{3.19}\rangle$	$\langle s_{4.74},s_{2.11},s_{6.23}\rangle$
C23	$\langle s_{4.66},s_{6.25},s_{6.23}\rangle$	$\langle s_{6.72},s_{7.72},s_{4.45}\rangle$	$\langle s_{4.50},s_{1.21},s_{3.19}\rangle$	$\langle s_{1.91},s_{7.78},s_{5.91}\rangle$	$\langle s_{1.66},s_{2.62},s_{5.49}\rangle$	$\langle s_{5.53},s_{1.16},s_{6.70}\rangle$	$\langle s_{1.44},s_{2.15},s_{2.25}\rangle$
C24	$\langle s_{2.03},s_{5.18},s_{1.16}\rangle$	$\langle s_{4.71},s_{7.40},s_{3.73}\rangle$	$\langle s_{3.52},s_{1.90},s_{7.51}\rangle$	$\langle s_{5.03},s_{2.12},s_{3.26}\rangle$	$\langle s_{1.43},s_{1.51},s_{1.16}\rangle$	$\langle s_{3.77},s_{5.34},s_{3.73}\rangle$	$\langle s_{4.19},s_{1.59},s_{3.00}\rangle$
C31	$\langle s_{5.49},s_{3.946},s_{1.74}\rangle$	$\langle s_{1.69},s_{1.69},s_{4.71}\rangle$	$\langle s_{5.19},s_{2.43},s_{3.48}\rangle$	$\langle s_{3.71},s_{5.6},s_{5.49}\rangle$	$\langle s_{7.72},s_{2.86},s_{2.25}\rangle$	$\langle s_{2.43},s_{7.54},s_{2.72}\rangle$	$\langle s_{5.78},s_{7.72},s_{1.00}\rangle$
C32	$\langle s_{1.37},s_{2.42},s_{7.23}\rangle$	$\langle s_{3.33},s_{4.91},s_{5.78}\rangle$	$\langle s_{4.42},s_{3.60},s_{6.00}\rangle$	$\langle s_{6.72},s_{2.33},s_{4.19}\rangle$	$\langle s_{2.17},s_{6.91},s_{2.21}\rangle$	$\langle s_{5.01},s_{2.50},s_{5.72}\rangle$	$\langle s_{1.18},s_{4.00},s_{5.74}\rangle$
C33	$\langle s_{1.84},s_{1.97},s_{5.72}\rangle$	$\langle s_{3.52},s_{1.41},s_{4.22}\rangle$	$\langle s_{1.64},s_{5.93},s_{2.44}\rangle$	$\langle s_{5.03},s_{1.75},s_{1.66}\rangle$	$\langle s_{1.00},s_{6.79},s_{1.00}\rangle$	$\langle s_{2.55},s_{3.47},s_{1.91}\rangle$	$\langle s_{1.21},s_{2.85},s_{4.74}\rangle$
C41	$\langle s_{1.18},s_{5.44},s_{5.00}\rangle$	$\langle s_{2.48},s_{1.9},s_{7.11}\rangle$	$\langle s_{3.88},s_{1.87},s_{1.41}\rangle$	$\langle s_{3.26},s_{3.58},s_{3.89}\rangle$	$\langle s_{5.03},s_{1.81},s_{1.18}\rangle$	$\langle s_{7.53},s_{2.00},s_{6.00}\rangle$	$\langle s_{1.00},s_{1.44},s_{6.51}\rangle$
C42	$\langle s_{5.74},s_{7.17},s_{3.00}\rangle$	$\langle s_{4.74},s_{5.70},s_{1.22}\rangle$	$\langle s_{2.00},s_{6.00},s_{6.27}\rangle$	$\langle s_{1.37},s_{1.69},s_{6.7}\rangle$	$\langle s_{4.45},s_{4.68},s_{2.00}\rangle$	$\langle s_{6.00},s_{6.16},s_{1.18}\rangle$	$\langle s_{3.69},s_{2.86},s_{4.17}\rangle$
C43	$\langle s_{1.18},s_{5.71},s_{3.73}\rangle$	$\langle s_{1.39},s_{1.79},s_{6.20}\rangle$	$\langle s_{8.00},s_{1.47},s_{1.41}\rangle$	$\langle s_{1.43},s_{2.10},s_{4.22}\rangle$	$\langle s_{7.17},s_{2.00},s_{7.27}\rangle$	$\langle s_{3.26},s_{4.36},s_{7.27}\rangle$	$\langle s_{3.71},s_{2.68},s_{2.96}\rangle$
C44	$\langle s_{3.26},s_{1.91},s_{6.04}\rangle$	$\langle s_{1.64},s_{2.43},s_{1.44}\rangle$	$\langle s_{7.03},s_{6.98},s_{1.64}\rangle$	$\langle s_{1.21},s_{2.38},s_{1.64}\rangle$	$\langle s_{1.74},s_{2.25},s_{7.51}\rangle$	$\langle s_{7.7},s_{7.03},s_{8.00}\rangle$	$\langle s_{3.13},s_{6.7},s_{1.39}\rangle$
C51	$\langle s_{2.12},s_{2.31},s_{2.00}\rangle$	$\langle s_{2.48},s_{1.64},s_{2.48}\rangle$	$\langle s_{5.59},s_{5.44},s_{6.51}\rangle$	$\langle s_{1.37},s_{4.71},s_{0.00}\rangle$	$\langle s_{3.71},s_{7.78},s_{2.50}\rangle$	$\langle s_{1.64},s_{1.43},s_{6.46}\rangle$	$\langle s_{4.00},s_{3.48},s_{6.00}\rangle$
C52	$\langle s_{6.25},s_{1.81},s_{2.18}\rangle$	$\langle s_{1.69},s_{1.22},s_{6.49}\rangle$	$\langle s_{7.27},s_{0.00},s_{2.21}\rangle$	$\langle s_{5.50},s_{7.11},s_{3.77}\rangle$	$\langle s_{1.00},s_{1.47},s_{7.23}\rangle$	$\langle s_{4.30},s_{6.47},s_{4.45}\rangle$	$\langle s_{6.94},s_{2.18},s_{2.18}\rangle$

Based on the deviations obtained, the final objective values of the weight coefficients (w_j^*, $j=1,2,...,18$):

$$w_{C11}^* = 0.0647; w_{C12}^* = 0.0529; w_{C13}^* = 0.0704; w_{C14}^* = 0.0459; w_{C15}^* = 0.0600; w_{C21}^* = 0.0431;$$
$$w_{C22}^* = 0.0725; w_{C23}^* = 0.0575; w_{C24}^* = 0.0359; w_{C31}^* = 0.0557; w_{C32}^* = 0.0530; w_{C33}^* = 0.0380;$$
$$w_{C41}^* = 0.0616; w_{C42}^* = 0.0479 w_{C43}^* = 0.0710; w_{C44}^* = 0.0655; w_{C51}^* = 0.0401; w_{C52}^* = 0.0641.$$

Phase II: Determining the subjective values of the weight coefficients.

The subjective values of the weight coefficients were assigned by the experts. The local values of the weight coefficients were obtained from the subjective assessment of the experts. The global weights of the criteria were obtained by multiplying the weight coefficient of the clusters (C1, C2, C3, C4 and C5) with the weight coefficients of the sub-criteria.

After calculating the objective and subjective values of the weight coefficients of the criteria we obtained the combined values of the weights that we further used in the multi-criteria model, Table 3.

Table 3. *The final values of the weight coefficients*

Criteria	Subjective (w_j)	Objective (w_j)	Final (w_j)	Rank
C11	0.0235	0.0647	0.0283	14
C12	0.0272	0.0529	0.0268	15
C13	0.0172	0.0704	0.0225	16
C14	0.0336	0.0459	0.0287	13
C15	0.0126	0.0600	0.0141	18
C21	0.0546	0.0431	0.0438	11
C22	0.0423	0.0725	0.0571	9
C23	0.0308	0.0575	0.0329	12
C24	0.0221	0.0359	0.0148	17
C31	0.0454	0.0557	0.0470	10
C32	0.0650	0.0530	0.0641	7
C33	0.1000	0.0380	0.0708	6
C41	0.0812	0.0616	0.0930	3
C42	0.0873	0.0479	0.0778	5
C43	0.0647	0.0710	0.0854	4
C44	0.0484	0.0655	0.0590	8
C51	0.1282	0.0401	0.0957	2
C52	0.1159	0.0641	0.1382	1

3.3. Application of the LNN MABAC model

After determining the final values of the weight coefficients of the criteria, the alternatives were evaluated using the LNN-MABAC model. Four experts carried out an evaluation of seven unmanned aircraft denoted as A1 to A7. As with the OS model, the experts evaluated the alternatives by assigning a certain value from a set of linguistic variables, $S=\{s_i \mid i\in[0,8]\}$, where $s=\{$*s_0 – exceedingly low, s_1– pretty low, s_2– low, s_3– slightly low, s_4 – medium, s_5– slightly high, s_6– high, s_7– pretty high, s_8– exceedingly high*$\}$.

Step 1. Forming the expert correspondence matrix.

Step 2. Calculating the elements of the normalized expert correspondence matrix. Using equation (7) normalization of the expert correspondence matrices was carried out.

Step 3. Calculating the elements of the aggregated normalized matrix. Based on the normalized expert correspondence matrices, using expression (9) aggregation of the values was carried out and an aggregated normalized matrix obtained, Table 2.

Step 4. Calculating the elements of the weighted matrix. The elements of the weighted matrix were obtained by multiplying the final values of the weight coefficients with the elements of the aggregated normalized matrix (Table 2).Using expression (10) we obtained the elements of the weighted matrix, Table 4.

Table 4. *The weighted matrix*

Crit.	A1	A2	A3	A4	A5	A6	A7
C11	$\langle s_{0.21},s_{7.69},s_{7.78}\rangle$	$\langle s_{0.04},s_{7.9},s_{7.99}\rangle$	$\langle s_{0.31},s_{7.78},s_{7.83}\rangle$	$\langle s_{0.74},s_{7.88},s_{7.97}\rangle$	$\langle s_{0.11},s_{7.84},s_{7.76}\rangle$	$\langle s_{0.52},s_{7.57},s_{7.84}\rangle$	$\langle s_{0.04},s_{7.95},s_{7.8}\rangle$
C12	$\langle s_{0.15},s_{7.73},s_{7.64}\rangle$	$\langle s_{0.14},s_{7.82},s_{7.9}\rangle$	$\langle s_{0.03},s_{7.64},s_{7.82}\rangle$	$\langle s_{0.11},s_{7.84},s_{7.99}\rangle$	$\langle s_{0.04},s_{7.75},s_{7.6}\rangle$	$\langle s_{0.04},s_{7.74},s_{7.94}\rangle$	$\langle s_{0.03},s_{7.74},s_{7.98}\rangle$
C13	$\langle s_{0.17},s_{7.85},s_{7.93}\rangle$	$\langle s_{0.02},s_{7.75},s_{7.63}\rangle$	$\langle s_{0.14},s_{7.67},s_{7.85}\rangle$	$\langle s_{0.15},s_{7.99},s_{7.79}\rangle$	$\langle s_{0.13},s_{7.67},s_{8}\rangle$	$\langle s_{0.15},s_{7.67},s_{7.77}\rangle$	$\langle s_{0.29},s_{7.99},s_{7.66}\rangle$
C14	$\langle s_{0.13},s_{7.63},s_{7.8}\rangle$	$\langle s_{0.16},s_{7.54},s_{7.87}\rangle$	$\langle s_{0.16},s_{7.83},s_{7.95}\rangle$	$\langle s_{0.4},s_{7.85},s_{7.97}\rangle$	$\langle s_{0.06},s_{7.71},s_{7.95}\rangle$	$\langle s_{0.04},s_{7.83},s_{7.89}\rangle$	$\langle s_{0.05},s_{7.86},s_{7.91}\rangle$
C15	$\langle s_{0.11},s_{7.92},s_{7.93}\rangle$	$\langle s_{0},s_{7.83},s_{7.79}\rangle$	$\langle s_{0.14},s_{7.77},s_{7.97}\rangle$	$\langle s_{0.12},s_{7.93},s_{7.93}\rangle$	$\langle s_{0.06},s_{7.77},s_{7.95}\rangle$	$\langle s_{0.23},s_{7.84},s_{7.95}\rangle$	$\langle s_{0},s_{7.96},s_{7.85}\rangle$
C21	$\langle s_{0.31},s_{7.85},s_{7.37}\rangle$	$\langle s_{0.11},s_{7.82},s_{7.84}\rangle$	$\langle s_{0.76},s_{7.41},s_{7.4}\rangle$	$\langle s_{0.31},s_{7.87},s_{7.93}\rangle$	$\langle s_{0.25},s_{7.91},s_{7.93}\rangle$	$\langle s_{0.25},s_{7.63},s_{7.84}\rangle$	$\langle s_{0.46},s_{0},s_{7.59}\rangle$
C22	$\langle s_{0.06},s_{7.46},s_{7.83}\rangle$	$\langle s_{1.49},s_{7.72},s_{7.94}\rangle$	$\langle s_{0.1},s_{7.42},s_{7.69}\rangle$	$\langle s_{0.11},s_{7.91},s_{7.97}\rangle$	$\langle s_{0.46},s_{7.74},s_{7.47}\rangle$	$\langle s_{0.61},s_{7.97},s_{7.59}\rangle$	$\langle s_{0.4},s_{7.41},s_{7.89}\rangle$
C23	$\langle s_{0.23},s_{7.94},s_{7.93}\rangle$	$\langle s_{0.47},s_{7.99},s_{7.85}\rangle$	$\langle s_{0.21},s_{7.52},s_{7.76}\rangle$	$\langle s_{0.07},s_{7.99},s_{7.92}\rangle$	$\langle s_{0.06},s_{7.71},s_{7.9}\rangle$	$\langle s_{0.3},s_{7.51},s_{7.95}\rangle$	$\langle s_{0.05},s_{7.66},s_{7.67}\rangle$
C24	$\langle s_{0.03},s_{7.95},s_{7.77}\rangle$	$\langle s_{0.1},s_{7.99},s_{7.91}\rangle$	$\langle s_{0.07},s_{7.83},s_{7.99}\rangle$	$\langle s_{0.12},s_{7.84},s_{7.89}\rangle$	$\langle s_{0.02},s_{7.81},s_{7.77}\rangle$	$\langle s_{0.07},s_{7.95},s_{7.91}\rangle$	$\langle s_{0.09},s_{7.81},s_{7.89}\rangle$
C31	$\langle s_{0.42},s_{7.69},s_{7.44}\rangle$	$\langle s_{0.09},s_{7.44},s_{7.8}\rangle$	$\langle s_{0.38},s_{7.56},s_{7.69}\rangle$	$\langle s_{0.23},s_{7.87},s_{7.86}\rangle$	$\langle s_{1.17},s_{7.62},s_{7.54}\rangle$	$\langle s_{0.13},s_{7.98},s_{7.6}\rangle$	$\langle s_{0.47},s_{7.99},s_{7.26}\rangle$
C32	$\langle s_{0.1},s_{7.41},s_{7.95}\rangle$	$\langle s_{0.27},s_{7.75},s_{7.83}\rangle$	$\langle s_{0.4},s_{7.6},s_{7.85}\rangle$	$\langle s_{0.89},s_{7.39},s_{7.68}\rangle$	$\langle s_{0.16},s_{7.92},s_{7.37}\rangle$	$\langle s_{0.49},s_{7.42},s_{7.83}\rangle$	$\langle s_{0.08},s_{7.65},s_{7.83}\rangle$
C33	$\langle s_{0.15},s_{7.25},s_{7.81}\rangle$	$\langle s_{0.32},s_{7.07},s_{7.65}\rangle$	$\langle s_{0.13},s_{7.83},s_{7.36}\rangle$	$\langle s_{0.54},s_{7.18},s_{7.16}\rangle$	$\langle s_{0.08},s_{7.91},s_{6.91}\rangle$	$\langle s_{0.21},s_{7.54},s_{7.23}\rangle$	$\langle s_{0.09},s_{7.44},s_{7.71}\rangle$
C41	$\langle s_{0.12},s_{7.72},s_{7.66}\rangle$	$\langle s_{0.27},s_{7},s_{7.91}\rangle$	$\langle s_{0.48},s_{6.99},s_{6.81}\rangle$	$\langle s_{0.38},s_{7.42},s_{7.48}\rangle$	$\langle s_{0.7},s_{6.97},s_{6.7}\rangle$	$\langle s_{1.86},s_{7.03},s_{7.79}\rangle$	$\langle s_{0.1},s_{6.82},s_{7.85}\rangle$
C42	$\langle s_{0.75},s_{7.93},s_{7.41}\rangle$	$\langle s_{0.54},s_{7.79},s_{6.91}\rangle$	$\langle s_{0.18},s_{7.82},s_{7.85}\rangle$	$\langle s_{0.12},s_{7.09},s_{7.89}\rangle$	$\langle s_{0.49},s_{7.67},s_{7.18}\rangle$	$\langle s_{0.82},s_{7.84},s_{6.89}\rangle$	$\langle s_{0.38},s_{7.38},s_{7.6}\rangle$
C43	$\langle s_{0.11},s_{7.77},s_{7.5}\rangle$	$\langle s_{0.13},s_{7.04},s_{7.83}\rangle$	$\langle s_{8},s_{6.92},s_{6.9}\rangle$	$\langle s_{0.13},s_{7.14},s_{7.58}\rangle$	$\langle s_{1.41},s_{7.11},s_{7.94}\rangle$	$\langle s_{0.35},s_{7.6},s_{7.94}\rangle$	$\langle s_{0.41},s_{7.29},s_{7.35}\rangle$
C44	$\langle s_{0.24},s_{7.35},s_{7.87}\rangle$	$\langle s_{0.11},s_{7.46},s_{7.23}\rangle$	$\langle s_{0.94},s_{7.94},s_{7.29}\rangle$	$\langle s_{0.08},s_{7.45},s_{7.29}\rangle$	$\langle s_{0.11},s_{7.42},s_{7.97}\rangle$	$\langle s_{1.41},s_{7.94},s_{8}\rangle$	$\langle s_{0.23},s_{7.92},s_{7.22}\rangle$
C51	$\langle s_{0.23},s_{7.1},s_{7.01}\rangle$	$\langle s_{0.28},s_{6.88},s_{7.15}\rangle$	$\langle s_{0.87},s_{7.78},s_{7.84}\rangle$	$\langle s_{0.14},s_{7.6},s_{0}\rangle$	$\langle s_{0.46},s_{7.98},s_{7.16}\rangle$	$\langle s_{0.17},s_{6.78},s_{7.84}\rangle$	$\langle s_{0.51},s_{7.39},s_{7.78}\rangle$
C52	$\langle s_{1.52},s_{6.52},s_{6.68}\rangle$	$\langle s_{0.26},s_{6.17},s_{7.77}\rangle$	$\langle s_{2.25},s_{0},s_{6.7}\rangle$	$\langle s_{1.19},s_{7.87},s_{7.21}\rangle$	$\langle s_{0.15},s_{6.33},s_{7.89}\rangle$	$\langle s_{0.81},s_{7.77},s_{7.38}\rangle$	$\langle s_{1.95},s_{6.68},s_{6.68}\rangle$

Step 5. Calculating elements of the border approximation area matrix (BAA). Using equation (11) we obtained the elements of the border approximation area matrix.

Step 6. Calculating the matrix of the distance of the alternatives from the border approximation area. We used equation (12) to determine the distance of the alternatives from the BAA, Table 5.

Table 5. *Distance of the alternatives from the border approximation area*

Crit.	A1	A2	A3	A4	A5	A6	A7
C11	-0.014	0.012	-0.012	0.041	-0.012	0.032	-0.015
C12	-0.022	0.007	-0.012	0.008	-0.023	-0.003	0.005
C13	0.006	-0.022	-0.016	0.010	-0.018	-0.018	0.021
C14	-0.013	-0.018	0.006	0.022	-0.006	-0.007	0.007
C15	0.008	-0.011	0.013	0.009	-0.009	0.017	-0.008
C21	-0.033	0.018	-0.046	0.018	0.021	-0.006	-0.553
C22	-0.027	0.088	-0.030	0.018	-0.031	0.034	-0.027
C23	0.007	0.024	-0.029	0.009	-0.015	-0.031	-0.024
C24	-0.011	0.006	-0.008	-0.007	-0.013	0.003	-0.008
C31	-0.021	-0.036	-0.022	0.016	0.065	-0.015	-0.032
C32	-0.023	0.007	0.012	0.051	-0.038	0.024	-0.012
C33	-0.034	-0.040	0.021	-0.046	-0.049	-0.019	-0.020
C41	0.040	-0.026	-0.063	0.019	-0.075	0.109	-0.037
C42	0.031	-0.048	0.027	-0.057	-0.028	-0.057	-0.026
C43	-0.042	-0.032	0.550	-0.029	0.074	0.024	-0.028
C44	-0.032	-0.061	0.072	-0.058	-0.027	0.084	-0.058
C51	-0.045	-0.055	0.052	-0.534	0.034	-0.068	0.035
C52	-0.079	-0.074	-0.515	0.073	-0.075	0.059	0.099

Step 7. Ranking the alternatives. Based on the distance of the alternatives from the BAA, using equation (13),we obtained the final values of the criterion functions of the alternatives and the final ranking of the alternatives, Table 6.

Table 6. *Criterion functions and ranking of the alternatives*

Alternative	Q_i	Rank
A1	-0.303	5
A2	-0.258	4
A3	-0.001	2
A4	-0.433	6
A5	-0.225	3
A6	0.164	1
A7	-0.680	7

4. CONCLUSION

Research has shown that the selection of the optimal UAV, in addition to being influenced by predictable indicators, is also influenced by numerous unknown and partially known indicators. The LNN OS-MABAC model takes all parameters into consideration that affect the final decision, regardless of the degree and nature of their uncertainty. This model makes it possible to process qualitative subjective expert preferences, even when decisions are made on the basis of data that are partially known or even not very well known at all. In this way, it makes it easier for decision makers to express their own preferences, while taking into account subjectivity and the lack of information about certain occurrences. In addition, the LNN OS model for determining the weight coefficients of the criteria introduces objective values of weight coefficients, which reduces the subjective impact of the expert preferences on the final values of the weights of the criteria. Bearing in mind the given advantages, one of the improvements of this model will be the creation and implementation of software for real-world applications, which now can be one of the limitations and managerial implications. This will make the model much closer to users and will enable full exploitation of all the benefits stated in the paper.

Further integration of the LNN approach in traditional MCDM models, such as in the Best-Worst and AHP methods, would make it possible to determine the degree of consistency of the expert comparisons. This would indirectly be able to determine the degree of reliability of the results obtained, which would significantly contribute to the validation of the model.

ACKNOWLEDGMENTS

The work reported in this paper is a part of the investigation within the research project Innovative scientific and artistic research in the field of activity of the Faculty of Technical Sciences supported by the Ministry for Science and Technology (Republic of Serbia). This support is gratefully acknowledged.

LITERATURE

[1] Pamučar, D., & Ćirović, G. (2015). The selection of transport and handling resources in logistics centers using Multi-Attributive Border Approximation area Comparison (MABAC). Expert systems with applications, 42(6), 3016-3028.

[2] Fang, Z., & Ye, J. (2017). Multiple attribute group decision-making method based on linguistic neutrosophic numbers. Symmetry, 9 (7), 111.

[3] Garg, H. (2018). Linguistic single-valued neutrosophic prioritized aggregation operators and their applications to multiple-attribute group decision-making. Journal of Ambient Intelligence and Humanized Computing, 9(6), 1975-1997.

[4] Zavadskas, E.K., Baušys, R., & Lazauskas, M. (2015). Sustainable assessment of alternative sites for the construction of a waste incineration plant by applying WASPAS method with single-valued neutrosophic set. Sustainability, 7(12), 15923-15936.

[5] Biswas, P., Pramanik, S., & Giri, B. C. (2016). TOPSIS method for multi-attribute group decision-making under single-valued neutrosophic environment. Neural computing and Applications, 27(3), 727-737.

[6] Aleksić, P. & Jančić, G., (2011). The protection of forest from forest fires in a public company "Srbijasume", Šumarstvo, 1-2, 95-110 [In Serbian].

[7] Vidović, A., & Diminić, D. (2014). Possibility of implementing unmanned aerial vehicles in firefighting operations. In Znanost i razvitak prometa, ZIRP 2014.

26 | Review paper I Прегледни научни рад
ISSN 2566-4484 I Doi 10.7251/STP2014288S
pages 288-298

Dragoljub Sekulović, dragoljub.sekulovic@fpsp.edu.rs, Faculty of Information Technology and Engineering, University Union "Nikola Tesla"

Miloš Basarić, ivan.garic@yahoo.com, Military Geographical Institute, Belgrade

Ivan Garić, mbasaricbp@gmail.com, Military Geographical Institute, Belgrade

HELMERT TRANSFORMATION ON THE CASE OF GAUSS-KRÜGER AND UTM

Abstract:

Globally, maps are our primary source of comprehensive information about the shape, size and arrangement of Earth features. Maps are the only way we can get a unique and comprehensive view of the world. Unfortunately, globally, all maps are somehow deformed, affecting our perception and understanding of the various geometrical properties of the world. Cartographic projection is a way of mapping points from an ellipsoid to a plane and as such is the basis for making a mathematical map basis. The two projections most used in our geospatial are the Gauss-Krüger projection and the UTM (Universal Transverse Mercator) projection. The paper deals with Helmert's transformation of these two projections.

Keywords: Helmert transformation, Gauss-Krüger projection, UTM projection

ХЕЛМЕРТОВА ТРАНСФОРМАЦИЈА НА ПРИМЕРУ ГАУС-КРИГЕРОВЕ И УТМ ПРОЈЕКЦИЈЕ

Сажетак:

На глобалном нивоу, карте су нам примарни извори свеобухватних информација о облику, величине и распореду карактеристика Земље. Карте су једини медијум са којег можемо добити јединствен и свеобухватан поглед на свет. Нажалост, на глобалном нивоу све карте су на неки начин деформисане, и утичу на нашу перцепцију и спознају различитих геометријских својстава света. Картографска пројекција представља начин пресликавања тачака са елипсоида на раван и као таква представља основ за израду математичке основе карата. Две пројекције које су се највише користиле на нашем геопростору су Гаус-Кригерова пројекција и UTM (Universal Transverse Mercator) - Трансферзална Меркаторова пројекција. У раду се обрађује Хелмертова трансформација ових двају пројекција.

Кључне ријечи: Хелмертова трансформација, Гаус-Кригерова пројекција, УТМ пројекција

1. INTRODUCTION

The acqusition and conceptualization of spatial knowledge are important topics in human spatial cognition. In general, maps are our primary graphic source of information. However, they deform characteristics of Earth, such as size and shape. The coordinate system is a set of parameters that uniquey identify the location of an any object in a given coordinate system. Transforming coordinates from one coordinate system to another is a common activity. In it's simplest terms, a map projections is transformation of spherical set of global data into plane. Mathematically, transformation from three dimensions into two is called „projection". Projection includes deformations in form of changes in shapes, length and angles. The three basic categories of map projection are equivalent, conformal and equidistant. Equivalent projections preserve equality of surface, conformal preserve similarity of shapes and equidistant preserve equality of lengths. For a relatively small geographical area, deformations can be negligible. However, for large geographical areas, especially at the global level, the distortions are significant and unavoidable. Through this article, our aim is to improve understanding in how to identify and interpret deformations, in hope this will help improving the study of deformations of the projections and restricting wrong decoding of informations derived from the maps.

2. HELMERT TRANSFORMATION

Most of us come across geographical maps every day. In order to correctly interpret information presented on these maps, especially when they includes large areas, we need to understand pattern of deformations presented on the map. Maps can be considered as a represented communication tool between the cartographer and the user who need to use his (her) knowledge to decode the cartographic and geographic symbols [1]. In order to understand the aspect of communication and interpretation of maps, we need to understand users perception of maps. Previous research on the impact of map projections has been limited [2]. Studies based on perception of projection properties on maps have mainly focused on the basic understanding of map properties, such as visual preference for projections and basic skills needed them to understand the projections [2]. Cartographic projection is a mathematically defined mapping of the surface of an ellipsoid or sphere on a map plane [3]. It establishes a coincidence between the geographical coordinates on the Earth's ellipsoids and the orthogonal coordinates of the same points on the plane. The number of possible projections is unlimited [4]. Although projections are a difficult topic to study, successful interpretation of geographic information – even at the basic level – requires the ability to visually access the accuracy of spatial features on a map. This does not mean, that the technical knowledge of map projections is unnecessary, but we should be able to determine deformations produced by projection [5].

When coordinates of geodetics points are calculated in different coordinate system, it is necessary to transform the coordinates from one coordinate system to another. If coordinates of some points are given on local coordinate system, then is necessary to determine their corresponding coordinate values in the state coordinate system. The transition from one coordinate system to another is called the transformation of coordinates.

The study of deformations and some other important property of projection is based on a comparison of corresponding elements of ellipsoidal surface and the elements in projection [6]. One of the basic characteristics of all spatial data is their spatial connection. If it is necessary to represent point in other coordinate system, it is necessary to perform datum transformation. Geodetic datum defines the size and the shape of Earth's ellipsoid, the coordinate origin and orientation of the system relative to the Earth. The parameters that define datum transformation are called transformation parameters. For datum transformation, seven parameters need to be known: 3 translation parameters, 3 rotation parameters and the scale parameter. This transformation is also known as Helmert transformation [7, 8].

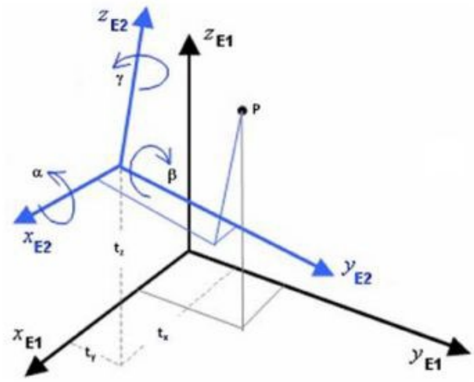


Figure 1. *Helmert transformation [7]*

For two points from two different coordinate systems, it is possible to share data if coordinate systems have an associated spatial reference. In Gauss-Krüger projection points are obtained by projecting the Bessel ellipsoid onto the intersecting transverse cylinder, while the coordinates in the UTM projection are obtained by projecting the WGS84 ellipsoid onto intersecting transverse cylinder. In addition to the fact that the parameters of these two ellipsoids differ, the coordinate systems in which these two ellipsoids are placed are also different [8].

The Bessel ellipsoid was created in 1841 by the German Wilhem Bessel. This ellipsoid is very accurate for the territories of Europe and Euroasia, despite the fact that its axes are about 700 meters shorter then the axis of the ellipsoid WGS84, which are calculated from satellite measurements. In Serbia, it represented the official datum until October 2009, when it become the ellipsoid WGS84. WGS84 (World Geodetic System 1984) is a realization of the conventional terrestrial reference system and as such is the official terrestrial reference of the US Departmen of Defense, both for positioning and navigation, as well as for all cartographic and surveying activities. The advent of Global Positioning System (GPS) has significantly contributed to the promotion of the WGS84 ellipsoid as a global datum standard. WGS84 contains a geocentric Cartesian coordinate system, which is defined by the station coordinates of control GPS segment [9].

3. GAUSS-KRÜGER PROJECTION

Gauss-Krüger projection belongs to group of conformal cylindrical projection. The mapping from the ellipsoid is made to a transverse cylinder, so that it touches the ellipsoid along meridian. The basic characteristics of projection are [10]:

- projection is conformal,
- scale along the central line is equal to one and does not depend on latitude and
- the central line is mapped as a straight line and adopted for the X-axis of the Cartesian coordinate system, and the equator is mapped as a straight line perpendicular on central line and adopted as Y-axis of Cartesian coordinate system; other meridians are mapped as curved lines symmetrical with the respect to central line; the other parallels are mapped as curved lines symmetrical with the respect to the equator.

The projection is called Gauss-Krüger, because its basic theory was given by a German scientist and professor, Karl Friedrich Gauss, and the working formulas where presented by German professor and surveyor, Luis Krüger [6].

The essence of mapping points from the ellipsoid to a plane in a Gauss-Krüger projection is to calculate Cartesian coordinates of those points based on geographical coordinates. The equations used to perform this calculation are derived under the following conditions [11]:

- on the Earth's ellipsoid, a cylinder is conceived so that rotational axis of that cylinder lies in the equatorial plane, and the cylinder touches the ellipsoid by one meridian, as shown in the figure 2 and
- points from the surface of the ellipsoid should be mapped directly onto the surface of the cylinder so that, after developing the cylinder into a plane by cutting one derivate from a plane containing the equator, a conformal projection of the mapped surface is obtained.

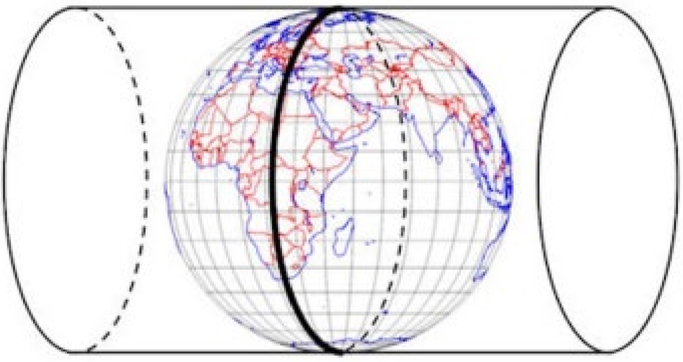


Figure 2. *Mapping from a rotating ellipsoid to a cylinder [12]*

When defining projection, the condition is set that the deformations of the length must not exceed 0.0001, that is, the maximum deformation over a length of one kilometer may be one decimeter. After setting this condition, it is determined how wide the meridional zone can be, and that the deformations remain within the limits of the set condition. The calculation showed that for the given condition the maximum width of the zone could be $2°31'$, and at the end of the zone, the scale factor would be $m = 1 + 0.0001$. If the cylinder is positioned so that it cuts the ellipsoid symmetrically with respect to the central meridian of the zone, the scale factor in the central meridian would be $m_0 = 1 - 0.0001$. By moving away from the central meridian of the zone, the scale factor increases, first becoming equal to the one at the contact meridians, and at the ends of the mapping zone reaches $m = 1 + 0.0001$. Following this condition, states north of 40th parallel may have a zone width of $3°$. It has been defined that the mapping will be performed on a cutting cylinder and that the width of the zone is $3°$, because the Serbia is between the 42nd and 46th northern parallels [10].

4. UTM PROJECTION

UTM (Universal Transverse Mercator) – a transverse Mercator projection, an adaptation of the Mercator projection, is a projection in which an ellipsoid intersects a cylinder whose axis lies in the equatorial plane. Although this projection is under this name, it is essentially Gauss-Krüger projection applied in a special way. The meridians and parallels of the UTM projection are not straight lines, as in the case of Mercator projection, except for the equator and the central meridian of the zone, as well as any meridian that is 90° from the central. Deformations grow east and west from the central meridian. In order to increase the surface in which deformations can be tolerated, a cutting cylinder is applied. In this case, we have two meridians on which the scale factor is equal to one [13, 14].

The UTM is conformal projection. For this reason, surface and lengths are mapped with some deformations. When defining projection, the condition was set that the deformations of the lengths should not exceed 0.0004, that is, the maximum deformation over a length of one kilometer could be four decimeters. After setting this condition, it is determined how wide the mapping zone can be so that the deformations remain within the limits of set condition. If the cylinder is positioned that it cuts the ellipsoid symmetrically with respect to the central meridian of the zone, the scale factor at the central meridian of the zone is $m_o = 1 - 0.0004$. By moving away from the central meridian of the zone, the scale factor increases, first becoming equal to one on the conctat meridians, and at the ends of the mapping zone is $m_o = 1 + 0.0004$ [10, 14].

5. TRANSFORMATION FROM GAUSS-KRÜGER PROJECTION INTO UTM PROJECTION

A complete transition from the Gauss-Krüger projection to the UTM projection is shown on the following scheme:

$$(y, x)_{GK} \rightarrow (B, L)_{Bessel} \rightarrow (X, Y, Z)_{Bessel} \rightarrow (X, Y, Z)_{WGS84} \rightarrow (B, L)_{WGS84} \rightarrow (E, N)_{UTM}$$

This algorithm implies that the geodetic datum transformation is performed on the basis of Helmert transformation and that the ellipsoidal height (*h*) of the point whose coordinates are transformed is known [11].

The course of transformation itself based on a given scheme follows next steps [11, 15]:

- the Cartesian coordinates *y* and *x* of some point in the plane in Gauss-Krüger projection is converted to the corresponding geodetic coordinates *B* and *L* (latitude and longitude) on the Bessel ellipsoid;
- coordinates *B* and *L* with the associated ellipsoidal height *h* are converted to the spatial Cartesian coordinates *X, Y* and *Z* on the Bessel ellipsoid;
- then the spatial Cartesian coordinates *X, Y* and *Z* on the Bessel ellipsoid are transformed into the spatial Cartesian coordinates *X, Y* and *Z* related to the WGS84 ellipsoid;
- coordinates *X, Y* and *Z* related to the WGS84 ellipsoid are converted to the geodetic coordinates *B, L* and *h* on the WGS84 ellipsoid and
- coordinates *B* and *L* are converted to coordinates *E and N* in the UTM projection.

In the first step, the Cartesian coordinates *y* and *x* of some point in the Gauss-Krüger projection are transformed into the corresponding geodetic coordinates *B* и *L* (latitude and longitude) on the Bessel ellipsoid. The following applies in this step:

- $a = 6377397{,}155$ - the large axis of the Bessel ellipsoid,
- $b = 6356078{,}96325$ - the small axis of the Bessel ellipsoid,
- $m_o = 0{,}9999$ - scale along the central meridian of the Gauss-Krüger,
- $y_o = 6500000$ and $L_o = 18°$ for points in the zone 6 of the Gauss-Krüger projection or
- $y_o = 7500000$ and $L_o = 21°$ for points in the zone 7 of the Gauss-Krüger projection.

First, the unmodulated coordinates are calculated using the following:

$$y' = \frac{y - y_o}{m_o}$$

$$x' = \frac{x}{m_o} \tag{1}$$

After that, following parameters are calculated:

$$e = \sqrt{1 - \frac{b^2}{a^2}}\ ;\ e' = \sqrt{\frac{a^2}{b^2} - 1} \tag{2}$$

$$m_1 = \frac{x'}{a\left(1 - \frac{e^2}{4} - \frac{3e^4}{64} - \frac{5e^6}{256}\right)} \tag{3}$$

$$e_1 = \frac{1 - \left(1 - e^2\right)^{1/2}}{1 + \left(1 - e^2\right)^{1/2}} \tag{4}$$

$$B_1 = m_1 + \left(\frac{3}{2}e_1 - \frac{27}{32}e_1^3\right)\sin 2m_1 + \left(\frac{21}{16}e_1^2 - \frac{55}{32}e_1^4\right)\sin 4m_1 + \\ + \frac{151}{96}e_1^3 \sin 6m_1 + \frac{1097}{512}e_1^4 \sin 8m_1 \tag{5}$$

$$V_1 = \frac{a}{\left(1 - e^2 \sin^2 B_1\right)^{1/2}} \tag{6}$$

$$M_1 = \frac{a\left(1 - e^2\right)}{\left(1 - e^2 \sin^2 B_1\right)^{3/2}} \tag{7}$$

$$T_1 = \tan^2 B_1; C_1 = e'^2 \cos^2 B_1 \text{ и } D = \frac{y'}{V_1} \tag{8}$$

Using the given parameters, the required coordinates are obtained using the following formulas:

$$B = B_1 - \frac{V_1 \tan B_1}{M_1}\left[\begin{array}{l}\frac{D^2}{2} - \left(5 + 3T_1 + 10C_1 - 4C_1^2 - 9e'^2\right)\frac{D^4}{24} + \\ + \left(61 + 90T_1 + 298C_1 + 45T_1^2 - 252e'^2 - 3C_1^2\right)\frac{D^6}{720}\end{array}\right] \tag{9}$$

$$L = L_o + \frac{1}{\cos B_1}\left[\begin{array}{l}D - \left(1 + 2T_1 + C_1\right)\frac{D^3}{6} + \\ + \left(5 - 2C_1 + 28T_1 - 3C_1^2 + 8e'^2 + 24T_1^2\right)\frac{D^4}{120}\end{array}\right] \tag{10}$$

In the second step, the coordinates *B* and *L* , obtained from the previous step, with assigned ellipsoidal height *h* are converted into Cartesian coordinates *X, Y* and *Z* relating to the ellipsoid of the Bessel. The procedure is as follows:

$$V = \frac{a}{\left(1 - e^2 \sin^2 B\right)^{1/2}} \tag{11}$$

$$X = \left(V + h\right)\cos B \cos L$$

$$Y = \left(V + h\right)\cos B \sin L$$

$$Z = \left[V\left(1 - e^2\right) + h\right]\sin B \tag{12}$$

The third step is the transformation of Cartesian coordinates *X, Y* and *Z* related to the Bessel ellipsoid into *X, Y* and *Z* coordinates related to the WGS84 ellipsoid. For the transformation itself between two datum, it is necessary to know the transformation parameters. These parameters are derived from points whose coordinates are known in both systems [11, 15].

To calculate transformation parameters it is necessary to know the coordinates of at least two corresponding points and the height of the third point in both coordinate system (datums) [16]. The transformation parameters are than evaluated through the adjustment by the method of the least squares. This method is based on the principle that the sum of the squares of the measurement result corrections (residuals) is minimal. In this case, the differences between the known coordinates of identical points and their coordinates obtained by transformation are minimized [17]. This model is in literature often referred to the model Bursa-Wolf. If this model is applied to the geodetic networks of a smaller scope, the translation and the rotation parameters are highly correlated. An alternative model is Molodensky-Badekas model which is a more general transformation model in which rotations are relative to the grid centroid in the new datum [16]. When it comes to the final result, the two models give different parameters of translation, but the rotation parameters and the scale factor remain the same [17]. Higher number and better distribution of this points in the observed territory are prerequisite for the set of parameters that result in better fit. Parameters can be calculated by the user himself or downloaded by national surveyor or mapping agency or any other appropriate institution. As an example, in table 1 are shown transformation parameters given by national surveyor agency of Serbia – Republic geodetic authority. Parameters are determined by 1217 points of the state trigonometric network. For military use in Serbia, parameters are provided by Military Geographic Institute [15].

Table 1. *Transformation parameters (Republic Geodetic Authority, 2017) [15]*

Transformation parameters	Value	Standard deviation
Translation x	574.040907 m	$\sigma(t_x)$=0.015 m
Translation y	170.129711 m	$\sigma(t_y)$=0.015 m
Translation z	401.553949 m	$\sigma(t_z)$=0.015 m
Rotation x	-4.88790271″	$\sigma(\varepsilon_x)$=0.032″
Rotation y	0.66492609″	$\sigma(\varepsilon_y)$=0.049″
Rotation z	13.24674576″	$\sigma(\varepsilon_z)$=0.044″
Scale	6.88937746 ppm	$\sigma(k)$=0.106 ppm

From the calculated coordinates from the previous step, a vector r_{Bessel} is formed, from parameters of transition a vector $t=\begin{bmatrix} X_0 & Y_0 & Z_0 \end{bmatrix}$, and from the three rotation parameters around the coordinate axes *X, Y* and *Z* for the angles α, β and γ respectively, a rotation matrix *R* is formed. The scale factor between the two coordinate system is indicated by dm. The vector of Cartesian coordinates related to the WGS84 ellipsoid is calculated by the following expression:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{WGS84} = (1+dm)R^T \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{Bessel} + \begin{bmatrix} X_0 \\ Y_0 \\ Z_0 \end{bmatrix} \tag{13}$$

Matrix *R* is:

$$R = \begin{bmatrix} \cos b \cos g & \cos a \sin g + \sin a \sin b \cos g & \sin a \sin g - \cos a \sin b \cos g \\ -\cos b \sin g & \cos a \cos g - \sin a \sin b \sin g & \sin a \cos g + \cos a \sin b \sin g \\ \sin b & -\sin a \cos b & \cos a \cos b \end{bmatrix}$$

Matrix *R* can also be written in the developed form:

$$R = R_1(\varepsilon_X)R_2(\varepsilon_Y)R_3(\varepsilon_Z) \text{, wherein:}$$

$$R_1(e_x) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos e_x & \sin e_x \\ 0 & -\sin e_x & \cos e_x \end{bmatrix}$$

$$R_2(e_y) = \begin{bmatrix} \cos e_y & 0 & -\sin e_y \\ 0 & 1 & 0 \\ \sin e_y & 0 & \cos e_y \end{bmatrix}$$

$$R_3(e_z) = \begin{bmatrix} \cos e_z & \sin e_z & 0 \\ -\sin e_Z & \cos e_z & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

where $\varepsilon_X, \varepsilon_Y$ and ε_Z are the rotation parameters for corresponding axes.

The four step is the conversion of Cartesian coordinates from the WGS84 ellipsoid to the geodetic coordinates *B, L* and *h* on the WGS84 ellipsoid. The following parameters of the WGS84 ellipsoid are used for this conversion:

- a = 6378137 – the large axis of WGS84 ellipsoid and
- b = 6356752,31425 – the small axis of WGS84 ellipsoid.

Following parameters are used for this step:

$$e = \sqrt{1 - \frac{b^2}{a^2}}; e' = \sqrt{\frac{a^2}{b^2} - 1};$$

$$p = \sqrt{X^2 + Y^2} \text{ and } q = \arctan\frac{Za}{pb} \tag{14}$$

Geodetic coordinates on the WGS84 ellipsoid are calculated using the following formulas:

$$B = \arctan\frac{Z + e'^2 b\sin^3 q}{p - e^2 a\cos^3 q}$$

$$L = \arctan\frac{Y}{X}$$

$$h = \frac{p}{\cos B} - N \tag{15}$$

where *N* is calculated by the formula:

$$N = \frac{a}{\sqrt{1 - e^2\sin^2 B}} \tag{16}$$

The geodetic latitude *B* and ellipsoidal height *h* are usually calculated by a more complex iterative procedure. However, the solution obtained by the above formulas for our territory are in accordance with iterative procedure.

The fifth step is the conversion of geodetic coordinates *B* and *L* on the WGS84 ellipsoid into Cartesian coordinates E and *N* in the UTM projection. The following parameters are used:

- $m_o = 0,9996$ - scale factor among the central meridian of UTM zone and
- $L_o = 21°$ - for points in the 34th UTM zone.

Parameters that need to be calculated before the final step are:

$$A = \left(L - L_o\right)\cos B$$

$$T = \tan^2 B$$

$$C = e'^2\cos^2 B$$

$$V = \frac{a}{\left(1 - e^2\sin^2 B\right)^{1/2}} \tag{17}$$

$$M = a\left[\left(1 - \frac{1}{4}e^2 - \frac{3}{64}e^4 - \frac{5}{256}e^6\right)B - \left(\frac{3}{8}e^2 + \frac{3}{32}e^4 + \frac{45}{1024}e^6\sin 2B\right) + \\ + \left(\frac{15}{256}e^4 + \frac{45}{1024}e^6\sin 4B\right) - \frac{35}{3072}e^6\sin 6B\right] \tag{18}$$

$$y' = V\left[A + \left(1 - T + C\right)\frac{A^3}{6} + \left(5 - 18T + T^2 + 72C - 58e'^2\right)\frac{A^5}{120}\right] \tag{19}$$

$$x' = M + V\sin B\left[\frac{A^2}{2} + \left(5 - T + 9C + 4C^2\right)\frac{A^4}{24} + + \left(61 - 58T + T^2 + 600C - 330e'^2\right)\frac{A^6}{720}\right] \quad (20)$$

and finally:

$$E = y'm_o + 500000$$
$$N = x'm_o \quad (21)$$

6. TRANSFORMATION FROM UTM PROJECTION INTO GAUSS-KRÜGER PROJECTION

The transformation from UTM to Gauss-Krüger projection is done analogous to the transformation from Gauss-Krüger to UTM projection. The transformation process is shown in the following scheme:

$$(E, N)_{UTM} \rightarrow (B, L)_{WGS84} \rightarrow (X, Y, Z)_{WGS84} \rightarrow (X, Y, Z)_{Bessel} \rightarrow (B, L)_{Bessel} \rightarrow (y, x)_{GK}$$

The flow of the transformation itself based on the given scheme is as follows [11, 15]:

- Cartesian coordinates *E* and *N* of some point in the UTM projection are converted to the corresponding geodetic coordinates *B* and *L* (latitude and longitude) on the WGS84 ellipsoid;
- the coordinates *B* and *L* with the associated ellipsoidal height *h* are converted to the spatial Cartesian coordinates *X, Y* and *Z* related to the WGS84 ellipsoid;
- then the spatial Cartesian coordinates *X, Y* and *Z* on the WGS84 ellipsoid are transformed into the spatial Cartesian coordinates *X, Y* and *Z* that refer to the Bessel ellipsoid;
- the coordinates *X, Y* and *Z* relating to the ellipsoid of the Bessel are converted to geodetic coordinates *B, L* and *h* on the Bessel ellipsoid and
- coordinates *B* and *L* are converted to *y* and *x* coordinates in the Gauss-Krüger projection.

In the first step, Cartesian coordinates *E* and *N* of a point in UTM projection are transformed in appropriate geodetic coordinates *B* and *L* (latitude and longitude) on the ellipsoid WGS84. In this step, the following applies:

- $a = 6378137$ - the big semi-axis of the WGS84 ellipsoid,
- $b = 6356752,31425$ - the small semi-axis of the WGS84 ellipsoid,
- $m_o = 0,9996$ - scale along the central meridian of the UTM zone and
- $L_o = 21°$ for points in the 34th UTM projection zone.

First, the unmodulated coordinates are calculated:

$$y' = \frac{E - 500000}{m_o}$$
$$x' = \frac{N}{m_o} \quad (22)$$

After that, the calculations are performed according to formulas (2) to (10).

The second step is conversion of the coordinates *B* and *L* along with the associated ellipsoidal height *h* into Cartesian coordinates *X, Y* and *Z* that are refer to the WGS84 ellipsoid. Formulas (11) and (12) are used in this step.

In third step, the Cartesian coordinates *X, Y* and *Z* on the WGS84 ellipsoid are transformed into Cartesian coordinates *X, Y* and *Z* that refer to the Bessel ellipsoid. The procedure is analogous as in the third step of the transformations of coordinates from Gauss-Krüger projection to UTM projection. From the calculated coordinates from the previous step, a vector r_{WGS84} is formed, from the translation parameters vector $t = \begin{bmatrix} X_0 & Y_0 & Z_0 \end{bmatrix}$, and from three rotation parameters around the coordinate axis *X, Y* and *Z* for the angles α, β and γ respectively, a rotation matrix *R* is formed. The vector of Cartesian coordinates related to the Bessel ellipsoid is calculated by the following expression:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{Bessel} = (1 + dm) R^T \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{WGS84} + \begin{bmatrix} X_0 \\ Y_0 \\ Z_0 \end{bmatrix} \tag{23}$$

The fourth step in the transformation is a conversion of the coordinates *X, Y* and *Z* relating to the Bessel ellipsoid in a geodetic coordinates *B, L* and *h* on the same ellipsoid. The ellipsoidal parameters used in this step are:

$$a = 6377397{,}155$$

$$b = 6356078{,}96325$$

In the following, formulas (14) - (16) are used.

The fifth and the final step in this transformation is the conversion of coordinates *B* and *L* into the coordinates *y* and *x* in the Gauss-Krüger projection. The following parameters are used in this step:

- $m_0 = 0{,}9999$ - scale along the central meridian of the Gauss-Krüger projection,
- $y_0 = 6500000$ and $L_0 = 18°$ for points in zone 6 of the Gauss-Krüger projection or
- $y_0 = 7500000$ and $L_0 = 21°$ for points in zone 7 of the Gauss-Krüger projection.
- Formulas (17) - (20) are used for calculation, after which the following formulas are used:

$$y = y' m_0 + y_0$$

$$x = x' m_0 \tag{24}$$

The transformation of coordinates requires specialized geodetic knowledge, especially in part which refers to the selection of models and parameters of transformation, because it affects on accuracy of transformed coordinates. However, if the procedure and formulas are cleared, users can transform coordinates without such knowledge.

7. CONCLUSION

Cartographic projections represent the way points from an ellipsoid are mapped to a plane. Due to the mapping between such surfaces, there is a deformation of the projection sizes. There are many map projections, each with its own purpose, each with its own advantages and disadvantages. When choosing a map projection, it is very important to keep in mind which area is being mapped and what sizes we want to preserve. The two most significant projections used in our country are the Gauss-Krüger and UTM (transverse Mercator projection) projections.

After 85 years of using Gauss-Krüger projection in our country, there is a need to standardize geospatial data with other countries. In this regard, the Government of the Republic of Serbia made a decision in October 2009 to switch to a UTM map projection, the datum of which will be the WGS84 ellipsoid. The transition to a new map coordinate system is a long process.

There is no indication that the map projection that will serve as the basis for the national survey will change in the near future. With the growing representation of UTM projection in various applications and systems, there is a growing range of users interested in the procedures and methods of transitioning from Gauss-Krüger to UTM projection, and vice versa. The question of choosing the transformation method and transformation parameters requires specialized geodetic knowledge, since the accuracy of the transformed coordinates depends on these choices.

LITERATURE

[1] Battersby, E. S., „The Effect of Global-Scale Map-Projection Knowledge on Perceived Land Area", Cartographica, Vol. 44, No 1, pp. 33-44, 2009.

[2] Downs, R. M. and Liben, S. L., „The Development of Expertise in Geography: A Cognitive-Developmental Approach to Geographic Education", Annals of the Association of American Geographers, Vol. 81, pp. 304-327, 1991.

[3] Серапинас, Б. Б., Математическая картография, Естественньие науки, Высшее профессиональное образование, ACADEMA, Москва, 2005.

[4] Астахова, И. А., Картография, Учебно-методическое пособие, Факультет аграрных технологий, Майкоп, России, 2016.

[5] Battersby, S. E., and Kessler, F. C., „Cues for Interpreting Distortion in Map Projections", Journal of Geography, Vol. 111(3), pp. 93-101, 2012.

[6] Јовановић, В., Математичка картографија, Војногеографски институт, Београд, 1983.

[7] Божић, Б., Рачун изравнања, Грађевински факултет, Београд, 2013.

[8] Вушовић, Н., Просторни референтни системи, Институт за рударство и металургију Бор, Бор, 2012.

[9] Благојевић, Д., Увод у сателитску геодезију, Граљевински факултет универзитета у Београду, Београд, 2014.

[10] Регодић, М., Војна топографија, Медија центар одбрана, Београд, 2012.

[11] Радојчић, С., „Трансформација координата између Гаус-Кригерове и светске попречне Меркаторове пројекције за територију Србије", Војнотехнички гласник, Вол. 56, Бр. 4, Београд, стр. 89-95, 2008.

[12] GiS by ESRI, Understending Map Projections, ESRI, New York, 2004.

[13] STANAG 2211, Geodetic Datums, Projections, Grids and Grid References, North Atlantic Treaty Organization, Military Agency for Standardization, Edition 6, 2000.

[14] Sekulović, D.J., Đurković, V.P., Milošević, M.B., „Positioning, orientation and determination of the distance to target on a self-propelled multiple rocket launcher system using GPS and electronic maps", Vojnotehnički glasnik, Vol. 58, No. 3, pp. 32-46, 2010.

[15] Gojković, Z., Radojčić, M., Vulović, N., „Application for coordinate transformation between Gaus - Kruger projection: Bessel ellipsoid and UTM projection: WGS84 ellipsoid", Underground Mining Engineering, No. 30, pp. 29-45, 2017.

[16] Ilic, A., Cirovic, G., Sekulovic, D., Regodic, M., Pamucar, D., „Mathematical basis for direct map projection transformation", Tehnics Technologies Education Management, Vol. 8, No. 2, pp. 574-584, 2013.

[17] Vasic, D., „Estimating the influence of point heights in computing datum transformation parameter", Geonauka, Vol. 2, No. 3, pp. 17-25, 2014.

27 | Preliminary report I Претходно саопштење
ISSN 2566-4484 I Doi 10.7251/STP2014299P
pages 299-309

Ljubomir Palikuća, ljubomir.palikuca@yahoo.com, Integral Inženjering a.d. Laktaši
Zlatko Langof, langofzlatko@gmail.com, Integral Inženjering a.d. Laktaši
Đorđe Raljić, djordje.raljic@integralgrupa.com, Integral Inženjering a.d. Laktaši
Boško Miljević, bosko.miljevic@integralgrupa.com, Integral Inženjering a.d. Laktaši

GEOTECHNICAL PROBLEMATICS OF DIRECTED RESEARCH IN ROCK MASSES

Abstract:
During the construction of Civil Engineering structures in rock masses, different and specific problems may occur. Engineering Geological research has a significant role in their solving. With this kind of research relevant data can be obtained with purpose to get detailed insight in engineering - geological rock mass characteristics and its geological structure. Absence or insufficient scope and quality of the mentioned research may result in occurrence of the problems during design and performance of Civil Engineering structures, which in this work has been shown on the example of road construction in the cut in the rock mass.

Keywords: Engineering-geological research, rock mass, problems

ГЕОТЕХНИЧКА ПРОБЛЕМАТИКА УСМЈЕРЕНИХ ИСТРАЖИВАЊА У СТИЈЕНСКИМ МАСАМА

Сажетак:
Приликом изградње грађевинских објеката у стијенским масама појављују се разни специфични проблеми у чијем рјешавању значајну улогу имају инжењерско – геолошка истраживања. Овим истраживањима се добијају релевантни подаци који служе за детаљно сагледавање инжењерско – геолошких карактеристика стијенске масе. Одсуство или недовољан обим и квалитет поменутих истраживања за посљедицу има настанак проблема приликом пројектовања и извођења грађевинских објеката, што је у раду и приказано на примјеру изградње саобраћајнице у засјеку у стијенској маси.

Кључне ријечи: Инжењерско – геолошка истраживања, стијенска маса, проблеми

1. INTRODUCTION

One of the basic steps during structure design is thorough research work implementation. Different environment conditions, as well as types of constructions require different kind of research works in order to obtain the desired information which is necessary for quality design. Rock mass research represents specific field considering the fact that adoption and determination of parameters is a serious challenge. During research implementation it is necessary to pay attention equally to the intact rock research and discontinuity. The scope and research type should adapt to the type of the structure which is performed, as well as to the cutting size in the slopes. Depending on the structure type and size, a division of the basic research can be done, which is necessary for implementation during research process. Several common cases are considered:

- Cuts in the rocks – orientation and slopes of the primary and secondary cracks, phreatic surface; degree of the crack roughness.
- Foundation structures – deformation modules; ground homogeneity degree; strengths.
- Tunnels – uniaxial strength; RQD; discontinuity distance; discontinuity state; discontinuity stretch and slope; phreatic surface.
- Landslides in the rocks – sliding surfaces depth determination; physical – mechanical parameters of the soils susceptible to sliding.

2. GEOTECHNICAL PROBLEMATICS IN ROCK MASS RESEARCH IN THE CUTS

During design and realization of the routes of the new highways, contemporary practice implies application of the great notch and snaps. Depending on the environment conditions, it is often necessary to insure them by supporting structures which provide security and road persistence during exploitation period. Parameters gained by research works have major significance during design of support constructions (Figure 1) [3:55-56].

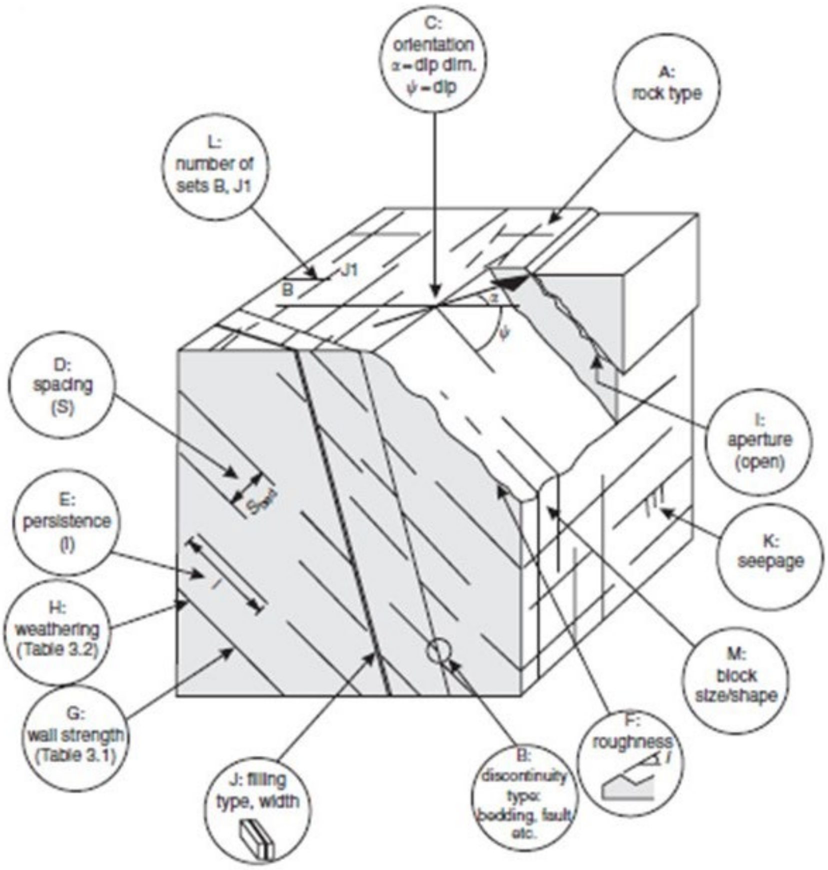


Figure 1. *Defined parameters by rock masses*

There is some key information when defining physical-mechanical parameters (Figure 2):

- slopes of the primary and secondary systems;
- crack fill;
- shear resistance along cracks;
- water permeability;
- phreatic surface.

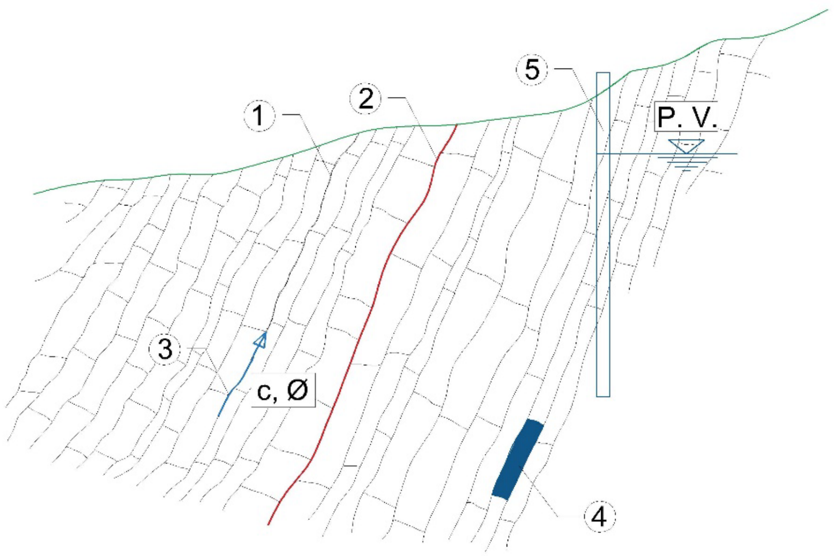


Figure 2. *Physical – mechanical parameters*

Data analysis of drilled core of the wells lead to the conclusion that is possible to state the string of factors which provide information about the state in the ground. If discontinuity is detected on the wells core, further analysis requirements, concerning orientation, thickness, fill, material characteristics which fill discontinuities are imposed. There is a sequence of applicable methods, nevertheless making inclined boreholes imposes as one of simpler and better methods (Figure 3).

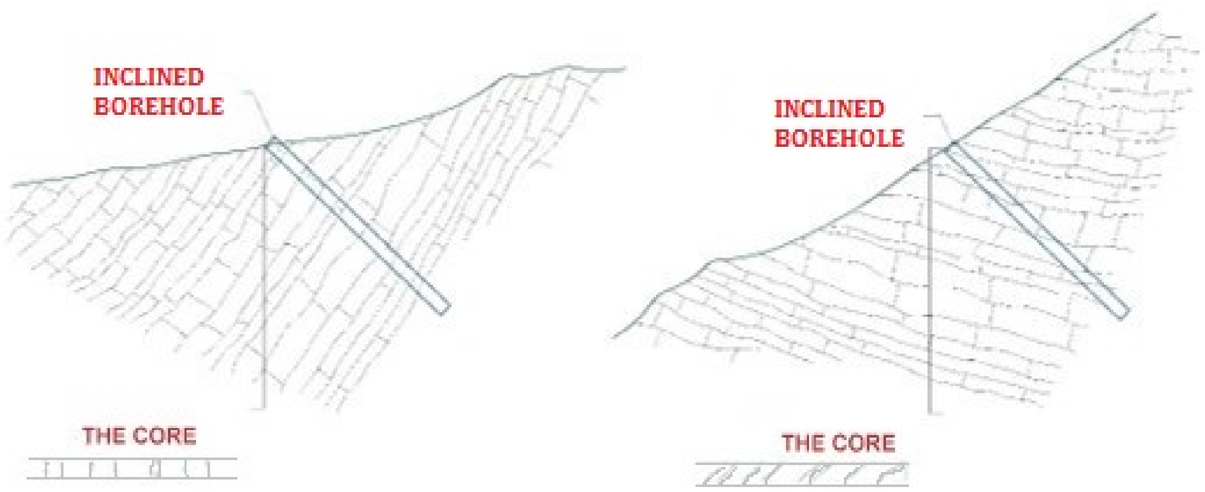


Figure 3. *Inclined borehole with core*

Information obtained by making inclined boreholes can be supplemented additionally by review and opened profile analysis if existing (Figure 4).

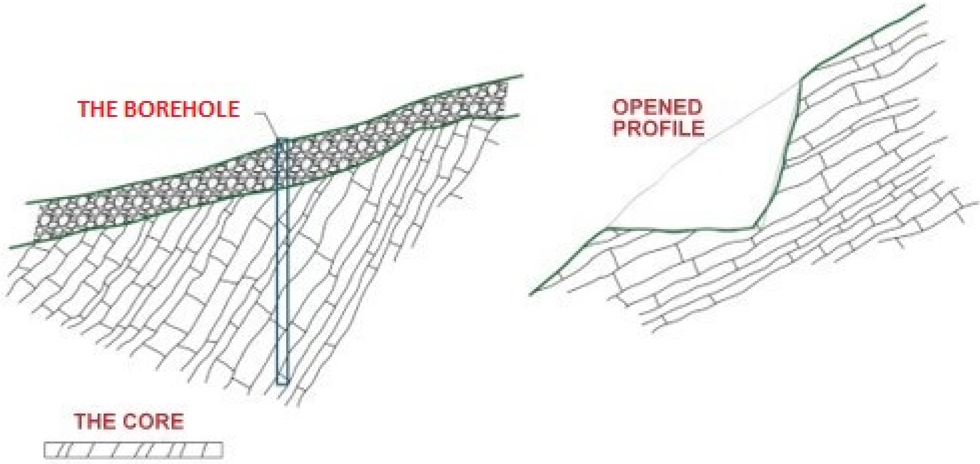


Figure 4. *The borehole and opened profile in the rock*

Discontinuities slopes, which decline is directed toward the excavation zone or snap, will enable unhindered falling of the blocks or moving of the greater rock mass, depending on the number of other factors (Figure 5).

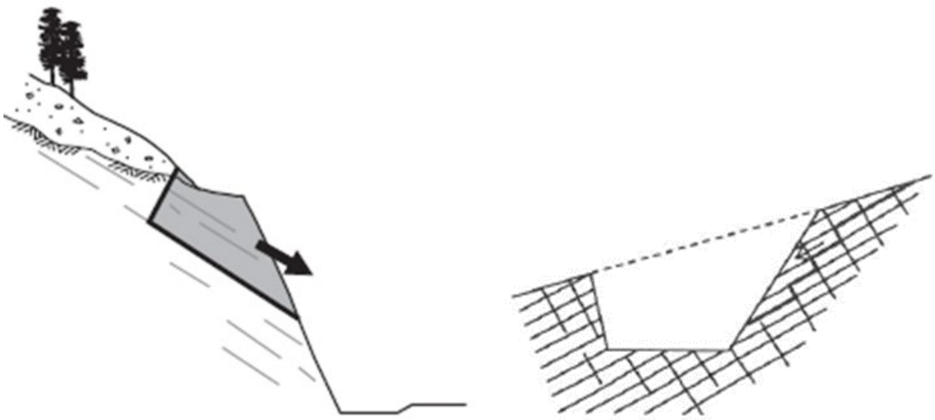


Figure 5. *Unfavorable discontinuity slope*

That is precisely the reason why notches with such discontinuity orientation should be avoided. Shear strength parameters will have major influence on stability of the blocks, and they are directly conditioned by shape and roughness of the discontinuity surface, rock waste state on the discontinuity surface, and fills. In case of the discontinuity, namely the blocks whose contact zone will enable matching, rocks stability will be less questionable. Considering that anomalies on the natural rock masses can be called discontinuities, thus the quality waste and disruption of the rocks are the most easily realized on these places. A number of factors can lead to an increase in rock solidity, primarily the environment influence, the rock massif characteristics, as well as the intact rock characteristics. Climate and chemical impacts are imposed as the most significant influences which encourage the rock waste [3:22-27].

When making the inclined boreholes the arrangement of the cracks must be taken into account. Depending on the drilling angle selection, it is possible that crack orientation will give completely wrong view about the natural state on the field. In case that the drilling axis occupies the upright position at the angle of discontinuity inclination, a clear view of their arrangement would not be obtained by drilling, there is even a possibility of they could be even neglected. Figure 6 shows the effects of the drilled core analysis. Likewise, they show, to a large extent, how high mistake level can occur if minor research scope is conducted during research works.

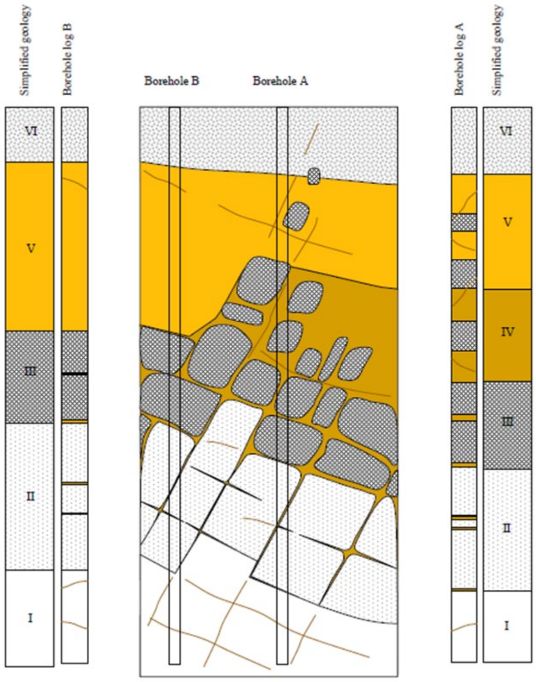


Figure 6. *Researching wells with coreing*

The water flow is an additional aggravating circumstance in case of the notch performing in the grounds with unfavorable oriented crack system. Beside flushing effects and crack fill weakening, water causes the hydrostatic pressure occurrence (Figure 7).

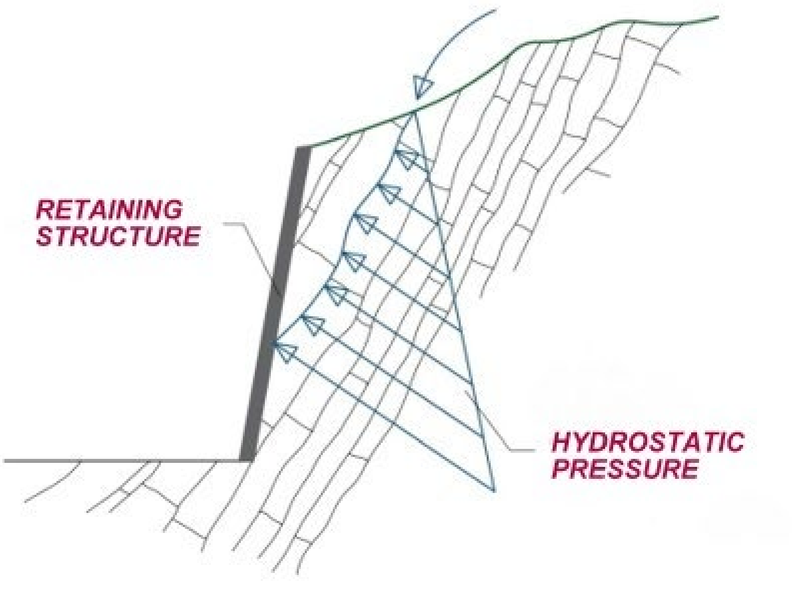


Figure 7. *Profile with unfavorable orientation of the crack systems*

It is necessary to take care of the numbers of this pressure, considering the fact that, in case of the high hydrostatic pressure presence, in fact it can be the reason of cancellation and initiation of a particular part of the rock massif. These negative impacts can be prevented by applying solutions shown on the figure 8.

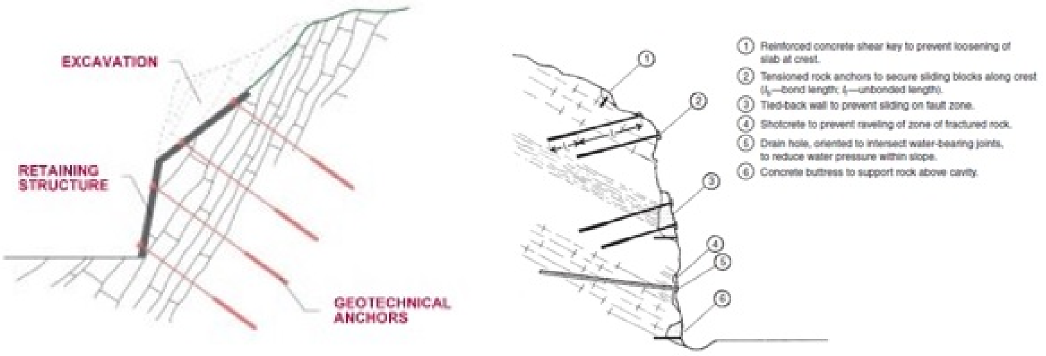


Figure 8. *Construction with geotechnical anchors*

During designing solutions, it is not uncommon to use large excavations. During excavation, natural stability is disrupted due to unloading. The material, which was previously on the excavation position was a natural counterweight that impeded the slipping and falling of blocks, therefore leading to occurrence of deep slippages and the global stability of the slope (Figure 9) [2:13-14].

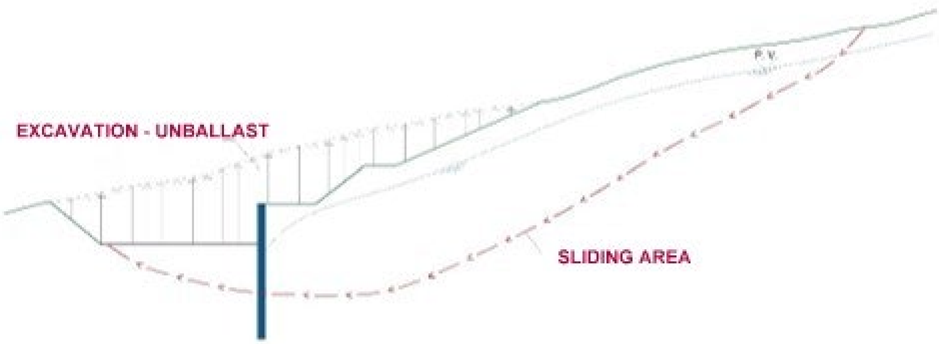


Figure 9. *Damaged slope stability*

When it comes to the span discontinuity, the significance of the research work in rock masses has been mentioned before. There are other methods that can be used to estimate the discontinuity parameters. The most favorable case is direct width discontinuity measuring when there are conditions for it. However, there is a number of other methods which can determine the widths. Discontinuity prevalence within the rock massif will have a major impact on its stability. Dense arrangement of discontinuity can cause the cohesion weakness of the rock mass, while scarce arrangement can cause clamping of the blocks. If there is a very small discontinuity disposition, it may cause the occurrence of the circular sliding plates, which in general are not characteristic of the rock massif. The discontinuity orientation significantly contributes to the stability if they are positive oriented discontinuities, while at the same time they may have completely negative influence if it is negative orientation. Positive and negative orientation of discontinuities may not be considered until the route or structure positioning is performed in relation to rock massif. Therefore, the character of excavation is defined. The basic parameters which define the orientation are stretching, inclination and inclination discontinuity direction. All three parameters are interdependent, which leads to complete definition of orientation necessary for their determination, without excluding any of them. The discontinuity roughness is one of the factors which also has direct influence on the slope stability during the rock cutting. The discontinuity width has impact on various factors, and it can be defined as distance of the discontinuity walls without considering the fill presence or fill absence. Natural processes that have occurred during both, their rock origin and existence period, have direct influence on the discontinuity occurrence. The effect of the natural influences is mostly visible on the surface zones, where the discontinuity presence is a very common occurrence. The discontinuity width directly conditions fill presence as well as the influence of the roughness between disheveled members of the rock massif. The wasting processes cause discontinuity width increase, which contributes to the stability disruption [3:52-59].

Discontinuity fill by its nature almost always has different kind in comparison to the basic rock, considering the fact that the filling material is practically secondary raw material (Figure No.10). Roughness and compressive strength are considered to be the basic deformation and strength parameters of discontinuities case without fill, while physical and mineral filling characteristics are imposed as basic parameters in case of discontinuity which has been filled. Humidity, permeability, state of consistency, shear strength and other factors are necessary during definition of the fill character. It is not uncommon to perform macroscopic observation and field testing of the mineral structure from the fill materials during research and testing. The strength can also be determined by field observation, geologist evaluation in the field, using a pocket knife, geological hammer or some other instrument. The recommendation is to use the pocket penetrometer or Schmidt's hammer [6:47-48].

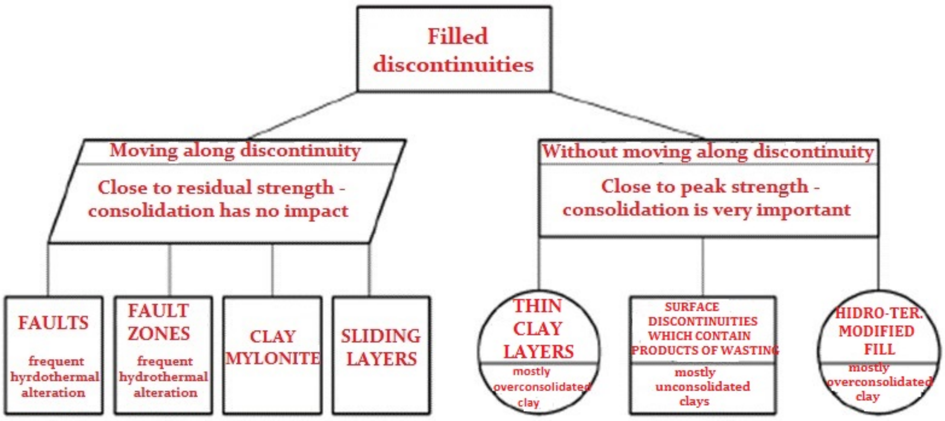


Figure 10. *Fill in discontinuites*

All previously listed factors have indisputable influence on the strength and therefore on the slope stability during rocks cutting. Discontinuities characteristic will also have a major impact on water permeability, that is, conditions of the water moving in the rock. If the rock massif has very small degree of rupture, conditions of the water movement will be rather difficult, almost disabled. However, if the rocks have increased, degree of rupture, and connected crack network, the water will flow through cracks. The movement and water presence in the cracks will contribute significantly to the process of development of wasting rock, that is, to the physical and chemical changes which the intact rock to weak. The presence of the water will contribute to the decrease of physical-mechanical fill parameters in discontinuities and will contribute to the transport of eroded materials. Water often has crucial significance in the aspect of destabilization of slopes by fine-grained materials, considering it causes stress state change and attenuation of internal friction angle and cohesion of natural material. Determination of the physical-mechanical characteristics parameters of the rock massif implies a number of field and laboratory experiments, which must have a high level of connection between each other in order to describe their natural state more adequately. Capital value of the investment, exploitation period and various other effects will directly influence on the scope of research works. For an adequate introduction of the state in the field, it is necessary to define optimal number of the wells, in order to be able to present with certainly geological view of macro and micro location which is a subject of the design. During works realization, it is not uncommon to perform research wells just in the flange of the future snap. The problem occurs when they are the only wells performed for the snap design, which is the case with an example from the practice which will be processed further in the text. Insufficient knowledge of the geological conditions right on the slope in the later stages of the project realization may complicate the solution multiple and increase the costs. The studies testify that value of research works in comparison with the total investment value about 0,1 – 4 % of the total quantity of funds necessary for project realization [1: 3-4]. For many years, it is endeavoring to somehow define the quantity of the research works for different structure types. The quality of the drilled core, percent of the obtained core, quantity of the cracks caused by drilling and a number of other factors will influence on the final result, and that is categorization of the rock massif. Contemporary practice knows and uses a number of different accesses, in the terms of ground, as well as in terms of laboratory classification. Each classification depends on quality and scope of performed works. One of the key factors in research works is definition of the research stages. Every design stage requires certain degree of research works in terms of the ambit thus the recommendation is to perform research works in several stages. In case of road design, less than 5 research works on one hectare is considered to be low research degree [1: 12-13]. Geotechnical experts work on the development of the research phases, for a long period of time, which depend on various factors, such as structure size, structure kind, ground conditions, capital value of the project and a number of other factors. The depth of the research wells is in direct relation with research quality. In particularly depends on the kind and size of the structure, and is directly proportional to the quality of the designed solution. Likewise, quantity and size of the research sample have a great influence on ground state knowledge. The size of the ground particles directly influences on the needed quantity of the research sample, which is necessary for quality implementation of the laboratory research. The percentage of conducted laboratory, reflects on quality of the conducted works. Less than 10 % of tested samples observed in comparison to total quantity of delivered samples in laboratory is considered as a low degree of the conducted research [1: 12-13]. Correct discontinuity definition will determine the designer on reliable calculation model of the rock massif in stability capacity for the given conditions.

3. PROJECT SOLUTIONS AND RESULTING PROBLEMS THROUGH PROJECT REALIZATION

The subject of the work analysis is designed road in the notch during which performance the landslide startup occurred. Contractor approached to the work performing with second, new project solution. The cause of the problem during conducting is inadequate performance of research works in the initial design stages. During the initial research stage in period 2009-2010, first research works were done for the purpose of the main project. The main characteristic of this research works is that they have been conducted entirely on the slope base which should be cut. There were 7 wells, carried out on the field, depth 6-8 m, and they could not give an adequate data with which design could be commenced. Additional research works conducted during 2015 were necessary, considering that during initial work stages on the excavation and slope arranging, extremely large deviation was noted in comparison to adopted parameters values, necessary for making the main project. The additional research works implied performing of 9 research wells with depth of 10 – 25 m, which included research works on the slope above planned route zone, in order to gain insight into ground characteristics. Based on works from 2015, several stages of the implementation project were conducted. In addition, several project variants of slope rehabilitation above the route were conducted as well. Rehabilitation projects were necessary and inevitable, considering that during the project realization, cutting and removing of the sliding flange were conducted, which caused movement of the ground layers in the upper slope zones.

Project for implementation, and later for the slope rehabilitation implied several modifications. At first, the road was conducted according to the first project, which caused the landslide to start, after which the second project was prepared. With this project, the slope rehabilitation was treated, as well as the rest of the slope where the vertical notch in the ground and making the supporting wall with micro piles and geotechnical anchors were provided. During the execution of the works, major changes in the quality of the rock mass were observed at the total length of the cut. Geological conditions in the area of the supporting structure were significantly worse than anticipated and presented to the previous geotechnical studies, which lead to the second project. Due to the above-mentioned issues, development of the third version of the project was launched, on the basis of which the supporting structure was derived (Figure 11).

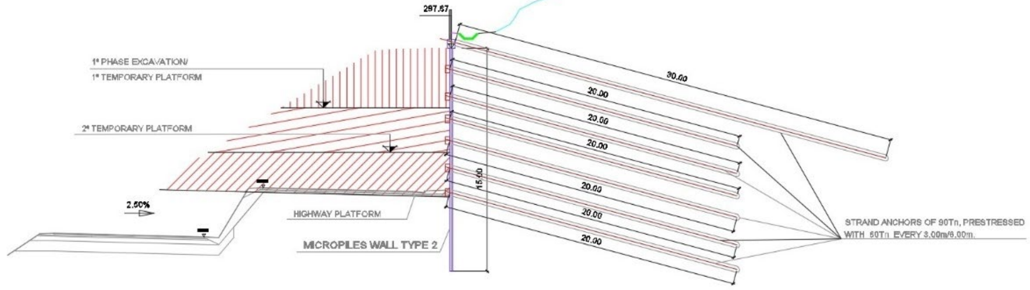


Figure 11. *Performed supporting structure*

After finishing work on the supporting structure, the control works on the field were done behind the performed structure, and it was identified that geological soils deteriorated drastically in quality, which caused doubt in terms of the structure's durability and stability. The control stability and capacity calculations were done, and it was established that ground in the hinterland of the support structure was in the conditional equilibrium, and that it was necessary to apply additional measures in order to increase the sliding stability factor, and thus increase structure durability and stability, as well as the ground behind it (Figure 12).

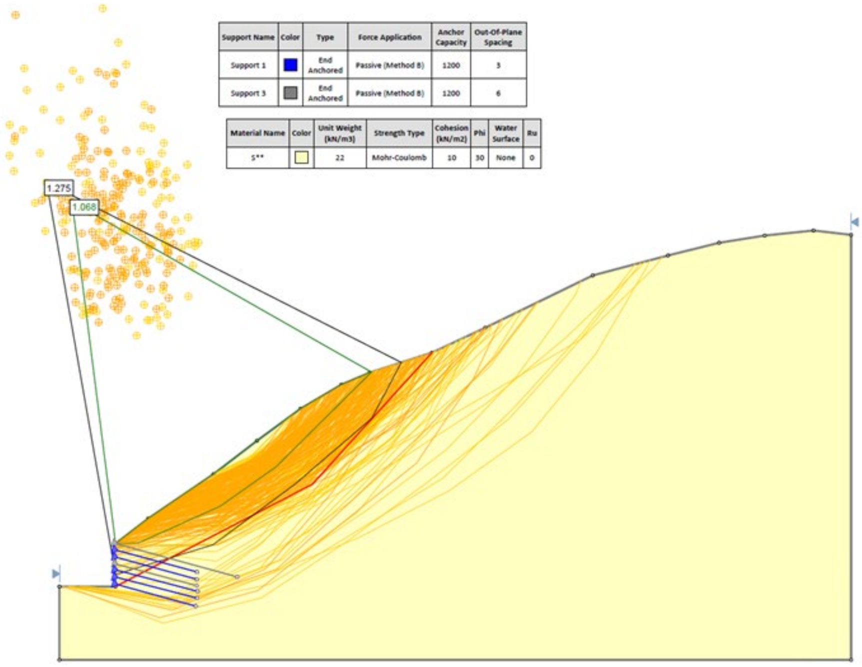


Figure 12. *Slope stability calculation*

A project for slope stabilization behind performed structure commenced, which caused unloading and slope arranging above the structure and the road, in order to decrease an influence on geotechnical anchors, and thus contribute to the slope stability and its structure which ensured the route. During design process, a number of stability analyses were done, particular and a whole as well, berm individually, and several berms in combination as well (Figure 13).

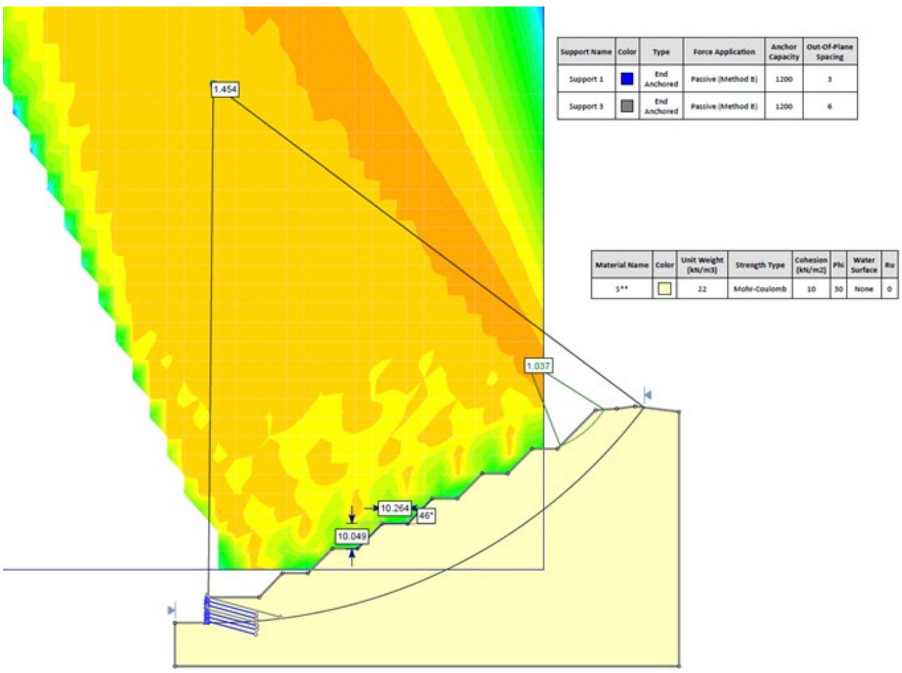


Figure 13. *Slope stability analysis after unloading*

Predicted slope arranging in the listed design phase implied making of 6 sections with slope incline 1:1,2 in combination with SN anchors (Ø 25 mm, long 9 m, 12 m and 15 m) and composite load-bearing network (Figure 14) [4].

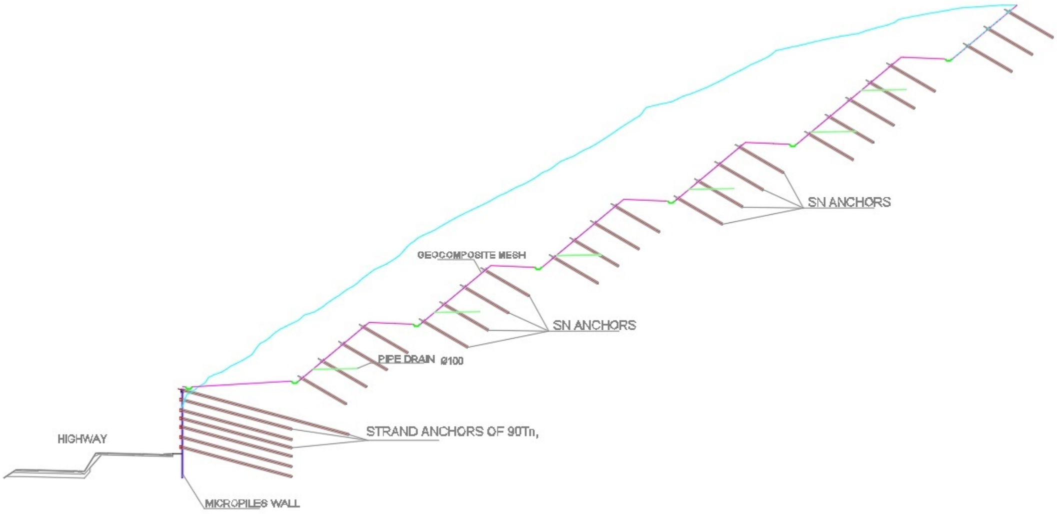


Figure 14. *Slope unloading on sections*

During 2019, works commenced according to the project, and during initial relief phases, a large number of slip-prone zones were indicated. Also, it turned out that designed slopes could not be kept on the project predicted slope long enough to bring about stabilization activities, which lead to project changes.

The realization of the design stabilization solution provided an insight into the condition of the rock mass, pointed to major changes in the composition of the rock mass, changes in the material of the cracks filling, and a very high degree of degradation of the green shale, which is largely widespread in the subject location. All above mentioned, initiated development of additional investigative works that were carried out during October and November 2019, and on that occasion, 6 exploratory 30-50 m deep wells were constructed and two inclinometers were installed to monitor the occurrence of any additional slope movement [6:3-4]. What is particularly significant is that the realization of these exploratory works was carried out on the derived berms of the slope in question and thus contributed to a better knowledge of geological conditions of the site. In terms of geological engineering characteristics, two groups of materials were identified:

- a group of solid rock formations comprising of lower crystallinity shales comprising green shales;
- a group of bound or weakly bound rocks, which include diluvial formations and colluvial masses [6:12-13].

4. CONCLUSION

Based on all previously listed data, it is concluded that the collection of existing data and conducting of research works represent one of the basic steps in the design process. Quality of research works is of major importance, because they directly condition the quality of the data of ground parameters. A lack of research works and inadequate determined physical – mechanical ground parameters will inevitably lead to the occurrences which have been described in the work.

All above mentioned is the result and consequence of inadequate risk analysis from hazardous phenomena. That is the case with landslides and slips on the roads. The design approach should reduce these occurrences to the minimum risk level, at the time of construction and during the operation on the road as well. Thus, it can be concluded with great certainty, that the influences leading to a hazardous phenomenon will always be less than the resistance of the occurrence of that hazard, during the life of the structure. Such approach would require a reassessment of the reliability of all parameters underlying calculation models and the reliability of the traffic in question. The reliability of the road defined in this way should be the basis for obtain the same. Design solutions would be based on such analyses, in order to meet the defined reliability based on the analysis of the risk analysis of hazardous events during the existence of the road.

LITERATURE

[1] Burt Look, Handbook of geotechnical investigation and design tables, pp. 1-15.

[2] Derek H. Cornforth, Landslides in Practice, Investigation, Analysis and Remedial/Preventive Options in Soil, pp. 14-15.

[3] Duncan C. Wyllie and Christopher W. Mah, Rock slope engineering, civil and minning 4th edition, 2005, pp. 22-59.

[4] Project documentation

[5] Sanja Dugonjić Jovančević, Inženjerska mehanika stijena - skripta, Građevinski fakultet sveučilišta u Rijeci, pp. 47-48.

[6] Study – Aditional geotechnical field investigation works and laboratory tests, Landslide at Cut No. 4, km 878+775 – 879+100, Predejane, 2019. pp. 3-13

28 | Preliminary report | Претходно саопштење
ISSN 2566-4484 | Doi 10.7251/STP2014310A
pages 310-317

Naida Ademović, naidadem@yahoo.com, University of Sarajevo, Faculty of Civil Engineering
Snježana Cvijić Amulić, snjezana.cvijic@gmail.com, Republic Hydrometeorological Institute, Banja Luka

SEISMIC RISK IN BOSNIA AND HERZEGOVINA BASED ON BUILDINGS' VULNERABILITY

Abstract:
The region of South-East Europe is characterized by one of the most complex seismotectonic features in the World. Bosnia and Herzegovina is located in the heart of this region. The world is facing an increasing number of natural disasters among which earthquakes are on the top of the list. After extreme temperatures, it is earthquakes that cause the largest amount of deaths. To obtain an overview of the expected human and economic losses seismic risk assessment methods are used. In this paper, an example of a rapid assessment method is presented with the usage of the new hazard seismic map and its presentation, and census data for Bosnia and Herzegovina. Cities with a high-risk level are identified needing further detailed analysis.

Keywords: seismic risk assessment, seismic hazard map, BIH, urban areas

СЕИЗМИЧКИ РИЗИК У БОСНИ И ХЕРЦЕГОВИНИ НА ОСНОВУ ОШТЕТЉИВОСТИ ЗГРАДА

Сажетак:
Регија Југоисточне Европе има једну од најкомплекснијих сеизмотектоника на свијету. Босна и Херцеговина је смјештена у срцу ове регије. Свијет је суочен са све већим бројем природних катастрофа међу којима су земљотреси на врху листе. Након екстремних температура потреси су ти који узрокују највећи број жртава. Како би се добио преглед очекиваних економских и људских губитака користе се методе процјене сеизмичког ризика. У овом раду приказан је примјер брзе методе за процјену ризика уз примјену нове карте сеизмичког хазарда и њене израде, и података из пописа становништва Босне и Херцеговине. Идентифицирани су градови високог нивоа ризика који захтијевају даљњу детаљну анализу.

Кључне ријечи: процјена сеизмичког ризика, карта сеизмичког хазарда, БИХ, градска подручја

1. INTRODUCTION

Apart from floods, fires, and volcano eruptions, earthquakes are one of the most devastating natural phenomena that can be defined as frightening and disastrous phenomena [1]. This is confirmed with the data throughout the 20th century where the number of casualties caused by earthquakes was over 1.5 million due to the failure of buildings, this is 90% of direct deaths [2].

To determine the seismic risk of a particular region it is necessary to obtain necessary data about the overall region regarding seismicity, general properties and vulnerability features of the buildings, and exposure of the population. In this respect, the information that is needed is the seismic hazard map, the main features of buildings and the exposure of the population. To have more detailed information one needs to upgrade the fundamental information with the specific features, e.g. soil characteristics, age of the population, gender, etc. The seismic risk has increased in the urban regions due to the constant migration of people from rural to urban cities, leading to the concentration of citizens in zones that might be prone to earthquakes. On the other hand, the old building stock without adequate maintenance and inadequate seismic features increase the vulnerability. To be able to make priorities and identify regions that should be assessed in more detail it is of the utmost importance to conduct a rapid assessment of the existing building stock.

The seismic risk assessment in Bosnia and Herzegovina is in its initial stage. It is only in 2018 that the first seismic hazard map based on the peak ground acceleration was created replacing the seismic map based on the intensity and presented by the Mercalli–Cancani–Sieberg scale. In 2020 Ademović et al. [3] conducted a rapid seismic assessment for Bosnia and Herzegovina. In this paper, the new hazard map is presented together with the first rapid assessment method done in Bosnia and Herzegovina.

2. RELATIVE SEISMIC RISK

2.1. Seismic Hazard Map

The new Hazard Map for Bosnia and Herzegovina resulted as one of the outcomes of the cooperation project "Support of Capacities of the Institute for Standardization of Bosnia and Herzegovina in the Area of Implementation of EUROCODES" that was financed by the Czech Republic. Local experts and experts employed by UNMZ Czech Office for Standards, Metrology and Testing were involved in the entire process. Detailed information can be found in the paper [4] which is currently under review.

In this study two seismotectonic models were used, one areal and one fault model. The data that was used in this process was the earthquake catalogue (seismological data), information about the active faults and geological units (tectonic data).

Earthquake catalogue of Bosnia and Herzegovina has been drafted by Snježana Cvijić Amulić from the Republic Hydrometeorological Service of Republic of Srpska, within the preparatory work for an edition of the national annex to the BAS EN 1998-1 [5]. The catalogue covers a period from the year 306 to 2015 covering the entire territory of Bosnia and Herzegovina and surroundings up to about 100 km. The catalogue consists of 1944 earthquake records of M_w magnitude from 3.5 to 7.1. The map of earthquake epicenters is shown in Figure 1. The strongest event was the so-called "Ragusa earthquake" (today's Dubrovnik) which occurred on 6th April 1667. This event is of great importance for the southern part of Bosnia and Herzegovina territory, since it significantly affects the seismic hazard assessment. The latest assessment of this event has been done Albini [6] and subsequently by Markušić et al. [7]. For computing the seismic hazard it was necessary to eliminate the foreshocks and aftershocks from the catalogue, i.e. to carry out a procedure of declustering. This was done with the application of the automated algorithm developed by Hakimhashemi and Grünthal [8]. This is a statistical approach based on a deviation criterion, which applies to stationary, nonstationary, and even multimodal nonstationary seismicity rates. The preceding methods used a Poisson process, as a predefined stationary pattern for the seismic rate, or a specific distribution for determination of the catalogue completeness. The new method is simple to apply, as the only parameter used for determining the completeness time is the variance of earthquake interevent times [9].

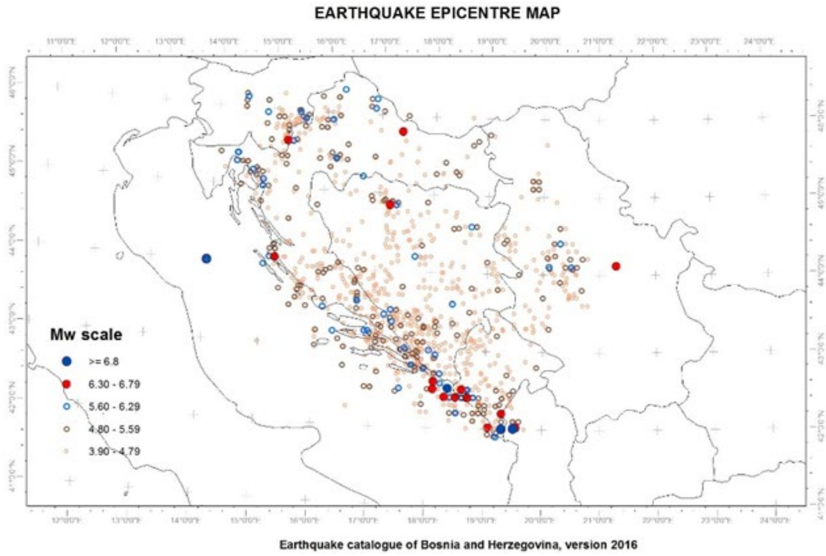


Figure 1. *Map of earthquake epicenters [5]*

Two seismotectonic models were created and used during the seismic hazard computation. The first model was based on an approach, where the source zones of the size of hundreds of km^2 are delineated using the depicted earthquake catalogue. Areas with scattered weak events (in any case lower than M_w magnitude 5) are pronounced as the zone with diffuse seismicity. An advantage of this approach (using wide source zones) is an easier and more accurate determination of the distribution parameters of the source zones – the *b* parameter of the Gütenberg-Richter distribution or *a* parameter, which is defined as a mean value of the earthquake occurrence in the time unit with magnitude higher than 0.0. As a result of this approach, an areal model was obtained. On the other hand, accepting the theory that strong earthquakes are nearly always connected with an activity of the particular seismogenic fault, it is necessary to delimit the source zone as a linear zone representing the individual significant seismogenic fault or fault system. This approach resulted in the linear source model. In this study, ground type A was taken into account characterized by the shear wave velocity $v_{s,30}$ = 800 m.s^{-1} for peak ground acceleration (PGA) values presented in the resulting seismic zoning maps.

The Probabilistic Seismic Hazard Analysis (PSHA) was calculated by the OpenQuake Engine, developed by the Global Earthquake Model Foundation's (GEM). It is state-of-the-art, free, open-source and accessible software collaboratively developed for earthquake hazard and risk modeling. The calculation was based on the logic tree which was able to capture and quantify the epistemic uncertainty associated with the inputs to PSHA and enabled the estimation of the resulting uncertainty in the hazard. More details can be found in [4] that is under review.

As a final output new seismic hazard maps based on the peak ground acceleration were obtained for return periods (95, 475 and 2475 years) and different percentiles (16% percentile; 50% percentile; mean value; 84% percentile). The map which is used in the rapid risk assessment is presented in Figure 2.

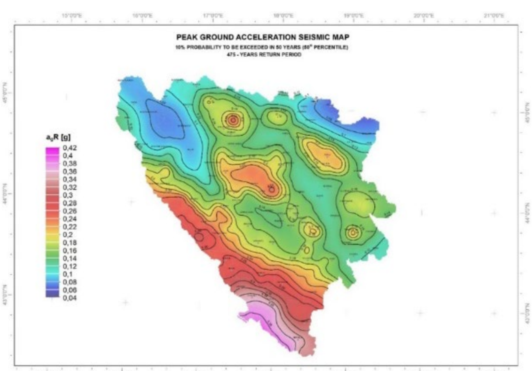


Figure 2. *Seismic hazard map for Bosnia and Herzegovina (475 years) in the function of PGA [3, 5]*

2.2. Exposure of Population and Building Vulnerability

The information from the census data [9] from 2013 was used for the determination of population exposure and building's vulnerability. The feature that was taken into account concerning population was the population density (Figure 3).

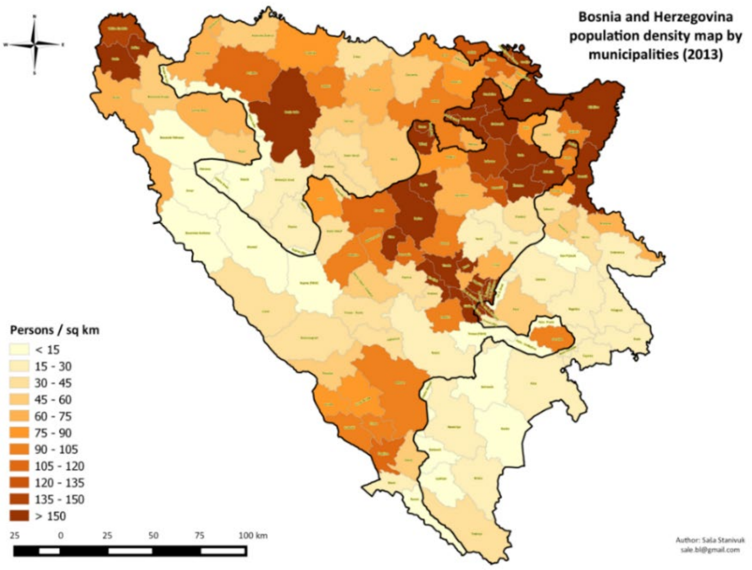


Figure 3. *Population density map by municipalities in Bosnia and Herzegovina from Census 2013 [3]*

The features that were take into account in the process of determination of the seismic vulnerability of buildings were the construction age as this is directly connected to the enforced codes and regulations valid at a certain time, the material of the loadbearing structure and the number of storeys as it has a direct implication on the response of the structure on the earthquake motion. It is quite difficult to determine the vulnerability of the building before an earthquake as one is dealing with many unknowns. In this respect, statistical probability methods have to be combined with the subjective expert judgment, however in these cases, one may argue rather mandatory. In total 1,078,156 buildings were taken into account which were classified depending on the construction age (Figure 4) which was connected to certain building codes. In total six groups were formed. The material was divided into three groups. The first group consists of structures made of stone, brick, and concrete, which makes up to 60% of all structures, the second group consist of reinforced concrete structures and steel frames which make more than a third of all the structures, and the remaining, around 4%, are wooden structures (Figure 5). With respect to the number of stories, 98.88% of all buildings are up to two stories, only 0.88% are building having four to six stories, and the remaining 0.23% are structure having more than 7 stories.

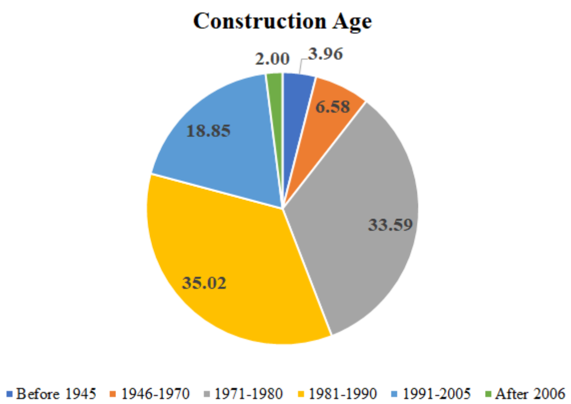


Figure 4. *Buildings in respect to their construction age given in percentage*

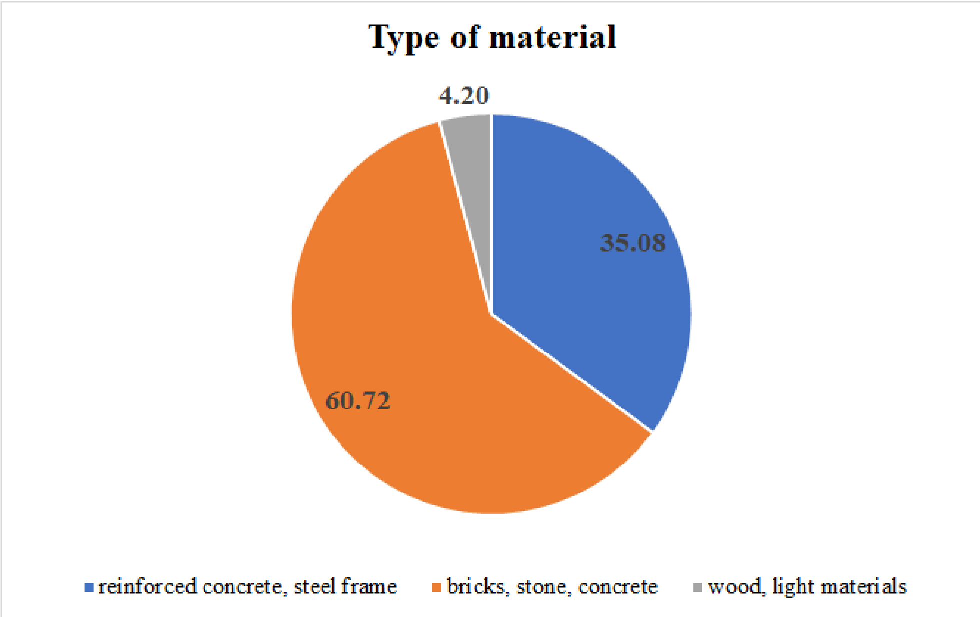


Figure 5. *Type of material of the structural system given in percentage*

2.3. Risk Assessment Methods

Depending on the available data and the purpose of the seismic risk assessment different methods can be applied. In the last years, seismic risk assessment of large cities has been done, from Kolkata City in India [10], Quebec [11] and Montreal [12] in Canada, to European cities like Sion and Martigny [13], Barcelona [14], Lorca [15], Athens [16]. In many of these cases, a large amount of different data was used. The collection of such a large value of data is possible in the case of some cities and mainly for developed ones. However, in the case of undeveloped countries with inadequate database and lacking information it is not possible to conduct very refine and detailed seismic vulnerability assessments.

However, in the case of limited resources and data, as well as lack of historical information regarding earthquake damages fast seismic risk assessment found its application especially for risk management in developing counties [17]. A rapid risk assessment was done for several cities like Eskisehir [18] which is located in the northwestern part of Turkey which is seismically quite active zone. In this case, a screening technique developed by [19, 20] was used. It has been shown that this is a simple and effective method for rapid seismic risk assessment of building stock in the urban cities. Additionally, rapid assessment methods can be used for single buildings. Işık [21] applied three rapid assessment methods for a single building that was damaged after the 2003 Bingöl earthquake. In his work, he used Japan Seismic Index Method, Canadian Seismic Screening Method, and Turkish First Stage Evaluation Method. The rapid seismic assessment method used for Croatia [22] was used as the basis for the development of a new i-rapid method for Bosnia and Herzegovina [3].

In this respect, risk is defined as a function of the convolution between hazard H_i and vulnerability V_e during and exposition period T.

$$Rie|_T = f(H_i \otimes V_{e)}|_T \qquad (1)$$

where ⊗ is convolution [23]. In that respect, the risk is seen as a product of the seismic hazard, building vulnerability, and population exposure.

The most frequently used function for determination of the fragility curves and seismic risk is the lognormal distribution function [24]. The cumulative seismic hazard impact factor which is a function of the peak ground acceleration is denoted as F_H and the function is presented in Figure 6.

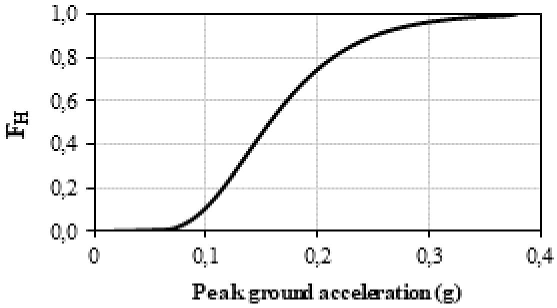


Figure 6. *Seismic hazard impact factor F_H for Bosnia and Herzegovina*

From equation (1) it is clear that a low seismic hazard does not automatically lead to low seismic risk and vice versa. If an area is densely populated and the structures are made in a period during which seismic regulations were not very strict, even locations with low PGA may lead to medium seismic risk. In that respect, these elements have to be elaborated. On one side the risk of buildings being damaged due to the earthquake action (Equation 2) and on the other the exposure of population which is connected to the population density (Equation 3).

$$R_b = F_H \cdot V_b \tag{2}$$

$$R_p = F_H \cdot E_p \tag{3}$$

The lognormal distribution function was used for each building class and weigh factors were taken into account to cover each class, with the application of the Pairwise Comparison Method (PCM). This method transfers the comparisons of all pairs of factors to quantitative weights under the matrix containing the pairwise comparison judgments for certain criteria (age of buildings for the vulnerability of buildings) [3]. The same principle was utilized for different types of material and number of stories. As a final result of these calculations, a relative seismic risk in Bosnia and Herzegovina was obtained (Figure 7).

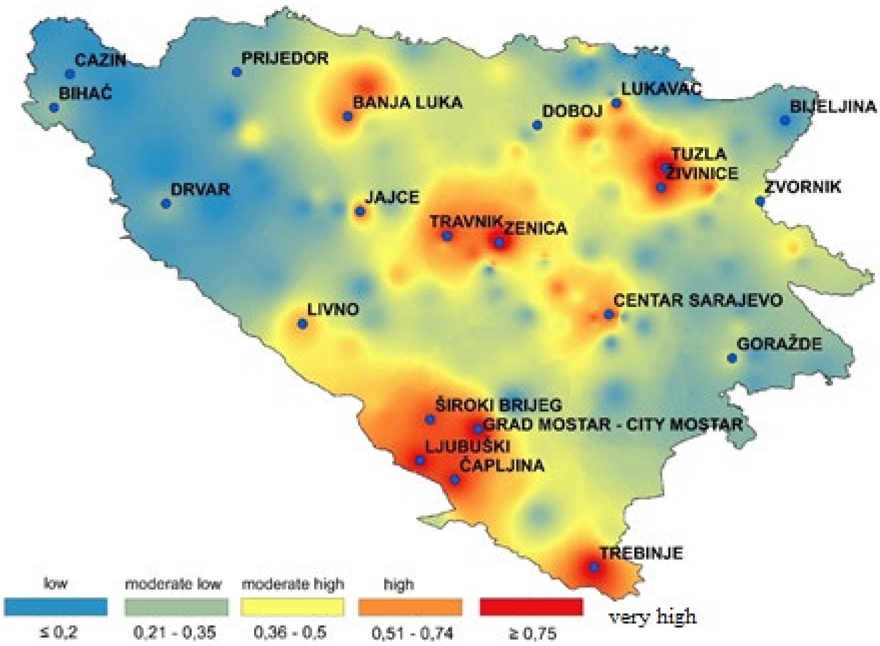


Figure 7. *Distribution of relative seismic risk in Bosnia and Herzegovina [3]*

From Figure 7 several areas are marked as areas of very high risk:

- The area around the city of Banja Luka
- The area around Jajce
- The area around Tuzla, Živinice, Lukavac

- The area around Zenica and Travnik
- The area around Sarajevo and Visoko
- The area around Livno
- A large area including cities Široki Brijeg, Mostar, Ljubuški, Čapljina and their surroundings
- The area around Trebinje

3. CONCLUSION

Until today no rapid seismic risk assessment was done for Bosnia and Herzegovina. The first research activity was conducted by Ademović et al. [3]. As Bosnia and Herzegovina is an earthquake-prone country, this is a very important step as it can be used as preliminary information for further studies and more detailed studies for the cities with higher seismic risk. Additionally, this information can be used for better preparedness for emergency response. This analysis identified cities and areas in Bosnia and Herzegovina which have a high risk of seismic actions and these cities and areas should be analyzed in more detail and with the application of a more detailed seismic assessment method. In the near future, it is planned to extend this new i-rapid analysis and to conduct detailed analysis in several cities of high exposure to earthquake actions.

LITERATURE

[1] N. Ademović, M. Hrasnica, D.V. Oliveira "Pushover Analysis and Damage Assessment of a Typical Masonry Residential Building in Bosnia and Herzegovina", *Engineering Structures*, vol. 50, pp.13-29, 2013.

[2] N. Lantada, L.G. Pujades, A.H. Barbat "Vulnerability index and capacity spectrum based methods for urban seismic risk evaluation: A comparison", *Natural Hazards*, vol. 51, pp. 501-524, 2009.

[3] N. Ademović, T. Kalman Šipoš, M. Hadzima-Nyarko "Rapid assessment of earthquake risk for Bosnia and Herzegovina", *Bulletin of Earthquake Engineering*, vol. 18, pp.1835-1863, 2020.

[4] N. Ademović, V. Demir, S. Cvijić-Amulić, J. Málek, I. Prachař, J. Vackar "Compilation of the Seismic Hazard Maps in Bosnia and Herzegovina", Soil Dynamics and Earthquake Engineering (under review), 2020.

[5] BAS EN 1998-1:2017. Projektiranje potresne otpornosti konstrukcija-1. dio: Opća pravila. potresna djelovanja i pravila za zgrade. Eurocode 8: design of structures for earthquake resistance. Part 1: general rules–seismic actions and rules for buildings.

[6] P. Albini "The Great 1667 Dalmatia Earthquake. An In-Depth Case Study." Springer International Publishing, 2015, pp.95.

[7] S. Markušić, I. Ivančić, I. Sović "The 1667 Dubrovnik earthquake – some new insights". *Studia Geophysica et Geodaetica*, vol. 61, pp.587-600, 2017.

[8] A.H. Hakimhashemi, G. Grünthal "A Statistical Method for Estimating Catalog Completeness Applicable to Long-Term Nonstationary Seismicity Data", *Bulletin of the Seismological Society of America*, vol. 102 (6), 2530-2546, 2012.

[9] Bureau of Statistics [CBS] (2013) National population and housing census 2013 (national report). Agency for Statistics of Bosnia and Herzegovina.

[10] S.K. Nath, M.D. Adhikari, N. Devaraj, S.K. Maiti "Seismic vulnerability and risk assessment of Kolkata City, India" *Natural Hazards and Earth System Sciences*, vol 15, pp.1103-1121, 2015.

[11] A. Abo El Ezz, M.-J. Nollet, M. Nastev, M "Assessment of earthquake-induced damage in Quebec city, Canada", *International Journal of Disaster Risk Reduction*, vol. 12, pp.6-24. 2016.

[12] U. Tamima, L. Chouinard "Development of evacuation models for moderate seismic zones: A case study of Montreal", *International Journal of Disaster Risk Reduction*, vol. 16, pp.167-179, 2016.

[13] P. Lestuzzi, S. Podestà, C. Luchini, A. Garofano, D. Kazantzidou-Firtinidou, C. Bozzano, P. Bischof, A. Haffter, J.-D. Rouiller "Seismic vulnerability assessment at urban scale for

two typical Swiss cities using Risk-UE methodology”, *Natural Hazards*, vol. 84, pp.249-269, 2016.

[14] N. Lantada, J. Irizarry, A.H. Barbat, X. Goula, A. Roca, T. Susagna, L.G. Pujades “Seismic hazard and risk scenarios for Barcelona, Spain, using the Risk-UE Vulnerability Index Method”, *Bulletin of Earthquake Engineering*, vol. 8, pp.201-229, 2010.

[15] J.L. Ródenas, S. García-Ayllón, A. Tomás “Estimation of the Buildings Seismic Vulnerability: A Methodological Proposal for Planning Ante-Earthquake Scenarios in Urban Areas”, *Applied Sciences*, vol 8, pp.1-17, 2018.

[16] A.K. Eleftheriadou, A. D. Baltzopoulou, A.I. Karabinis “Seismic Risk Assessment of Buildings in the Extended Urban Region of Athens and Comparison with the Repair Cost.” *Open Journal of Earthquake Research*, vol. 3, pp.115-134, 2014.

[17] C.A. Villacis, C.N. Cardona, B.Tucker “Implementation of Fast Earthquake Scenarios for Risk Management in Developing Countries”, *in Proceedings 12th World Conference on Earthquake Engineering,* 2000*,* paper 0796, pp.1-8.

[18] U. Albayrak, M. Canbaz, G. Albayrak “A rapid seismic risk assessment method for existing building stock in urban areas”, *Procedia Engineering*, vol. 118, pp.1242-1249, 2015.

[19] H. Sucuoğlu, U. Yazgan “Simple survey procedures for seismic risk assessment in urban building stocks”, in Seismic Assessment and Rehabilitation of Existing Buildings, 1st ed. vol, 29, S.T. Wasti, G. Ozcebe, Ed. London, Earth and Environmental Sciences: Kluwer Academic Publishers, 2003, pp. 97-118.

[20] H. Sucuoğlu, U. Yazgan, A. Yakut, A. “A screening procedure for seismic risk assessment in urban building stocks”, *Earthquake Spectra*, vol. 23, pp.441-458, May 2007.

[21] E. Işık “Investigation of an Existing RC Building with Different Rapid Assessment Methods. BitlisEren University”, *Journal of Science and Technology*, vol. 5, pp.71-74, 2015.

[22] T. Kalman-Šipoš, M. Hadzima-Nyarko “Rapid Seismic Risk Assessment”, *International Journal of Disaster Risk Reduction*, vol. 24, pp.348-360, 2017.

[23] O.D.Cardona, A.H. Barbat,“El Riesgo Sısmico y su Prevenci´on, Calidad Siderurgica”, Madrid, Spain, 2000.

[24] S.A. King, A.S. Kiremidjian, D. Pachakis, P. Sarabandi “Application of empirical fragility functions from recent earthquakes”, *in Proceedings of 13th World Conference of Earthquake Engineering*, 2004, paper 2829, pp.1-14.

29 | Preliminary report | Претходно саопштење
ISSN 2566-4484 | Doi 10.7251/STP2014318I
pages 318-329

Maja Ilić, maja.ilic@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

Sandra Kosić-Jeremić, sandra.kosic-jeremic@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

Dajana Papaz, dajana.papaz@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

CAN SPATIAL ABILITY BE TRAINED – THE ANALYSIS OF PREPARATORY COURSE FOR ENROLMENT AT THE FACULTY OF ARCHITECTURE

Abstract:

Spatial abilities are becoming an increasingly important predictor of success, especially in professions that balance analytical and creative thinking, such as architecture, especially with the increasing presence of digital media and technology, and the importance of the spatial presentation of one's ideas. There are differing opinions as to whether these abilities can be improved, or whether a spatial thinking strategy can be developed. At the Faculty of Architecture and Geodesy in Banja Luka (FACEG), spatial abilities have long been part of the entrance exam, and this paper will address the analysis of preparatory teaching at FACEG in this area and the success of the entrance exam for two groups of candidates - those who attended preparatory classes and those who prepared independently.

Keywords: entrance exam, spatial skills, spatial abilities, training, architecture

МОГУ ЛИ СЕ ПРОСТОРНЕ СПОСОБНОСТИ РАЗВИТИ – АНАЛИЗА ПРИПРЕМНЕ НАСТАВЕ ЗА УПИС НА СТУДИЈ АРХИТЕКТУРЕ

Сажетак:

Просторне способности постају све важнији предиктор успјеха, нарочито у струкама које балансирају између аналитичког и креативног мишљења, као што је архитектура, а нарочито са повећањем присутности дигиталних медија и технологије, те важности просторне презентације замишљених идеја. Постоје различита мишљења да ли се ове способности могу побољшати, односно, да ли се може развити стратегија просторног мишљења. На Архитектонско-грађевинско-геодетском факултету у Бањој Луци (АГГФ) просторне способности су већ дуго дио пријемног испита, те ће се овај рад бавити анализом припремне наставе на АГГФ-у из ове области и успјехом на пријемном испиту за двије групе кандидата – оне који су похађали курс припремне наставе и оне који су се спремали самостално.

Кључне ријечи: пријемни испит, просторне вјештине, просторне способности, тренинг, архитектура

1. INTRODUCTION

1.1. On spatial abilities and their relevance to engineers

In psychology, term *spatial ability* still does not have a clearly accepted definition, and it owes it to the fact that spatial intelligence, as a broader term, includes multiple factors and components. One of the interpretations given by Khine says that spatial ability is *"the capacity to perceive the visual images accurately, construct mental representations and imaginary of visual information, understand and manipulate the spatial relations among objects"*, characterizing it as a "*powerful indicator of personal quality and individual differences"*. [1] It is clear that this ability implies different cognitive operations - from arranging cubes to map reading and spatial orientation, and their influence in particular professions such as medicine, engineering, mathematics, geology, chemistry have been researched in several studies [2]–[6] showing moderate-to-strong correlational relationships with predictive validity of performance.

Spatial abilities are not sufficiently represented in the educational system, in comparison to verbal and quantitative ones, although research shows that spatial abilities are an important predictor for discovering talent and creativity. Wai and colleagues [7] summarize and extend five decades of spatial abilities research examining a sample of 400,000 high school students (grades 9 through 12) tracked via Project TALENT in the 1960s and 1970s along with contemporary GRE data and the Study of Mathematically Precocious Youth [8]. The authors demonstrate mathematical and spatial abilities are the two greatest predictors of STEM career success and degree attainment, and that spatial ability predicts success in STEM fields beyond just mathematical aptitude. [1]

It is possible that the reason for neglecting these abilities in the early educational system lies in the large gender differences, where men show an advantage over women, which dates from childhood and early differentiation in training these abilities through prejudice about toys (girls played with dolls, while boys were more forced to play with dice, cars or other mechanically driven toys). The second reason is the rigid school curriculum, which does not allow to easily change, and which also includes teachers to go through specialized training. [9]

Many of previously conducted studies show that spatial abilities could be developed over time, and that certain types of exercises can improve them [10]–[13]. Because of all the above stated, it is important to continue further research on spatial abilities, its factors, and influences on other scientific fields, and to determine if it is possible to develop them in later ages. If so, what are the right methods to do that, and what influence will they have on other occupations, specifically those concerning engineering.

1.2. Need for students of architecture to understand space

Spatial abilities are of particular importance in the field of architecture. This profession combines creativity, technology and space consumption where the initial architectural idea must be put in the space and materialized. Spatial solving tasks can be a key component of student success in architecture studies. For this reason, entrance exams often include some form of spatial aptitude tests - sometimes they are tested with standardized mental rotation, cross-section or spatial orientation tasks, or through a drawing that should present the applicant's ability to visualize space.

At the Faculty of Architecture, Civil Engineering and Geodesy in Banja Luka, the spatial aptitude test is an important part of assessing the competency of candidates for this study program. Since spatial abilities are generally not addressed during secondary and elementary school education, prior to enrollment, the candidate's spatial skills are at a basic level. Before enrollment, the faculty offers a preparatory course that aims to provide candidates with basic training during the two-week course and instruct them on strategies that can help them address spatial tasks.

Solving these kinds of problems, or spatial intelligence, in general, comes down to two components - flexible strategy choice between constructing and transforming mental images and more analytic thinking. Hegarty has demonstrated that even relatively simple spatial tasks included in psychometric tests of spatial ability include analytic thinking, although people also report mental imagery as the dominant strategy by which they perform these tasks. With more complex forms of thinking involved in mechanical reasoning and scientific thinking, it appears to be even more important to supplement mental imagery with more analytical forms of thinking. The second component of spatial intelligence that Hagerty identified includes the ability to choose the optimal external representation for a task, and to use novel external representations, such as interactive visualizations, effectively [14]. This means that the success of solving spatial tasks depends on the strategies adopted (analytical or spatial) and the tasks themselves and their representation.

1.3. Spatial tests and spatial factors

The issue of standardized spatial tests is still an open topic in the field of psychology, most often because of the lack of researchers' consensus on factors that assess spatial abilities. There are many types of tasks that are used for assessing spatial abilities in literature, and the most common are: The Mental Rotation Test (MRT), The Differential Aptitude Test: Space Relations (DAT: SR) and the Mental Cutting Test (MCT).

In an attempt to address these issues, some authors have defined the categories of spatial ability, assuming that there is no single, all-encompassing definition of spatial visualization ability. Maier [15] and Maresch [16] have proposed the following five components that form the spatial ability of a person:

- spatial visualization – ability to see the shape in whole, presented by its rotated parts. Guilford describes this factor as "an ability to think of changes in objects - changes in position, orientation, or internal relationship". This component often includes subcomponent of spatial relations and spatial perception
- spatial relations – ability to make a relation of pieces in order to form a given shape
- spatial perception – includes the ability for identifying the horizontal and vertical directions, wherein the orientation of one's body plays an important role in relation to other
- spatial orientation
- mental rotation

Within these broad categories there is some overlap. For example, there are certain activities that could be classified in the category of spatial relations and in the category of spatial orientation, depending on the task type. An overview of the classification of the most common task types are given in [17].

1.4. Entrance exams at the Faculty of Architecture, Civil Engineering and Geodesy in Banja Luka

In addition to the tests in mathematics and free-hand drawing, tests of spatial ability are also used in assessing the competence of prospective students at the Faculty of Architecture, Civil Engineering and Geodesy in Banja Luka (FACEG). The content of these tests varied from year to year. Table 1 shows an overview of the spatial ability tasks used in the entrance exam for architectural studies in the past 15 years. Data were collected from student office and archives at the Faculty of Architecture, Civil Engineering and Geodesy in Banja Luka.

Table 1. *Implementation of classified spatial tasks in architectural studies entrance exams*

Group	Type	Number	Task	Year														
				2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
2D		1	Form Board															
		2	Card Rotations													•		
		3	Hidden Figures				•											
3D	1	1	Arial Orientation	•													•	•
		2	Guilford– Zimmerman Spatial Orientation			•												
	2	1	Differential Aptitude Test: SR (DAT:SR)		•													
		2	3D Surface Development						•							•	•	
		3	Paper folding test													•		
		4	Shepard-Metzler Mental Rotation Test	••	•	•	•	•	•			•		••	•		•	•
		5	Purdue Spatial Visualization Test: Rotations (PSVT:R)	••		•					•			•		•		
		6	Complement Cube Test		•													
		7	Cube Comparisons Test							••	•							
	3	1	Spatial relation															•
		2	Tube figures		•				•									
		3	Snake in a cube*		•	••	••	•	•	••	•	•		••	•		•	••
		4	Lappan Test															
	4	1	Mental Cutting Test MCT					•	•					••	•		•	•
		2	Surface of water in a vessel															

	Total number of tasks in the test	5	5	5	5	6	5	5	4	4	N/A	8	5	6	6	9
	Number of tasks with multiple choice	0	3	2	0	1	2	2	0	1	N/A	5	3	2	3	3
	Number of tasks that require candidate's solution	5	2	3	5	5	3	3	4	3	N/A	3	2	4	3	6
	Number of unclassified tasks				1	3		1	2	2	N/A	2	2	2	1	3

According to the mentioned classification, the tasks are divided into two basic groups (two-dimensional and three-dimensional), and then the three-dimensional are divided into 4 types:

- TYPE 1: Tasks of orientation where the subject is moved, transformed or rotated in relation to an object
- TYPE 2: Tasks of spatial manipulation with objects. This type requires an ability of mental rotation and spatial relations.
- TYPE 3: Tasks that require visualization of objects given with its projection.
- TYPE 4: Tasks that require visualization of intersecting elements.

Which tasks develop which spatial factor is difficult to define, as individual tasks require multiple cognitive operations to be solved. Some solutions can be driven analytically, while others require a higher level of native spatial ability.

The tasks found in these entrance exams are more complex than the standardized tasks found in the literature. The table is sorted by type, and complexity depends on the task itself, and on whether the task has multiple choice answers offered or the candidate has to sketch the solution himself. From the table, it is evident that in about 30% of the tasks, the multiple-choice is offered, while in the others the candidate offers his solution. For architecture students, this is important because it tests the candidate's ability to draw and represent three-dimensional shapes in two dimensions. Table 1 further shows that there are many tasks that are not classified. These tasks include more complex processes that require minimal knowledge of perspective drawing, some "out-of-the-box" thinking tasks that require creative thinking, and solid intersection tasks.

Table 1 shows that types 2, 3, and 4 are most commonly represented, specifically the tasks of mental rotation (2.4), spatial visualization (3.3) and mental cutting (4.1).

According to this analysis, the preparatory course at FACEG contained training by tasks and spatial factors, and its structure will be presented in more detail in the following pages. The main objective of this paper is to determine whether this type of training improves spatial abilities, and the broader context of this topic will imply the question of whether such tests can assess the performance of candidates in further studies.

2. RESEARCH QUESTIONS AND METHODOLOGY

The 20-hour long preparatory course at the FACEG in Banja Luka has been held for the past two years (2018 and 2019) shortly before the entrance exam. 129 candidates took to the entrance exam in total, of which 61 candidates attended the preparatory course. At the beginning of the enrollment period, the faculty publishes the Bulletin for the entrance exams, which contains the examples of tasks from the previous entrance exams with the correct answers, but without the steps for solving them. This means that part of the candidates was preparing on their own, while those who went to the preparatory course received appropriate training where they learned about various analytical strategies for solving such tasks.

At the beginning and at the end of the course, the candidates took a test similar to the entrance exam. Comparison of these results may give us insight into whether the course contributed to the improvement of spatial abilities of the candidates while comparing the results of the entrance exam between the candidates who attended the course and those who did not should provide an answer as to whether this course had an impact on the performance at the entrance exam as well.

The basic research questions that will be addressed are:

RQ1: Did the preparatory course improve the candidates' spatial competencies for the entrance examination? Here, the results of the first and second tests that candidates took at the beginning and end of the course will be compared.

RQ2: Were these candidates more successful than those who did not attend the preparatory course? Here, the results of the entrance exam of candidates who have attended the preparatory course and those who have not will be compared.

For the statistical analysis, we used the SPSS v.20 analytical-statistical software package, using descriptive statistics for presenting and summarizing data, the Paired Samples t-Test, nonparametric Mann-Whitney U test, and Spearman's rank correlation coefficient. The variables observed in this study did not have a normal distribution.

Table 1 shows that the number of tasks in the entrance exam varied every year. The reason for this is the change of the entrance exam structure in recent years, where the representation of the spatial ability assessment in the entire entrance exam has varied from 40% -100%. Therefore, the data and scoring during the data analysis were considered as a percentage, that is, the percentage of success in solving certain types of tasks.

2.1. Preparatory course - dynamic and structure

The preparatory course for the entrance exam (called *Spatial perception and presentation course)*, which serves also to assess the spatial abilities of the candidates, was held in the previous two years in the month of June two weeks before the entrance exam at the FACEG and lasted 10 days (2 hours/day). At the beginning and at the end of the course, the candidates took a test (two similar, but not identical tests with the same task types) that contained the types of spatial tasks that had appeared in the entrance exams in the past few years. The course is taught according to the spatial factors and task typology defined in Table 1, as follows:

0. Planar geometry and spatial relations - shapes and their rotation within the plane (this part of the course is an introductory, the most common example of such tasks are the so-called "tangram" tasks and problems of dividing the shape into equal parts - Figure 1)

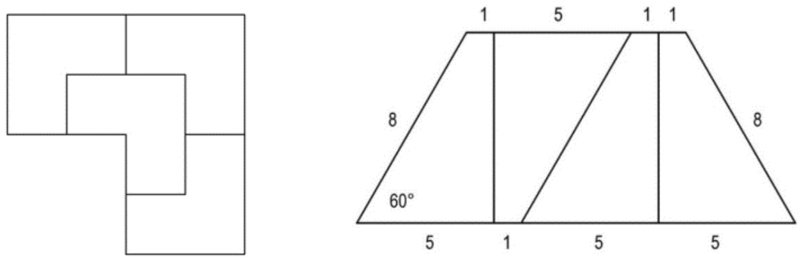


Figure 1. *Task example (divide given areas into 4 equal parts)*

A. Mental rotation (A1) and surface development (A2) - here are the tasks of mental rotation, the more complex tasks of developing a solid surface, as well as a combination of those two subtypes (Figure 2.)

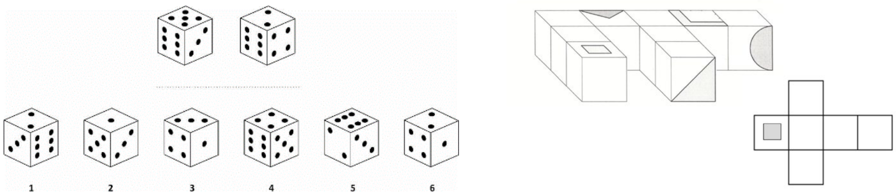


Figure 2. *Examples of A-type tasks (left: mark the answer that shows a cube given above cube, presented in other position (rotated), right: if the cube tumbles across the floor and takes the positions given in the left picture, draw the net of the cube with the signs on its sides)*

B. Planar (B1) and spatial intersection (B2) - these are tasks that fall into the types of mental cutting tasks (two-dimensional and three-dimensional) (Figure 3).

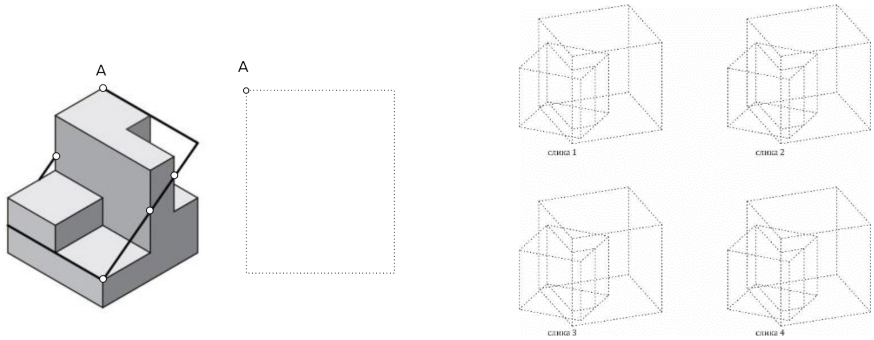


Figure 3. *Mental cutting tasks examples (left: draw a section of a plane with a given solid, right: draw what the two solids would look like if they would a) join, b) intersect c,d) subtracted one from another)*

C. Proportions and Projections - Tasks that are specific to the architectural profession and address the ability to draw the orthogonal views of an object based on a given three-dimensional view, and vice versa - draw a three-dimensional view based on given projections. Task complexity varies with of the shape of the object - full solids or wire models (Figure 4.)

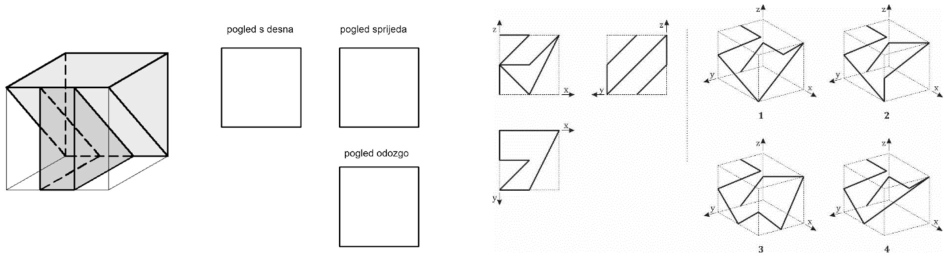


Figure 4. *Examples of object projection tasks (left: draw the orthogonal views of the given object, right: mark the answer that shows the wire given on the left picture with its orthogonal projections*

D. Orientation - spatial orientation tasks (Figure 5).

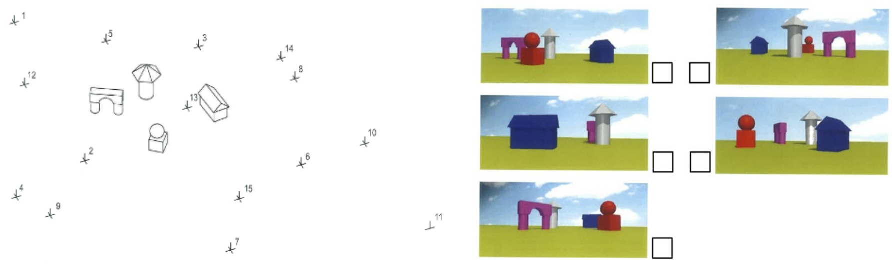


Figure 5. *Example of spatial orientation tasks (write in the boxes next to the pictures on the right number of the viewer's position given on the left)*

E. Symmetry and mirroring - these are the tasks that are very similar to mental rotation and they consist of drawing the object in different positions relative to the given position, as well as paper-folding tasks (Figure 6).

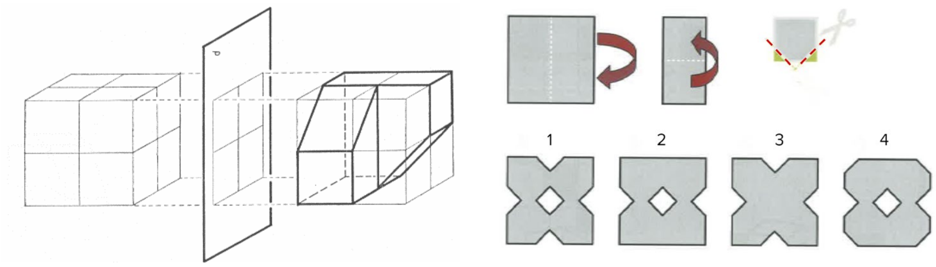


Figure 6. *Symmetry task example (left: draw an object viewed in the mirror, right: mark the answer that shows what a piece of paper would look like when folded and cut as shown in the picture above)*

F. Perspective - the tasks of constructing a perspective drawing based on the given ground scheme (Figure 7)

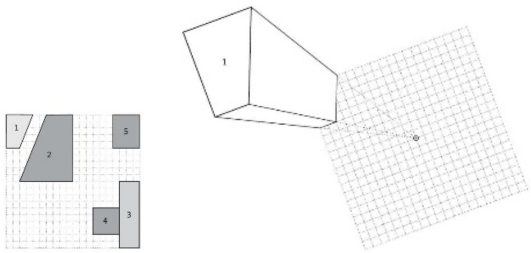


Figure 7. *Example of perspective drawing task*

Classes were conducted in such a way that the candidates solved some of the tasks presented on the board in the group, that is, they discussed and tried to explain the strategies they used in solving them. Individual tasks were given in the paper form, which they solved on paper independently, and then the lecturer explained for each type of task a possible analytical strategy for solving if the solution was not reached intuitively. In addition to paper assignments, during the breaks, candidates also had at their disposal didactic material in the form of wooden cubes or other solids, paper and scissors, or possible physical models on which they could practice their spatial skills.

The initial and the control test is taken at the beginning and at the end of the course consisted of 5 tasks from 5 selected spatial factor groups. In the following section, a comparative analysis of the results that the course participants achieved in both tests in the total and individually by tasks will be presented.

2.2. Entrance exam

The entrance exam at the FACEG has undergone several transformations in the past decade. However, the assessment of spatial abilities has always been an essential part of the entrance exam. In 2018, the percentage of the Spatial perception and presentation section of the entrance exam was 40%, while in 2019 it was 100%. The tasks are similar to the tasks shown in section 2.1 of the paper, and some of them were also used during the course. The structure of the entrance exam varies in the number and complexity of the tasks, so for the purposes of the research, the percentage of the performance of individual spatial factors was analyzed so that the results could be compared across two generations, as well as with the results achieved by the candidates in the preparatory course.

3. RESULTS AND DISCUSSION

A sample of 129 candidates who took the entrance exam at the AGGF in Spatial perception and presentation during the past two years were taken to analyze the research, of which 61 attended preparatory classes and 68 of them prepared on their own (Table 2). It should be emphasized that the candidates were provided with the faculty Bulletin, which contains a collection of tests used in previous years with correct answers, but without instructions for solving them, and a number of candidates decided to prepare themselves independently. It is unknown whether those candidates had any help with the preparation or were able to complete the tasks themselves.

There are also four times more female applicants (105) enrolled in architectural studies than male candidates (24), and a greater percentage of women (almost 50%) choose to attend preparatory classes than men (about 40%).

Table 2. *Number of candidates by age and gender*

Gender			YEAR 2018	YEAR 2019	Total
F	Prep_course	Y	**25**	**29**	**54**
		N	**21**	**30**	**51**
	Total		**46**	**59**	**105**
M	Prep_course	Y	**0**	**7**	**7**
		N	**8**	**9**	**17**
	Total		**8**	**16**	**24**
Total	Prep_course	Y	**25**	**36**	**61**
		N	**29**	**39**	**68**
	Total		**54**	**75**	**129**

Table 3. *Attendance of the preparatory course by type of secondary school*

		high school: Civil Engineering high school	high school: Gymnasium	high school: Other technical schools	high school: Other schools	Total
Prep_course	Y	**19**	**36**	**0**	**6**	**61**
	N	**22**	**35**	**6**	**5**	**68**
Total		**41**	**71**	**6**	**11**	**129**

Candidates also come from different secondary schools where some had a subject of Descriptive Geometry, so the analysis showed that 82 (63.6%) of all candidates did not have a subject of Descriptive Geometry in high school, of which only half attended the preparatory course. Of 47 (36.4%) that had Descriptive Geometry in high school, a total of 19 candidates attended the course. It is expected that two-thirds of the candidates did not have DG in high school, because in the last two years the most candidates applying for enrollment in the architecture program come from Gymnasium - 55% (Table 3).

3.2. Comparison of initial and control test for candidates who have attended the course

The initial test at the course consisted of 5 tasks, classified by types:

- A1 - Mental rotation
- A2 - Surface development
- B1 - Mental cutting (2D)
- B2 - Solid intersection
- C – Proportion and projections

Table 4. *Descriptive statistics by task pairs on the initial and control test*

		Mean	N	Std. Deviation	Std. Error Mean
A1	c_p_u1	**.7111**	**45**	**.27155**	**.04048**
	c_p_i1	**.8556**	**45**	**.22918**	**.03416**
B1	c_p_u2	**.2667**	**45**	**.44721**	**.06667**
	c_p_i2	**.2356**	**45**	**.35939**	**.05357**
C	c_p_u3	**.1978**	**45**	**.31730**	**.04730**
	c_p_i3	**.5267**	**45**	**.42287**	**.06304**
A2	c_p_u4	**.4133**	**45**	**.43096**	**.06424**
	c_p_i4	**.8889**	**45**	**.24884**	**.03709**
B2	c_p_u5	**.1489**	**45**	**.29203**	**.04353**
	c_p_i5	**.4867**	**45**	**.35714**	**.05324**
TOTAL	c_p_utot	**.3476**	**45**	**.18773**	**.02798**
	c_p_itot	**.5987**	**45**	**.20628**	**.03075**

The first task on the initial test was done with 71% success and the first task on the control test with 85% success (Table 4). The first task on the control test was also statistically significantly done with more success with a statistical significance of 0.005 (Paired Samples t-test,t=-3.292, df=44, p=0.002).

The success rate of solving the second task on the initial test was around 27% and on the control test 23.5% (Table 4). On the control test, the candidates had less success as shown by the t-test of paired samples (Paired Samples t-test, t=0.391, df=44, p=0.698).

The success rate of solving the third task on the initial test was around 20% and on the control test 53% (Table 4). On the control test, the third task was statistically significantly better done with a statistical significance of 0.005 (Paired Samples t-test, t=-5.022, df=44, p=0.000).

The success rate of solving the fourth task on the initial test was around 41% and on the control test 89% (Table 4). On the control test, the fourth test was statistically significantly better done with a statistical significance of 0.005 (Paired Samples t-test, t=-7.029, df=44, p=0.000).

The success rate of solving the fifth task on the initial test was around 15% and on the control test 49% (Table 4). On the control test, the fifth task was statistically significantly better done with a statistical significance of 0.005 (Paired Samples t-test, t = -5.893, df = 44 p = 0.000). This task had the lowest success rate of all the tasks in the initial test.

By comparing the overall success on the initial and control test, the paired samples t-test showed a significant improvement on the control test (Paired Samples t-test t = -8.420, df = 44, p = 0.000). The initial test was done with a 35% success rate and the control test with an almost 60% success rate (Table 4). Also, statistics show a mean positive correlation between the initial and control test in the total score, Sperman's rank correlation coefficient is $r_s = 0.394$, p = 0.007.

Improvement in the spatial abilities of candidates is evident in all factors, except for the task with mental cutting, while the candidates showed great improvement in the tasks of the solid intersection.

3.3. Comparison of entrance exam (e_p_tot) and control test (c_p_itot) by task types for candidates that attended the preparatory course

A few days after the preparatory course was completed, the candidates took the faculty entrance exam. A comparison was made between the success on the control test at the course and the entrance exam in total and by tasks. 6 candidates are missing data, as some of the candidates are withdrawn their submissions for the faculty. As entrance exams have varied over the past two years, 4 common task groups for the entrance exam and course tests have been identified: A1 - mental rotation, B1 - mental cutting, C - proportions and projections, B2 – solid intersection.

A statistically significant difference in success on the control test and entrance exam is shown. (p = 0.000). The entrance exam was done statistically significantly better (Paired Samples t-test t = 7.370, df = 38, p = 0.000). The average performance on the control test of candidates was approximately 60%, and on the entrance examination, it was almost 80% (Table 6). There is a high positive correlation between the control test and the entrance exam in the total score, Sprrman's rank correlation coefficient is $r_s = 0.669$, p = 0.000.

Table 5. *Descriptive statistics by task pairs on the course control test and entrance exam*

		Mean	N	Std. Deviation	Std. Error Mean
A1	e_p_A1	**.8908**	**39**	**.19506**	**.03124**
	c_p_i1	**.8462**	**39**	**.23379**	**.03744**
B1	e_p_B1	**.6000**	**39**	**.49630**	**.07947**
	c_p_i2	**.2462**	**39**	**.37406**	**.05990**
C	e_p_C	**.8000**	**39**	**.31119**	**.04983**
	c_p_i3	**.5282**	**39**	**.41228**	**.06602**
B2	e_p_B2	**.7949**	**39**	**.33478**	**.05361**
	c_p_i5	**.4949**	**39**	**.35611**	**.05702**
TOTAL	e_p_tot	**.7885**	**39**	**.18883**	**.03024**
	c_p_itot	**.5974**	**39**	**.20351**	**.03259**

Table 6. *Success rate by task pairs*

	Entrance exam success rate	Control test success rate
e_p_A1 - c_p_i1	89%	85%
e_p_B1 - c_p_i2	60%	25%
e_p_C - c_p_i3	80%	53%
e_p_B2 - c_p_i5	80%	50%
e_p_tot – c_p_tot	79%	60%

Tables 5 and 6 show that candidates performed better on the entrance exam than on the control test for all tasks (grouped by type of task), and on all but the first group of tasks A1 they performed significantly better.

Compared to the results obtained by a comparative analysis of the initial and control test at the course, there is evident progress in the mental cutting task (B1). The candidates had a few more days to prepare for the entrance exam. However, there is a relevant question here as to whether some spatial ability factors require an "incubation" time, that is, a certain time distance for the acquired knowledge to be applied.

3.4. Comparison of entrance exam results between candidates who attended the preparatory course and those who did not

The answer to the question of whether the preparatory course prepared the candidates better than they would have done on their own also speaks of whether innate spatial abilities can be developed.

We compared the results of the entrance exam for candidates who participated in the preparatory course and those who did not in total and by a group of tasks. In addition to the groups mentioned above, a comparison was made here for the group of spatial orientation tasks (D), since this task was found in the entrance exam in both years.

The Mann-Whitney U test showed a statistically significant difference in the score in the entrance test between candidates who took the course (N = 51, Md = 0.8) and those who did not (N=31, Md=0.6616) (Table 7) (U=559.500, Z=-2.211, p=0.027)

There was also a statistically significant difference in success between these candidates by type of assignment **A1** (N = 51, Md = 1.00) (Table 7) (U=426.500, Z=-3.731, p=0.000), and also type **C** between candidates who took the course (N=51, Md=1.00) and those who did not (N=31, Md=0.67) (Table 7) (U=536.000, Z=-2.562, p=0.010). **Candidates who attended the course showed better results** (for 47 candidates there are missing data).

Table 7. *Descriptive statistics for the entrance exam results*

	Preparatory course																	
	Y						N						Total					
	N	Mean	Std. Dev.	Md	Min	Max	N	Mean	Std. Dev.	Median	Min.	Max.	N	Mean	Std. Dev	Md	Min	Max
e_p_tot	51	.77	.19	.80	.24	1.00	31	.66	.20	.67	.21	1.00	82	.73	.20	.75	.21	1.00
A1	51	.86	.21	1.0	.33	1.00	31	.65	.27	.50	.00	1.00	82	.78	.25	.92	.00	1.00
B1	51	.62	.48	1.0	.00	1.30	31	.54	.46	.5000	.00	1.00	82	.59	.47	1.0	.00	1.30
C	51	.77	.33	1.0	.00	1.00	31	.55	.42	.67	.00	1.00	82	.69	.38	.82	.00	1.00
D	51	.89	.24	1.0	.00	1.00	31	.92	.16	1.0	.50	1.00	82	.90	.22	1.0	.00	1.00
B2	51	.71	.38	1.0	.00	1.00	31	.54	.40	.50	.00	1.00	82	.65	.39	.80	.00	1.00

We also analyzed whether the Descripive Geometry course that some candidates had in high school had an impact on their performance in the entrance exam.

Table 8. *Success at the entrance exam of all the candidates in relation to attending the DG course in high school*

DGhs	N	Mean	Std. Deviation	Median	Minimum	Maximum
Y	**33**	**.7227**	**.20749**	**.7500**	**.24**	**1.00**
N	**49**	**.7292**	**.19651**	**.7500**	**.21**	**1.00**
Total	**82**	**.7266**	**.19975**	**.7500**	**.21**	**1.00**

There wasn't a statistically significant difference in success between candidates who had the subject of Descriptive Geometry in highschool (N = 33, Md = 7.50) (Table 8) and and those who had not have (N = 49, Md = 7.50) (Table 8) by the score in the entrance exam results (Mann-Whitney U test U=803.000, Z=-0.052, p=0.958).

We did the same comparison for candidates who did not attend preparatory courses.

Table 9. *Success at the entrance exam of the candidates that did not attend the preparatory course in relation to havong the DG course in high school*

DGhs	N	Mean	Std. Deviation	Median	Minimum	Maximum
Y	**14**	**.6557**	**.19138**	**.6500**	**.42**	**1.00**
N	**17**	**.6665**	**.21860**	**.6700**	**.21**	**.94**
Total	**31**	**.6616**	**.20344**	**.6700**	**.21**	**1.00**

The Mann-Whitney U test didn't show a statistically significant difference in the score in the entrance exam between candidates who had the subject of Descriptive Geometry in highschool (N = 14, Md = 6.50) (Table 9) and and those who had not have (N = 17, Md = 6.70) (Table 2) (U=108.500, Z=-0.417, p=0.677).

This means that the course of Descriptive geometry in high school did not have a significant impact on performance of the candidates on the entrance exam.

4. CONCLUSION

Spatial abilities are considered as an important predictor of success in the engineering professions, especially those related to creative thinking, such as architecture. The low level of spatial abilities with which candidates approach the entrance exam at the Faculty of Architecture, Civil Engineering and Geodesy is a consequence of the systematic neglect of these skills during lower education. But the question is whether these abilities are innate or can be developed. This paper presents an analysis of preparatory teaching at the FACEG aimed at developing strategies and analytical thinking in solving these tasks, and which should prepare candidates for the entrance exam.

The results show that during the two-week course, students achieved progress in spatial abilities compared to the initial level in 4 assessed spatial ability factors, except for mental cutting factor, and also showed statistically significant progress at the entrance exam compared to candidates who prepared by themselves.

Tha analysis also showed that the course of Descriptive Geometry that some of the candidates had in highschool did not have a significant impact on their performance on entrance exam.

This suggests that strategies for solving spatial problems can be developed and that this topic should be addressed in greater detail in order to increase student performance in further architectural studies. Also, these results show that a more detailed approach to defining the importance of individual factors for assessing spatial abilities and their specificity for other professions, not just engineering, is needed. One of the important issues related to this is the relevance of these competencies to the success in their respective professions, so it is necessary to examine the correlation between these abilities, entrance exams and the faculty success of enrolled candidates in further studies.

LITERATURE

[1] M. S. Khine, Ed., Visual-spatial Ability in STEM Education. 2016.

[2] K. Rochford, “Spatial learning disabilities and underachievement among university anatomy students,” Med. Educ., vol. 19, no. 1, pp. 13–26, 1985.

[3] M. Kozhevnikov, M. A. Motes, and M. Hegarty, “Spatial visualization in physics problem solving,” Cogn. Sci., vol. 31, no. 4, pp. 549–579, 2007.

[4] C. J. Ormand et al., “The spatial thinking workbook: A research-validated spatial skills curriculum for geology majors,” J. Geosci. Educ., vol. 65, no. 4, pp. 423–434, Nov. 2017.

[5] M. Harle and M. Towns, “A Review of Spatial Ability Literature, Its Connection to Chemistry, and Implications for Instruction,” J. Chem. Educ., vol. 88, no. 3, pp. 351–360, 2010.

[6] S. M. Markey, “The relationship between visual-spatial reasoning ability and math and geometry problem-solving,” 2009.

[7] J. Wai, D. Lubinski, and C. P. Benbow, “Spatial Ability for STEM Domains: Aligning Over 50 Years of Cumulative Psychological Knowledge Solidifies Its Importance,” J. Educ. Psychol., vol. 101, no. 4, pp. 817–835, Nov. 2009.

[8] D. Lubinski, “Spatial ability and STEM: A sleeping giant for talent identification and development,” Pers. Individ. Dif., vol. 49, no. 4, pp. 344–351, 2010.

[9] M. Stieff and D. Uttal, “How Much Can Spatial Training Improve STEM Achievement?,” Educ. Psychol. Rev., vol. 27, no. 4, pp. 607–615, Dec. 2015.

[10] D. I. Burin and A. R. Delgado, “Solution strategies and gender differences in spatial visualization tasks,” Psicológica, pp. 275–286, 2000.

[11] R. Wright, W. L. Thompson, G. Ganis, N. S. Newcombe, and S. M. Kosslyn, “Training generalized spatial skills,” Psychon. Bull. Rev., vol. 15, no. 4, pp. 763–771, 2008.

[12] L. Baranová and I. Katreničová, “Role of Descriptive geometry course in the development of students’ spatial visualization skills,” Ann. Math. Informaticae, vol. 49, pp. 21–32, 2018.

[13] G. P. Adanez and A. D. Velasco, “Training visualization ability by Technical Drawing,” J. Geom. Graph., 2004.

[14] M. Hegarty, “Components of Spatial Intelligence,” in Psychology of Learning and Motivation - Advances in Research and Theory, vol. 52, no. C, 2010, pp. 265–297.

[15] P. H. Maier, Räumliches Vorstellungsvermögen: Ein theoretischer Abrißdes Phänomens räumliches Vorstellungsvermögen ; mit didaktischen Hinweisen für den Unterricht. Donauwörth: Auer, 1999.

[16] G. Maresch, “Raumintelligenz - Die Phasen der Raumintelligenzforschung,” 2013.

[17] M. Ilic and A. Djukic, “Typology of spatial ability tests and its implementation in architectural study entrance exams,” Facta Univ. - Ser. Archit. Civ. Eng., vol. 15, no. 1, pp. 1–14, 2017.

30 | Professional paper | Стручни рад
ISSN 2566-4484 | Doi 10.7251/STP2014330C
pages 330-341

Mehmed Čaušević, mcausevic@gradri.uniri.hr, Faculty of Civil Engineering, University of Rijeka

Saša Mitrović, sasa.mitrovic@itt.hr, i.t.t. d.o.o., M. Albaharija 10a, Rijeka

NON-LINEAR ANALYSIS OF BUILDING STRUCTURES IN SEISMIC AREAS ACCORDING TO THE EUROPEAN STANDARDS, CASE STUDY

Abstract:

For the design and construction of buildings in seismic areas the European Standard EN 1998-1: 2004 offers two non-linear methods, namely: a non-linear pushover based static method and a non-linear dynamic method. This paper discusses those methods which differ from one another in respect to accuracy, simplicity and transparency. Non-linear static procedures were developed in the world with the aim of overcoming the insufficiency and limitations of linear methods, whilst at the same time maintaining a relatively simple application. All procedures incorporate performance-based concepts paying more attention to damage control. Application of the presented procedures is illustrated by means of an example of an eight-story reinforced concrete frame building.

Keywords: non-linear static procedure, pushover, non-linear dynamic time-history analysis, seismic demand, seismic capacity

НЕЛИНЕАРНА АНАЛИЗА КОНСТРУКЦИЈА ЗГРАДА ПРЕМА ЕУРОПСКИМ НОРМАМА ЗА СЕИЗМИЧКА ПОДРУЧЈА, НУМЕРИЧКИ ПРИМЈЕР

Сажетак:

За пројектирање и изведбу зграда у сеизмичким подручјима Европска норма ЕН 1998-1:2004 прописује двије нелинеарне методе и то: нелинеарну статичку методу поступног гурања и нелинеарну динамичку методу у времену. Овај рад презентира ове методе, које се међусобно разликују с обзиром на точност, једноставност, транспарентност и теоријске подлоге. Нелинеарни статички поступци развијени су у свијету с циљем превладавања недостатака и ограничења линеарних метода, истодобно пружајући релативно једноставну примјену. Нелинеарни статички поступак презентиран у овом раду укључује "*performance-based*" концепт. Примјена представљених поступака илустрирана је на примјеру осмокатне оквирне армирано-бетонске конструкције зграде.

Кључне ријечи: нелинеарна статичка анализа, поступно гурање, нелинеарна динамичка анализа, сеизмички захтјев, сеизмички капацитет

1. INTRODUCTION

In order to pay greater attention to damage control in the past ten years new methods of seismic analysis containing performance-based engineering concepts have been developed in the world. For obtaining seismic actions more realistically the displacement-based approach has proven itself as a much better choice than the traditional force-based approach.

The European standard EN 1998-1: 2004 [1] offers four methods of design for the effects of earthquake forces, Table 1: two linear methods (the force-based approach) and two non-linear methods (the displacement-based approach), namely non-linear static pushover method and nonlinear dynamic time-history method.

Between the linear methods and non-linear dynamic analysis, a non-linear static approach based on the pushover analysis is being imposed as a link and the most economical solution at the moment.

Table 1. Metods of seismic analysis of structure defined in EN 1998-1:2004

Analysis of structure	Static	Dynamic
Linear	Linear analysis using equivalent static forces	Modal analysis using response spectra
Nonlinear	Non-linear static analysis (pushover-based method)	Non-linear dynamic time-history analysis

The most precise description of the problem is by far the non-linear dynamic seismic analysis, made by applying time-history records which, in the long term, represents the correct development path. Yet, due to its complexity and high standards it goes beyond the frames of practical application and is appropriate only for the research and analysis of structures of special significance.

Nonlinear static structural analysis is based on the N2 method. This pushover-based method was developed at the University of Ljubljana [2], [3] and has found its place in the European standard EN 1998-1. Originally, this method was intended to be use in design of regular structures where only the first mode is predominant. The development of N2 method has resulted in a wide range of its use, namely:

- Analysis of regular constructions in which higher modes are also taken into account [4],
- Analysis of structures with special impact of torsion [5].

In the second generation of the European standard EN 1998, which is in the process of being adopted and which contains radical changes to the current standard, torsion effects and higher-mode effects have been taken into account through correction factors [6]. Specifically, the second generation of the current European standard EN 1998-1: 2004 is divided into two parts, EN 1998-1-1 and EN 1998-1-2. Part EN1998-1-1 defines new elastic and reduced response spectra and data relating to the application of all parts of the second generation of Eurocode 8. Part EN 1998-1-2 applies to buildings only. A complete second generation of Eurocode 8 is expected to be technically complete by the end of 2022, followed by its translation into the official EU languages [6].

There are nonlinear static methods that have already been developed in the world, e.g. in the USA [7], which will not be discussed here.

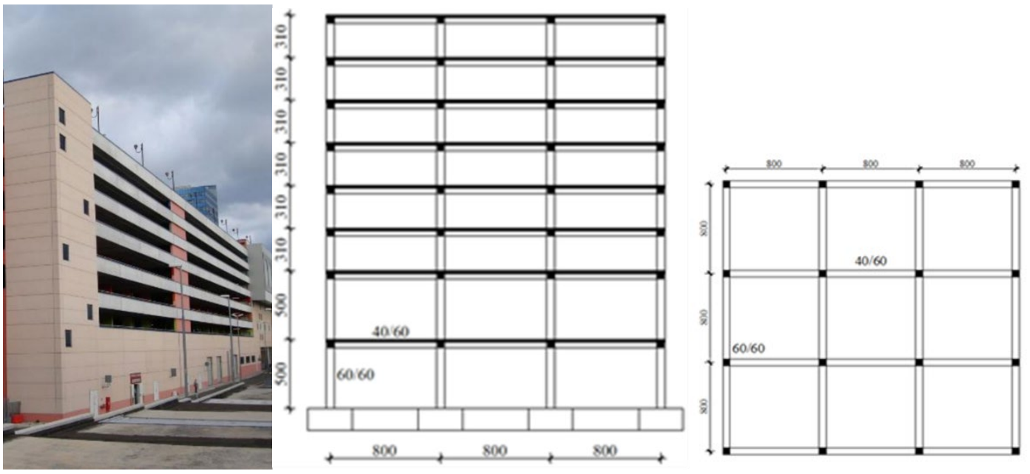
Both nonlinear methods are presented in this paper using the example of the reinforced concrete frame structure, Fig. 1, i. e. the obtained results for nonlinear static method are compared to the "accurate" results reached by a non-linear time-history analysis.

2. DESCRIPTION OF THE BUILDING AND THE LOADING (SEISMIC DEMAND)

Application of non-linear static and dynamic procedures is illustrated here by means of an example of an eight-storey reinforced concrete frame building. The first two storeys are 5.00m high and the other 3.10m (Fig. 1).

In order to perform nonlinear analysis, cross sections and the amount of reinforcement must be assumed first (Fig. 2), and as a result deformations (displacements and relative displacements), i.e. structural damage (plasticization of certain cross sections) will be obtained, while in linear methods the reinforcement is obtained as the ultimate result.

All the columns have dimensions 60x60cm with steel reinforcement equal for all cross sections. The beams have dimensions 40x60cm, also with steel reinforcement equal for all cross sections, Fig. 2. The plate is 20cm thick. The concrete is C25/30 class and the steel reinforcement is B500. Story frame mass for 3.10m high stories is 66.96t and story mass for 5.00m high stories is 73.80t which results in total mass of 549.36t.



(a) (b) (c)

Figure 1. *(a) Building of garage of the Tower Centre, Rijeka, Croatia; (b) Cross-section; (c) Plan of one segment of the garage structure*

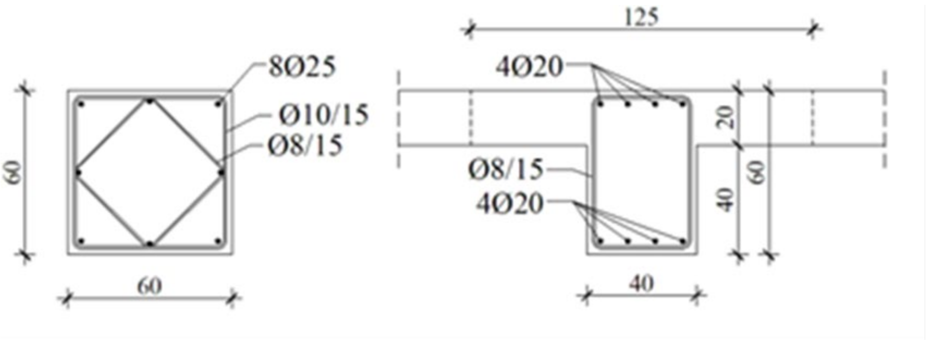


Figure 2. *Cross-sections of columns and beams with steel reinforcement*

The structure in Fig. 1 was designed according to the European standard EN 1998-1: 2004 with the following parameters: ground type B, importance class II (γ_I=1), Type 1 elastic response spectra (the expected surface-wave magnitude M_s larger than 5.5) and viscous damping ratio (in percent) $\xi = 5\%$. The analysis will be performed for the reference peak ground acceleration $a_{gr} = 0.3g$. A behaviour factor $q = 5.85$ was taken into account for the DCH (Ductility Class High) structures.

Since the structure meets the regularity requirements by its plan view and by its height, the current analysis was made on one plane frame, Fig. 3. Due to symmetry only one direction of seismic action was analysed and the fundamental period $T_1 = 1s$ for plane frame is obtained. According to the previously introduced parameters, the elastic acceleration response spectrum and the corresponding design spectrum are presented in Fig. 4 which represents the seismic demand. The fundamental period is in the spectrum range with constant velocities ($T_C < T_1 < T_D$).

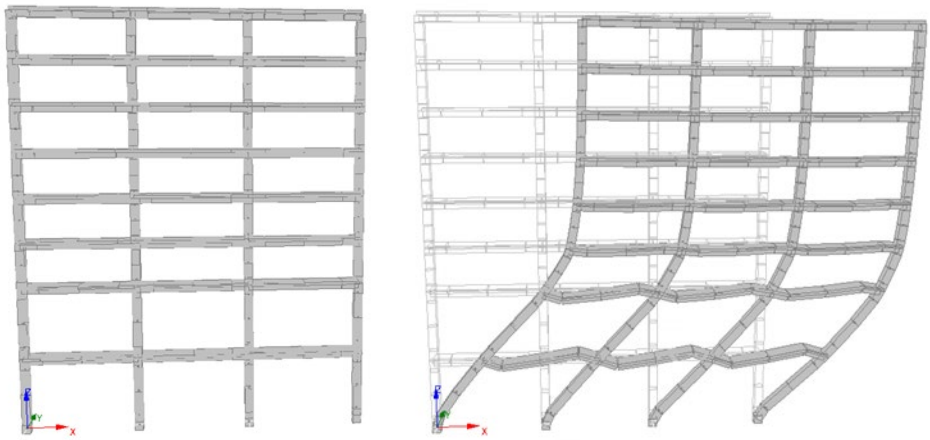


Figure 3. *Plane frame of the current structure and its fundamental mode ($T_1 = 1s$)*

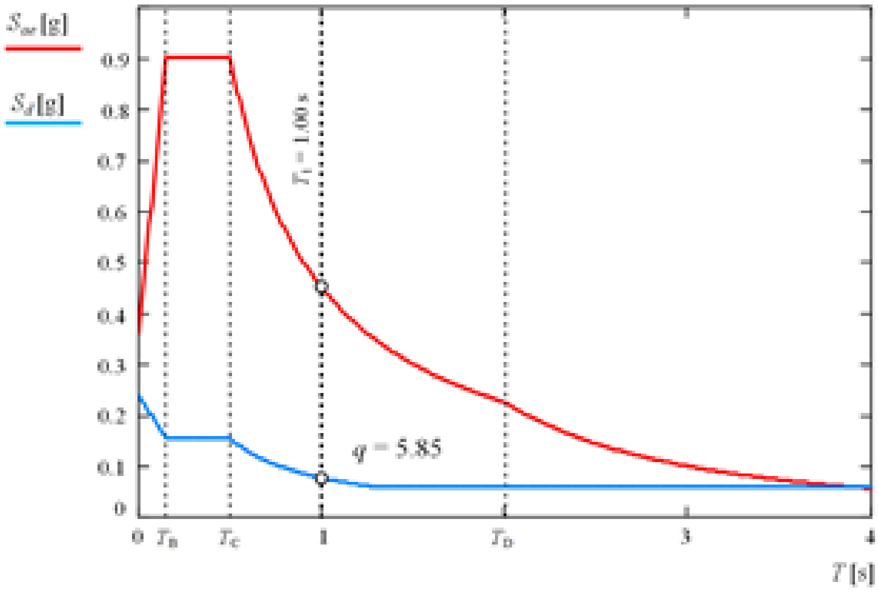


Figure 4. *Elastic acceleration response spectrum (read) with 5% viscous damping ratio for peak ground acceleration 0.3g, ground type B and corresponding design spectrum for behavior factor 5.85 (blue)*

The pushover and time-history analyses were performed by using the SeismoSoft programs [8], [9] whose main purpose is nonlinear static and dynamic analysis of frame structures. Other software packages may be used for the same purpose [10], [11]. Material inelasticity and the cross-section behavior are represented through the so-called fiber modelling approach where each fiber is associated with a uniaxial stress-strain relationship. Each cross section has a number of fibers (200 to 400) and for each fiber a non-linear ratio ε-σ is defined.

A typical reinforced concrete section consists of unconfined concrete fibers, confined concrete fibers and steel fibers, Fig. 5. A non-linear constant confinement concrete model and bilinear steel model with kinematic strain hardening are used. An incremental iterative algorithm with the employment of Newton-Raphson procedures is used to obtain the solution. The dynamic time-history analysis is computed by direct integration of the equations of motion with the Newmark scheme.

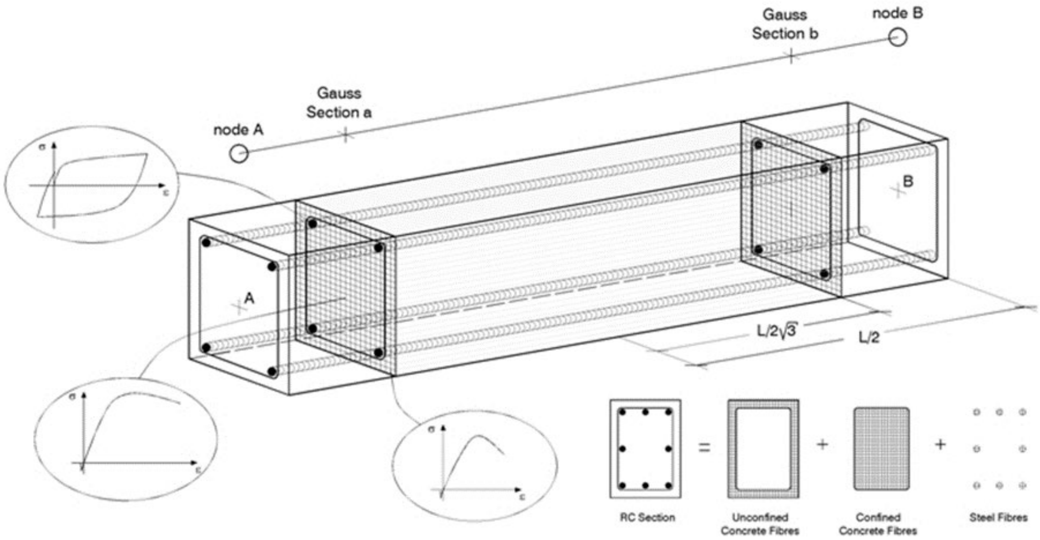


Figure 5. *Fiber modelling approach: unconfined concrete fibers, confined concrete fibers and steel fibers*

3. THE NON-LINEAR STATIC PUSHOVER METHOD

The non-linear static pushover method used in Eurocode 8 [1] is based on the N2 method [2], [3]. The N2 method combines the pushover method of model with several degrees of freedom with a spectral analysis of the equivalent system with one degree of freedom, hence the name. The letter N states that it is a non-linear analysis and the number 2 states that two mathematical models are applied.

The main assumptions in the N2 method are: 1) its application to the structures which have no significant contribution of higher vibration modes; 2) the predominant mode does not change when the seismic intensity is changed (due to the formation of plastic hinges).

In case of the analyzed structure in Fig. 1, the acceleration spectrum which represents **the seismic demand** is plotted in Fig. 4.

The N2 method gives in the given procedure the elasto-plastic **capacity of structure**, Fig. 6.

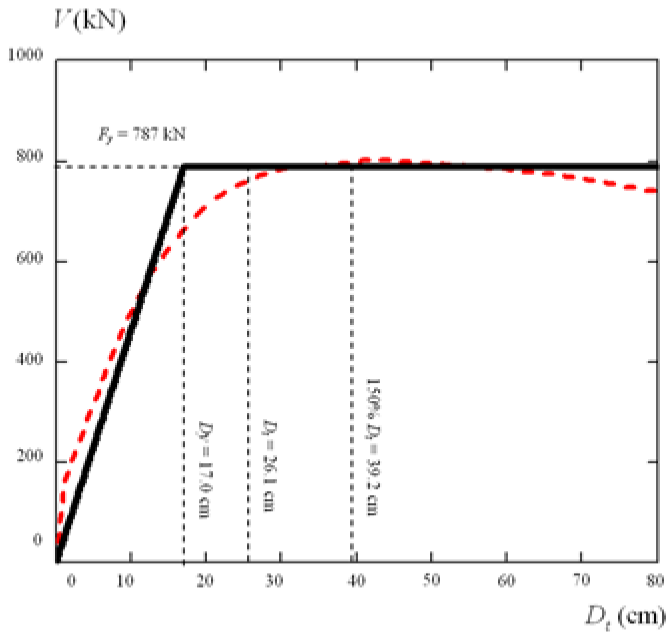


Figure 6. *Capacity curve for the assumed triangular displacement form: the dotted line for the real capacity curve and the solid line for the elasto-plastic idealization*

The method uses a non-linear spectrum in the acceleration – displacement (AD) format, which is obtained in the procedure given in [2], [3], [12]. The format AD enables **the simultaneous review of seismic demand and structural capacity**, Fig. 7. Intersection of seismic demand and structural capacity curves represents **the required target displacement** which corresponds to the required ductility μ.

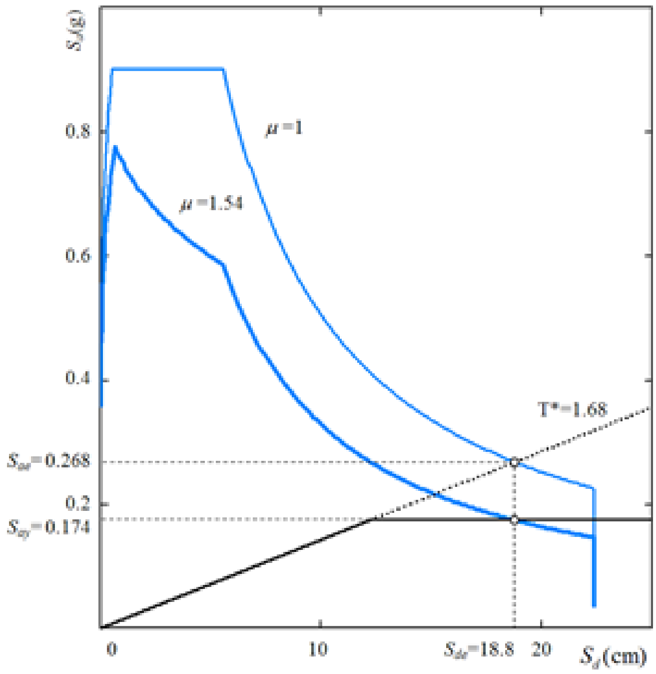
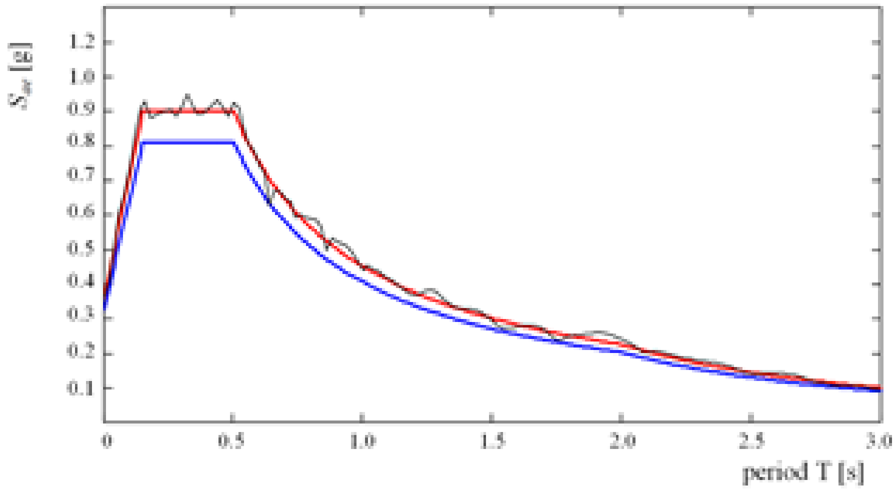


Figure 7. *The demand spectrum for ground acceleration 0.3g (soil class B) and capacity spectrum for structure in Fig. 1 ($\mu = 1.54$)*

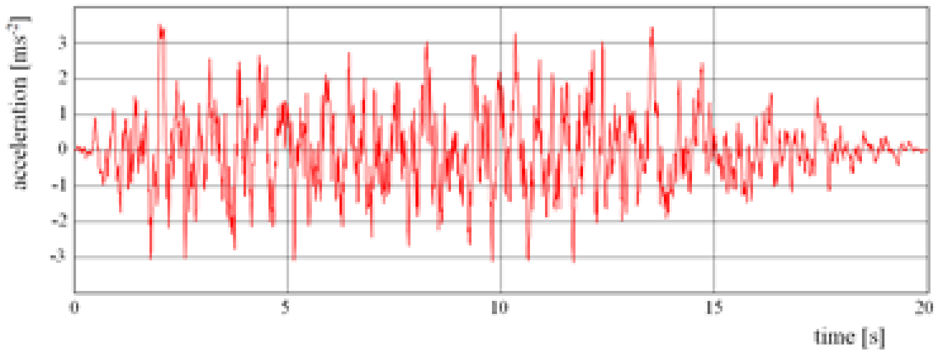
4. THE NON-LINEAR DYNAMIC TIME-HISTORY METHOD

In order to evaluate the results obtained by non-linear static methods, a time-history dynamic analysis was conducted first by using a total of 14 time-history records, seven of which were artificial, and the remaining seven as authentic (real). The artificial time-history records were used for obtaining the mean value of structural responses which corresponds to the specified seismic demand. Processing of artificial and real time-history records was performed by using the *SeismoSignal* program.

Seven artificial time-history records for this example were generated by the program SIMQKE_GR (SIMulation of earthQuaKE GRound motions – Massachusetts Institute of Technology) [13] for peak ground acceleration of 0.3g and soil class B with a 5% viscous damping ratio. The earthquake duration was set on 20s. In the zone near the fundamental period there is no value of elastic spectrum which is calculated from all artificial time-history records, which is less than 90% of the corresponding value of the elastic spectrum response [1] (Fig. 8).



(a)

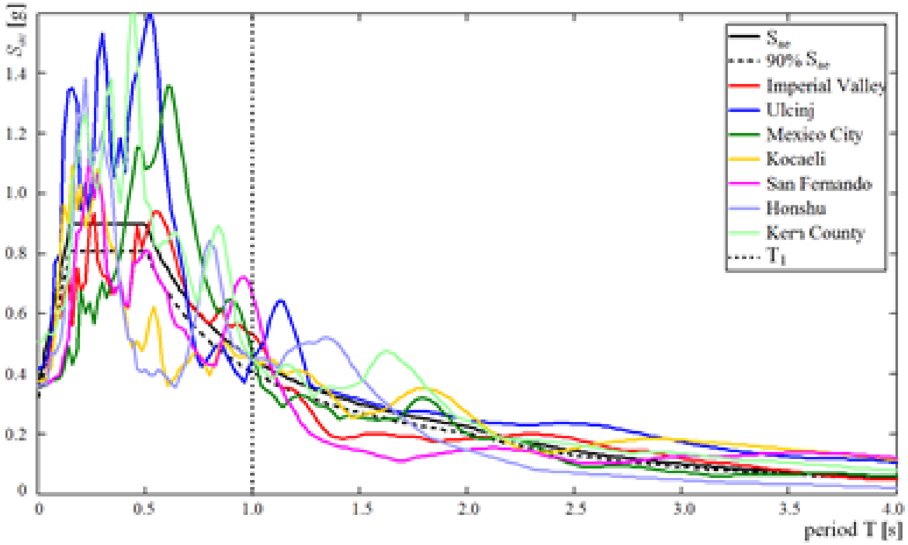


(b)

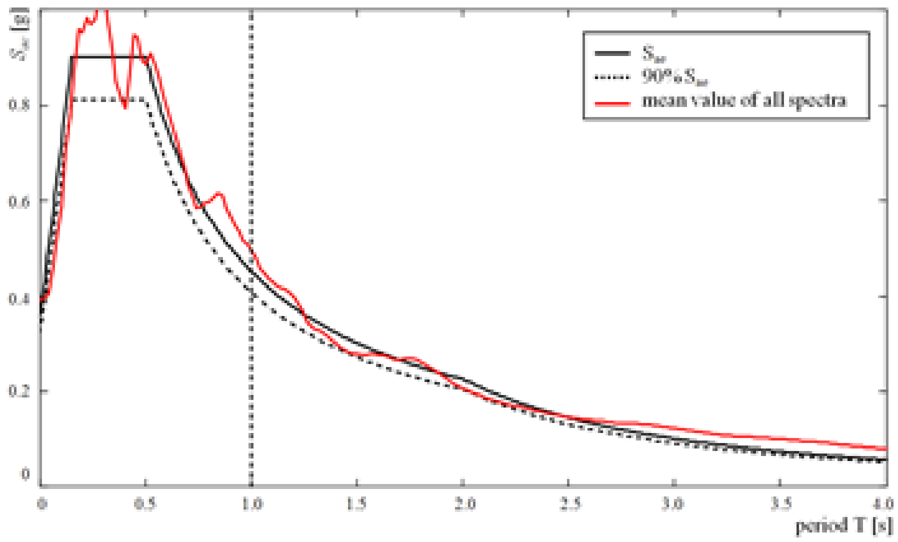
Figure 8. *(a) Response spectrum with 5% viscous damping ratio for ag = 0.3g and soil class B (in red), its 90% value (in blue) and the response spectrum for the artificial time-history record no. 1 (in black); (b) the corresponding artificial digitalized time-history record no. 1*

The real time-history records were taken from the libraries of The National Information Service for Earthquake Engineering, Berkeley, California and The Canadian Association for Earthquake Engineering (CAEE) [14]. All the selected real time-history records were registered on the soil class A or B. The ratio of the maximum velocity to maximum acceleration (v_{max}/a_{max}) for all the selected records lies within the interval from 83 to 125, which corresponds to earthquakes of medium intensity [15]. The following records were selected for obtaining the acceleration response spectrum, Fig. 9:

- Imperial Valley, California, USA (May 18th, 1940, El Centro);
- Ulcinj, Montenegro (April 15th, 1979, Hotel Albatros, Ulcinj);
- Mexico City, Mexico (September 19th, 1985, La Villita, Guerrero Array);
- Kocaeli, Turkey (August 17th, 1999, Sakaria);
- San Fernando, California, USA (February 9th 1971, 3838 Lankershim Blvd., L.A.);
- Honshu, close to the east coast, Japan (August 2nd, 1971, Kushiro Central Wharf);
- Kern County, California, USA (July 21st, 1951, Taft Lincoln School Tunnel).



(a)



(b)

Figure 9. *(a) Acceleration response spectrum of the selected real earthquakes together with the required response spectrum and its 90% value; (b) mean value of all spectrum*

5. COMPARATIVE ANALYSIS OF OBTAINED RESULTS

Fig. 10 presents displacement shapes and storey drifts obtained by using artificial records. Fig. 11 shows the results of using real records. It is observed good agreement between the mean values of responses obtained by artificial records to the mean values of responses obtained by real records.

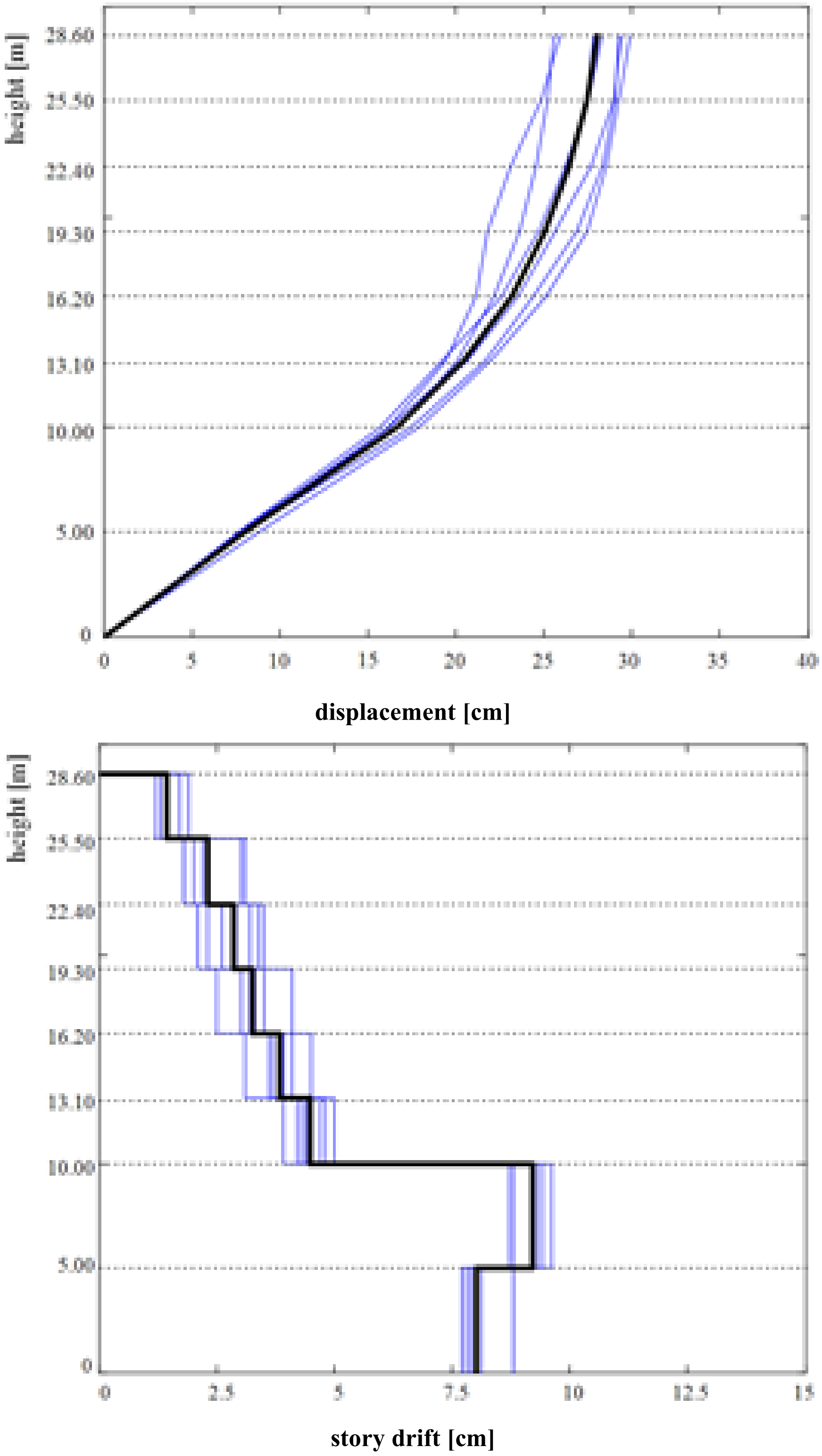


Figure 10. *Displacements and story drifts for structure in Fig. 1 for all seven artificial time-history records (in blue) and their mean value (in black)*

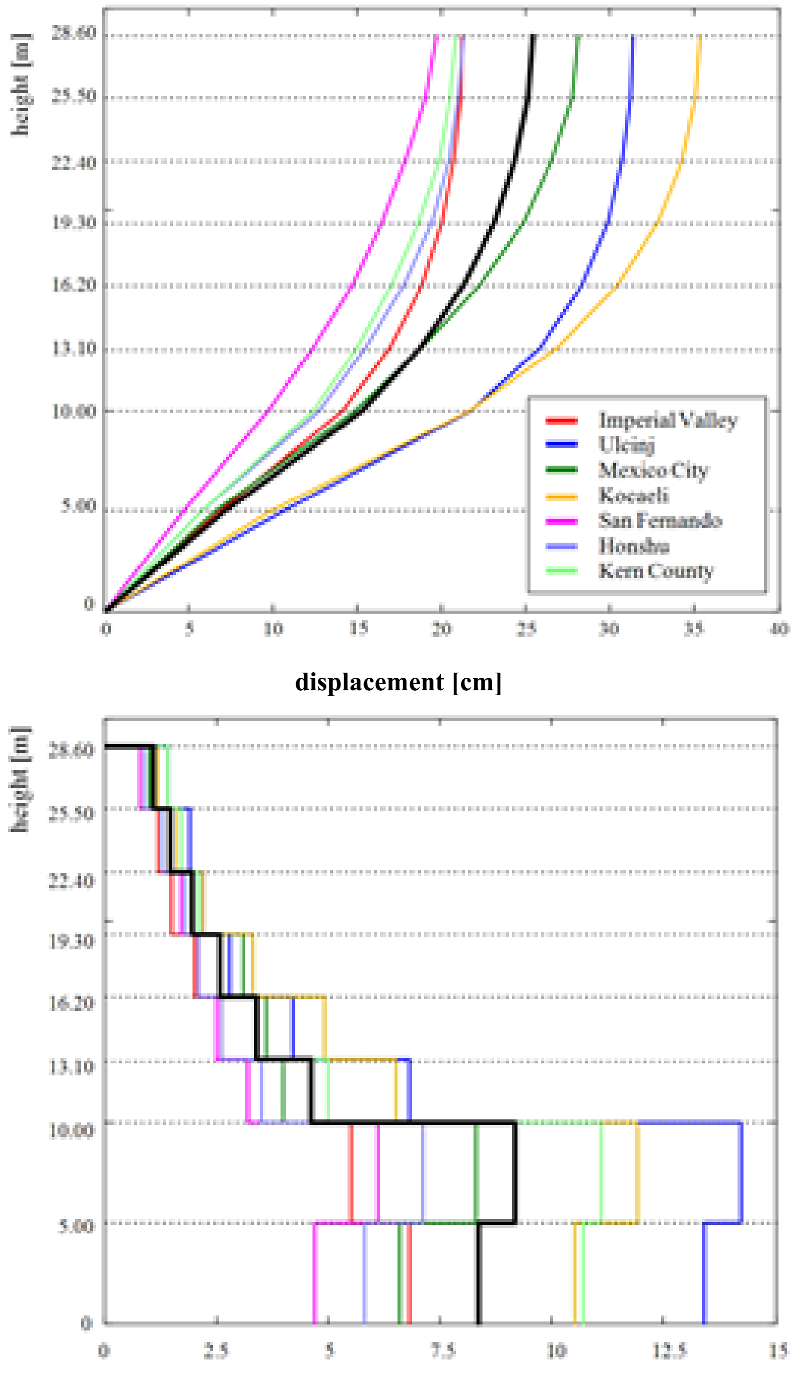


Figure 11. *Displacements and story drifts for structure in Fig. 1 for all 7 real time-history records and their mean value (in black)*

Fig. 12 and Fig. 13 present the comparison of maximum absolute displacements and maximum storey drifts calculated by all methods presented in Table 1, i. e. by equivalent static forces, modal analysis of response spectra for both un-cracked sections and cracked sections, nonlinear static method and nonlinear dynamic method using 7 artificial time-history records and 7 real time-history records.

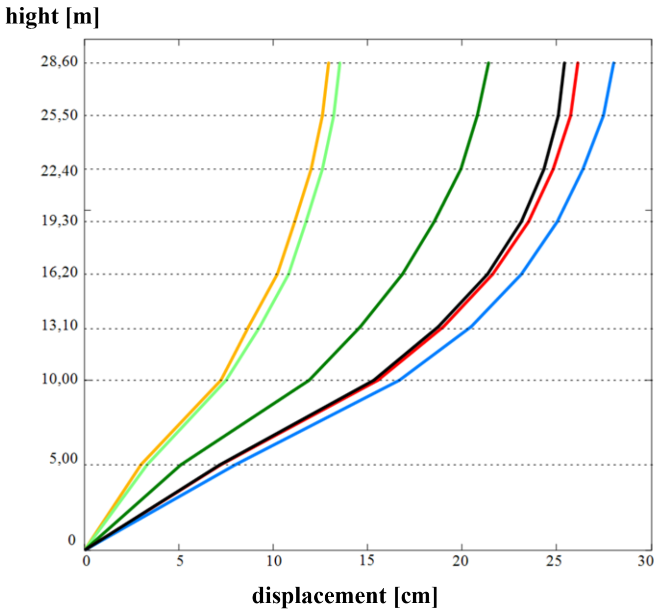


Figure 12. *Comparison of maximum absolute displacements calculated by equivalent static forces (yellow), modal analysis of response spectra for un-cracked sections (light green) and cracked sections (green), N2 method (red) and non-linear dynamic analysis using 7 artificial time-history records (black) and 7 real time-history records (blue)*

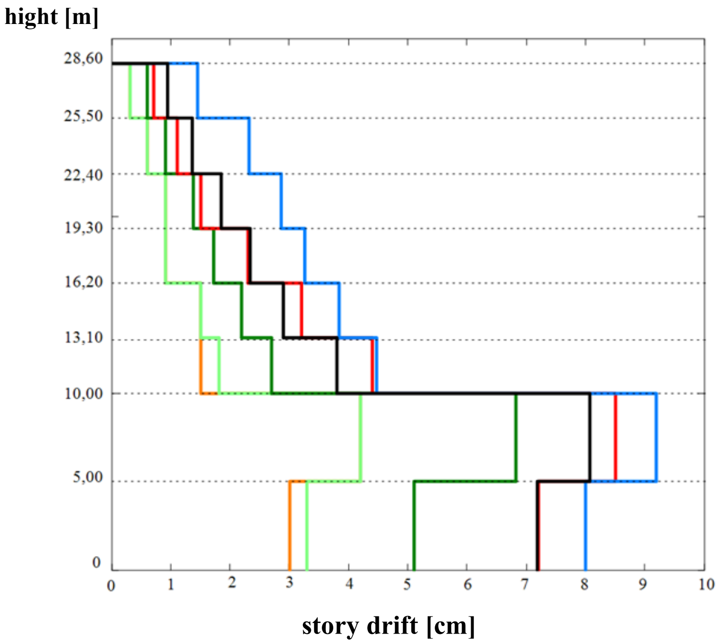


Figure 13. *Comparative representation of maximum story drifts calculated by equivalent static forces (yellow), modal analysis of response spectra for non-cracked sections (light green) and cracked sections (green), N2 method (red) and non-linear dynamic analysis using 7 artificial time-history records (black) and 7 real time-history records (blue)*

6. CONCLUSIONS

- Designers will soon only be doing more accurate nonlinear calculations of structures loaded by earthquake forces, especially for important structures. Applying more accurate methods of calculation takes more time to calculate, but in a nonlinear dynamic analysis, considering the actual behavior of the structure in an earthquake (performance-based analysis) after dimensioning, a more economical construction is obtained.

- Simplifications of calculations for concrete structures result in an increase in the amount of reinforcement, Fig. 12 and Fig. 13.
- If nonlinear analysis of structures with their cracked elements is not applied, in modelling and calculation by linear methods the characteristics of non-cracked concrete and masonry elements (their shear and flexural rigidity) should be taken with 50% of values for cracked sections, corresponding to [1], Fig. 12 and Fig. 13.
- In order to perform nonlinear analysis, cross sections and the amount of reinforcement must be assumed first as presented in Fig. 2 and as a result deformations (displacements and storey drifts), i.e. structural damage (plasticization of certain cross sections) will be obtained, while in linear calculation methods the reinforcement is obtained as the ultimate result.
- In the second generation of the European standard Eurocode 8 (will enter into power in 2022), which is in the process of being adopted and which contains radical changes to the currently valid standard, both nonlinear methods described in this paper are remained and extended for their use. For example, torsion effects and effects of the influence of higher modes in the nonlinear static method will be taken into account through correction factors [4], [5], [6].

LITERATURE

[1] Eurocode 8 (2004) Design of structures for earthquake resistance, Part 1: General rules, seismic actions and rules for buildings, European standard EN 1998-1. European Committee for Standardization (CEN), Brussels.

[2] P. Fajfar, “Capacity spectrum method based on inelastic demand spectra.” Earthq Eng Struct Dyn 28(9), pp. 979–993, 1999.

[3] P. Fajfar, “A nonlinear analysis method for performance-based seismic design.” Earthquake Spectra 16(3), pp. 573–592, 2000.

[4] M. Kreslin and P. Fajfar, “The extended N2 method taking into account higher mode effects in elevation.” Earthq Eng Struct Dyn., 40(14), pp. 1571–1589, 2011.

[5] P. Fajfar, D. Marušić and I. Peruš, “Torsional effects in the pushover-based seismic analysis of buildings.” J Earthq Eng 9(6), pp. 831–854, 2005.

[6] M. Čaušević and M. Bulić, “Response spectrum in the second generation of Eurocode for seismic area”, in press, Građevinar, Zagreb, 2020.

[7] M. Causevic and S. Mitrovic, “Comparison between non-linear dynamic and static seismic analysis of structures according to European and US provisions.” Bulletin of Earthquake Engineering, Volume 9, Issue 2, pp 467-489, 2011.

[8] SeismoSoft SeismoStruct A computer program for static and dynamic nonlinear analysis of framed structures, 2020 version, URL: http://www.seismosoft.com.

[9] SeismoSoft SeismoSignal A computer program for processing strong-motion data, 2020 version, URL: http://www.seismosoft.com.

[10] P. Gelfi, “Telaio2D, Programma agli elementi finiti per l'analisi sismica, lineare e nonlineare, di telai piani”. University di Brescia, Italy, 2006.

[11] ZEUS-NL, A System for Inelastic Analysis of Structures, User Manual, 2008.

[12] M. Čaušević, Dinamika konstrukcija: Potresno inženjerstvo – Aerodinamika – Konstrukcijske euronorme. Golden marketing – Tehnička knjiga, Zagreb, 2014.

[13] P. Gelfi, “SIMQKE_GR, Programma per la generazione di accelerogrammi artificiali spettro-compatibili.” University of Brescia, Italy, 2007.

[14] N. Naumoski, “Representative Ensembles of Strong Earthquake Records.” CAEE - The Canadian Association for Earthquake Engineering, 1988, http://www.caee.uottawa.ca/

[15] N. Naumoski, W. K. Tso and A. C. Heidebrecht, “A selection of representative strong motion earthquake records having different A/V ratios.” Earthquake Engineering Research Group, McMaster University, Hamilton, Ont., EERG Report 88-01, 1988.

31 | Professional paper | Стручни рад
ISSN 2566-4484 | Doi 10.7251/STP2014342U
pages 342-350

Mato Uljarević, mato.uljarevic@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

Snježana Milovanović, snjezana.milovanovic@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

Radovan Vukomanović, radovan.vukomanovic@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

COMPARISON OF SEISMIC IMPACTS THROUGH DIFFERENT REGULATIONS

Abstract:

This paper presents the basic principles of seismic analysis of structures according to the YU81 and European norm EN 1998-1: 2004. The aim of the paper is a critical review of comparative analysis of seismic impacts in the design of building structures according to these standards. EC8 involves several innovative approaches for the design and construction of structures, such as no structural failure, limiting the degree of structural damage, important public use facilities must remain usable. Purpose of this research is to compare the value of seismic force according to YU81 and EC8, for the same type of structure, depending on the parameters variation, such as different soil categories, different seismicity class, different building structural systems.

Keywords: seismic analysis, ductility, linear analysis, EC8, YU81

ПОРЕЂЕЊЕ СЕИЗМИЧКИХ УТИЦАЈА КРОЗ РАЗЛИЧИТЕ ПРОПИСЕ

Сажетак:

У овом раду представљени су основни принципи асеизмичког пројектовања према YU81 и Еврокоду EN 1998-1:2004. Циљ је критичко поређење анализа сеизмичких утицаја при пројектовању грађевинских конструкција. EC8 укључује неколико темељних приступа за пројектовање и изградњу објеката, од критеријума спрјечавања отказа конструкције, ограничавања степена оштећења конструкције, одржавања употребљивости важнијих јавних објеката. Сврха овог истраживања је упоређивање вриједности сеизмичке силе према YU81 и EC8, за исти тип конструкција, са варирањем одређених параметара, као што су различите категорије тла, различите класе сеизмичности, различити конструктивни системи.

Кључне ријечи: асеизмичко пројектовање, дуктилност, линеарна анализа, EC8, YU81

1. INTRODUCTION

The area of Bosnia and Herzegovina belongs to the seismically active regions, which means that in the process of designing and building the structure, special attention must be paid to the resistance of the structures to the effects of the earthquake. In the process of implementation of European codes, as has been done in other fields, it is necessary to consider and analyze in detail what are the novelties and differences in this field in relation to the currently valid regulations. The aim of this paper is to identify and compare the difference in design of seismically resistant structures between reinforced concrete structures designed under current regulations (YU81) and current European regulations (Eurocode) that are under implementation in BiH.

First of all, European codes provide a more detailed analysis of seismic effect and pay special attention to the design of structural details, introducing different values of the behavior factor (q) for different types of reinforced concrete structures. Unlike the YU81, different ductility classes are introduced: LD-low ductility, MD-medium ductility, and HD-high ductility, [1], [2]. Seismic load decreases with increasing of ductility, but the calculations are more complex in terms of shaping details, cross section reinforcement, minimum reinforcement coefficients, and length of anchoring and continuation of reinforcement.

The analysis covers different systems (wall systems and frame systems) in different ground types and with different degrees of seismic activity, in order to draw conclusions and a comprehensive comparison of structures depending on which of the mentioned regulations is used for calculation.

2. BRIEF REVIEW OF YU81 AND EC8 STANDARDS

This chapter gives a brief review of the basic principles of European standards and valid YU81 regulations. EC8, considering its detail, as the basic requirements defines the need for designing structures by engineers with extensive experience and knowledge, proper checking of project design documentation, building structures by the person with the necessary knowledge and licenses, using the materials with certificate that meet the requirements defined by European codes. In addition, special attention is paid to the durability and proper maintenance of the structures, and the user-defined construction to the intended purpose. Due to their comprehensiveness and breadth, the specific values given by European codes are given only as recommended, the closer ones will be defined by the national annexes that each country adopts, such as certain coefficients, intensity maps of certain parameters related to snow, wind, temperature and seismics, [3].

In the general provisions of YU81, aseismic design implies that high-rise structures are designed so that earthquakes of the highest intensity may cause damage to load-bearing structures, but no destruction of the structures shall occur. In contrast to the above, EC8 implies several approaches to the design and construction of structures, with the following conditions being met with certain statistical reliability: a) no structural failure; b) limiting the degree of structural damage; c) that important public use facilities remain usable.

In chapter IV YU81 classifies structures into five categories and defines the coefficient of the object category (K_o) as follows: non-category objects, category I (K_o=1.5), II. category (K_o=1.0), III. category (K_o=0.75), IV category. That chapter also describes what types of objects belong to which category, and category II was selected for the research in this paper. Which includes residential buildings, hotels, restaurants, public buildings not classified in the first category and industrial buildings not classified in the first category, [2]. EC8 gives the classes of significance of the object and the corresponding coefficients of significance depending on the consequences of the destruction on human lives, also their importance for public safety and the protection of people in the immediately after earthquake, and on the social and economic consequences of the destruction. The objects are classified into four categories (I, II, III and IV) With coefficients of significance γ_I that are 0.8, 1.0, 1.2, 1.4, respectively, and which correspond approximately to the classes of consequences CC1, CC2 and CC3 that are defined in EN 1990: 2004, Annex V, [1].

Seismic parameters are defined by the degree of seismicity of individual regions based on detailed seismic regionalization and seismic micro-regionalization. According to YU81, a design earthquake is the strongest expected earthquake that can hit an object during its service life, and represent an earthquake that occurs once every 500 years. The regions are represented with a certain coefficient of seismicity (K_s). According to earthquake intensity, the magnitude of the Mercalli-Cancani-Sieberg (MCS) scale, we have zones VII (K_s=0.025), VIII (K_s=0.050) and IX (K_s=0.100). The EC8 for load-bearing capacity states of the aforementioned category of objects also uses the probability of occurrence once every 500 years, and defines seismic parameters through the reference values of maximum ground acceleration (a_g) with values 0.1g to 0.4g.

According to the parameters of soil on which building is based, YU81 in chapter 9. divide three soil categories, depending on its characteristics, from rock-like formations, through compacted and dense or medium-dense soil, to the third category of loose to medium-cohesionless soil. Chapter 25. defines for each soil category formula for dynamic coefficient (K_d), and its limit values, as a function of the period of oscillation of structure. That coefficient is also included in the formula for seismic force calculation. EC8 standards, considering the impact of local soil conditions on seismic loading through five soil types: A, B, C, D, E and two types of liquefaction soils S1 and S2. EN 1998-1: 2004, in chapter 3.2.2.2 gives a horizontal elastic response spectrum that manifests movement due to an earthquake at a point on the ground surface. Horizontal movement due earthquake is described by two orthogonal, mutually independent components that are represented by the same response spectrum. According to [4], the relationship between acceleration and earthquake intensity can be represented as:

$$a_g = 10^{-2.4+0.34I}. \quad (1)$$

Here I is the intensity and according to [6], it can be given as:

$$I = 1.5M - 0.5, \quad (2)$$

where M is the magnitude of the earthquake.

A magnitude of 5.5 corresponds to an acceleration of 0.175g, so for accelerations greater than this, the region in which the object is located is classified as a high seismicity region, and the recommended Type 1 of the elastic response spectrum shown in Figure 1a is adopted, while for smaller ground accelerations it is used Type 2, shown in Figure 1b.

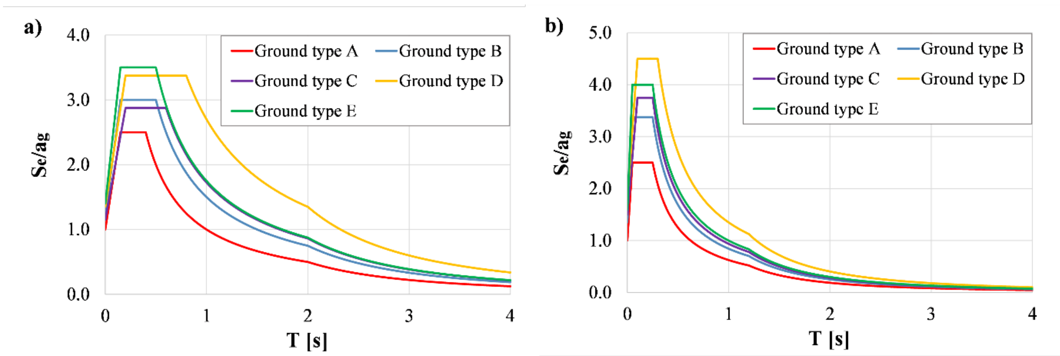


Figure 1. *Recommended types of elastic response spectra for ground types A to E (5% damping): a) Type 1 for magnitude greater than 5.5, b) Type 2 for magnitude not greater than 5.5*

By analyzing the velocity of seismic waves propagating through the soil and by descriptive comparison of different soil categories, it was concluded that the five basic types according to European standard can be identified with three categories according to YU81 so that the soil of category I corresponds to the soil of category A, while the soil of category II corresponds to classes B and C. Bad soil category III corresponds to D and E soil type according to EC8. Liquid soils S1 and S2 were not treated by the YU81 regulations and were therefore omitted from the analyzes in this paper.

When it comes to calculation methods, YU81 provides the equivalent static load method or dynamic analysis method. Structures are calculated as linear-elastic structures by ultimate limit state theory, with coefficients of safety 1.30 for reinforced concrete, 1.15 for steel and 1.50 masonry structures, or by elasticity theory (with 50% increase in permissible stresses). Maximum horizontal deflection of structure for prescribed seismic loads $f_{dop}=H/600$, where H is the height of the building.

According to EC8, structures are designed by one of four methods: linear analysis, equivalent lateral force method (subject to certain conditions of object regularity), multimodal spectral analysis (which can be applied to all types of buildings), as well as non-linear pushover analysis methods and nonlinear (dynamic) time response analysis. Due to complexity and detail calculation according to EC8, it is especially necessary to fulfill requirements that define the parameters of ductility, stability, serviceability limit states... All structural elements as well as entire structure must have sufficient ductility to ensure a capacity design method for stability loss. Then, the structure must have sufficient stability for all possible load combinations and the required load-bearing capacity of foundations. According to the serviceability limit states, there is a limited interfloors movement due the structural damage ($d_r/v \leq$ h/250 for structures with non-structural elements attached to structural, and $d_r/v \leq$ h/167 for structures with non-structural elements separated from structural ones). It is also important to mention the behavior factor (q), which is also a novelty of EC8, used in design to reduce the forces obtained by linear analysis, in order to take into account the nonlinear response of the structure, with regard to material, structural system and design procedures. This factor takes values up to 8, but not less than 1.5.

Structural design for seismic load according to YU81 is an analysis of the effect of horizontal seismic forces in two orthogonal directions, without their interaction. Design combination take into consideration dead load (g), 50% of liveload (p), snow load (s), horizontal seismic force defined by the standard as:

$$S = K \cdot G, \qquad K = K_0 \cdot K_s \cdot K_d \cdot K_p, \tag{3}$$

where K_o is object category coefficient, K_s is seismic intensity coefficient, K_d is dynamic coefficient and K_p is ductility and damping coefficient. Safety factor for the loads is γ=1.3.

According to EC8, regular structures are analyzed for the dominant seismic directions as two in plane models, but also with the coefficient of interaction, as well as the calculation of torsion (accidental torsion) effects. The load taken into calculations are dead load (g), a live load (p) with a combination coefficient (Ψ=0.3-1.0). The total horizontal seismic force for regular reinforced concrete structures is:

$$F_b = S_d(T_1) \cdot m \cdot \lambda. \tag{4}$$

In this paper, due to its purpose of research, it is not go into details of the distribution of seismic force to structural elements, as well as a design and detailing of individual elements of structure. The aim is to compare the value of seismic force according to YU81 and EC8, on the same type of structure, depending on the parameters variation, such as different soil categories, different degree of seismicity (acceleration), different structural systems (wall systems and frame systems).

3. COMPARATIVE ANALYSIS

The structures chosen for the analysis satisfy the requirements given by provisions of EC8 for lateral force method of analysis. Two types of constructions of importance class II by EC8 and II by YU81 were tested, for which the Base Shear coefficients (B.S.) were determined for the adopted acceleration value. Base Shear coefficient represents the ratio of the total horizontal seismic force and the weight of the structure, that is:

$$B.S. = \frac{F_b}{W} = \frac{S_d(T_1) \cdot \lambda}{g}. \tag{5}$$

According to Yugoslav regulations, the Base Shear coefficient corresponds to the coefficient K, the total seismic coefficient for the horizontal direction.

The following figures (Figure 2 - Figure 4) show the results of the analysis of frame structures and structures with concrete shear walls, with Base Shear coefficients calculated for different vibration periods of the structure for the acceleration of 0.17g. According to YU81, this acceleration corresponds to the VIII zone of seismic activity, so the coefficient of seismicity K_s=0.05 was used for the calculation. Analysis by the method of lateral forces was performed by following provisions of EC8, whereby the recommended elastic response spectra Type 2 for magnitudes less than 5.5 was adopted in the analysis.

The calculation also takes into account different ground types from A to E, which are compared with the corresponding soil categories I, II and III according to YU81. The values of the behavior factor, which is also a measure of the energy dissipation of the structure, have higher values for frame structures. In the case of lower vibration periods, the Base Shear coefficient obtained using the method of analysis given EC8 is higher than in the case of analysis by following the provisions of regulation YU81, which is particularly pronounced for soils with poorer quality. Also, the obtained function of the Base Shear coefficient for the middle class ductility (DCM) for ground type A, the area covered by ground types B and C, as well as the area covered by ground types D and E, gives lower values than the high ductility class and therefore seismic forces, which is expected since the difference in the values of the factors of behavior.

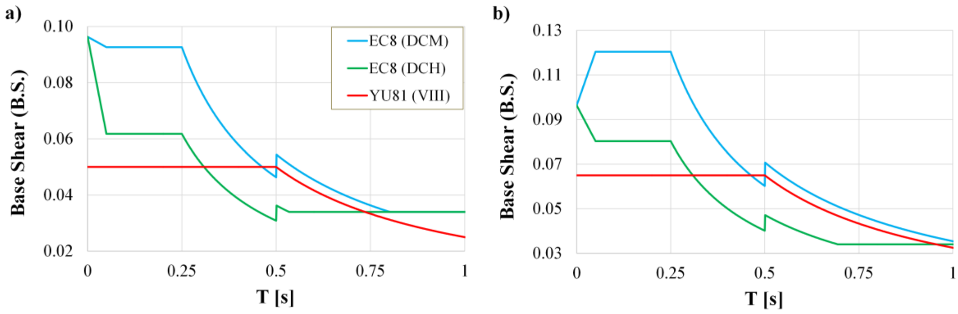


Figure 2. *Base Shear coefficient for ground type A (a_g=0.17g): a) frame systems b) wall systems*

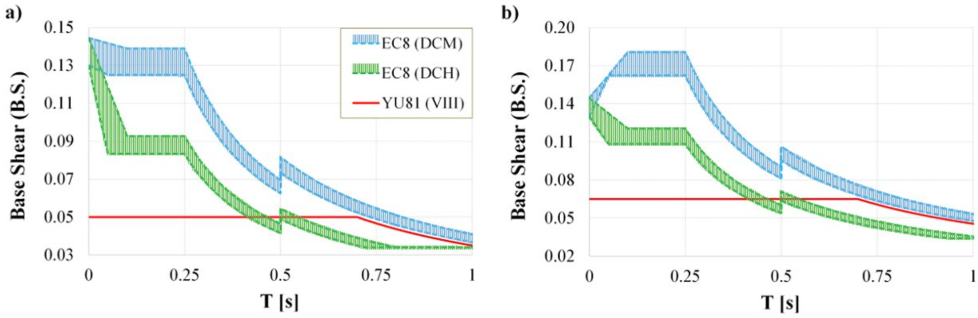


Figure 3. *Base Shear coefficient for ground types B and C (a_g=0.17g): a) frame systems b) wall systems*

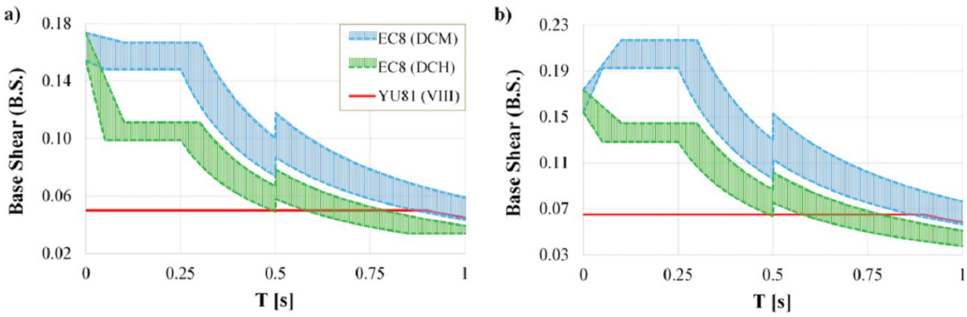


Figure 4. *Base Shear coefficient for ground types D and E (a_g=0.17g): a) frame systems b) wall systems*

The same analysis was performed for the acceleration value of 0.25g, with the adoption of the recommended elastic spectrum Type 1. The results were compared with those obtained for the IX zone according to YU81 and it can be observed that at higher vibration periods smaller differences in the Base Shear coefficient values were obtained for high class ductility (DCH), Figure 5 - Figure 7. Also, it can be observed that EC8 offers a wide range of coefficient values unlike the YU81 which offers only the total seismicity coefficient for different values of vibration periods.

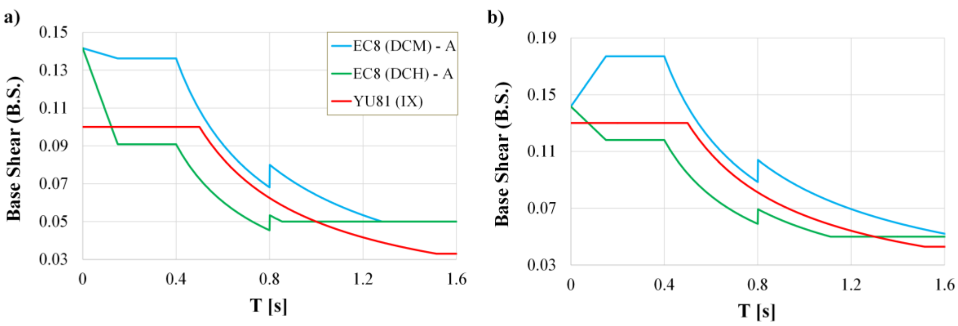


Figure 5. *Base Shear coefficient for ground type A (a_g=0.25g): a) frame systems b) wall systems*

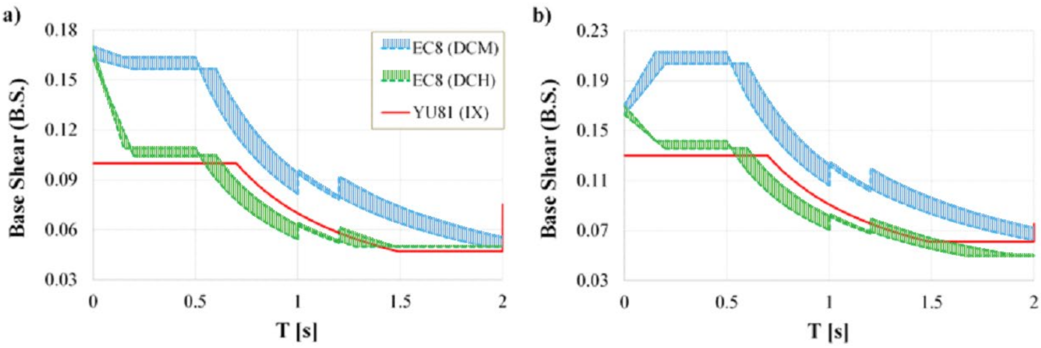


Figure 6. *Base Shear coefficient for ground types B and C (a_g=0.25g): a) frame systems b) wall systems*

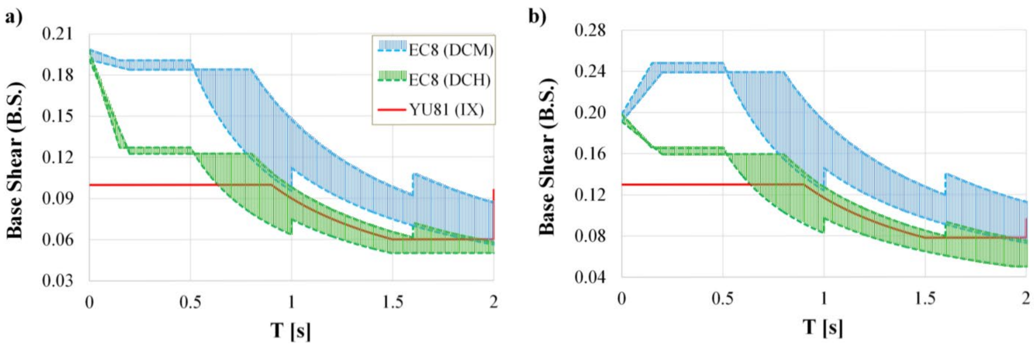


Figure 7. *Base Shear coefficient for ground types D and E (a_g=0.25g): a) frame systems b) wall systems*

In the further analysis, the Base Shear coefficient values were obtained for different values of acceleration and ground types A-E. The results were obtained by calculating the frame structure with the vibration period T=0.9 s and the structure with concrete shear walls with the vibration period T=0.6 s. The following figures show that the values of Base Shear coefficients obtained by applying EC8 greatly deviate from those obtained by applying the provisions of YU81 for accelerations corresponding to the IX zone of seismicity (0.2g-0.4g).

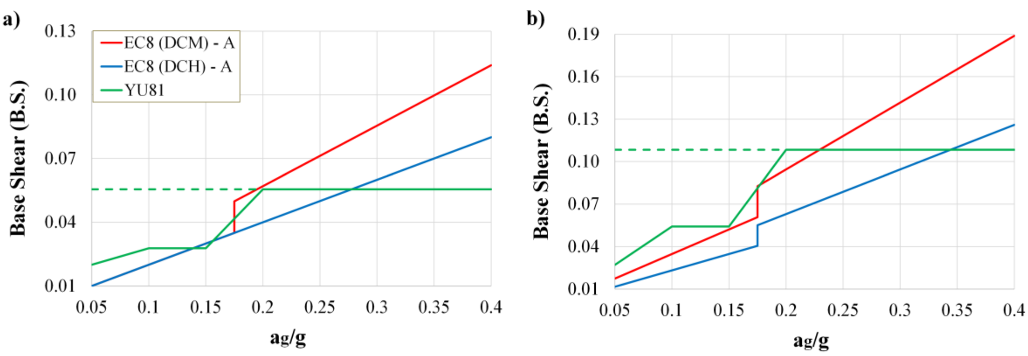


Figure 8. *Base Shear coefficient for ground type A : a) frame system (T=0.9 s) b) wall system (T=0.6 s)*

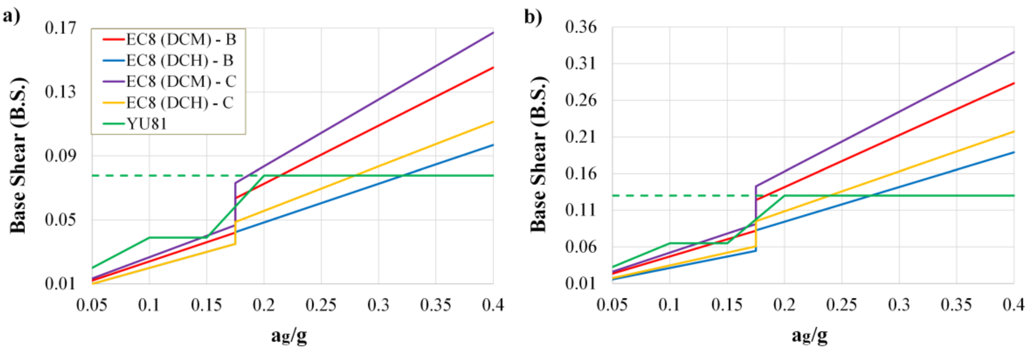


Figure 9. *Base Shear coefficient for ground types B and C : a) frame system (T=0.9 s) b) wall system (T=0.6 s)*

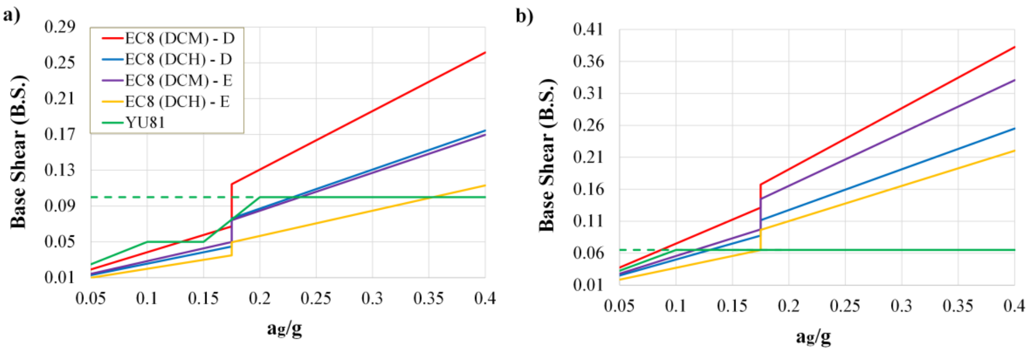


Figure 10. *Base Shear coefficient for ground types D and E : a) frame system (T=0.9 s) b) wall system (T=0.6 s)*

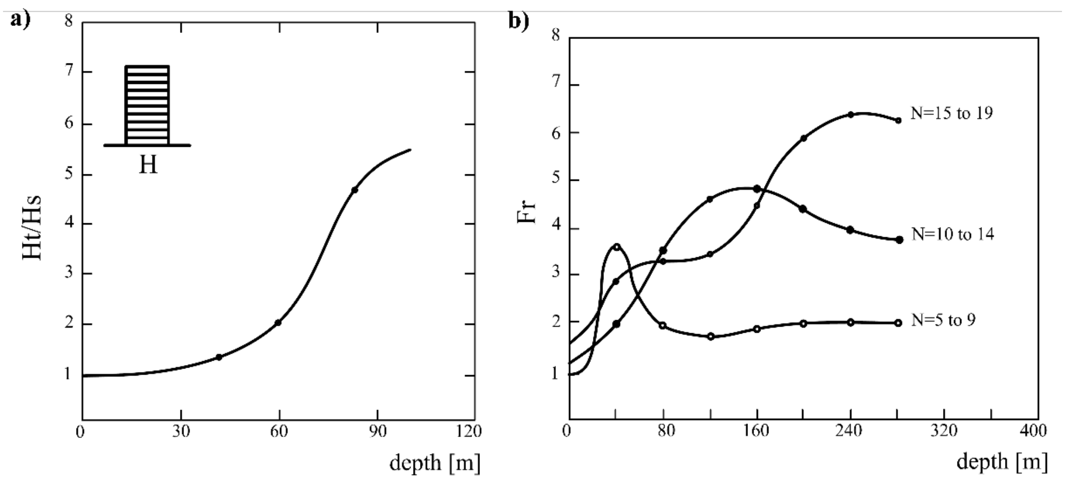


Figure 11. *a) Influence of soil depth on the maximum value of the total shear force at the foundation level for a building, as shown in the earthquake in San Fernando, California b) Index of possible structural damage, [5]*

Figure 11a shows the functional dependence of the increasing force at the base of a building constructed on soil of different thicknesses relative to the seismic force for a rock-based building. The results are for the building with 10 floors, with weight of 63 600 *kN* and vibration period *T*=1.2 *s*. The significance of the thickness of the soil above the base of the rock is also evident from Figure 11b, where the damage index function is given as:

$$F_r = \frac{(B.S.)_{\max} T}{W \cdot C}, \tag{6}$$

Here T is the vibration period, W is the weight of the building and C is the coefficient of design lateral load. The values are given as a function of the thickness of the soil above the base rock for different values of number of floors N.

In aseismic designing, the proper choice of the method by which the analysis will be performed is of great importance. In the selected example [6], an eight floor frame structure with vibration period T=0.93 s and importance of class II was tested for three acceleration values. The differences in seismic load level are given in Table 1. For structures where there is no significant contribution of higher oscillation modes to response, according to the provisions of EC8, two static analyzes were introduced: the method of equivalent lateral forces and the nonlinear static pushover method (N2 method). The nonlinear static method N2 gives a better insight into the resistance and ductility of the structure, monitoring of structural behavior and estimate of damage. It applies two mathematical models and combines the Pushover analysis of the multi-degree model with spectrum analysis of an equivalent system with one degree of freedom. According to YU81, the analysis is performed using an equivalent static load based on spectrum analysis.

Table 1. *Comparison of different methods of analysis*

<table>
<tr><th rowspan="4">a_g</th><th colspan="7">Base Shear coefficient [%]</th></tr>
<tr><th colspan="4">EN 1998-1:2004</th><th colspan="3" rowspan="2">YU81</th></tr>
<tr><th colspan="2">Latheral force method of analysis</th><th rowspan="2">Modal response spectrum analysis</th><th rowspan="2">Non-linear static (pushower) analysis</th></tr>
<tr><th>DCM</th><th>DCH</th><th>VII</th><th>VIII</th><th>IX</th></tr>
<tr><td>0.3g</td><td>10.5</td><td>7.0</td><td>10.0</td><td>13.6</td><td rowspan="3">2</td><td rowspan="3">3.8</td><td rowspan="3">7.5</td></tr>
<tr><td>0.2g</td><td>7</td><td>4.7</td><td>6.7</td><td>13.6</td></tr>
<tr><td>0.1g</td><td>2.3</td><td>2.0</td><td>3.3</td><td>7.7</td></tr>
</table>

4. CONCLUSIONS

The aim of this paper is to critically review the application of individual regulations in analyzing seismic impacts in the design of building structures. From the results of comparative analyzes it can be concluded:

- Proper seismic design of objects requires the development of seismic micro-rayonization of the actual area on which the realization of the object is planned, made by probabilistic analysis of the causes of seismic activity in the analyzed area
- Very important approach in aseismic design is to define the seismic activity of the site as accurately as possible, as well as the geological composition of the soil profile planned for construction. Properly considering the composition and behavior of the soil in response to the seismic activity will direct the designer to the correct selection of the type of structure,
- Proper selection of the type of structure, in response to the seismic activities of the site, is more important than the mere calculation of seismic forces by (once) questionable methodologies.
- The paper clearly emphasizes, through diagrams and tables, the importance of determining the reliable composition (characteristics) of the ground in defining the seismic force, and thus the proper design of the structure,
- It is clearly shown that the defining the seismic force in the analysis of the structure depends on many factors, not just the degree of seismic activity in simplified analyzes.

The performed analyzes provide some of the reasons why to prioritize structural calculations for seismic activity according to EC8 over the procedures defined in YU81 regulations:

- More detailed analysis of the seismic effect where special attention is directed to the design of structural details,
- Different values of behavior factors (q) are introduced for different types of reinforced concrete structures, which more properly considers (describes) the response of the structure to seismic action. Different ductility classes are also introduced: LD-low ductility, MD-medium ductility and HD-high ductility. The seismic load decreases with increasing ductility, but the calculations are more complex in terms of shaping details, designing cross sections of the shear reinforcement (minimum reinforcement coefficients and length of anchoring and continuing the reinforcement),

- Seismic parameters are defined by the degree of seismic activity of individual regions, based on detailed seismic regionalization and seismic micro- regionalization,
- EC8 involves several approaches for the design and construction of structures, with the following conditions being met with certain statistical certainty: a) no structural failure; b) limiting the degree of structural damage; c) that important public use facilities remain usable,
- The effect of local soil conditions on seismic load is taken into account through five ground types; A, B, C, D, E and two categories of liquidation soil S1 and S2,
- According to EC8, the regular structures are analyzed as two plane models for the dominant seismic directions, but also with the correlation coefficient for different direction, as well as the calculation of torsion effects (accidental torsion effects),
- According to EC8, structures are calculated by one of four methods: linear analysis, lateral force method of analysis (subject to certain conditions of regularity of the object), modal response spectrum analysis (which can be applied to all types of buildings), as well as non-linear static (pushover) analysis and nonlinear time history (dynamic) analysis,
- And of course, statistically, the reliability of structures in terms of reducing the risk to human lives is certainly measured by the progress of technical regulations in this area. In this regard, EC8 is the norm on more than 600 edited pages provides more reliable analysis compared to YU81 regulations from about 30 pages.

LITERATURE

[1] EN 1998-1:2004: Proračun seizmički otpornih konstrukcija, Deo 1: Opšta pravila, seizmička dejstva i pravila za zgrade, Beograd, 2009.

[2] Pravilnik o tehničkim normativima za izgradnju objekata visokogradnje u seiymičkim područjima, Službeni list SFRJ, br.31/81 i dopune, Beograd, 1981.

[3] D. Aničić, P. Fajfar, B. Petrović, A. Szavits-Nossan, M. Tomažević, Zemljotresno inženjerstvo – visokogradnja, Građevinska knjiga, Beograd, 1990.

[4] V. Sigmund, M. Bošnjak-Klečina, I. Guljaš, A. Stanić, Usporedba primjene hrvatskih propisa i Eurokoda 8, Građevinar, Zagreb, 2000.

[5] Idriss, I. M. and Seed, H. Bolton (1968b), “An Analysis of Ground Motions During the 1957 San Francisco Earthquake,” Bulletin of the Seismological Society of America, Vol. 58, No. 6, pp. 2013-2032, 1968.

[6] Čaušević M., Dinamika konstrukcija, potresno inženjerstvo, aerodinamika, konstrukcijske euronorme, Tehnička knjiga, Zagreb, 2010.

32 | Professional paper I Стручни рад
ISSN 2566-4484 I Doi 10.7251/STP2014351C
pages 351-361

Snježana Cvijić Amulić, snjezana.cvijic@gmail.com, Republic Hydrometeorological Institute, Banja Luka

Sanja Tucikešić, sanja.tucikesic@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

ACCELEROMETRIC NETWORK AND ELASTIC RESPONSE SPECTRUM FOR GROUND TYPE A IN THE REPUBLIC OF SRPSKA

Abstract:

This paper presents the content of an analysis of available relevant accelerometric data, which aims at identifying a group of nationally determined parameters in the field of seismological activity that was used in the preparation phase of the B&H national annex for Eurocode 8. Seismological data analysis related to parameters that are in Eurocode 8 open to national choice, refer to the: soil classification, horizontal elastic response spectrum and reference ground acceleration, respectively seismic hazard map.

Keywords: Eurocode 8, elastic response spectra, peak ground acceleration, seismic hazard

АКЦЕЛЕРОМЕТРИЈСКА МРЕЖА И СПЕКТРИ ОДГОВОРА ЕЛАСТИЧНЕ СРЕДИНЕ ЗА ТЛО ТИПА А У РЕПУБЛИЦИ СРПСКОЈ

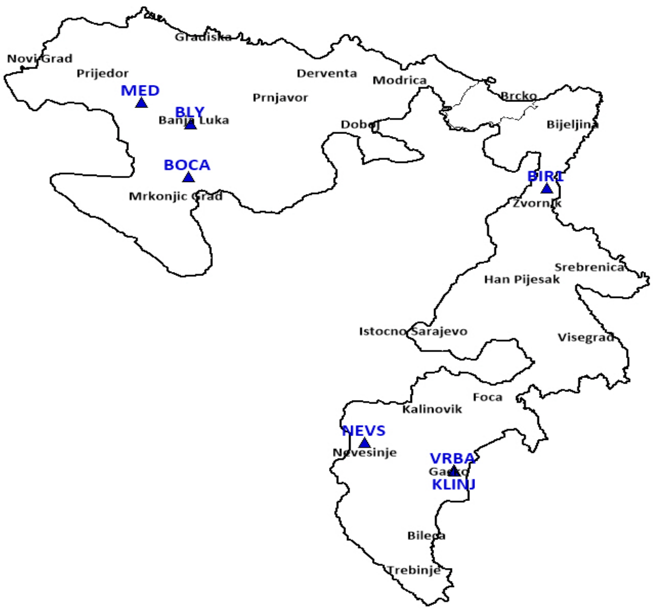
Sadržaj:

У овом раду је приказан садржај анализе расположивих релевантних акцелерометријских података који има за циљ могућност утврђивања групе национално детерминисаних параметара из области сеизмолошке дјелатности која је коришћена у фази припреме националног анекса БиХ за Еврокод 8. Анализа сеизмолошких података се односила на параметре који су у Еврокоду 8 отворени за национални избор, а односе се на: класификацију тла, хоризонтални спектар одговора еластичне средине и референтно убрзање тла, односно карту сеизмичког хазарда.

Кључне ријечи: Еврокод 8, спектар одговора еластичне средине, референтно убрзање тла, сеизмички хазард

1. УВОД

Акцелерометријска мрежа је значајна за утврђивање параметара осциловања тла при дејству јаких земљотреса, који су неопходни у процесу сеизмички сигурног пројектовања, планирања и грађења објеката у Републици Српској, као и за потребе утврђивања реалног степена сеизмичког хазарда и очекиваног нивоа сеизмичког ризика. Активности на формирању акцелерометријске мреже Републике Српске започете су 2009. године. Први акцелерометар у мрежи Републике Српске инсталиран је у Бањој Луци, 2009. године заједно са широкопојасним сензором, што представља стандард савремених европских сеизмолошких мрежа у сарадњи са Институтом за вулканологију и геофизику из Рима. С обзиром на то да би формирање акцелерометријске мреже на споменути начин изискивало значајна финансијска средства којима Завод не располаже, Завод се окренуо сарадњи са привредним субјектима који управљају високим бранама које према Правилнику о техничким нормативима за сеизмичко осматрање високих брана (Службени Лист СФРЈ број 06/88) и Правилнику о вршењу техничког прегледа објеката, издавању одобрења за употребу и осматрање тла и објеката у току грађења и употребе (Службени Гласник Републике Српске број 46/11), морају имати инсталиран прописан број акцелерометара с циљем сеизмичког осматрања за регистровање динамичког понашања тла, темеља и тијела бране за вријеме јаких земљотреса. На овај начин остварена је сарадња са Рудником жељезне руде Омарска (MED) и Рудником и термоелектраном Гацко (VRBA и KLINJ), од јануара 2011. године са Водоводом из Невесиња на брани Алаговац (NEVS), затим са фабриком Алумина из Зворника (BIR1) и са Хидроелектраном Бочац (BOCA), Слика 1.



Слика 1. Акцелерометријске станице на простору Републике Српске

На свим локацијама су инсталирани инструменти америчког призвођача Kinemetrics чији је преглед дат у Табели 1.

Табела 1. Акцелерометријске станице у Републици Српској са кодним називом и инструментаријем

Код	Мрежа	Латитуда N (°)	Лонгитуда E (°)	Надморска висина (m)	Дигитализатор	Сензор
BLY	WS	44.749	17.175	256	Q730	Episensor FBA-EST
VRBA	WS	43.174	18.579	1112	Basalt	Episensor FBA-EST
MED	WS	44.847	16.911	200	Q330	Episensor FBA-EST
BIR1	WS	44.457	19.076	197	Basalt	Episensor FBA-EST

BOCA	WS	44.508	17.163	308	Q330	Episensor FBA-EST
NEVS	WS	43.299	18.103	894	Basalt	Episensor FBA-EST
KLINJ	WS	43.169	18.585	1076	Basalt	Episensor FBA-EST

Сигнали на свим станицама се дигитализују са 100 узорака у секунди и резолуцијом од 24 бита. Регистрација пуне скале износи +/- 4 g, а преузимање података се врши путем IP протокола. У Табели 2 су приказани параметри акцелерометријских станица, као и класификација тла у сагласности са Еврокодом 8.

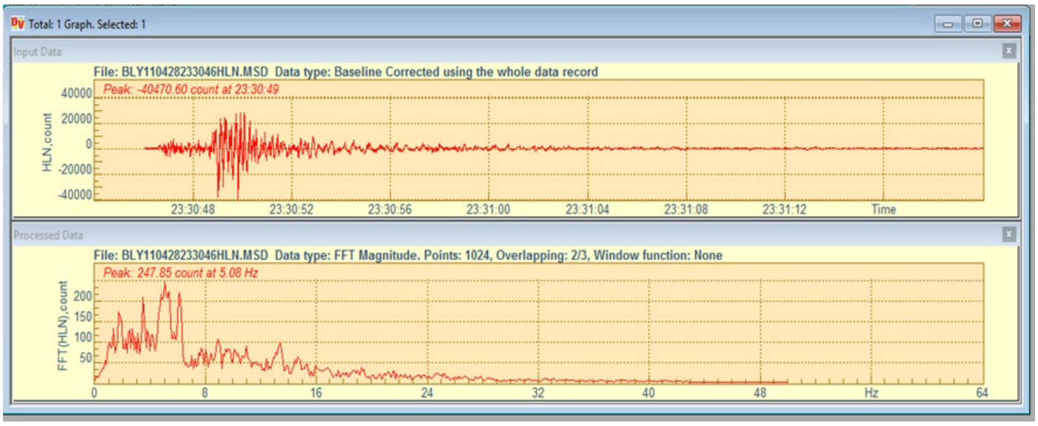
Табела 2. Параметри акцелерографских станица и класификација тла на локацији

Код	Геолошки састав тла	Класификација тла по EN98-1
BLY	Слојевити доломити са глиновитим прослојцима око 0.5 m при површини	A
VRBA	Еоценски флиш, танкослојевити хетерогени материјали	B
MED	Хумус, жутосмеђе пјесковите глине, сивосмеђи пјешчар са прослојцима алевролита (6-100 m)	B
BIR1	Кречњак испуњен са доста глиновитог материјала	B
BOCA	Слојевити до банковити кречњаци	A
NEVS	Глацијални седименти, шљунак са глином	B
KLINJ	Еоценски флиш, танкослојевити хетерогени материјали	B

Класификација тла на локацијама акцелерографских станица дата је на бази површинске геологије. Како не постоје подаци о дебљини појединих геолошких формација (глина, шљунак, итд) ова класификација тла се не може узети као коначна, већ су потребна геофизичка истраживања којима би се одредила вриједност смичућих таласа на локацијама станица.

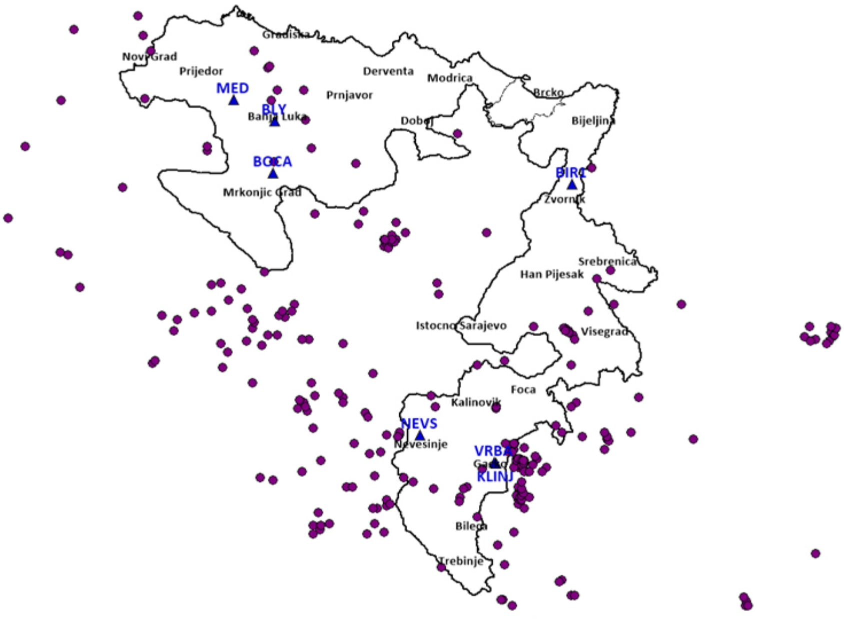
1.2. База података са историјама убрзања

Осциловање тла током дејства земљотреса се може приказати преко временских историја убрзања тла (акцелерограма) и повезаних величина (брзина и помјерај). Сеизмичка побуда се може описати кроз анализу акцелерограма, који се генеришу путем физичке симулације извора и механизма пропагације сеизмичких таласа кроз тло. База акцелерограма Сектора за сеизмологију Републичког хидрометеоролошког завода Републике Српске се састоји од временских историја који су регистровани од маја 2009. године када је инсталирана прва акцелерометријска станица у Бањој Луци. Ова база података се састоји од 264 акцелерограма за 88 земљотреса магнитуда $3.0 \leq ML \leq 4.9$ степени по Рихтеру, од којих је један акцелерограм приказан на Слици 2 са FFT спектром.



Слика 2. Акцелерограм земљотреса (N-компонента) са FFT спектром од 28. априла 2011. године у 23:30:43 (GMT), ML=4.3, I0=60MCS, који се десио у околини Бање Луке

На Слици 3 приказани су епицентри земљотреса који су регистровани на акцелерометријским станицама који су даље коришћене у анализи параметара за припрему овог рада. Сви акцелерограми су екстраховани из континуалних записа и архивирани у mseed формату.



Слика 3. Просторна дистрибуција епицентара земљотреса који су регистровани на акцелерометријским станицама РХМЗ РС

2. СПЕКТАР ОДГОВОРА ЕЛАСТИЧНЕ СРЕДИНЕ

Разорно дејство јачих земљотреса нарочито је изражено у густо изграђеним градским срединама у којима се могу очекивати најтеже посљедице за људе и грађевинске објекте. У урбаним градским срединама већину грађевина чине постојеће зграде које у највећем броју не испуњавају услове одређене најновијим техничким прописима за пројектовање и извођење грађевина изложених утицају земљотреса. Основни циљ правилног пројектовања и извођења грађевина јесте очување људских живота. То значи да се зграде, и при најјачим потресима који се очекују у вијеку трајања грађевине, не би требале срушити, али се значајна оштећења не могу избјећи.

Осим разматрања тзв. сигурносних потреса, некада желимо установити и за коју јачину потреса можемо очекивати појаву првих оштећења на носивим и неносивим елементима. Такви потреси се могу појавити више пута у вијеку трајања неке грађевине. Посебно значење имају грађевине у којима су смјештена критична постројења, значајна за функционисање цијелог друштва. Таква постројења би требала да функционишу и након снажнијих земљотреса. Због тога је важно познавати, односно претпоставити како ће се понашати нека посматрана конструкција за очекивани потрес на том подручју. Другим ријечима, неопходно је провјерити да ли су њена носивост, крутост[4] и дуктилност[5] довољни да би се постигло:

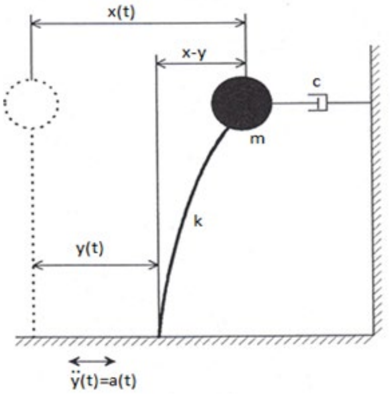
- ограничење деформација
- жељени ниво носивости конструктивних елемената и
- дисипацију енергије унесене потресом.

Ови захтјеви представљају основне циљеве за добро пројектоване асеизмичке конструкције. Након сагледавања могућег одзива конструкције на потрес може се приступити корекцији ако неки од захтјева није испуњен. Као што је познато, земљотрес је веома сложен природни феномен при којем долази до различитих појава, али са инжењерског становишта најважнија је појава помјерања површинских слојева тла.

Иако су многе методе прорачуна засноване на помјерањима, у свим савременим сеизмичким прописима као што су Еврокодови, уобичајене сеизмичке прорачунске процедуре и даље су засноване на силама. Конструкције се прорачунавају за гранично стање носивости на основу јединственог спектра сеизмичког хазарда за различите вриједности повратног периода. За инжењерске потребе приликом пројектовања битна је релација између максималног хоризонталног убрзања тла и интензитета потреса, односно магнитуде, као и спектри одговора еластичне средине добијени на основу записа регистрованих јачих земљотреса. Под појмом спектара одговора еластичне средине подразумијевају се спектри помјераја, брзине и убрзања. У пракси се највише користе спектри убрзања и они су саставни дио свих савремених техничких норми за планирање и грађење у сеизмичким подручјима. Спектар одговора еластичне средине се може дефинисати као скуп максималних одговора система са једним степеном слободе на побуду у облику акцелерограма потреса. Спајањем максималних одговора добија се крива која се назива спектар одговора. Спектар одговора еластичне средине је добијен уз претпоставку о линеарном, односно еластичном понашању средине кроз коју сеизмички талас пролази. Из угла пројектанта, у току земљотреса долази до вибрационог кретања темељног тла на којем је објекат фундиран, те сеизмичко дејство има изразито динамички карактер.

Приказ земљотресног дејства преко спектра одговора еластичне средине условљава анализу конструкције у фреквентном домену, а када је дејство могућег земљотреса дато преко временске историје убрзања тла, анализа се спроводи у временском домену.

Понашање једноставних облика конструкције, са јединственом сопственом периодом осциловања T, при дејству земљотреса се може апроксимирати реакцијом механичког осцилатора (еластичног система) са једним степеном слободе, Слика 4. При томе се његово понашање може квалитетно изразити преко спектра одговора еластичне средине (енг. *elastic response spectra*) на дејство земљотреса, које је репрезентовано регистрованом историјом убрзања тла. Спектар одговора еластичне средине таквог система представља његов максимални одзив у времену, у функцији сопствене периоде побуде манифестоване кроз историју убрзања тла која је саопштена том осцилатору.



Слика 4. Математички модел механичког система са једним степенм слободе

[4] стабилност конструкције и њених елемената да се на одговарајући начин супротставе, свим облицима деформација које изазивају спољашње силе, односно, да настале деформације не прекораче неке дозвољене вриједности

[5] особина материјала да се под утицајем спољашњег напрезања пластично деформише прије него што наступи лом

Осциловање таквог еластичног система је могуће описати тзв. нехомогеном линеарном диференцијалном једначином другог реда, а његов еластични одзив се може срачунати вишеструком сукцесивном нумеричком интеграцијом те једначине, за различите вриједности сопствених периода осцилатора.

Према математичком моделу механичког система са једним степеном слободе, можемо, користећи услов равнотеже свих хоризонталних сила, написати сљедећу диференцијалну једначину кретања:

$$\mathrm{m}[\ddot{u}(t) + \ddot{y}(t)] = -k \cdot u(t) - c\dot{u}(t), \quad (1)$$

гдје је са m обиљежена маса, c пригушење, k крутост система, $\mathrm{u}(t) = x(t) - y(t)$ генералисана координата (релативно помјерање масе), $x(t)$ је апсолутно (укупно) помјерање масе, $y(t)$ помјерање тла, а $\ddot{u}(t)$ убрзање тла.

Даље слиједи:

$$m\ddot{u}(t) + m\ddot{y}(t) + c\dot{u}(t) + ku(t) = 0\,, \quad (2)$$

Дијељењем обје стране једначине (2) са m добијамо:

$$\ddot{u}(t) + \frac{c}{m}\dot{u}(t) + \frac{k}{m}u(t) = -\ddot{y}(t)\,, \quad (3)$$

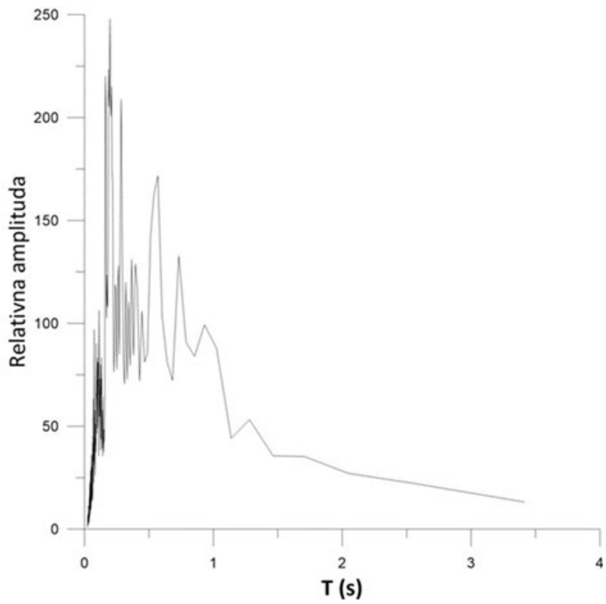
Ако замјенимо да је $\frac{c}{m} = 2n; \frac{k}{m} = \omega^2;\ \ddot{y}(t) = a(t)$ добићемо сљедећи дефинитивни облик једначине кратања:

$$\ddot{u}(t) + 2n\dot{u}(t) + \omega^2 u(t) = -a(t). \quad (4)$$

Рјешавањем дифернцијалне једначине (4) добија се одговор конструкције $\mathrm{u}(t)$ на задато кретање тла у току потреса. Са познатим помијерањем $\mathrm{u}(t)$, сеизмичке силе за вријеме земљотреса одређују се као:

$$F_s(t) = k \cdot u(t) \quad (5)$$

Оваквим поступком се добија спектар одговора еластичне средине који се најчешће представља дијаграмом максималног одзива симплификоване конструкције, односно механичког осцилатора са једним степеном слободе, у функцији сопствене периоде осциловања (*Слика 5*), као и у зависности од задатог пригушења тог система (у пракси се најчешће користи пригушење од 5%).



Слика 5. Ненормирани спектар одговора еластичне средине за земљотрес од 28. априла 2011. године у околини Бање Луке са степена Рихтерове скале (N- компонента)

Конкретан одзив система са једним степеном слободе се може срачунати као функција његовог убрзања, брзине или помјераја. Код осцилација са врло малим периодама, односно код врло крутих конструкција, спектар убрзања еластичне средине тежи вриједности која је еквивалентна величини очекиваног максималног убрзања тла на тој локацији, односно тзв. PGA. Због тога се вриједности убрзања, добијеног спектром одговора еластичне средине, приликом графичког приказивања нормирају са вриједношћу PGA, који је утврђен за одговарајући повратни период времена. Такође се, спектар одговора еластичне средине за одређене вриједности пригушења, увијек приказује у виду апсолутних вриједности.

2.2. Хоризонтални спектар одговора еластичне средине

У Еврокоду 8 за хоризонталне компоненте сеизмичког дејства, препоручени облик пројектног спектра $S_e(T)$ је дефинисан функцијом коју чине четири гране, дефинисане сљедећим изразима, Слика 6:

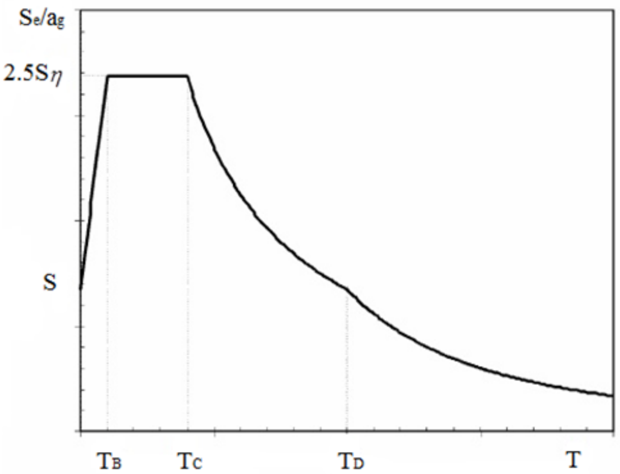
$$S_e(T) = a_g S\left[1 + \frac{T}{T_B}(\eta \cdot 2.5 - 1)\right]; 0 \leq T \leq T_B \quad (6)$$

$$S_e(T) = a_g \cdot S \cdot \eta \cdot 2.5; T_B \leq T \leq T_c \quad (7)$$

$$S_e(T) = a_g \cdot S \cdot \eta \cdot 2.5\left[\frac{T_c}{T}\right]; T_c \leq T \leq T_D \quad (8)$$

$$S_e(T) = a_g S \cdot \eta \cdot 2.5\left[\frac{T_C T_D}{T^2}\right]; T_D \leq T \leq 0.4s \quad (9)$$

при чему је: $S_e(T)$ спектар одговора еластичне средине, a_g пројекто убрзање тла за тло типа А $\left(a_g = \gamma_1 \cdot a_{gR}\right)$, T период вибрација линеарног система са једним степеном слободе, T_B доња граница периода у области са константним спектралним убрзањем, T_c горња граница периода у области са константним спектралним убрзањем, T_D вриједност периода која дефинише почетак области спектра са константним одговором помијерања у спектру, S фактор тла, η фактор корекције пригушења са референтном вриједношћу $\eta = 1$ за вискозно пригушење од 5%.



Слика 6. Облик спектра одговора еластичне средине [1]

Ове четири гране, као што је речено, су одвојене са три карактеристична периода T_B, T_c и T_D, као и фактор тла S, који се у Национаном анексу утврђују као национално одређени параметри омогућавајући прилагођавање спектралног облика сеизмогенетским карактеристикама сваке земље. Избор облика спектра одговора еластичне средине који ће бити коришћен, мора бити дефинисан у Националном анексу. Приликом избора одговарајућег облика спектра, треба да се разматра магнитуда земљотреса која највише доприноси сеизмичком хазарду у пробабилистичкој оцјени хазарда, више него максималан вјеродостојан земљотрес дефинисан за ту потребу.

Дејство потреса у хоризонталној равни се описује са две ортогоналне компоненте које се третирају као међусобно независне и које су приказане истим спектром одговора. За три компоненте сеизмичког дејства, један или више алтернативних облика спектра одговора може да се усвоји, у зависности од сеизмичких жаришта и магнитуда које се генеришу. Када се земљотреси који утичу на дату локацију генеришу из веома различитих жаришта, треба да се размотри могућност да се користи више од једног облика спектра како би било омогућено адекватније приказивање сеизмичког дејства. У таквим околностима, различите вриједности a_g ће бити потребне за сваки тип спектра и земљотреса. Вриједност периода T_B, T_c и T_D као и фактора тла S којима се дефинише облик спектра одговора еластичне средине зависи од категорије тла. Ако се дубока геологија не узима у обзир Еврокод 8 препоручује употребу два типа спектра: тип 1 и тип 2. Уколико су земљотреси који највише доприносе сеизмичком хазарду за посматрану локацију у пробабилистичкој оцјени хазарда, са магнитудама површинских таласа $M_s \leq 5.5$ препоручује се да се узме спектар типа 2, док за земљотресе са магнитудама површинских таласа $M_s > 5.5$ препоручује спектар типа 1. Вриједности параметара који описују препоручене спектре одговора за тип тла А су дати у Табели 3.

Табела 3. Вриједности параметара за земљотресе типа 1 и типа 2 на тлу типа А

Спектар	Категорија тла	S	T_B	T_c	T_D
Тип 1	А	1.0	0.15	0.40	2.0
Тип 2	А	1.0	0.05	0.25	2.0

Вриједност фактора пригушења η може се одредити према изразу:

$$\eta = \sqrt{\frac{10}{5+\xi}} \geq 0.55 \qquad (10)$$

гдје је ξ релативно вискозно пригушење конструкције, изражено у процентима.

Еластични спектар одговора помјерања $S_{De}(T)$ може да се одреди директном трансформацијом спектра одговора убрзања еластичне средине $S_e(T)$ коришћењем сљедећег израза:

$$S_{De}(T) = S_e(T) \cdot \left[\frac{T}{2\pi}\right]^2. \qquad (11)$$

Израз (11) може да се нормално примјењује за периоде вибрација који не прелазе 4.0 s. За конструкције чији је основни период дужи од ове вриједности, неопходна је потпунија дефиниција спектра помјерања.

2.3. Вертикални спектар одговора еластичне средине

Вертикална компонента сеизмичког дејства је представљена еластичним спектаром одговора $S_{ve}(T)$ дефинисан са четири гране сљедећим изразима:

$$S_{ve}(T) = a_{vg} S\left[1 + \frac{T}{T_B}(\eta \cdot 3.0 - 1)\right];\ 0 \leq T \leq T_B \qquad (12)$$

$$S_{ve}(T) = a_{vg} \cdot S \cdot \eta \cdot 3.0;\ T_B \leq T \leq T_c \qquad (13)$$

$$S_{ve}(T) = a_{vg} \cdot S \cdot \eta \cdot 3.0 \cdot \left[\frac{T_c}{T}\right];\ T_c \leq T \leq T_D \qquad (14)$$

$$S_{ve}(T) = a_{vg} \cdot S \cdot \eta \cdot 3.0 \left[\frac{T_C T_D}{T^2}\right];\ T_D \leq T \leq 0.4s \qquad (15)$$

Вриједности које се додијељују параметрима T_B, T_c и T_D и a_{vg} за сваки облик вертикалног спектра који се користи у земљи треба да се дефинише у Националном анексу. Препоручени избор је употреба два типа вертикалног спектра: тип 1 и тип 2. Као и за спектар којим се дефинише хоризонтална компонента сеизмичог дејства, уколико земљотреси који највише доприносе сеизмичком хазарду, дефинисаном за локацију у пробабилистичкој оцјени хазарда, имају магнитудуе површинских таласа $M_s \leq 5.5$ препоручује се да се усвоји спектар типа 2, док за $M_s > 5.5$ препоручује се спектар типа 1. Карактеристични периоди $T_B = 0.05$, $T_c = 0.15$ и $T_D = 1.0$ који описују вертикални спектар одговора су исти за свих пет типова тла, A, B, C, D и E, док се ове препоручене вриједности не односе на специјалне типове тла S_1 и S_2. Однос $\frac{a_{vg}}{a_g}$ =0.9 се препоручује за спектре одговора типа 1, а $\frac{a_{vg}}{a_g} = 0.45$ за спектре одговора типа 2. Фактор тла S не утиче на вертикални спектар одговора еластичне средине. Примјена метода анализе спектара одговора еластичне средине је веома значајна у савременом грађевинарству. У Еврокоду 8 су дефинисани препоручени облици спектра еластичне средине за различите типове тла, али је наведено да су надлежне националне институције мјеродавне за утврђивање оправданости усвајања или измјене препоручених облика спектара одговора. Пројектно помјерање тла d_g које одговара пројектном убрзању тла a_g израчунава се из израза:

$$d_g = 0.025 \cdot a_g \cdot S \cdot T_c \cdot T_D \qquad (16)$$

гдје су чланови у изразу дефинисани у Табели 3 за тло типа А.

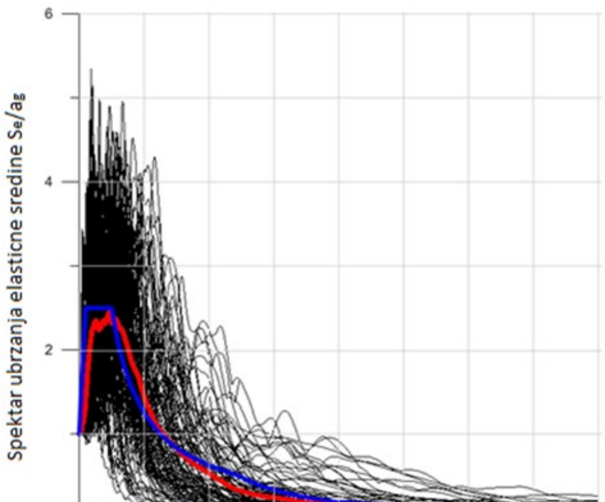
3. СПЕКТАР ОДГОВОРА ЕЛАСТИЧНЕ СРЕДИНЕ ЗА ТЛО ТИПА А У РЕПУБЛИЦИ СРПСКОЈ НА ОСНОВУ ОБРАДЕ БАЗЕ ПОДАТАКА УБРЗАЊА

Национална база акцелерограма Републике Српске садржи само акцелерограме за земљотресе типа 2, тј. земљотресе магнитуда $M_s \leq 5.5$. Из укупне базе акцелерограма за подручје Републике Српске, односно БиХ издвојена је група акцелерограма од 2009. до маја 2015. године за услове чврстог тла, за случај земљотреса типа 2, у циљу поређења облика пројектних спектара са препорученим облицима у Еврокоду 8.

За потребе прорачуна спектара одговора еластичне средине коришћен је компјутерски програм, развијен у Сектору за сеизмологију, Завода за хидрометеорологију и сеизмологију Црне Горе, базиран на нумеричком приступу и рјешењу које су публиковали Nigam и Jennings 1969. године.

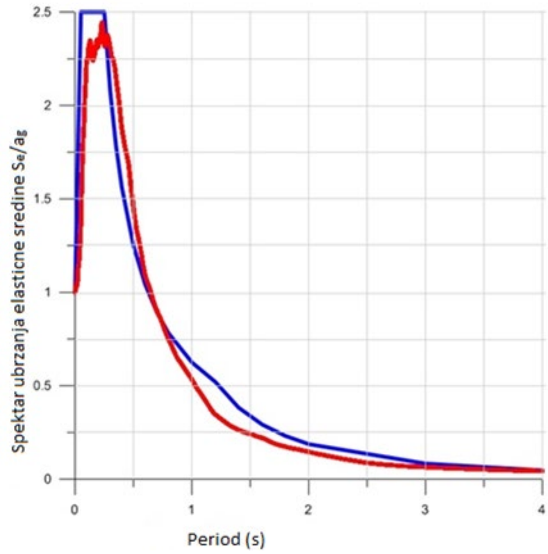
Анализом добијене средње вриједности прорачунатих спектара одговора еластичне средине за 140 временских историја убрзања тла, за тип тла А и земљотресе типа 2, може се генерално констатовати добра корелација са одговарајућим препорученим обликом спектра у највећем домену периода (Слика 7). Срачуната средња вриједност спектара одговора означена је црвеном дебљом линијом, стандардна девијација те функције дебљом зеленом линијом, а препоручени облик пројектног спектра је представљен плавом бојом. Детаљнијом анализом је могуће утврдити сљедеће закључке:

- Периода $T_B = 0.05$, која по препорученом облику пројектног спектра износи 0.05 секунди, на бази обраде хоризонталних историја убрзања, има вриједност око 0.10 секунди.
- Препоручена периода T_c за тип 2 земљотреса на тлу типа А износи 0.25 секунди, док на основу резултата обраде износи око 0.30 секунди.



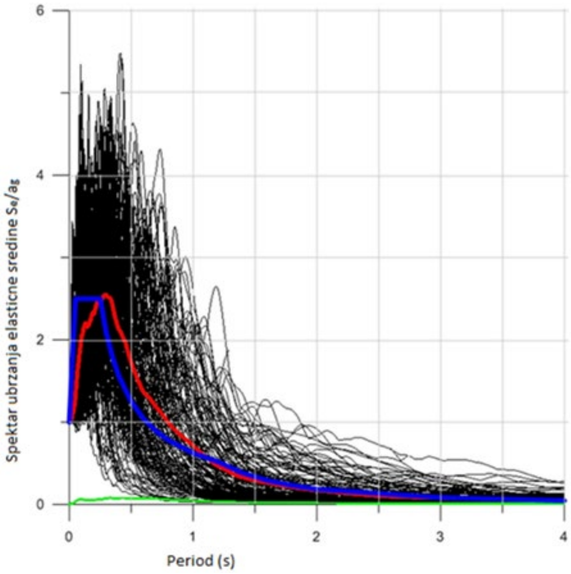
Слика 7. Нормирани хоризонтални спектар одговора еластичне средине у функцији сопствене периоде T за 140 историја убрзања тла и тип 2 земљотреса $M_s \leq 5.5$

Дакле, резултати обраде базе акцелерограма за тло типа А, за случај земљотреса типа 2 су исказали мало, али конзистентно повећање вриједности периода за карактеристичне тачке T_B и T_c на препорученом облику спектра одзива (Слика 8).



Слика 8. Срачунате средње вриједности хоризонталних спектара одговора за тип земљотреса 2 (црвена линија) у поређењу са кореспондентним препорученим обликом пројектног спектра, по Еврокоду 8 (плава линија)

Изложене резултате треба узети у обзир приликом детерминисања параметара у Националном анексу Еврокода 8. Временске историје убрзања тла које су коришћене за прорачун спектара одговора односе се на земљотресе који су регистровани на ближим (до 100 km, Слика 7) и даљим (већим од 100 km, Слика 9) епицентралним растојањима од акцелерометријских станица. Међутим, база акцелерација Републике Српске садржи већи број временских историја убрзања тла за земљотресе који су регистровани на већим епицентралним растојањима од акцелерометријских станица. Стога је извршена и обрада спектара одговора за базу акцелерација која садржи већи број земљотреса регистрованих на даљим епицентралним растојањима, а резултат је приказан *на Слици 9*.



Слика 9. Нормирани хоризонтални спектар одговора еластичне средине у функцији сопствене периоде T за 176 историја убрзања тла и тип 2 земљотреса $M_s \leq 5.5$

Срачуната средња вриједност спектара одговора означена је црвеном дебљом линијом, стандардна девијација те функције дебљом зеленом линијом, а препоручени облик пројектног спектра је представљен плавом бојом. Резултати обраде спектара одговора за 176 акцелерограма, за тип тла А са акцелерометријске станице Бања Лука (BLY) за случај земљотреса типа 2 исказује значајно повећање вриједности периода за карактеристичне тачке T_B и T_c у односу на препоручени облик спектра одговора. Наиме, како је спектар одговора еластичне средине, за земљотресе на већим епицентралним растојањима богатији у домену дужих периода, то је и средња вриједност срачунатих спектара одговора, за карактеристичне тачке и већа у домену дужих периода. Анализирајући многе земљотресе и њихове ефекте на површини тла запажено је да локални услови имају велики утицај на дистрибуцију штета. Да би се урадила карта сеизмичког хазарда за површину локалног тла, неопходна је набавка и постављање већег броја акцелерометара на цијелом простору Републике Српске.

4. ЗАКЉУЧАК

У овом раду је извршена спектрална анализа базе акцелерограма РХМЗ-а ради утврђивања хоризоналног спектра одговора еластичне средине за тло типа А. Без обзира на чињеницу да су на простору Републике Српске, односно БиХ, у ранијој историји, а и даље генерисани и јачи земљотреси од 5.5 степени Рихтерове скале, због недостатка акцелерација јачих земљотреса $\mathrm{M}_s > 5.5$ није било могуће добити карактеристични спектар периода одговора еластичне средине за земљотресе типа 1 на тлу типа А, а тиме ни интервал у којем се могу очекивати максималне могуће амплитуде будућих јачих земљотреса.

Анализом добијених резултата за прорачун хоризонталног спектра одговора за тип тла А и земљотресе типа 2, односно земљотреса за $\mathrm{M}_s \leq 5.5$ еластичне средине, констатована је добра корелација између срачунатих и вриједности препоручених Еурокодом 8, за карактеристичне периоде T_B и T_c. На основу анализиране базе акцелерација Републичког хидрометеоролошког завода Републике Српске, која садржи већи број временских историја убрзања тла за земљотресе који су регистровани на већим епицентралним растојањима (преко 100 km) од коришћене акцелерометријске станице, карактеристични периоди су помјерени у домену виших периода. То представља ограничење у спроведеној анализи, с обзиром на количину и врсту доступних података са којим се располагало. Под тим се подразумијева да, у фонду података на којем је изведена ова анализа, постоје празнине усљед којих је интервал периода максималних очекиваних амплитуда земљотреса који ће бити генерисани у будућности, ускраћен за дио садржаја спектра.

У складу са савременим сеизмолошким мониторингом, Република Српска би требала да има мрежу акцелерометарских станица чији број вишеструко премашује број сеизмолошких станица. Да бисмо могли правилно процијенити сеизмички хазард, било би неопходно регистровати што је више могуће акцелерација једног сеизмичког догађаја, јер се њихове вриједности разликују зависно од удаљености од епицентра, али и од квалитета локалног тла. Ризик од земљотреса је питање јавне сигурности које захтијева одговарајуће мјере и средства управљања ризиком с циљем да се заштите имовина, становништво, инфраструктура, природна средина и културно насљеђе.

ЛИТЕРАТУРА:

[1] Eurocode 8: Design of structures for earthquake resstance - Part 1: General rules, seismic action and rules for buildings

[2] Snježana N. Cvijić, Analiza podataka u cilju određivanja nacionalnih parametara prema Evrokodu 8 za prostor Republike Srpske, magisarska teza, Beograd, 2016. godine

33 | Professional paper I Стручни рад
ISSN 2566-4484 I Doi 10.7251/STP2014362U
pages 362-367

Mato Uljarević, mato.uljarevic@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

Ljubomir Palikuća, ljubomir.palikuca@yahoo.com, Integral Inženjering a.d. Laktaši

RELIABILITY OF THE RISK ANALYSIS IN MAKING DECISIONS ABOUT VARIANT SOLUTIONS ACCEPTABILITY OF THE PLANNED ROAD

Abstract:

Realization of the infrastructural structures is connected with the decisions based on hazard geotechnical insight occurrence and risk analysis in the planned road zone. Adopting new road route, the risk which correspond to the subject route is accepted and it requires appropriate technical solutions. In this work, in example of the new road has pointed on the quality risk analysis importance by making decision about proposed route acceptance of the new road.

Keywords: New road, geotechnical hazard, risk, decision

ПОУЗДАНОСТ АНАЛИЗЕ РИЗИКА У ДОНОШЕЊУ ОДЛУКА О ПРИХВАТЉИВОСТИ ВАРИЈАНТНИХ РЈЕШЕЊА ПЛАНИРАНЕ САОБРАЋАЈНИЦЕ

Сажетак:

Реализација инфраструктурних објеката повезана је са одлукама темељеним на сагледавању хазардних геотехничких појава и анализи ризика у зони планиране саобраћајнице. Усвајањем трасе нове саобраћајнице прихваћен је и ризик који припада предметној траси, што захтијева одговарајућа техничка рјешења. У раду је, на примјеру нове саобраћајнице, указано на важност квалитетне анализе ризика у доношењу одлуке о прихватљивости предложене трасе нове саобраћајнице.

Кључне ријечи: Нова саобраћајница, геотехнички хазард, ризик, одлука

1. INTRODUCTION

The road design process is excelled with high complexion and multidisciplinary level. To define spatial position these structures which are "laying" on the ground, it is needed different kind parameter analysis, including risk analysis. The scope and kind of the previous analysis, depending of the road significance and desired service level will be different. The final result of all analysis and itself design process is the route, chosen so that with minimal environment disruption and minimal investments, acceptable solution can be provided [2:199-200]. The most important methodological step for appropriate risk management is risk assessment. Assessment and risk analysis is complex procedure which by indirect way describes all problem measure endangered environment and resulting repercussions. Risk analysis is the key phase in risk management and it provides basis for management risk system. In it needed data related for identified risks and realization of the set goals can be got. Risk analysis is very complicated procedure, in which many parameters and occurrences can be taking into consideration, analysis conducting always should perceive from costs aspect which it will produce. It is needed to do event generation on the project area, frequency determination, intensity and other properties potential catastrophic occurrences. Also, historical analysis data should be done and project area characteristics (seismic, geological, topographical, atmospheric) which may have influence on natural hazard probability in the future and consider probability and consequences of every hazard element on the environment, and do evaluation (low, middle, high). Probability and consequence for every hazard scenario should be considered for the subject risk [1]. Deficiency of quality assessment and risk analysis on the subject area of exploring in zone of planned road has become to the bad projected solutions and significantly price increase and prolongation of the works deadlines, which have been presented in this work.

2. DESCRIPTION OF THE SUBJECT ROUTE ROAD

In frame of this chapter the basic space and structural characteristic of the new projected highway E – 75 have been presented. The subject of analysis in this work is section Grdelica – Caričina Dolina. The highway route on this section is passing through two types of different topographical features: plains – highway route is on the South Morava river diluvium, hilly – with route in the cut or in the deep cut with the steep slopes of the left coast South Morava river. At the section beginning, the route comes in the Grdelica's gorge and extends in parallel to the Niš – Skoplje railway, to the highway M-1 and regional road R-214. Because of the topographical and infrastructural limitations, route passes along the valley and crosses the South Morava river seven times by structures of the different lengths. In the zone of the Predejane settlement, the highway route is in the tunnel because hilly ground in that area [3:21-22]. One very important area characteristic of the highway E -75 is existing of the intense exodynamic processes which occur in the way of the surface decomposition, erosion and layering but also sliding and scattering. The process of the surface decomposition is present on the whole area and thickness of the decomposed parts depends primarily from the age and lithological structure of rock mass, then from external influence intensity. The process of the surface erosion and linear erosion are especially visible in Grdelica's gorge. Relatively steep ground sides become to the uniform erosion transformation, to concentration atmospheric precipitate in waterfalls which destroy and taking away the ground. These waterfalls become torrent which thickness even goes up to the 20 m. The South Morava River has in total 2092 tributaries which genesis corresponds to the different hydrographical classes of the water roads family. Water spills were often in the past, especially in Grdelica's gorge area and this area can be considered like a world water phenomenon. Ditches are common for Grdelica's gorge area, where it has been registered them around 200. They are relatively fixed by dikes after catastrophic water spills. Sliding and dispersal process also is connected for the Grdelica's gorge area and it mainly arises in case of a half-bounded loose material [3:35-36].

3. PROJECT APPROACH ANALYSIS

On the figure 1. it has been shown subject road location. From point A to the point B it has been constructed a road in the cut in length of around ca. 1300 m. Another part from point B to the point C in length of ca. 1000 m a tunnel has been constructed (a variant solution constructed).

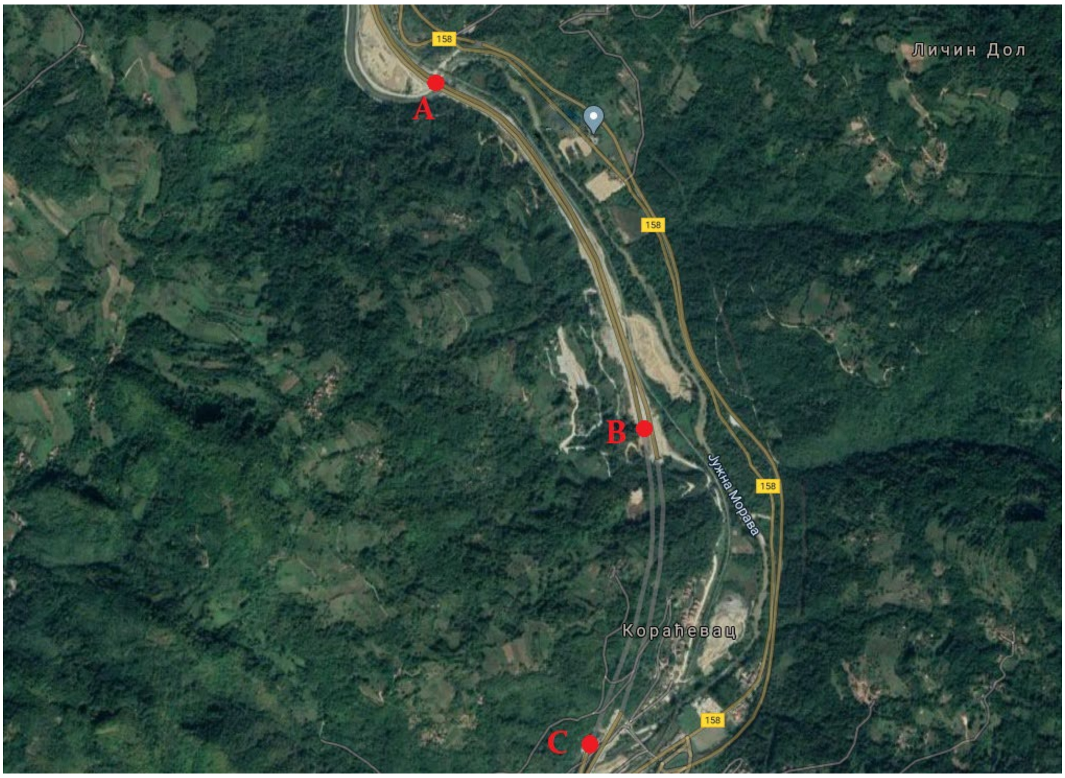


Figure 1. *The subject road*

Realization of this variant solution is constructed throught the phases. Based on previously collected data, designing has began and afterwards and performing. Immediately after works completion it has came to the stability disruption of conditionally stable slope and landslide activation just in front of the tunnel (Figure 2). Formed landslide was theatening the highway route, performed slopes and support structures but also structures beyond expropriation on the slope.

Figure 2. *Formed landslide on the slope 2*

By project task is required that rehabilitation solution for land slide and slope stabilization should be performed in phases with two supporting structures from piles K1 and K2. During structure K1 performing, which has a role to protect directly highway hull, certain sliding body activities have been registrated, and they have been interpreted by activating an even more unfavorable slip mechanism compared to the solution model. Considering that situation on the ground has been changed, beside almost designed supporting structures K1 and K2, another supporting structure was designed from pile K3 (Figure 3).

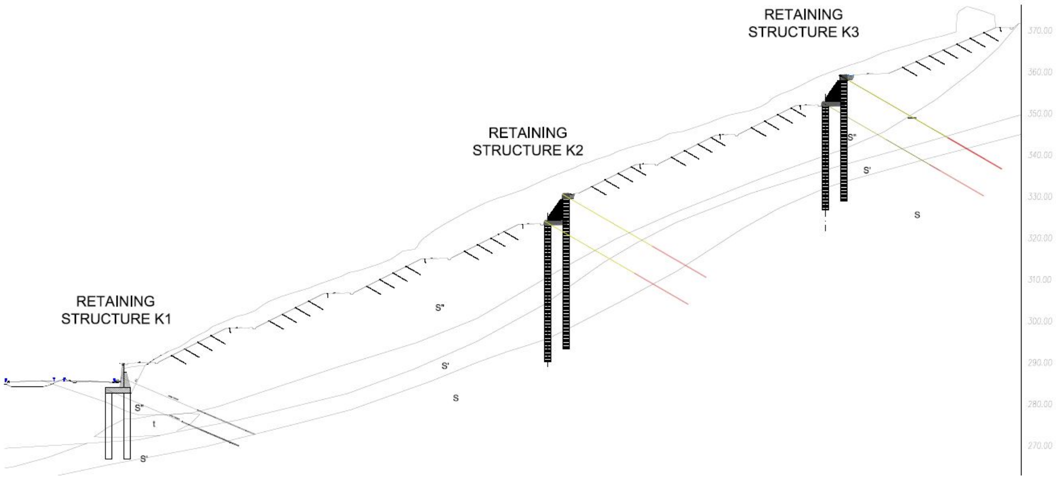


Figure 3. *Retaining structure*

In the meantime, additional geotechnical fieldwork, exploratory works and exploratory wells were carried out in which inclinometers and piezometers were installed, as well as an appropriate laboratory tests which were the basis for study which has served like one of the substrates to access the rehabilitation and stabilization process subject slope. Based on the results obtained geotechnical results, engineering-geological ground mapping and defined spread of the colluvial process on the slope, registered landslides elements (scars, jumps, belly, crack sand similar), it has been defined mechanism of the process which has served like basis for static analysis and slope stabilization problem solving.[4:1-2] Activities listed have caused prolongations of the completion deadlines and work price increase. Previous testing and exploring were not enough good analyzed hazard occurrence on subject location, and therefore the risk could not be analyzed, so it was not evaluated that sliding will occur. Parallel with work performing on the slope 2, the works on the slope 1 are performing also. It is about the same problem, so by original design solutions (supporting structure from micro piles with geotechnical anchors) it could not get the permanently solution. Unloading of the work and reinforcement of the slope with protective nets and anchors is carried out (Figure 4).

Figure 4. *Formed landslide on the slope 1*

If at the beginning there were complete information about geotechnical substrate, probably it would be considered other variant solutions. It is possible that design solution, in the goal of optimality, could require also the road route correction (by situation and by height). Probably and final defined solution would be optimal, but that done in the beginning phase, in the high measure would eliminate additional costs due to the work extension, deadlock in design, and finally, direct income loss from previous road commissioning [2:202-203]. By analyzing previous listed problems related for wrong assessment and risk analysis, a conclusion is imposed that all happenings could be avoided by tunnel tube prolongation from the point A to the point C (Figure 5).

Figure 5. *Tunnel tube extension*

Comparing two variants, there is conclusion that unsufficient research and unsufficient analysis, but also bad substrate preparation for designed documentation, inevitably leads to the performing works price increases and deadlines completition prolongation. Constructed tunnel is about one kilometer long (B-C). Contracted tunnel construction value along one meter was ca. 16 800 euros. Landslides rehabilitation construction value on the slope 2 is ca. 89 000 euros. Tunnel tube prolongation is about 1300 m. In the table 1 there were shown total structures lengths, also as performing time and costs. Listed data analysis gives the conclusion that the tunnel construction on the subject location would be more cost effective than slope rehabilitation, with less period of construction.

Table 1.

	Road A-B/Slope 2	Tunnel part of the road
Construction begining	2014./2017.	Assessment: ca. 2 years
Construction end	2020.	
Lenght (m)	1300 m/420 m	1300 m
Price (euros)	ca. 89 000 euros per m	ca. 16 800 euros per m

4. CONCLUSION

All listed problems in this work start on the bad risk analysis. Correct and good risk assessment for some hazard occurrence should show which problem we will potentially face with during designing and constructing. Based on the small cognition scope, on the concrete road example, the risk analysis was not correctly done what has caused multiple price increases of the project. There is always the question which scope of the geotechnical works is needed for good basis for design in all phases and how reliable that data is. Constructing of the geotechnical works (retaining structures and tunnels) is one of the most expensive and the most challenging activities in constructing. Time period and costs directly depend from geotechnical research works. Timely perceived geotechnical conditions can facilitate or, in opposite also to get worse constructing process. On time noticed and analyzed geotechnical conditions are base for quality design and successful and quality constructing. Reliability is defined like a safe work probability of the infrastructure system when the resistance of the system is grater or equal to the load. The reliability analysis thus set, does not consider time variability of the load and resistance, but observes the most unfavorable possible load, what in literature is called static reliability analysis. In cases when infrastructural systems have longer life span and they are susceptible to different natural processes, it is needed to follow the coincidence of load occurrence and possible resistance changes of the system during the time. Such examples are time-dependent reliability analysis. Geotechnical ground properties are of the particular importance for design, because in the high measure they have influence on the designed solution, feasibility and costs. Therefore, geotechnical researches and testing, also as observations present the base for design, constructing and structure maintenance. In many cases geological and geotechnical conditions can adjudicate for the variant (design) solution selection. This is especially related to an optimal corridor selection and new road route. On example of the highway route section, just in front of the tunnel, it is indicated on the importance of the quality risk analysis by making decisions about acceptability of the proposed new road route.

LITERATURE

[1] Miroljub D. Grozdanović, Evica I. Stojiljković, Risk Assesstment Methods, Niš, 2013.

[2] Ljubomir Palikuća, Mato Uljarević, Đorđe Raljić, Boško Miljević, „Geohazard's Analysis of Road Implementation“ in Proceedings of the 4th Regional Symposium on Landslides in the Adriatic - Balkan Region, 2019, pp. 199 – 203

[3] Preliminary Highway Design, Coridor X E-75 NIŠ – border BJRM section: Grabovnica – border BJRM, Environmental protection report – The Final version, May 2009, pp. 21 - 36

[4] Project documentation – Slope rehabilitation design, Suporting structures with piles K2 from km 879+371,38 to km 879+737,53 and suporting structures with piles K3 from km 879+403,81 to km 879+608,41, Belgrade, 2018.

34 | Professional paper I Стручни рад
ISSN 2566-4484 I Doi 10.7251/STP2014368J
pages 368-374

Vojkan Jovičić, keynote lecturer, vojkan.jovicic@irgo.si, University of Ljubljana

TUNNEL DESIGN CHALLENGES AT THE EXAMPLE OF DIVAČA KOPER RAILWAY LINE

Abstract:

New Divača-Koper railway runs through the karst area associated with the major thrust fault, which divides limestone and flysch strata known as the Karst Edge. Due to some 400m high difference in altitude between Divača and Koper most of the railway line runs underground, featuring two six to seven kilometers long tunnels. Two types of tunneling methods were considered: TBM and drill and blast method based on NATM. The advantages and shortcomings of each method are discussed and the set of reasons is given why TBM was not selected as a preferred solution. The main design challenges encompassing the overcoming of the karst phenomena and protection of the water resources are presented in the paper.

Keywords: tunnel design, karst phenomena, TBM, NATM, protection of water resources

ИЗАЗОВИ ПРИ ПРОЈЕКТОВАЊУ ТУНЕЛА НА ПРИМЕРУ ЖЕЛЕЗНИЧКЕ ПРУГЕ ДИВАЧА КОПЕР

Абстрацт:

Нова железничка пруга Дивача-Копер пролази кроз подручје краса кога карактеризира повратни расед који дели кречњачке и флишне слојеве, познат као Крашки руб. С обзиром на висинску разлику од 400 m између Диваче и Копра, највећи део железничке пруге пролази испод површине терена. Два тунела дужине шест и седам километара ће пролазити кроз високо карстифицирану стенску масу. Разматране су две методе тунелоградње: ТВМ и конвенционална метода NATM. Расправљене су предности и недостаци ових метода са приказом разлога због којих ТБМ није одабран. У чланку су представљени главни изазови при пројектовању тунела укључујући савлађивање карстних појава и заштиту водних ресурса.

Кључне ријечи: пројектовање тунела, карстне појаве, ТВМ, NATM, заштита водних ресурса

1. INTRODUCTION

The new Divača–Koper railway line connects the port of Koper with major logistic railway junction of Divača. The 27.1 km long route overcomes 400 m high difference in altitude between karst plateau and sea level in difficult ground conditions. The required maximum inclination of the railway track of 1.7% dictates that almost 75% of the railway line runs underground. The main challenge is the construction of the two tunnels T1 and T2, which are six to seven kilometres long and run through heavily karstified rock mass. The exemplary design solutions for tunnelling in karst are presented for tunnel T1. Similar design solutions were applied for tunnel T2 6.[1]. Tunnel T1 is the twin tunnel comprising the 6727 m long main tube and 6683 m service tube while tunnel T2 is also the twin tunnel comprising the 6017 m long main tube and 6028 m service tube.

Service tube will be used as a rescue facility and is equipped to provide access of the vehicles and to aid the ventilation in the case of fire. However, both tubes are of the same shape so that the service tube can host the railway track in the future. The size of the excavation profile for both tubes is some 75 m2, the operational bright width and height are 6,86 m and 7,00 m, respectively. There are 13 passages along the tunnel T1 and 12 along the tunnel T2, which are distributed at approximate distances of 500 m. The passages are designed to allow access to rescue vehicles and to host power supply stations.

2. GEOLOGICAL FEATURES ALONG THE ROUTE

Between Kozina and Koper there is the border area between Istria, belonging to Dinaric foreland, and Kras (Slovene word for Karst) that belong to the External Dinarides. This imbricate geological structure, formed between Eocene and Oligocene, is known as Karst Edge or Karst Rim. The main feature of Karst Edge is the sequence of thrust faults overlapping Cretaceous, Paleocene, Lower and Middle Eocene carbonate beds with transition to marl and flysch rocks of Eocene age. The faults were active in post-Miocene times due to under-thrusting of Istrian peninsula under the mainland External Dinarides 6.[9].

This sub-thrusting belt is a geomorphologic phenomenon that is intermittently exposed from Gulf of Kvarner to Gulf of Trieste (see Figure 1) in the form of high limestone cliffs overlying fertile flysch terraces. The overlap of thrust faults formed ideal conditions for the formation of karst features in the Slovenian Karst plateau, which extends east of Karst Edge.

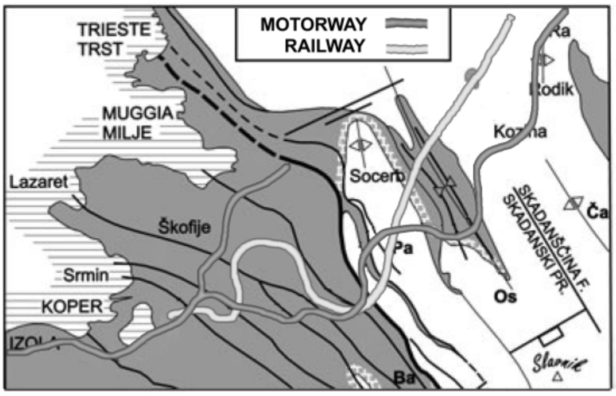


Figure 1. *Simplified scheme of Karst Edge (heavy black line), separating in parts flysch rock formations (in grey) from carbonate rocks (in white) 6.[9].*

In the typical sequence, the underlying flysch acts as an aquitard, holding the significant water retention to water bearing limestone above. As a result, a substantial karstification of the limestone is present at Karst plateau featuring the well-known Postojna and Škocjan caves, which are among the biggest cave systems in Europe. Additional karstification is occurring along sub-vertical faults and fractures giving way to vertical run-off of the almost entire net rainfall 6.[3].

As shown in Figure 1, the new Divača-Koper railway line is crossing Karst Edge in the close proximity to the existing motorway. The construction of the motorway was instrumental in obtaining the geological and hydrogeological information of this complex geological sequence. However, the motorway layout is spatially placed much higher than that of the railway. Additional site investigations, which were carried out at larger depths, revealed zones of different levels of karstification along the railway route. This is schematically shown in Figure 2 on the example of tunnels T1 and T2. It can be seen in the figure that most of the tunnel T2 runs through the highly karstified limestone with the expecting cavities of maximum diameters of up to 10 m. Tunnel T1 features three different levels of the expected karstification in terms of the cavity diameter (up to 5 m, 5-10 m and up to 10 m), as indicated in the figure. At the same time, both tunnels have transition fault zone to and sections in flysch geological sequence, which are some 0.7 km and 1.5 km long in T1 and T2 respectively.

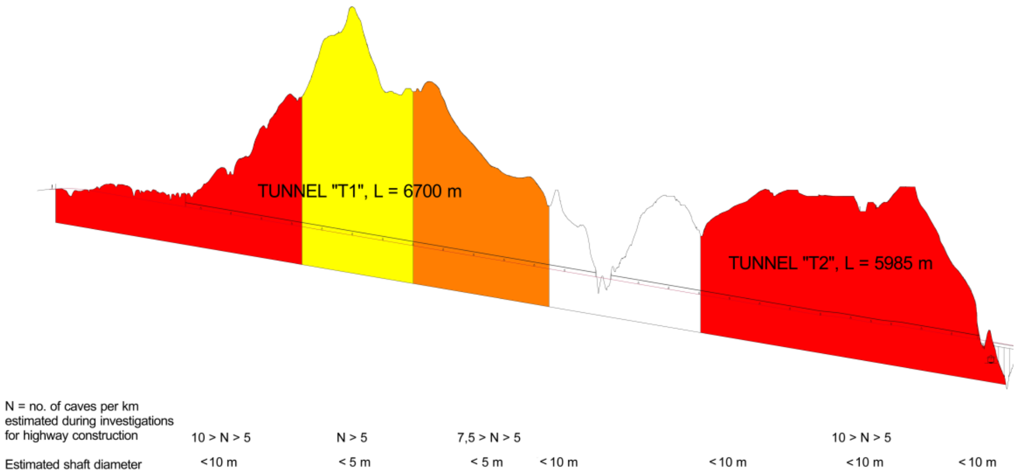


Figure 2. *Distribution of karstification along tunnels T1 and T2 (flysch sections in white).*

3. THE CHOICE OF TUNNELLING METHOD

The two types of tunnelling methods were considered: TBM (Tunnel Boring Machine) and drill and blast method based on the NATM (New Austrian Tunnelling Method) concept. The use of TBM method looked plausible, given that the lengths of the two main tunnels T1 and T2 were more than 6 km.

It is generally accepted that TBM method can be appropriate for tunnels, which are at least 3 to 4 km long. This condition is based on the assessment of the length of the drive needed to compensate the high mobilisation costs. In general, the TBM method is considered the most efficient in homogeneous rock mass or soil in which large lengths of sequence drives can be achieved using the same excavation tools and techniques. The success of TBM technology is dependent on the adequate preparation of the portal areas, resilience of the power supply, maintenance capability, competence of the crew, and above all the appropriate selection of TBM machine for the given variety of the geological conditions 6.[5]. As it will be explained further, not all of these circumstances could have been successfully met for the construction of the Divača-Koper railway.

The first consideration is that both tunnels have a sequence of considerable length in flysch geological sequence and there is a major fault transition from flysch into karstified limestone along the route, which is water bearing 6.[2]. For these difficult conditions an open type TBM, which will be otherwise fully appropriate for the limestone conditions, could not be used. A ″mixed shield″ machine would be needed, to offer appropriate alternations of the working regime 6.[5]. Additionally, in the conditions of the water-bearing fault, in which high inflow of water is expected an EPB type of the machine would be the most suitable to maintain the stability of the head of the excavation.

A further and decisive difficulty for using TBM in karst is the high probability of the total loss of the machine. This might occur due to a partial fall into the karst cave causing derailment and damage of the machine. The total loss can be caused also by a sudden flooding of the cavity. Both events are highly realistic scenarios for the given geological and hydrological conditions. Further on, along the full length of the both tunnels there would be sections, in which the karst features clash with the tunnel route. For these cases unique design solutions must be devised and implemented. Under these circumstances, the TBM method would not be useful, as it does not offer possibility of an easy access to the clash area needed for the immediate remedial action. There was no doubt that all these obstacles would significantly hamper the progress of TBM drive and slow it down, up to the point of no usability. For the reasons given above the TBM method was ruled out as a possible construction method.

It was considered that for the given geological and hydrogeological conditions the classic drill and blast method carries more flexibility and less risk for the tunnelling construction works. This method is easily adapted to any geological conditions and offers different solutions to overcome severe hydrological conditions (e.g. pre-drilling, pre-drainage and embracing drainage boreholes, use of pilot tunnels and others). Most importantly, the method enables direct access to the area of the cavity in the case of a clash. This allows for the immediate development of appropriate remedial and reconstruction measures 6.[6],6.[7].

4. PROTECTION OF WATER RESOURCES

Design solution considered mutual interference of ground water and tunnel construction. Hydrogeological investigation, that involved installation and long term monitoring of piezometers at significant locations, showed that most of the tunnel construction would be below the water table, with the maximum head of some 100 m 6.[3]. The design solution was governed by the necessity to release the water pressures so that majority of the tunnel was designed as ″drained″, featuring the drainage system comprising the watertight membrane and the longitudinal drainage pipes. Given that the water pressures will be released by the drainage system there was no need to reinforce the inner lining of the tunnel.

Certain sections of the tunnel were designed to be ″undrained″ so that they retain the hydrostatical water pressures. There were two reasons for this necessity: a) the water in the given karst conditions flows through the network of connected vessels so the oscillations in the water table can be quite rapid making the tunnel drainage capacity temporarily inadequate, and b) if the tunnel drainage takes too much water it can deplete water resources in the long term. The importance of the second argument was further amplified by the fact that part of tunnel T2 runs through the protected water-supply zone for the two major cities Koper and Trieste. For the ″undrained″ section, the tunnel was shaped to be almost circular and the lining was dimensioned to take 100 m of the water column pressures.

Given that the in the ″undrained″ variant the inner lining of the tunnel has to take the pressures of up to 10 bars, the necessary amount of reinforcement was significant. Consequently, the expense of the construction of the undrained variant of the tunnel is significantly higher (up to 30%) than for the drained variant. The decision on which part of the tunnel would be constructed in either of the variants was based on the consideration how much water will be permanently taken from the aquifer by the drained version of tunnel. If the estimate was that this amount will be unacceptably high (more than 20 l/minute per 100 m of tunnel length) at particular section the ″undrained″ variant will be considered. However, if at this section the limiting water pressure was expected to be higher than 10 bars, the drained version was still the only option. In that case the rock mass in the vicinity of the tunnel excavation will be grouted using cement grouting, with an aim to reduce the permeability of the rock mass up to the required level.

The issue of permanent water intake is defined by the amount of rock mass transmissivity along the certain section of the tunnel. The transmissivity is dependent on the thickness of the aquifer and on the type and magnitude of the conductivity of the rock mass. At this particular project the presence of karstic features added a considerable complexity to this consideration. In karstic aquifer, there is an interplay of matrix, fracture and channel (e.g. through karstic phenomena) porosity, which defines the magnitude of rock mass conductivity, as indicated in Figure 3 6.[4].

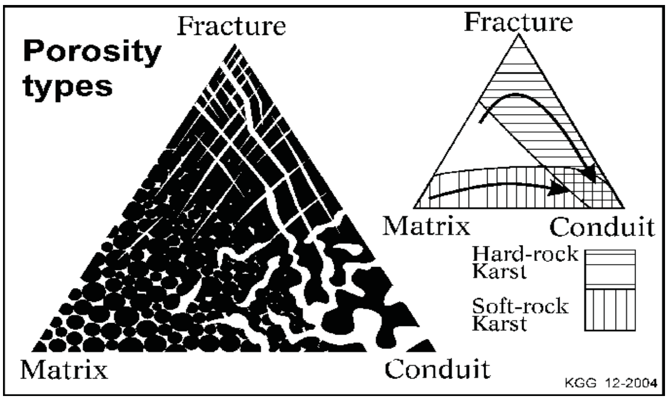


Figure 3. *Interplay between matrix, fracture and conduit porosity within karstified rock mass*

As it can be seen from the diagram of the piezometric measurement in real time, shown in Figure 4, as a result of channel permeability within karstic phenomena, certain water levels were oscillating up to 140 m in several hours following precipitation. On the other hand, other piezometers showed low sensitivity to precipitation indicating dominating impact of matrix or fracture porosity.

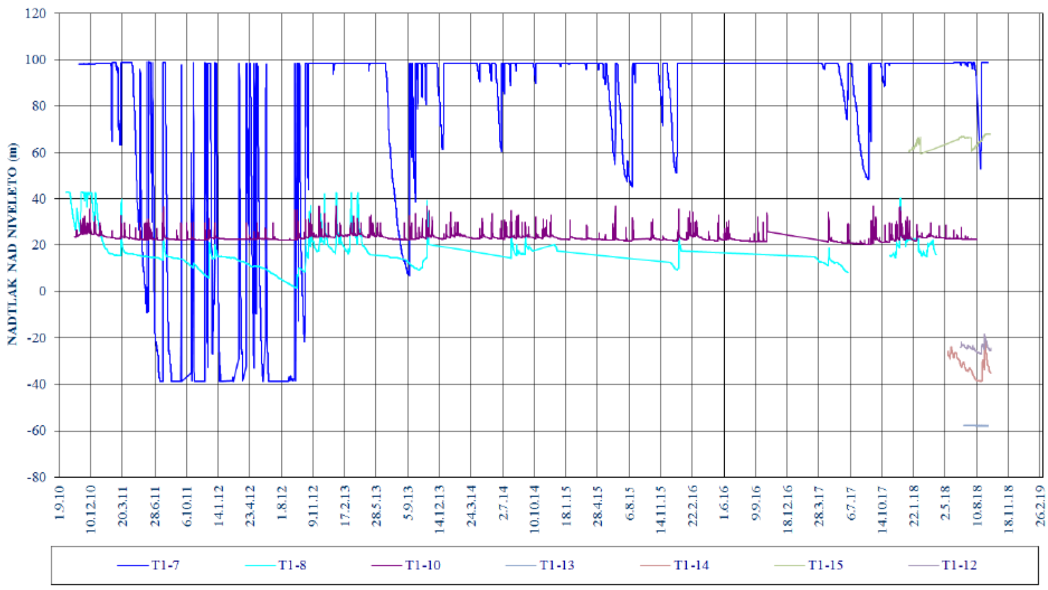


Figure 4. *Measurement of different piezometers in real time indicating the dominant type of porosity at particular location.*

In this case, it was necessary to develop a precise system of decision making by considering all the necessary information, which can be acquired using geological and geotechnical monitoring during the excavation of the tunnel. The geotechnical and hydrogeological monitoring was designed to provide with the following information: water pressures, immediate water inflow, pressures drop, the results of lugeon tests in the case of the absence of the water and the long-term water inflow along the critical section of the tunnel.

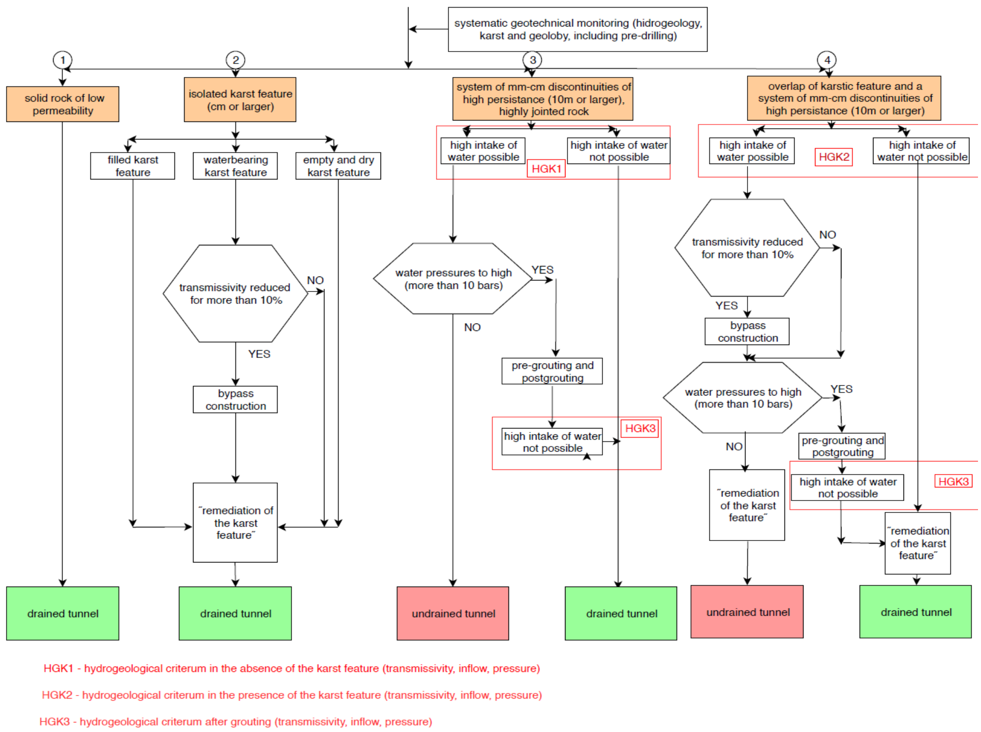


Figure 5. *A decision-making chart for the undrained and drained section of the tunnel*

A decision making chart on construction of drained or undrained variant of the tunnel at a certain section is presented in Figure 5. The decision making process considers three different types of porosities: a) matrix, b) conduit (isolated karst phenomena) and c) fracture, by dealing with four different activity scenarios: 1) use of cement grouting to lower the matrix or rock joint porosity, 2) diverting the water flow of isolated karst features, with an aim not to restrain conduit transmissivity, 3) construct the undrained tunnel to prevent the water intake overall and 4) a combinations of measures 1), 2) and 3) if there is an overlap of conduit and fracture porosity. As indicated in the figure, if the water pressures are too high for the undrained variant (e.g. higher than 10 bars) the grouting and the use of drained variant will be considered. The most complicated case is the interplay between fracture and conduit porosity, in which the measure of grouting might not be fully efficient. In this case a post-grouting will be carried out until the required water intake criteria is not satisfied.

The influence of the water inflow was also considered for the temporary conditions of the tunnel excavation. The protective ″water doors″ are designed to be installed along the tunnel at the frequency of the tube passages. In the case of the rapid water inflow the ″water doors″ are closed so that working force and machinery can be removed from the endangered zones into the safe tube and out.

As a last measure to prevent depletion of water resources, a design solution was developed to return the water collected in the ″drained″ sections of the tunnel into the aquifer in the areas of the karst caves. The discharge system is located in the ″undrained″ section so that the water collected along the ″drained″ section can be released back into the environment. The one-way system is closed so that allows the movement of water only in the direction of the discharge. The discharge equipment is planned to be installed in the separate niche so that it can be easily maintained.

5. TYPICAL DESIGN SOLUTIONS TO OVERCOME CLASHES WITH KARST FEATURES

The support measures in tunnel T1 were designed according to the principles of NATM method 6.[8] using Austrian standard ÖNORM B 2203-1. The tunnel route passes mainly through limestone and some 8% through flysch including a major fault zone in between the two rock formations.

For this geotechnical environment and for the given height of overburden (max. value of 400 m) some 5 different behavioural types (BTs) were devised, with a dominant type BT2, which is associated with deep continuous cracks and possible shear failure. There were 6 different matrix types to define 29 support types for ″drained″ and 9 for ″undrained″ type of profile. However, the sole application of the standards is not appropriate for the support measures in the clashing positions with the karst features, so the entirely different approach was needed to resolve this design challenge.

In order to develop a systematic approach in devising actions in the case of a clash, the karst features were divided into different categories by: a) position relative to the tunnel layout (middle, side, above and below), b) size (up to 5 m^3, 5 – 10 m^3, up to 50 m^3), c) filling (empty or filled with clayey material), and d) presence of water (dry or water bearing).

For each of the possible combination of the conditions a) to d) a matrix of actions was devised and remedial measures were defined in principle, so that karst obstacles can to be addressed on the basis of their significance. The key significant issues were isolated as: a) stability of the tunnel, both temporary and in the long run, b) sustainability of the maintenance and c) preservation of the encountered hydrogeological conditions and existing waterways. A set of actions was predicted to detect the type and the size of the clashing karst features including afore and radial pre-drilling and use of geophysical investigation methods. Remedial and reconstruction measures were further divided into several different categories relative to the impact they have on the progress of the works; a) not postponing the main excavation (e.g. 10 m^3 karst feature out of the main axis) b) delaying the main excavation and requiring immediate action (e.g. 50 m^3 karst feature with water inflow) and c) halting the main excavation (e.g. 100 m^3 karst feature with water inflow). These events were also categorised in terms of the risk of appearance and appropriate allowances for the delays were taken into account in the programme of the works and in the bill of quantities.

The remedial and reconstruction measures encompassed the following activities: filling, ground improvement, grouting, compaction, water-proofing, enforcement of the secondary lining and provisions of the drainage paths for the existing underground waterways. Some typical design solutions for the remedial and reconstruction measures are described in Figure 6.

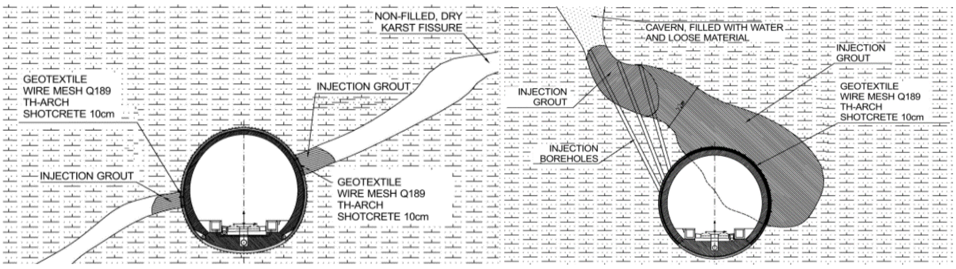


Figure 6. *Examples of remediation of the karst channels intersecting the tunnel.*

6. CONCLUSIONS

The paper presents demanding geological and hydrogeological conditions facing the construction of Divača- Koper railway line. A set of arguments is presented explaining why TBM technology was regarded not suitable for heavily karstifed rock at this location. The main governing principles for tunnel design are presented including the influence of ground water on tunnelling as well as clash of the tunnel layout with the karst features. Challenges in tunnel design were highlighted and design solutions were presented emphasizing the importance of geological and geotechnical monitoring during the tunnel excavation to aid the decision-making process in terms of selection of the type of tunnel construction.

LITERATURE

[1] Direkcija RS za infrastrukturo, 2018 št. 3610/P: Projekt PGD drugi tir železniške proge Divača- Koper, odsek Divača – Črni Kal z vsemi načrti, SŽ Projektivno podjetje, Ljubljana. (in Slovene)

[2] Zavod za gradbeništvo, 2010. Geološko-geotehnični podatki, pridobljeni na podlagi geološko-geotehničnih raziskav za fazo projekta PGD na območju predora T1, ki so zbrani v geološko-geotehničnem poročilu za predor T1, št. T1-2003353/7, november 2010. (in Slovene)

[3] ZRMK, d.o.o., 2018, Preliminarno poročilo s področja hidrogeologije, krasosolovja, strukturne geologije in geomehanike, št. 2006190-1/PP2. Ljubljana. (in Slovene)

[4] Grimes, K.G 2006. »Syngenetic Karst in Australia: a review«. Helictite. 39. 27-38.

[5] Maidl, B. et al. 2012. Mechanised Shield Tunnelling. Wilhelm und Sohn, Berlin. 470 p.

[6] Marinos, P. G. 2001. »Tunnelling and mining in Karstic Terrain; An Engineering Challenge«. Geotechnical and Environmental Applications of Karst Geology and Hidrogeology. Balkema publication.

[7] Milanović, P., 2000, Geological Engineering in karst. Zebra Publ. Belgrade 347p.

[8] Rabcevicz, L. v., 1964/1965. The new Austrian Tunelling Method. Water Power, part 1 and part 2, November 1964 pp. 511-515 and January 1965 pp. 19-24.

[9] Placer L. 2007 Kraški rob (Karst Edge landscape term), Geologic section along the motorway Kozina – Koper, GEOLOGIJA 50/1, 29–44, Ljubljana. (in Slovene)

35 | Professional paper | Стручни рад
ISSN 2566-4484 | Doi 10.7251/STP2014375L
pages 375-387

Dragan C. Lukić, drlukic.lukic@gmail.co, Faculty of Civil Engineering, Subotica, University of Novi Sad

Elefterija Zlatanović, elefterija.zlatanovic@gaf.ni.ac.rs, Faculty of Civil Engineering and Architecture, Univerisity of Niš

HIGH-SPEED TRAINS – MAGLEV TRAINS

Abstract:

The development of megacities, with a large population, imposes increasing mobility in order to maintain the economic and social development. There is a great necessity for a contemporary and new infrastructure at the urban, suburban, intercity, and international level. At the same time, there is also a need to improve transport in terms of environmental protection, to reduce effects such as noise, pollution, and congestion. The latest researches show that by 2050, carbon dioxide (CO_2) emissions need to be reduced by 75%. This reduction can be achieved only by applying new technologies of transportation systems. One of these technologies, which is shown in this work, is the Maglev system for trains of high speed.

Keywords: infrastructure, conventional rail, maglev system, route, levitation

ВОЗОВИ ВЕЛИКИХ БРЗИНА – МАГЛЕВ ВОЗОВИ

Сажетак:

Развој великих метропола, са великим бројем становника, захтева све већу мобилност како би се одржао економски и друштвени развој. Због тога постоји велика потреба за модерним и новим ифраструктурама на урбаном, приградском, међуградском и међународном нивоу. Истовремено постоји и потреба да се саобраћај побољша са аспекта очувања животне средине, да се смање ефекти као што су бука, загађење и загушење. Најновија истраживања показују да до 2050. године треба смањити емисију угљен-диоксида (CO_2) за 75%. То смањење је могуће извести само применом нових технологија транспортних система. Једна од тих технологија, која се се приказује у оквиру овог рада, јесте Маглев систем за возове великих брзина.

Кључне речи: инфраструктура, класична железница, маглев систем, траса, левитација

1. INTRODUCTION

Contemporary development of megacities and associated increasing urbanization have imposed heavy transportation conditions, as well as harmful effects upon environment [1]. Considering the results of recent studies, road transport prevails in the global transport industry with a percentage share of around 35%. On one hand, road transport contributes around 73% of total carbon dioxide (CO_2) emission resulting from the transportation, and on the other one, it consumes more than 75% of total transport energy demand [3]. According to this, there is a growing necessity for establishing clean and efficient transit systems. When it comes to the rail transportation industry, it has become apparent that this type of transportation has the capability to cope with the expanding transport network; however, on-wheel railways worldwide fulfill 60% of their total energy demand using petroleum-based products, which emphasizes the need for electrification of railways and for improvement of their technological performance [3]. These facts have attracted the attention of the researchers and manufacturers worldwide and given rise to the development of rail technology based on magnetic levitation – the so-called Maglev system. This railway system is a fully electrified system, which is in agreement with the renewable energy resources without any technological modifications, thus providing sustainability of the system [1-3].
The Maglev system use electricity, which has recently been increasingly sourced from sustainable alternative energy sources, much less from fossil fuels. In addition, the Maglev system uses less energy than other railway systems and is therefore more economical. Moreover, research has shown that the energy consumption of electric cars (whose technology is similar to the Maglev system) would be three times higher for the same transport route. On the other hand, the Maglev system is more economical for mass-transport, without causing any negative environmental consequences (noise, pollution, etc.)

Magnetic levitation represents a contemporary and highly-advanced technology of various uses and advantages. One of these is the lack of contact, thus contributing to elimination of wear and friction, and by that, to increase of efficiency, decrease of maintenance costs, as well as to increase of the service life of the system.

The main structural element of the Maglev system is the guideway, which supports and guides maglev trains to move over it and transfers the applied vehicle load to the ground. This element has big share of the system costs. There is a single- or double-track guideway. In addition, there is an option a guideway to be placed at-grade (ground-level) or to be elevated on columns with concrete, steel, or hybrid beams, in which case it occupies the least amount of land on the ground and avoids obstacles that exist along the route. In order to secure the safety of the Maglev trains, it is needed to provide no intersection between guideway and other forms of traffic routes, which could be assured by using elevated guideways. In contrast to classic-type railroad tracks, considering the Maglev-system guideways, a necessity for ballast, sleeper, rail pad, and rail fastenings to stabilize the rail gauge is avoided.

Considering the analysis and design of guideways, the most significant part the engineers should be aware of is structural loading, consisting of a dead load induced from its own weight, as well as live loads including the vehicle loads. In order to take into account the dynamic interaction between the guideway and the vehicle, the live load is multiplied by a dynamic amplification factor. Other types of loads, such as wind- and earthquake-induced loading, should also be taken into consideration.

The latest researches show that by 2050, carbon dioxide (CO_2) emissions need to be reduced by 75% [4]. This reduction can be achieved only by applying new technologies of transportation systems, such as the Maglev system of high-speed trains.

Today, several commercial maglev-system lines are in operation worldwide: the railway line Shanghai–Pudong Airport, the line from Incheon International Airport to the station Iongiu in South Korea, the Tobu–Kiurio Line (the so-called Linimo) in Japan, and the line from the Changsha Huanghu International Airport to the Changsha South Railway Station. The Maglev system as an urban transportation system, with a limited speed of up to 100 km/h, was applied so far only in Japan. Due to the large investment of construction and short distances, the Maglev system will have less application in urban transportation.

Analyses of the use of the Maglev system lines have shown their justification from all aspects, particularly the economic one. With this in mind, nowadays, an increasing number of research studies are underway considering the construction of new lines of this type of system in the world.

Some recent studies have indicated that, for the reason of high speed of transportation vehicles, the operation safety of Maglev train is influenced by the differential settlement due to different properties of soil layers, and by that, the operation of the Maglev train could contribute to increasing of the soil drowning.

Taking all into account, the Maglev system is believed to be capable of assuring safe and comfortable transport of passengers in the future.

2. COMPARISON OF RAILWAYS OF THE CLASSICAL TYPE AND OF THE ADVANCED MAGLEV SYSTEM

This section is dealing with the most important differences between the standard rail system and the Maglev system considering several points of view.

2.1. Vertical and lateral guidance

2.1.1. Conventional railway

Considering the traditional rail, there are both vertical and lateral guidance. The system of standard railways has a disadvantage of being very sensitive to geometric precision. However, there is a number of its advantages such as low resistance, especially at low speed. The force transmitted through the contact surface is 50-100 kN/cm^2, which is distributed to the ground through a series of components, such as rails, sills, drapes, etc.

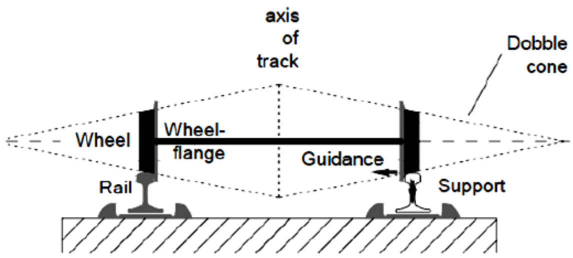


Figure 1. *Vertical and lateral guidance of the conventional rail [5]*

2.1.2. Maglev system

In case of the advanced Maglev system, vertical and lateral guidance is provided by levitation system without contact, which is based on the principle of magnetic field. In comparison with the traditional rail, the pressure between vehicle and infrastructure in this case is significantly reduced.

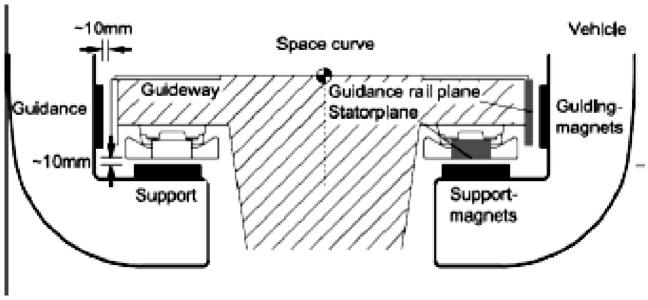


Figure 2. *Vertical and lateral guidance of the Maglev system [5]*

2.2. Drive

2.2.1. Conventional railway

Torque is transmitted to the rail over the contact surface of the wheel and the rail. The transfer of driving force by this mechanism requires a sliding movement in one part of this area (in the full area when the gliding conditions have been reached). This sliding movement creates wear. The force advantage depends on the wheel load.

2.2.2. Maglev system

The drive force is out of contact, which is achieved by creating electromagnetic force without mechanical movement and without wear. In case of low-speed maglev trains, the active part of the engine is located inside the vehicle and energy is powered by the energy transfer system. In case of high-speed maglev train, the active part of the engine is mounted on infrastructure, which facilitates contactless transmission of power to the vehicle.

2.3. Power supply

2.3.1. Conventional railway

Considering European countries, the voltages in electric traction occurring on contact networks are DC 3kV and AC 25kV/50Hz, which is also the most widespread locomotive power supply system. Energy is supplied from electric traction substations (EVPs) located along the contact grid.

2.3.2. Maglev system

Power is supplied by substations, which contain all the necessary components for the drive, power, and operating system of the Maglev technology, whereby the maximum distance between two substations on the route attains about 50 km.

2.4. Communications and operational control

The essential differences considering the standard rails and the advanced Maglev technology are attributed mostly to operational control, which allows the Maglev system to be fully automated. Communications technology could be interoperable, or content of information is different.

3. MAGNETIC LEVITATION

Magnetic levitation is an advanced technology, which is based on magnetism and in which one object hovers (levitates) over another without any mechanical support, but only with the help of a magnetic field. Accordingly, the effect of gravitational force is canceled out by the action of an electromagnetic force of the same intensity and direction, but in the opposite direction, thereby achieving hovering. With an aim to provide stabilisation of this system, electronic stabilisation of magnetic levitation is being used [1].

3.1. Electromagnetic suspension system (ems)

In order to achieve magnetic levitation, the design based on magnetically attractive forces between the guideway and the on-board electromagnets installed below the guideway is being used in this Maglev system, which accomplishes levitation even at zero speed. This system uses standard electromagnets that conduct in the presence of electric power supply only, which results in magnetic fields of comparatively lower intensity inside the passenger vehicles, and by that makes the travel for the passengers more comfortable.

On the other hand, however, lower intensity of magnetic field induces an appearance of a levitation air gap of 1 cm, whose controlling becomes more and more inconvenient with increasing the vehicle velocity. Therefore, the EMS system appeared to be suitable for the case of low- to medium-speed vehicles. In Shanghai, Korea, and Japan this system is used with the levitation and guidance circuits completely integrated (Fig. 3). In Germany, the EMS technology is used with the levitation and guidance circuits completely separated, which makes it suitable for high-speed operation due to the absence of interference between the two circuits [9-11].

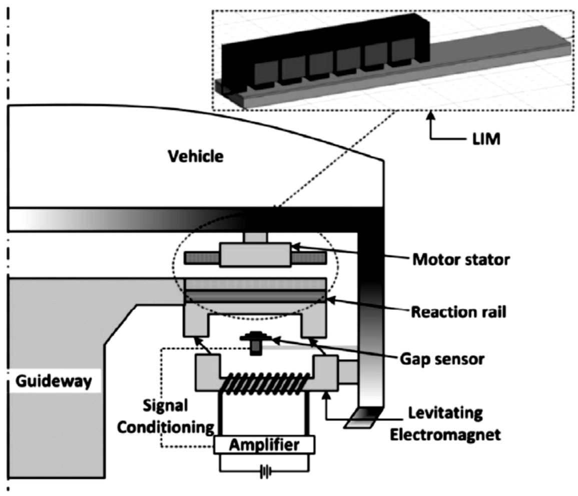


Figure 3. *Electromagnetic suspension (EMS) system [1]*

3.2. Hybrid electromagnetic suspension system (hems)

This system represents a modification of the previously presented EMS system (Fig. 4) and is established on an employment of permanent magnets and electromagnets, in order to reduce the electric power consumption of the conventional system and to achieve larger air gaps. At the beginning of a drive, the system uses both the electromagnets and permanent magnets to generate levitation. After accomplishing a steady-state air gap, the permanent magnets solely starts levitating the vehicle, thus cancelling out the power of the electromagnets. The permanent magnets produce a constant magnetic flux. Hence, in the HEMS system, the necessary air gap control is achieved by adjustment of the electromagnet's excitation, so the requirement for a controllable input source of greater variation is of paramount importance for exciting the electromagnets [12,13].

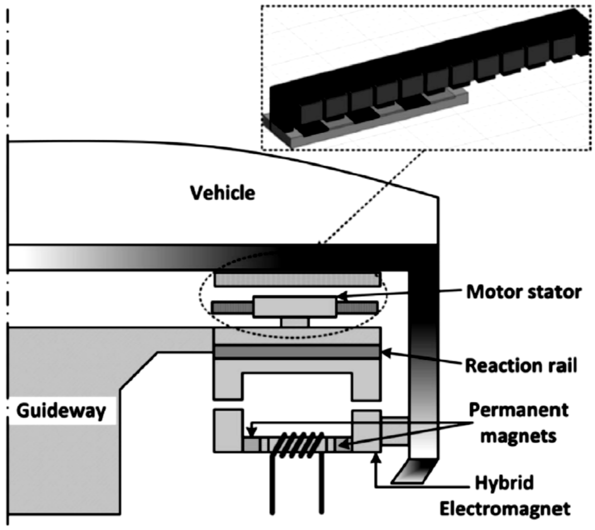


Figure 4. *Hybrid electromagnetic suspension (HEMS) system [1]*

3.3. Electrodynamic suspension system (eds)

In the EDS technology, levitation is achieved by usage of magnetic repulsive force (Fig. 5), which is being generated by moving forward of on-board magnets with the vehicle over the guideway that consists of inductive coils or conducting sheets, owing to interactions of on-board magnets with the currents induced in the guideway coils. The required levitation of the vehicle is provided by this repulsive force, and the levitation magnitude that can be achieved is of up to 10 cm. This system, however, suffers from the weak point, which is related to the requirement of rubber tires on which the train must roll initially until it reaches a lift-off speed of about 100 km/h. Furthermore, the EDS system employs superconducting magnets, which are super-cooled at frigid temperatures using a cryogenic system [1].

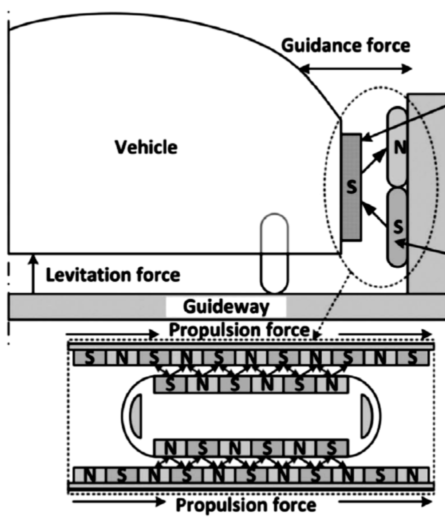


Figure 5. *Electrodynamic suspension (EDS) system [1]*

3.4. Permanent magnet – electrodynamic suspension system (pm-eds) – "inductrac" system

This system stands for a modification of the aforementioned EDS system, and is based on application of permanent magnets at room temperature, arranged in the form of a Halbach array (Fig. 6). Opposite to the EDS technology, this system does not require any super-cooled magnets, thus neutralising any cryogenic requirements. On the other hand, however, the PM-EDS system uses auxiliary wheels for acceleration of the vehicle until the moment it achieves some initial take-off speed, after which it starts levitating. This system has been under trial by General Atomics, USA, with suspension magnets separated from propulsion magnets [1].

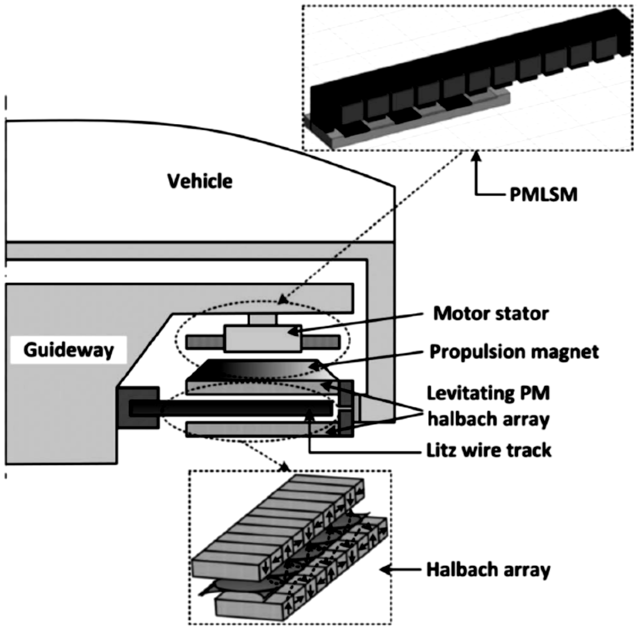


Figure 6. *Permanent magnet –electrodynamic suspension (PM-EDS) system [1]*

4. TECHNICAL PROPERTIES OF THE ROUTE

Considering the advanced Maglev railroad-track technology, several types of guideways can be distinguished [7], depending on certain configuration:

- At-grade guideway;
- Elevated guideway: Type A - single column;
- Elevated guideway: Type B - straddle bents;
- High-column bridges;
- Shallow tunnels: Type A;
- Deep tunnels: Type B .

4.1. Ground-level guideway

This configuration (Fig. 7) is predominantly used in open, flat rural regions, where the guideway can be placed at grade, along with avoiding intersection with roadways, utilities, streams, and other topographical shapes. Here, the precast concrete beams with spans up to 7.62 m are used, which, if required, can be curved and/or elevated in order to follow acceleration and alignment conditions.

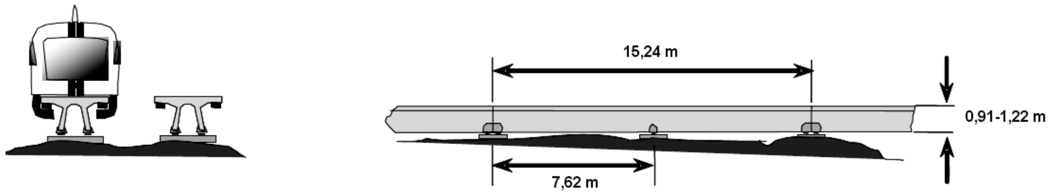


Figure 7. *Ground-level guideway configuration [7]*

4.2. Elevated guideway

The elevated-guideway configuration (Figs. 8 and 9) appeared to be applicable in congested urban areas, in which case columns can be placed in the median of a freeway and the guideway can travel over parkways, intersecting roadways and other facilities. The precast concrete girders, with spans up to 30.48 m, are similar to the ones tested at the Transrapid Test Facility in Emsland, Munich. The elevated guideway can also be curved and elevated in order to match geometric and lateral acceleration requirements. These beams are supported with single column (Type A, as shown in Fig. 8) or two-column (Type B, as shown in Fig. 9) straddle bents with heights of up to 19.81 m.

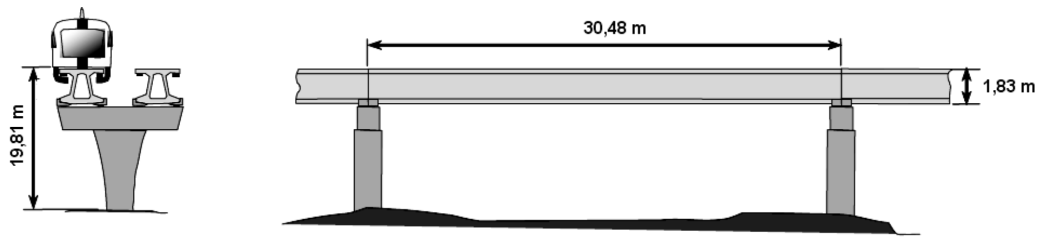


Figure 8. *Elevated-guideway configuration: Type A - single column [7]*

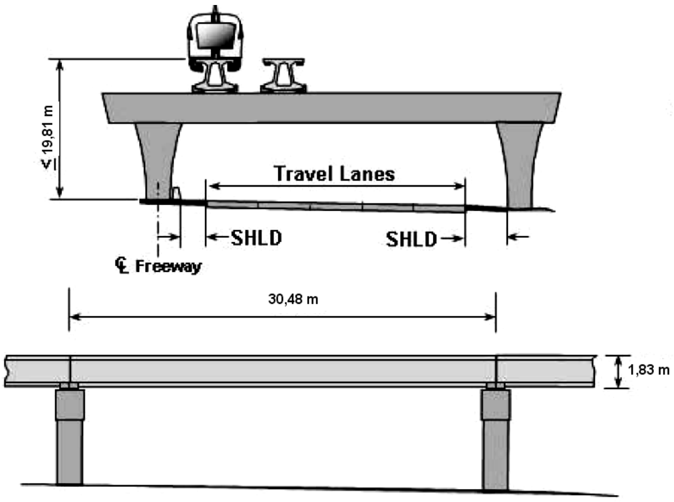


Figure 9. *Elevated-guideway configuration: Type B - straddle bents [7]*

4.3. Bridge structures

This configuration is needed to apply for spans over 30.48 m or column heights that exceed 19.81 m, which is a common situation in remote and mountainous areas. The bridge structures are usually made of precast concrete segments, constructed using the balanced cantilever method. The maximum size of span for this type of construction is assumed to be of about 60 m.

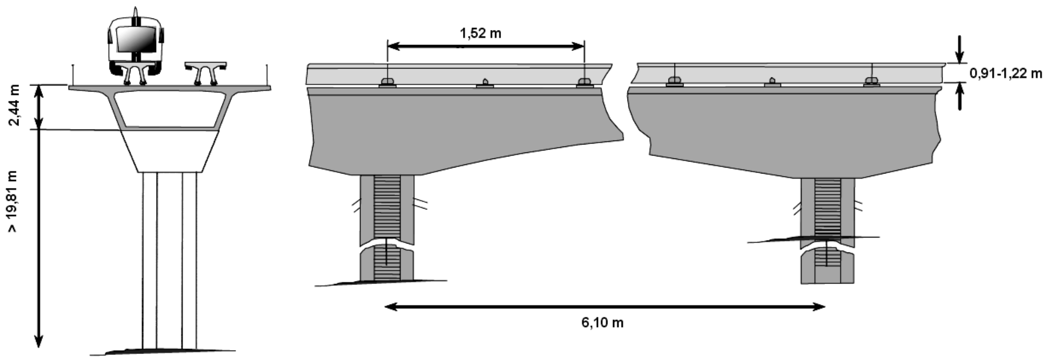


Figure 10. *Bridge-structure configuration [7]*

4.4. TUNNEL STRUCTURES

Considering hilly and mountainous terrains, design of tunnels will be suitable solution in case when satisfying longitudinal slope conditions is needed. There exist two types of tunnel structures: Type A considering shallow-laid tunnels (Figs. 11 and 12) and Type B including deeply embedded tunnels (Figs. 13 and 14). When it comes to deeply embedded tunnels, a design of the third auxiliary tunnel facility is foreseen for the purpose of the operation of the two main tunnels.

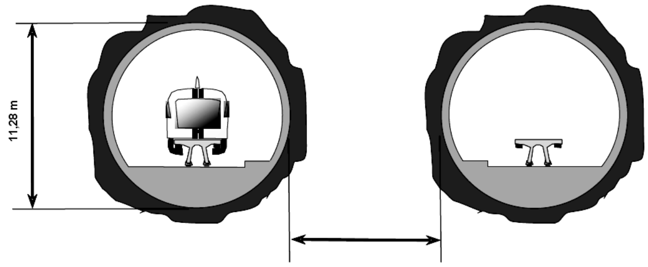


Figure 11. *Figure 11. Shallow-laid tunnels – Type A [7]*

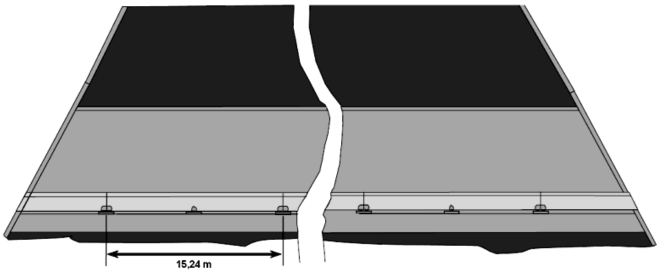


Figure 12. *Figure 12. Shallow-tunnel elevation – Type A [7]*

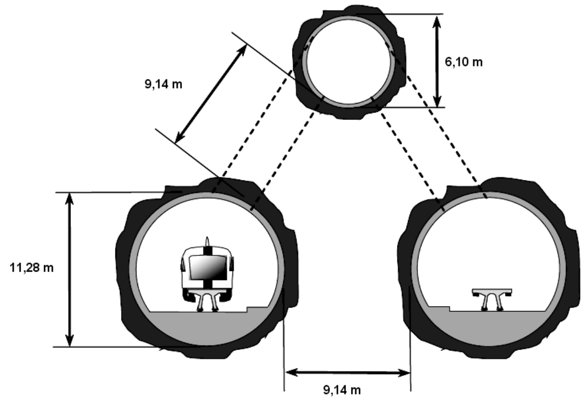


Figure 13. *Deeply embedded tunnels – Type B [7]*

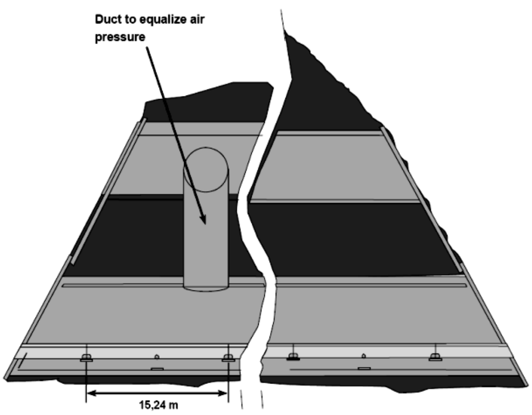


Figure 14. *Deep-tunnel elevation – Type B [7]*

5. GEOTECHNICAL PROPERTIES OF THE TERRAIN ALONG THE RAILWAY ROUTE

Taking into account that the Maglev advanced technology is characterized by very high speeds of transportation vehicles, the safety of the system considering operational stage should be of utmost importance. Namely, for the reason of high speed of transportation vehicles, the operational safety of Maglev train is highly influenced by the geotechnical properties of soil layers within terrain along the railway route.

Construction of the Maglev system is quite expensive, and consequently maintenance works are minimized. Accordingly, special attention must be paid to the construction process. The most sensitive part of this system is the connection of the structure to the ground. Settlement of the structure can cause deformation of the guideway, and thus to endanger the functioning of levitation. According to the Chinese high-speed railway regulations (including the Maglev system), the permissible settlement of the structure is 20 mm and the safe differential settlements (the difference in settlements of the points of the structure) are 5 mm. Any settlement, and in particular differential settlements, oversizing recommended allowable values in the operation stage, would result in disruption of traffic and major investment activities and, consequently, in enormous economic losses.

In order to prevent settlements and, by that, endangerment of the structure, extensive and detailed geotechnical investigations should be carried out. This is the best way to prevent subsidence, because a comprehensive analysis of the survey results will yield an optimal foundation solution and a correct choice of the corresponding ground stabilization technique to improve the soil properties if needed. A lack of systematic and precisely conducted geotechnical investigations will inevitably result in unsafe settlements and damage to the structure, thus leading to costly remedial measures.

In one of the recent studies [8], soil displacement monitoring (i.e., soil deformation along the route and soil settlement) was analyzed in detailed way for the existing Maglev route in Shanghai, overlying soil layers of poor bearing capacity. In addition, with an aim to investigate the settlements induced by the Maglev system and to improve the settlement monitoring, five soil observation stations along the route were installed on the Shanghai section. A typical geological profile with the layout of the layers and soil composition is presented in Fig. 15, whereby it should be emphasized that the thicknesses of the layers are different along the railway route, and by that, bellow the considered observation stations, for which the results of the performed measurements are depicted in the diagrams (Figs. 16-20). The results have revealed that the operational safety of high-speed Maglev train is strongly influenced by the differential settlements induced by diversity in properties of soil layers, whereby the operation of the Maglev train may induce a significant subsidence of the ground, i.e. a gradual shaking of the foundation can lead to damage if the sizing is uneven. The results also indicated that ground settlement has adverse effects on the structure above the foundation, due to which the operational life of the structure can be significantly reduced.

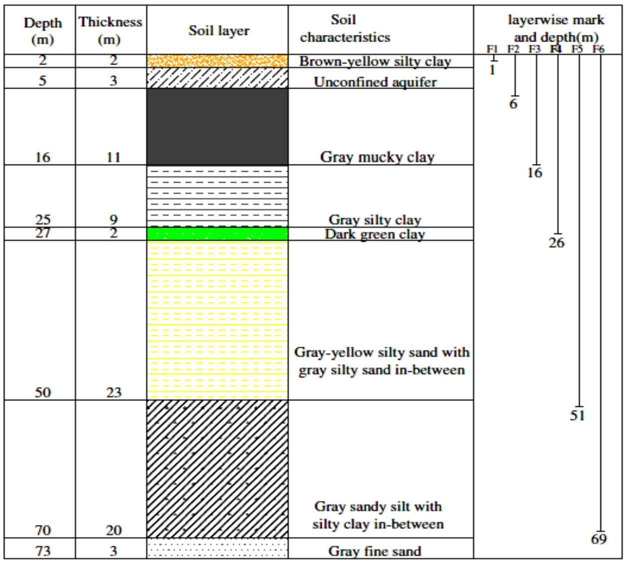


Figure 15. *Typical geological profile of the terrain along the Maglev route in Shanghai [8]*

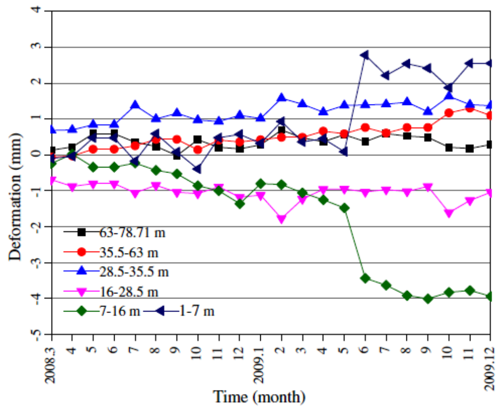


Figure 16. *Settlement at different depths as a function of time: station P1 [8]*

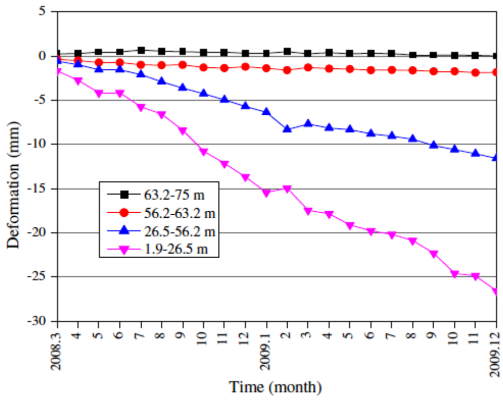


Figure 17. *Settlement at different depths as a function of time: station P2 [8]*

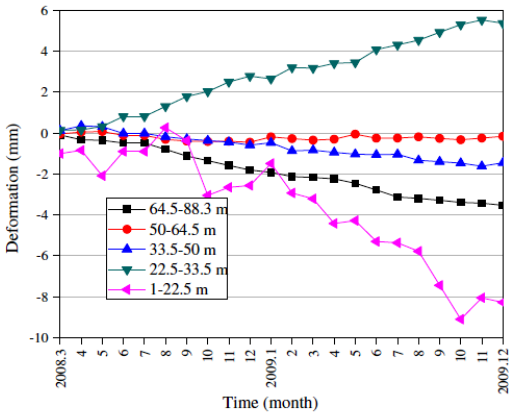


Figure 18. *Settlement at different depths as a function of time: station P3 [8]*

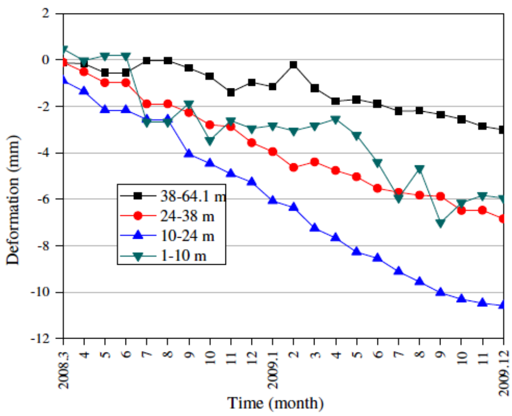


Figure 19. *Settlement at different depths as a function of time: station P4 [8]*

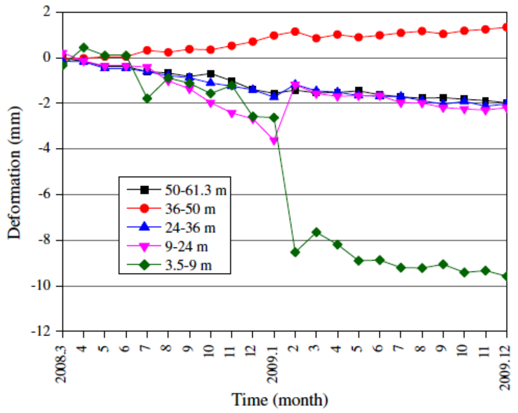


Figure 20. *Settlement at different depths as a function of time: station P5 [8]*

6. ADVANTAGES OF THE MAGLEV TECHNOLOGY OVER CONVENTIONAL SYSTEMS

The main advantages of the advanced Maglev technology over other types of transportation systems, and in particular over conventional railway system, can be summarized as follows:

- The Maglev system does not make noise; it is more economical and uses less energy than any other rail system.
- The possibility of the train falling out of the guides does not exist, and comfort is supreme at all speeds.
- The system is characterized by low consumption of required space for construction.
- The road guide takes less space in comparison with standard stripes and can be flexibly adjusted to accommodate existing natural areas and terrain forms along the route of the guide due to the small diameter of the curvature and high degree of climbing ability up to 10%.
- Due to a small embankment and a cutting, the nature disturbances are set to a minimal level.
- The Maglev train load is equally distributed across the guides (i.e., there is no point load), thus resulting in less static and dynamic loadings over the entire speed range, and therefore, less voltage on the guides.
- Maglev trains use small amount of energy, whereby all systems are powered by the harmonic oscillations of the magnetic field of the linear motor stator located on the line.
- If a power failure appears, the trains are supplied with batteries that maintain levitation for a certain period of time.
- The Maglev vehicle does not rely on rails; actually, it floats over an average reliable distance of about 1 cm from its guides owing to a highly reliable electronic control system.
- The distance between the top of the guide and the underside of the vehicle during contactless and frictionless hovering is 15 cm; this has the advantage of passing over some smaller objects or a layer of snow.
- The Maglev system is characterized with high acceleration and braking ability;
- The system requires less staff to operate and maintain, as well as fewer spare parts and materials, thus resulting in management costs that are less than those of rail systems of classic type. In addition, comfortable travel results in shorter travel times and is not too expensive.
- Space and land beneath elevated guideways can be used, for example, as land for agriculture, construction, etc.

7. CONCLUDING REMARKS

The development of large metropolises involves an increase in the number of citizens. The need to transport a large number of passengers, as well as goods, imposes the development of transportation systems such as the high-speed Maglev railway system. Magnetic levitation, i.e. contactless and frictionless movement of vehicles, is a new and advanced technology that is proved to have the potential to become a reality and is believed to be capable of assuring safe and comfortable transport of passengers in the future. It has a number of advantages over traditional systems, such as frictionless hovering, reduced noise, more comfortable driving, increased safety, independence from weather conditions, ability to cope with higher climbs, usage of narrower stripes mounted above the ground that do not interrupt the terrain, etc.

Just recently, owing to the aforementioned advantages, the Maglev system has been applied in some of the most developed industrial countries in the world. The applications of the Maglev system are justified for transport of a large number of passengers and goods from one megacity to another (which are often several hundred kilometers away), as well as for distances from large metropolitan areas to suburban airports (especially those for overseas traffic). Due to the large investments for construction and short distances, the Maglev system have less application in urban transportation with a limited speed of about 100km/h.

Maglev trains are considered to be an alternative to short- and medium-range aircraft (up to 1000 km) in the future. Even though train speeds are less than those of aircraft, considering the distance of the airports from the metropolitan centers, travel times are considerably shorter.

Nowadays, numerous researches are being performed considering the characteristics of magnetic levitation with an aim to improve the existing Maglev system. Essential problems could be considered to be solved, since a lot of has been done on the development in technological sense. However, the fact that high initial costs of construction are imposed by this technology, due to very complex computer systems for levitation management, could be considered as its essential shortcoming. This makes the construction of this type of railways suitable only in conditions of a large number of passengers and goods. The maintenance costs, on the other hand, considering both trains and tracks, are of lower value.

Nevertheless, taking into account all the former facts, numerous advantages of the Maglev technology are prevailing and this system can make a huge contribution to our everyday life.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the support of the Ministry of Education, Science, and Technological Development of the Republic of Serbia in the frame of the scientific–research project TR 36043.

LITERATURE

[1] N. Prasad, S. Jain, S. Gupta, "Electrical components of Maglev systems: emerging trends", Urban Rail Transit, vol. 5, no. 2, pp. 67-79, 2019.

[2] Passenger Department. "Passenger activities at UIC". International Union of Railways (UIC). https://uic.org/IMG/pdf/brochure_passagers.pdf , 2019.

[3] Passenger Department. "High speed rail fast track to sustainable mobility". International Union of Railways (UIC). https://uic.org/IMG/pdf/uic_high_speed_2018_ph08_web.pdf , 2018.

[4] Railway Handbook. "Energy consumption and CO_2 emissions focus on passenger rail services". International Energy Agency (IEA) and International Union of Railways (UIC). https://uic.org/IMG/pdf/handbook_iea-uic_2017_web3.pdf , 2017.

[5] A. Cassat, V. Bourquin, "MAGLEV – Worldwide status and technical review", in Proc. Électrotechnique du Futur, December 14–15, 2011, Belfort.

[6] M. Saied, M. Al-Shaher, "Harmonic distortion assessment and minimization for railway systems", Electr Power Compon Syst, vol. 37, no. 8, pp. 832-846, 2009.

[7] SANDAG, "Maglev Study Phase 1", Final Report, 2006, p. 185.

[8] Z.D. Zhen-Dong Cui, Q. Qiang Yuan, "Study on the settlement caused by the Maglev train", Nat Hazards, vol. 75, pp.1767-1778, 2015.

[9] P. Holmer, "Faster than a speeding bullet train", *IEEE Spectr,* vol. 40, no. 8, pp. 30-34, 2003.

[10] R.J. Kaye, E. Masada. "Comparison of linear synchronous and induction motors". Urban Maglev Technology Development Program Colorado Project. https://www.codot.gov/programs/research/pdfs/2004/inductionmotors.pdf , 2004.

[11] J. Meins, L. Miller, W.J. Mayer, "The high speed Maglev transportation system TRANSRAPID", *IEEE Trans Magn,* vol. 24, no. 2, pp. 808-811, 1988.

[12] Y.K. Chin, J. Soulard, "A permanent magnet synchronous motor for traction applications of electric vehicles", *in Proc. IEEE International Conference on Electric Machines and Drives "IEMDC 2003"*, June 1–4, 2003, Madison, USA.

[13] W. Zhang, J. Li, K. Cui, P. Zhang, "Design of magnetic flux feedback controller in hybrid suspension system*", Mathematical Problems in Engineering*, pp. 1-7, 2013.

36 | Professional paper I Стручни рад
ISSN 2566-4484 I Doi 10.7251/STP2014388L
pages 388-399

Marina Latinović, marina.latinovic@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

Zoran Mišković, zoran.miskovic@gmail.com, Faculty of Civil Engineering, University of Belgrade

Marko Popović, mare381@gmail.com, Faculty of Civil Engineering, University of Belgrade

DYNAMIC BEHAVIOR OF A CABLE-STAYED FOOTBRIDGE OVER RIVER VRBAS IN BANJA LUKA

Abstract:

This paper presents a dynamic behavior analysis of an old cable-stayed footbridge over river Vrbas in Banja Luka. Identification of modal parameters, of this prone to vibrations footbridge structure, was performed using Operational Modal Analysis with Frequency Domain Decomposition method. Experimental test setups and obtained results, compared to the numerical values obtained by FE model updating, are shown. Modal Assurance Criterion was used for the confirmation of the uniqueness of experimentally obtained mode shapes, and also for the comparison of FE model mode shapes to the experimentally obtained ones, in the locations of measurement.

Keywords: footbride vibration, Operational Modal Analysis, Modal Assurance Criteria, model updating

ДИНАМЧКО ПОНАШАЊЕ ВИСЕЋЕГ ПЈЕШАЧКОГ МОСТА ПРЕКО РИЈЕКЕ ВРБАС У БАЊОЈ ЛУЦИ

Сажетак:

У раду је приказана анализа динамичког понашања висећег пјешачког моста, преко ријеке Врбас у Бањој Луци. Идентификација модалних параметара овог моста, подложног осјетним вибрацијама, извршена је преко оперативне модалне анализе и *Frequency Domain Decomposition* методе. Приказане су поставке за експериментално испитивање, те добијени разултати, који су упоређени са вриједностима калибрисаног нумеричког модела. Процедура *Modal Assurance Criterion je* коришћена за потвду јединствености модалних облика добијених преко резултата мјерења, а такође при поређењу модалних облика добијених преко нумеричког модела са експерименталним резултатима, у тачкама у којима је извршено мјерење.

Кључне ријечи: вибрације пјешачких мостова, операциона модална анализа, калибрација модела

1. INTRODUCTION

When analyzing the dynamic characteristics of pedestrian bridges, attention is given to the analysis of the resonant phenomena occurrence and the maximum acceleration of the structure.

In regulations, nowadays, the dynamic problem of pedestrian bridges is solved by considering and limiting natural frequencies and accelerations in the structures' finite element models. Considered dynamic load cases for human walk take into account the basic parameters crucial for the resonance phenomena, such as the structure mode shapes, oscillation frequencies and corresponding damping, as well as the range of frequencies of a human walk. After applying defined load cases, the maximum acceleration of construction is considered, which is directly related to the perception of people, in terms of feeling of comfort or discomfort [1]–[4].

In this paper, the dynamic behavior of a lively cable-stayed footbridge over river Vrbas in Šeher, Banja Luka, is analyzed. Footbridge considered is prone to vibrations felt by pedestrians.

The bridge design dates from the seventies, when resonant phenomena occurrence and maximum accelerations were not considered, and it doesn't meet today's comfort criteria defined by the relevant norms.

Figure 1. *Figures and captions are centered. (use style*

To identify dynamic behavior of the footbridge structure, modal parameters were determined using Ambient Modal Identification, also known as Operational Modal Analysis (OMA), which is based on vibration data collected when the structure is under its operating conditions [5], [6].

Modal parameters identified by OMA are compared to modal parameters of the finite element numerical model, and manual model updating was performed.

2. FOOTBRIDGE STRUCTURE DATA

Footbridge structure data were given in the original design, found in the Archives of the Republic of Srpska. Design was made in 1961, and the bridge was constructed in 1963. Data obtained from the bridge design were verified by in-situ visual inspection and dimensional control.

The bridge is suspended, and the length of the main stiffening truss is 62,00 m. Stiffening truss consists of two vertical steel trusses, with upper and lower profiles [65x65x9 and L100x100x10, respectively. Profiles are connected with diagonal and vertical bars made of steel rails 700 kg/m'. The height of the vertical steel trusses is 900 mm. In the upper zone, horizontal bracing, connecting two trusses, is coupled with an 8 cm thick concrete deck. Horizontal bracings in lower and upper zone are also made of steel rails 700 kg/m'.

The main cable is steel wire Ø52 mm and suspenders are steel profiles Ø18. Main cable relays on 10 m tall diamond-shaped steel pylons.

Bridge disposition and cross-section are shown in Figures 2 and 3.

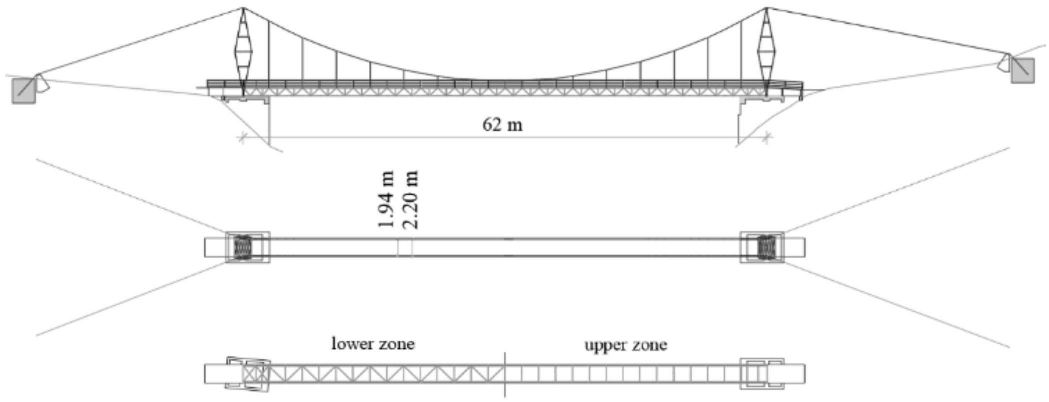


Figure 2. *Footbridge layout*

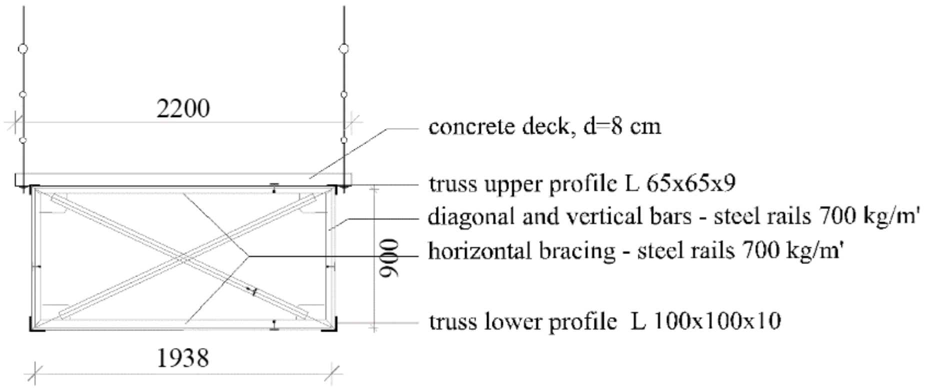


Figure 3. *Footbridge cross section*

3. IDENTIFICATION OF DYNAMIC PROPERTIES

Dynamic tests aimed to evaluate the modal properties of the bridge structure, and also the effects of pedestrian actions by measuring maximum accelerations under its operating conditions.

For dynamic identification of structural characteristics OMA was used, as for large structures, it is complicated and expensive to apply controlled exterior stimulation. In these cases, ambient excitation is a practical solution. Construction can be aroused by wind, traffic or human activities, and the excitation is not measured, only the response is [5].

As a method of identification, Multiple Test Setups Measurement Procedure was used, meaning that the applied sensors were moved from one set of positions to another, in several test setups [6]. Sensors were placed in the positions where the modes of interest are having a good response level, regarding the mode shapes. These positions were determined using the initial FE model of the footbridge, based only on the main design and visual inspection.

To get quality information about the structure vibrations, two main parameters, which significantly affect the ambient vibration measurement results, must be considered. These are the total sampling time and the time interval between the two samples - sampling frequency. In this case, the duration of the continuous measurement for each setup was 1 hour, which gave low frequency resolution. Used sampling frequency was 600 Hz, which is much more than the minimum recommended regarding the expected structure frequencies, and it contributes to the quality of the sampled signal.

3.1. Measuring equipment

Vibration responses were measured using universal measuring amplifier of the QuantumX series - MX840A, produced by Hottinger Baldwin Messtechnik – HBM with 24-bit resolution and simultaneous sampling, connected to Catman Easy software for visualization of signals during measurements. As sensors, high-sensitive accelerometers were used, model-2240, produced by the company Silicon Designs, with measuring range ± 2g.

For signal processing, a Butterworth low pass filter was applied, with a cut-off frequency of 50 Hz.

3.2. Test setups for mode shapes identification

To get clear mode shapes and to estimate a large number of natural modes, using Multiple Test Setups Measurement Procedure, dynamic behavior was recorded with 8 accelerometers, differently arranged in 5 different test setups.

In each test setup response was measured in five locations. On locations on the upstream part of the footbridge, accelerometers were positioned in two directions Z and Y, and on the downstream part of the bridge, only in the Z direction. In every test setup, 5 accelerometers measured response in the vertical, and 3 in the lateral direction. To sum up, in 5 test setups, vibrations were measured on 21 location, where the vertical response was measured at all locations, and horizontal at 11 locations, as shown in Figure 4.

On reference position, 2 accelerometers were placed, measuring response in both Z and Y direction. Reference accelerometers were not moved in test setups and they measured response in their positions during every measuring time interval. The purpose of reference accelerometers is to adjust the mode shape values obtained in different test setups. The reference position should be chosen so that the reference sensors have a good response during all setups, meaning that the mode shapes of interest should have a good amplitude in reference points. Since several first vertical, torsional and horizontal mode shapes could be predicted by the initial FE model, it is decided that one reference position for the planned measurements is enough, and it was placed in one-quarter of a span. The rest of the sensors were moved from one location to another in different setups.

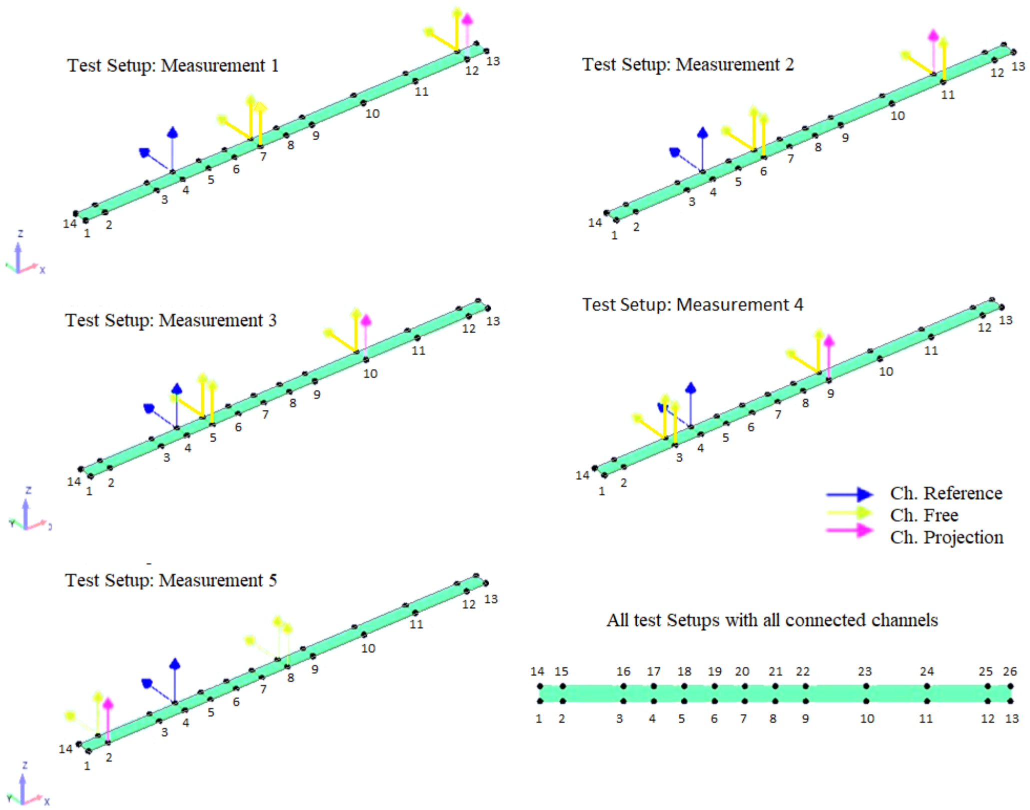


Figure 4. *Test setups disposition*

3.3. Data processing

For identification of modal parameters, Frequency Domain Decomposition (FDD) was performed, using ARTeMIS software package.

FDD is an output-only system identification technique, and by its implementation, a decomposition of the system response into a set of independent single degree of freedom (SDOF) systems is performed, one for each mode. After obtaining singular values of spectral density matrices, since multiple test setups were available, corresponding curves of all test setups are averaged, and modal information is presented in one display [6].

Candidate modes were estimated by the “Peak picking” method [6] and later verified by the Modal Assurance Criteria (MAC) method [6]–[8].

Since suspension footbridges can exhibit closely spaced modes of vibration, to estimate candidate modes, it is recommended to perform "Peak picking" on the average second, and third singular value curve.

To confirm the uniqueness of the obtained mode shapes, at extracted modal frequencies, mode shapes were compared using MAC procedure, and their similarity is represented by the MAC value. For two mode shapes, the scalar MAC value is defined as a normalized dot product of the complex modal vector (ψr, ψs), at each common node, and the resulting scalars are arranged into the MAC matrix [7]:

$$MAC(\{\psi_r\},\{\psi_s\}) = \frac{|\{\psi_r\}^t\{\psi^*{}_s\}|^2}{\{\psi_r\}^t\{\psi^*{}_r\}\{\psi_s\}^t\{\psi^*{}_s\}}\ , \tag{1}$$

MAC matrix is filled with values in the range of 0 to 1. For identical mode shapes, MAC will have a value of 1 (100%). If modes shapes are different, they are orthogonal, so the dot product of their modal vector will be 0, so as the MAC value [6]–[8].

3.4. Measurement results

Following procedure stated above, obtained mode shapes in ARTeMIS software and maximum accelerations are presented herein.

3.4.1. Mode shapes

As the preliminary FE model analysis indicated, measurement results confirmed that the first vertical and first lateral mode are closely spaced, so, as recommended in [6], in the process of estimation in ARTeMIS, the peaks on the first and second singular value curve are considered.

Figure 5 shows the singular values of spectral densities and the "Peak Picking" of dominant frequencies for all test setups, for frequencies ranges 0-15 Hz and 1-5 Hz.

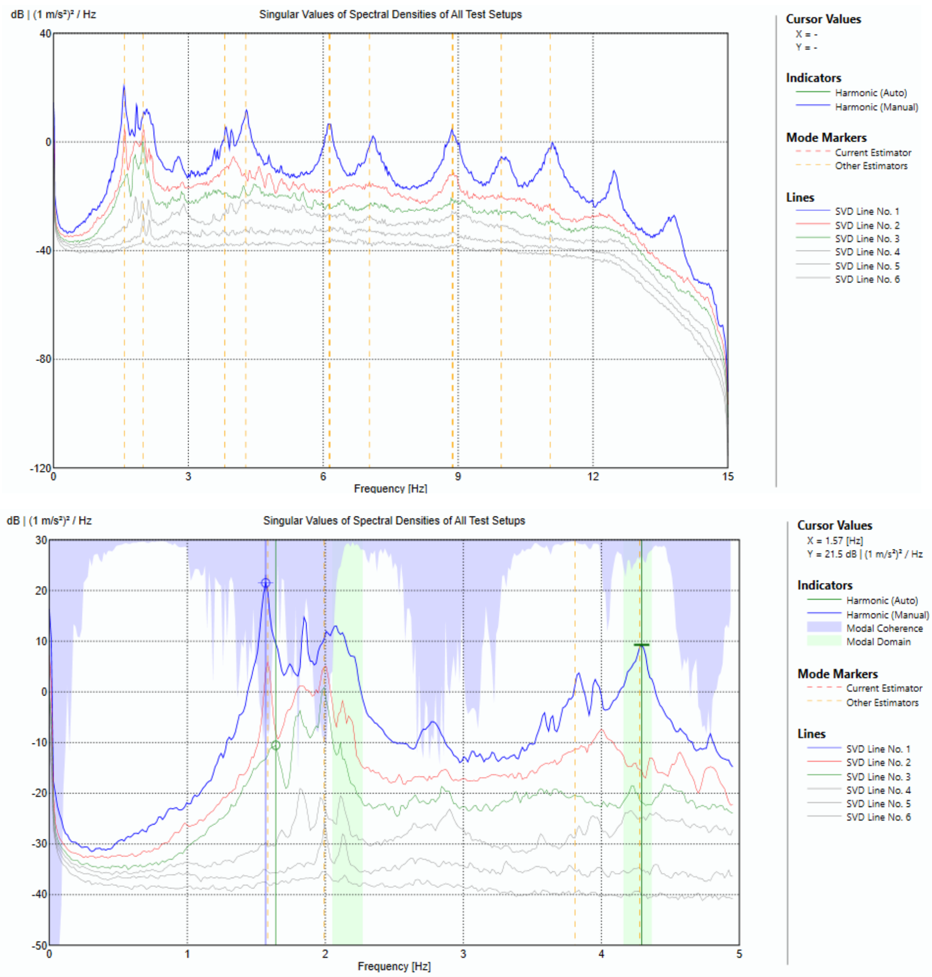


Figure 5. *Singular values of spectral densities and "Peak Picking" of dominant frequencies for all test setups and frequencies ranges 0-15 Hz and 1-5 Hz*

Graphical overview of the mode shapes of the bridge deck in ARTeMIS software, for the first nine modes, is given in Figure 6, along with measured modal frequency values. As shown, a clear mode shapes estimation is obtained.

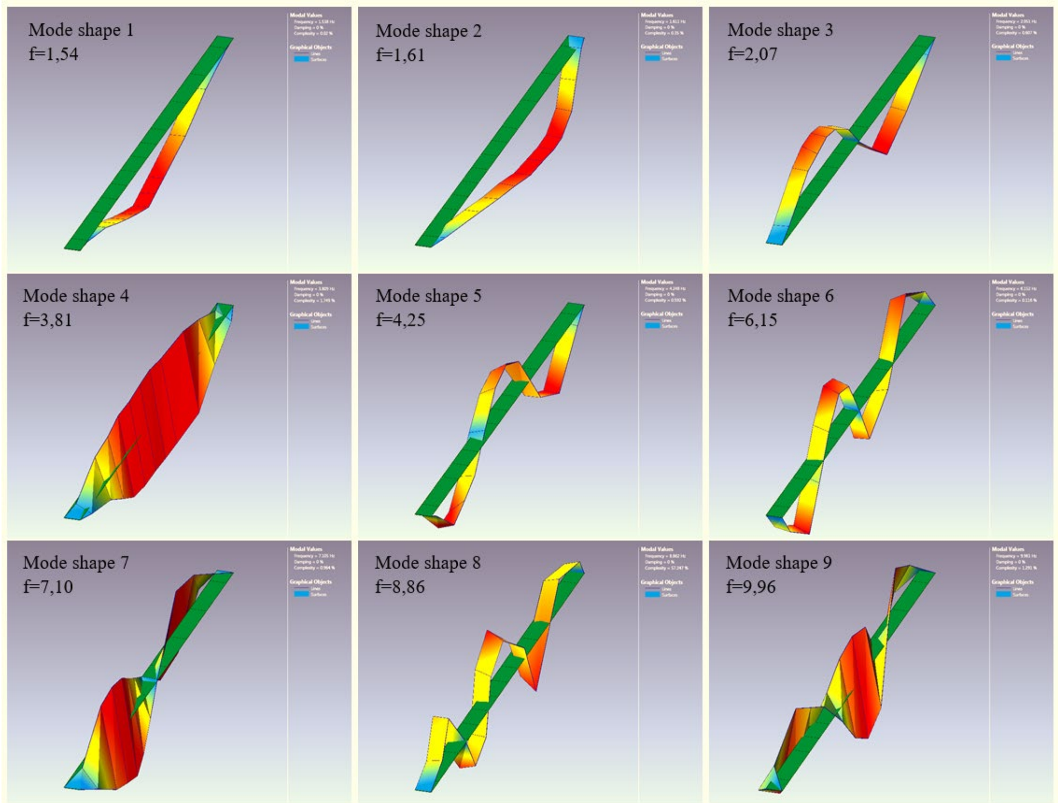


Figure 6. *Experimentally determined first nine mode shapes of vibration*

ARTeMIS has the option of tabular and graphical presentation of the values obtained by the MAC procedure. The diagonal elements of the matrix are a comparison of each mode shape with itself, and the value "1" is an indicator of the complete match of the shape. The elements outside of the matrix diagonal are a result of the comparison of the different modes, and their low values show the uniqueness of the observed modes.

MAC matrix for performed measurements on the footbridge in Šeher is shown in Figure 7.

	1.538 Hz	1.611 Hz	2.051 Hz	3.809 Hz	4.248 Hz	6.152 Hz	7.105 Hz	8.862 Hz
1.538 Hz	1	0	0.06	0	0.009	0.019	0	0.027
1.611 Hz	0	1	0.005	0.052	0.001	0	0.004	0.003
2.051 Hz	0.06	0.005	1	0	0.01	0.011	0	0.004
3.809 Hz	0	0.052	0	1	0.011	0	0.056	0.002
4.248 Hz	0.009	0.001	0.01	0.011	1	0.008	0.004	0.04
6.152 Hz	0.019	0	0.011	0	0.008	1	0.001	0.017
7.105 Hz	0	0.004	0	0.056	0.004	0.001	1	0.002
8.862 Hz	0.027	0.003	0.004	0.002	0.04	0.017	0.002	1

Figure 7. *MAC matrix for experimentally estimated modes*

3.4.2. Acceleration measurements

Results of acceleration measurements show that maximal vertical accelerations are about 50 mg in all measured setups.

In Figure 8, vertical and lateral accelerations induced by the pedestrians in ambient conditions are shown for one test setup and one measurement location.

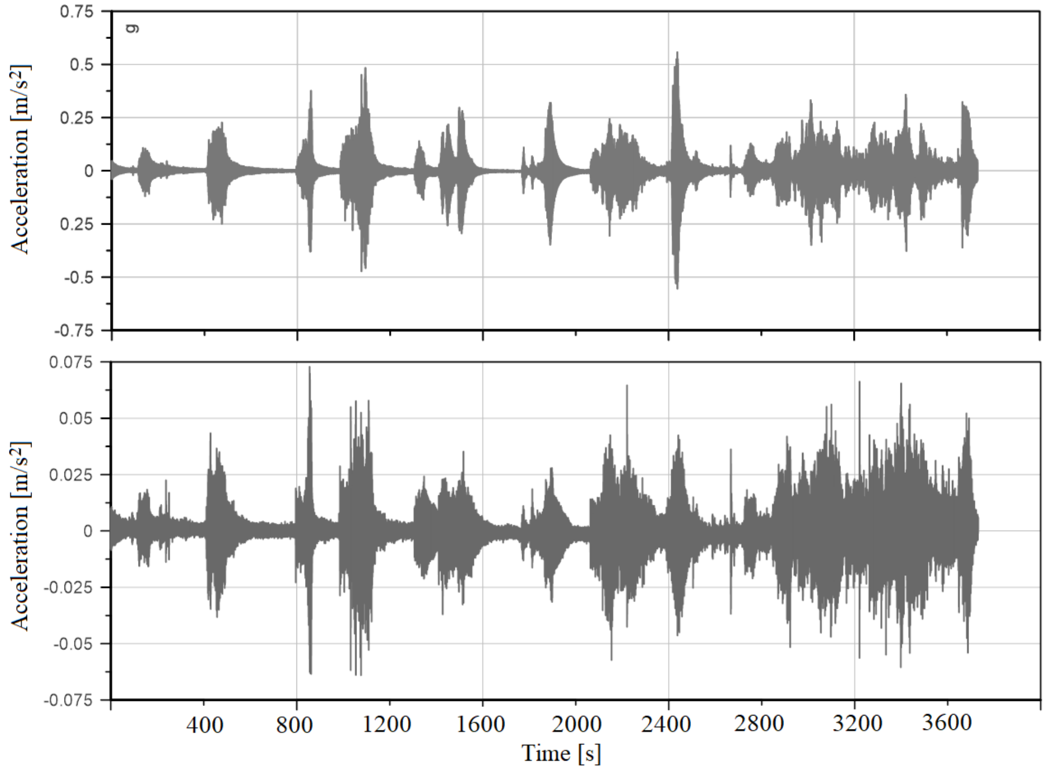


Figure 8. *Vertical and lateral acceleration for test setup 1, in the reference position*

Accelerations in many norms are highly related to the comfort criteria. As shown in Figure 8, the footbridge is very lively in both, vertical and horizontal direction, and these acceleration values under everyday conditions are unneglectable.

4. NUMERICAL FE MODEL

The FE model was developed in software CSI SAP2000 Version 20.0.0. Bridge structure data - material characteristics, profiles, and geometry were obtained from the original main design.

The cables were modelled by "cable" elements, and the suspenders were modelled as simple rods. The weight of the cables and suspenders was cancelled to avoid local vibrations of these elements. 8 cm thick concrete plate was modelled as an “area” section, with shell element. Horizontal bracings coupled with concrete plate in the upper zone, horizontal bracings in the lower zone, and main truss beam profiles, were modelled as “frame” elements.

Since experimentally and numerically obtained shape vectors and frequencies showed differences in values, the initial model was updated based on experimentally obtained results.

Parameters modified in model updating were supports, the properties of rail beams, cable properties, plate properties and the weight of asphalt layer over the concrete deck.

Previously mentioned MAC procedure (1) was used to compare mode shapes that originate from the FE model and OMA. If diagonal values of the MAC matrix are very high (close to 1), and off-diagonal values are very low (close to 0), the FE model is well calibrated.

4.1. Initial FE model

For preliminary dynamic analysis, in order to define measuring locations, initial numerical model was developed (Figure 9).

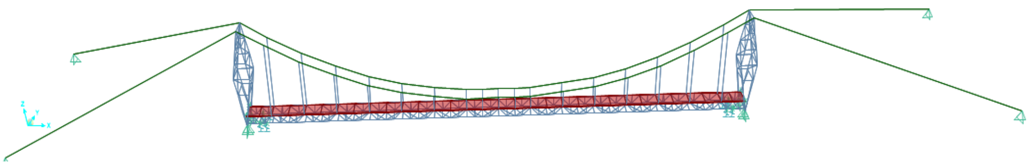


Figure 9. *Initial FEM model*

In the initial model, supports were modelled as stiff, and rail and cable properties were defined as in project documentation.

Initial material parameters were chosen based on project documentation and experience, since no laboratory tests for material properties were performed.

As a first step for model updating, quantification of the extent of differences between the initial model frequencies and the ones obtained by OMA is performed, as shown in Table 1.

In the initial model, several modes have close frequency values, but it is emphasized in the case of the first two modes. Compared to the measurement results, the first two mode shapes are reversed.

Table 1. *Frequencies gained in numerical analysis for initial model – "L" stands for lateral, "V" for vertical and "T" for torsional mode shape*

Mode number	Measured frequencies		FE initial model		
	Mode shape type	Measured frequencies (Hz)	Mode shape type	Calculated frequencies (Hz)	Difference %
1. mode	V1	1.54	L1	1.79	11.2*
2. mode	L1	1.61	V1	1.81	17.5*
3. mode	V2	2.07	V2	3.30	59.4
4. mode	T1	3.81	T1	3.42	10.2
5. mode	V3	4.25	V3	4.52	6.4
6. mode	V4	6.15	L2	4.76	-

* Compared to corresponding mode shape

In Table 2, comparison of experimentally obtained and numerically obtained mode shapes is shown.

Table 2. *MAC table for initial FE model*

ARTEMIS		SAP2000 *L1* 1.79	*V1* 1.81	*V2* 3.30	*T1* 3.42	*V3* 4.52	*L2* 4.76
V1	1.54	0.010	0.978	0.074	0.000	0.000	0.000
L1	1.61	0.988	0.003	0.002	0.005	0.000	0.062
V2	2.07	0.000	0.068	0.985	0.001	0.028	0.000
T1	3.81	0.005	0.002	0.001	0.283	0.092	0.060
V3	4.25	0.001	0.035	0.016	0.007	0.964	0.002

4.2. FE model updating

Since obtained modal shapes and frequencies did not match measured ones, parameters influencing the dynamic response of the structure were updated to improve the model.

Updating was carried out to minimize the differences between the numerically and experimentally obtained modal frequencies and shapes, so several relevant structure and material parameters were considered.

As for the initial model, differences between obtained frequencies for the updated models were calculated, and mode shapes were compared using MAC procedure.

Some of the model updating procedures are shown in [8]-[10]. In this paper, manual updating results were presented.

4.2.1. Selection of updating parameters

In Figure 10, bridge details that affected the uncertainties in the modelling of the structure are shown. Considered parameters for updating were the stiffness of supports, properties of rail beams (which affect the main truss properties and also stiffness of pylons), cable properties, concrete plate properties and the weight of asphalt layer over the concrete deck.

Figure 10. *Structure details: pylon, coupled pavement structure, vertical truss beam and bracings*

For *rail frame* element in different model variants, torsional moment of inertia, a transverse bending moment of inertia and a vertical bending moment of inertia were modified, in rational amount, as also material parameters of elements in terms of weight and Young's modulus.

Cable properties modified were Young's modulus and cross-section in small percentages (maximum 3%).

Parameter that mostly affected mode shapes was the *stiffness of supports*. As footbridge has supports on lower profiles of vertical trusses in 3 points, these supports were modelled as springs, with different lateral and vertical stiffness.

Bending and lateral *stiffness of deck*, and *asphalt cover weight*, were also varied.

4.2.2. Manual model updating

In total, there were 5 updating elements, each having several properties that have been varied in FE modeling. The total number of considered updating parameters was 12.

To reverse the first two modes in the initial model – vertical and horizontal stiffness of supports and plate parameters were modified, as this had the biggest impact on modal frequencies. Also, to tune frequency values, an asphalt mass, rail frame element properties and cable properties were modified.

The results of two updated FE model solutions are presented herein.

So, in the first modified FE model, the stiffness of supports and plate parameters were modified. In the second modified model, in addition to the modifications made in the first model, the weight of an asphalt layer, rail frame element properties, and cable properties were modified.

Differences in frequencies compared to measurement results are shown in Table 3.

Table 3. *Frequencies gained in numerical analysis for two FE models*

Mode number / Mode shape type	Experimental results	FE model 1 - updated model -		FE model 2 - updated model -	
	Measured frequencies (Hz)	Calculated frequencies (Hz)	Difference %	Calculated frequencies (Hz)	Difference %
1. mode – V1	1.54	1.62	5.2	1.46	5.2
2. mode – L1	1.61	1.71	6.2	1.50	6.8
3. mode – V2	2.07	2.11	1.9	2.03	1.9
4. mode – T1	3.81	2.91	23.6	3.36	11.8
5. mode – V3	4.25	4.09	3.7	4.12	3.1

As shown in Table 3, for the first updated model, differences in frequencies are somehow lower for the lower modes (2 and 3), compared to the second model. As for higher modes, 4 and 5, differences in frequencies are lower in the case of the second updated model.

In the comparison, only five first modes were shown, as 6th measured mode was 4th vertical, while in numerical model 2nd lateral mode is obtained as 6th.

Mode shape MAC matrix, for the first FE model is shown in Table 4.

Table 4. *MAC table for FE model 1*

			SAP2000					
			V1 1.62	*L1* 1.71	*V2* 2.11	*T1* 2.91	*L2* 4.09	*V3* 4.84
ARTEMIS	*V1*	1.54	0.986	0.000	0.053	0.000	0.000	0.053
	L1	1.61	0.001	0.938	0.001	0.009	0.063	0.000
	V2	2.07	0.093	0.000	0.975	0.001	0.000	0.005
	T1	3.81	0.000	0.004	0.002	0.294	0.005	0.051
	V3	4.25	0.000	0.001	0.021	0.006	0.005	0.944

The second modified FE model showed the best correlation with the experimental results, regarding mode shape vectors. Max matrix for the second model is shown in Table 5.

Table 5. *MAC table for FE model 2*

			SAP2000					
			V1 1.46	*L1* 1.50	*V2* 2.03	*T1* 3.36	*V3* 4.12	*L2* 4.31
ARTEMIS	*V1*	1.54	0.993	0.003	0.065	0.000	0.006	0.000
	L1	1.61	0.000	0.994	0.002	0.002	0.000	0.061
	V2	2.07	0.080	0.000	0.990	0.001	0.021	0.000
	T1	3.81	0.001	0.004	0.001	0.289	0.083	0.047
	V3	4.25	0.016	0.001	0.019	0.005	0.984	0.002

Mode shapes for the second modified FE model are shown on Figure 11.

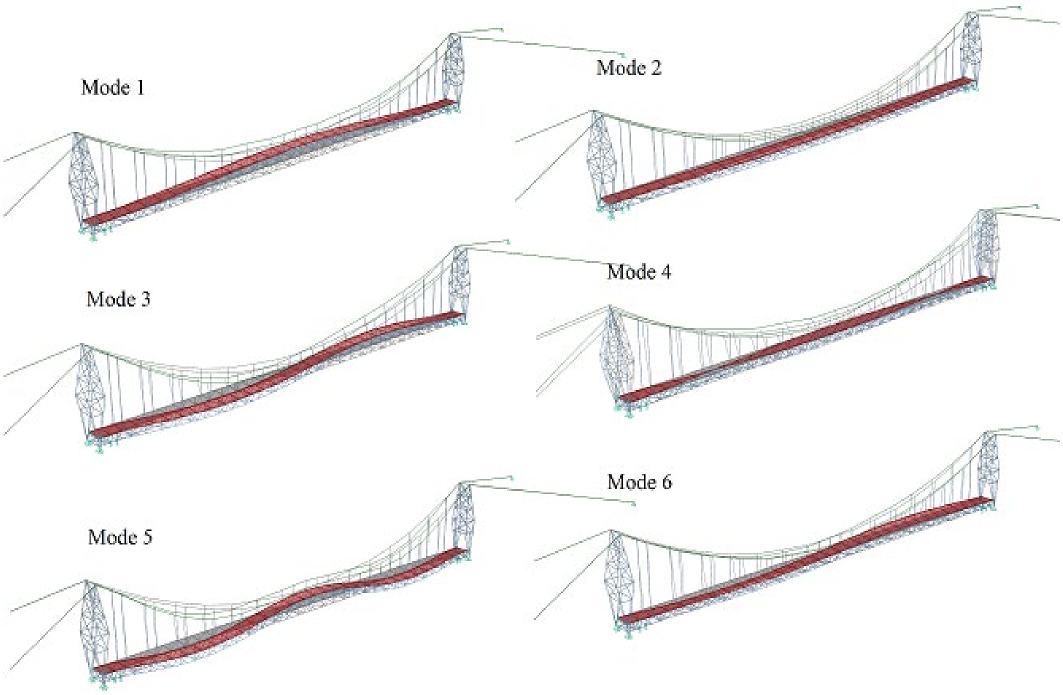


Figure 11. *Mode shapes for updated FM model*

An obvious difference between the numerically and experimentally obtained results is that the second horizontal mode, shown in the FE model, was not found in the measurement results.

4.2.3. Updated model analysis and further updating recommendations

As can be noted, the first torsional mode showed a low correlation with measurements, and the reason can be insimetricity of suspenders, several slack suspenders and also some deterioration damages, that were not considered in this stage of analysis.

Also, in the analysis of measuring results, the second horizontal mode was not detected in the first nine modes of vibration, unlike in the FE model. The possible reason could be that it was not „awakened“ enough, or/and its frequency was closely spaced with another mode and was not detected during the measurement result analysis.

In the process of finding an optimal solution for FE model, many data are unknown, and many parameters affect the mode shapes. Regarding that, it is difficult, and not practical to choose the best fit manually. Numerous combinations can be made considering possible structural and material properties. Also, subject footbridge has several deterioration damages, that also affect dynamic behavior, and should not be omitted from model updating.

Manual analysis is a good starting point for the further analysis of optimum parameters defining dynamic behavior, as it can indicate parameters that have the biggest impact on this behavior.

All parameters that affect dynamic behavior should be considered with a certain distribution of possible values, and the best modal shape and frequency match should be found using a probabilistic approach, and software with solver tools.

5. ANALYSIS AND CONCLUSIONS

An ambient vibration modal identification of so-called lively footbridge was performed, based on the Frequency Domain Decomposition method and Multiple Test Setups Measurement Procedure.

Results obtained by presented measuring layout and using described parameters in the process of measurement and data processing, resulted in clear modal frequency values and mode shapes, for five vertical, three torsional and one lateral mode.

In ARTeMIS software package, candidate modes were estimated by the “Peak picking” method and the obtained results were verified using MAC procedure.

For the subject bridge, the numerical model was developed using main design documentation, after visual verification of design parameters.

After comparing to the measurement results, numerical model was manually updated, choosing relevant updating parameters. The updated model’s frequencies were compared to the experimental results in terms of a difference in percentages. Numerical comparison of mode shapes obtained in FE models and by OMA was performed using, again, MAC formulation.

Considering that the bridge has several deterioration damages, geometrical irregularities (mostly regarding cable sag and suspenders), and also some other unknown parameters (as the behavior of the supports, and properties of rail beams), manually modified parameters provided a good correlation for the updated model’s values and measurement results, as shown in MAC tabular results.

Although the numerical model, manually updated, showed a relatively good fit with the measurement results, considering the nature of the bridge, further update is recommended using probabilistic analysis. Manual FE model update is a good starting point, as it helps in understanding the dynamic behavior of the subject structure, in terms of the effects of the main structure parameters on modal properties.

ACKNOWLEDGEMENTS

The presented research is part of 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*, financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia. The authors express their gratitude to the Ministry of Education, Science and Technological Development of the Republic of Serbia for partial financial support within the research project TR-36048.

LITERATURE

[1] S. d´Etudes T. des R. et A. SETRA, “Footbridges - Assessment of vibrational behaviour of footbridges under pedestrian loading,” 2006.

[2] Hivoss, “Design of Footbridges: Guidelines and background document,” 2007.

[3] FIB, “Guidelines for the Design of Footbridges - Guide to Good Practice, “ 2005.

[4] S. Živanović, A. Pavic, and P. Reynolds, “Vibration serviceability of footbridges under human-induced excitation: A literature review,” J. Sound Vib., vol. 279, no. 1–2, pp. 1–74, 2005.

[5] S. K. Jain, “Applications of Ambient Vibration Testing: An Overview,” Int. Res. J. Eng. Technol., vol. 2, no. 5, pp. 845–852, 2015.

[6] Structural Vibration Solutions, "The ARTeMIS Manual", Available: www.svibs.com, 2019.

[7] R. J. Allemang, “The modal assurance criterion - Twenty years of use and abuse,” Sound Vib., vol. 37, no. 8, pp. 14–21, 2003.

[8] D. J. Ewins, “Model validation: correlation for updating,” Sadhana - Acad. Proc. Eng. Sci., vol. 25, no. 3, pp. 221–234, 2000.

[9] S. Živanović, A. Pavic, and P. Reynolds, “Modal testing and FE model tuning of a lively footbridge structure,” Eng. Struct., vol. 28, no. 6, pp. 857–868, 2006.

[10] J. M. W. Brownjohn, P. Moyo, P. Omenzetter, and Y. Lu, “Assessment of highway bridge upgrading by dynamic testing and finite-element model updating,” J. Bridg. Eng., vol. 8, no. 3, pp. 162–172, 2003.

37 | Professional paper | Стручни рад
ISSN 2566-4484 | Doi 10.7251/STP2014400J
pages 400-410

Igor Jokanović, jokanovici@gf.uns.ac.rs, Faculty of Civil Engineering, Subotica, University of Novi Sad

Mila Svilar, mila.svilar@gmail.com, Faculty of Civil Engineering, Subotica, University of Novi Sad

Milica Pavić, pavic953@gmail.com, Faculty of Civil Engineering, Subotica, University of Novi Sad

Vladimir Đorđić, puteviiulice@gmail.com, Putevi i ulice d.o.o. Banja Luka

Dragan Topić, dragantopic@yahoo.com, Putevi i ulice d.o.o. Banja Luka

CONCEPT OF SOLVING THE STANDING TRAFFIC FOR THE CENTRAL CITY ZONE OF BANJA LUKA

Abstract:

Needs of standing traffic significantly burden the infrastructure and functioning of urban settlements. The problem is particularly acute in non-developed and developing countries whose cities are experiencing a virtually uncontrolled growth. Control of standing traffic is also an element of sustainable urban mobility. The paper presents the authors' idea to meet the needs of standing traffic through a disincentive of passenger cars in central city zone and construction of high capacity parking garages around the central zone to provide parking space as a service for the area free of motorized traffic.

Keywords: standing traffic, urban roads, central city zone, garage

КОНЦЕПТ РЈЕШАВАЊА САОБРАЋАЈА У МИРОВАЊУ ЗА ЦЕНТРАЛНУ ГРАДСКУ ЗОНУ БАЊАЛУКЕ

Сажетак:

Потребе саобраћаја у мировању значајно оптерећују инфраструктуру и функционисање урбаних насеља. Проблем је нарочито изражен у неразвијеним земљама и земљама у развоју чији градови доживљавају практично неконтролисан раст. Управљање саобраћајем у мировању је и елемент одрживе урбане мобилности. У раду је приказана идеја аутора у вези са задовољавањем потреба саобраћаја у мировању кроз дестимулацију доласка путничких аутомобила у централну зону града и изградњу капацитетних паркинг гаража по ободу уже централне зоне како би се осигурао паркинг простор као сервис за зону ослобођену моторног саобраћаја.

Кључне ријечи: саобраћај у мировању, градске саобраћајнице, централна градска зоне, гаража

1. INTRODUCTION

In larger cities, the population is continuously growing, automatically provoking local increase of motorization level, i.e. number of cars. This is particularly visible in underdeveloped and developing countries, where cities, due to uneven and incoherent territorial development, represent extreme zones of attraction for the population trying to generate sufficient income for a relatively normal life (social mobility and economic prosperity). At the same time, urban development itself is often uncontrolled, in the phase of concentric expansion, which, in traffic view, causes an increase in the length of travel so that there is less and less movement that can be done on foot or by bicycle. This concept of urban content development is receptive to the use of passenger cars that are in spatial, ecological, economic, etc. conflict with the urban environment. Very often, this goes along with the fact that in most such countries the urban road network does not have sufficient capacity to consume a large amount of cars, or motor vehicles in general.

As a consequence, traffic jams and problems with standing traffic occur, posing serious issues for many cities around the globe. Due to the nature of the organization of activities in the central parts of major cities, there is a high demand for space that would meet the needs of standing traffic, and one of the main characteristics of this type of traffic is the high intensity of land use. The need for parking is relevant for individual motorization, as passenger cars spend more than 95% of their working life idle [1, 2]. For this reason, stationary traffic occupies a large part of the space intended for motorized traffic. However, in the central parts of the cities, the available space is very limited so that it also affects the possibilities of organizing any form of parking.

The main goal of standing traffic management is to align parking demand with the appropriate supply. However, the strategy of organizing standing traffic has a strong impact not only on the operation of the parking system, but also on the entire urban traffic system and the city in general. The possible responses of drivers to the organization of standing traffic (primarily parking charges and time constraints) are diverse, but also largely uniform [3]. These include changing the type of parking, parking locations, mode of transport, occupancy of the car, destination, frequency of travel, travel time (with possible consequences on the duration of parking) and route [4]. Studies have shown that the most important factor in reducing car use is the cost of parking [5].

Although a good standing traffic management strategy has many positive indications for sustainable transport, a poor strategy can have the opposite effect. For example, an analysis of 16 studies from 11 cities worldwide [6] showed that about 30% of traffic in central urban areas are vehicles that cruise in search of parking, which is the result of poor management of standing traffic. In addition, there are doubts that the implementation of a standing traffic management strategy could adversely affect the competitiveness and efficiency of operations in a particular territorial area, or in some areas of the economy [7].

Standing traffic management is also one of the elements of sustainable urban mobility, which conceptually first appeared in major cities in the world in response to the pursuit of sustainable development. Following the basic definition of sustainability, sustainable mobility should be understood as a mobility model that allows for movement with minimal impact on space and the environment, and therefore, standing traffic is an integral part of this concept as a significant consumer of spatial resources.

Like in the many countries and cities around the world, Banja Luka, as the second largest city in Bosnia and Herzegovina, experiences significant urban traffic problems manifested through congestion on major streets and intersections, as well as through lack of space to serve the needs of individual motorized traffic for short- or long-term parking. During the past period, the authorities in Banja Luka have tried to solve certain problems of standing traffic, but without major successes and/or changes in the use of traffic space in the city. The aim of this paper, in the absence of an official and serious traffic study and planning basis for organization and management of urban traffic, is to provide an initial proposal for further analysis and consideration of strategic issues in the improvement of the Banja Luka urban road network and importance of defining particular parking areas for individual motorized traffic.

2. WESTERN BALKANS - BANJA LUKA

As one of major cities in the region, Banja Luka should be observed in the context of conditions, i.e. changes that occurred over the last twenty years, and that are still happening. In this respect, a brief summary of the analysis of the basic characteristics of the Western Balkans and urban transport and traffic infrastructure in this area is presented in the few paragraphs that follow [8].

The process of demographic transition, which the population of the Western Balkans has been undergoing in recent decades, has taken place simultaneously and interacted with the process of urbanization. Uncontrolled migration has particularly stimulated the intensified demographic and spatial expansion of urban and peri-urban zones (the process of unplanned and unorganized suburbanization) of cities, which has largely caused unplanned and informal construction. Such construction most often took place in an unclear urban matrix with insufficient and/or incomplete capacities of traffic and communal infrastructure, as well as other pronounced conflict phenomena that impede quality living and working conditions of the population.

The process of urbanization of the Western Balkans shows inconsistent characteristics. Focal points of the development are larger urban settlements, dominated by larger centers (national, regional and sub-regional). They exert influence and transform the environment by the power of their functions, and urbanized and deagrarized zones are created around them. These are peri-urban rings - gravitational regions that form around stronger functional centers. The expansion of urban spatial-functional systems of cities was also followed by a change in the structure of population activity in settlements located not far from urban centers, which eventually merged with them and were subsequently administratively annexed to them. In this way, the urban tissue of all major cities (Banja Luka, Belgrade, Mostar, Niš, Novi Sad, Podgorica, Sarajevo, Skopje, Tetovo, Tirana, Tuzla, Zenica, etc.) was expanded, which by developing industrial zones, locating commercial objects, building residential areas and increasing the capacity of infrastructure facilities and the supra-structural system were transforming the surrounding rural settlements.

The mobility of the population in the Western Balkans region is many times lower than in the developed European countries (in certain countries this ratio goes up to three to four times). The majority of over 90% of all travelers are daily migrants, in urban areas. Most of trips are made by passenger cars, public urban or suburban passenger transport, while the others comprise of intercity movements. Significant unevenness of urban travel is evident, with most of the trips being made in the largest urban settlements (mainly national and certain regional centers).

The supply of traffic infrastructure, i.e. the road network in urban areas, is generally inherited and occasionally adapted to the growing demands. Some major links (primary urban roads), usually in large urban settlements have been developed and/or modernized in the last fifty years. The availability and capacity of access streets in the older urban areas remained largely unchanged. New urban settlements built according to the plans are exceptions where the primary traffic infrastructure is planned and designed according to modern principles of adaptation to the size and function of a particular settlement, i.e. urban area, but it often happens that the secondary network (access streets and parking) is missing.

In addition to the classic urban traffic infrastructure, intercity and rural infrastructure (primarily roads) very often run through central urban areas. This is especially pronounced in smaller communities, so that these zones are unnecessarily burdened with transit traffic that is not in the service of life and work of such environment. Of course, this type of infrastructure alignment provides good connectivity, but significantly interferes local traffic, life and work.

Lack of parking space for individual vehicles in large urban areas is especially visible. As a result, urban roads are often adapted to the increasing demands of standing traffic by taking away space dedicated for regular traffic flow, even in primary urban roads with mobility function rather than access function. On-street parking is dominant, while organized surface parking lots and multi-story garages (underground or above ground) exist only in urban cores and plan-built parts of larger urban settlements/cities (although not sufficient). Smaller urban settlements, on the other hand, very often do not have any capacity for standing traffic other than space within private estates, and the vehicles are mostly parked on the part of the carriageway intended for through traffic (even on intercity and rural roads passing through those settlements) creating traffic jams and significantly affecting safety.

Banja Luka, as the second largest city in Bosnia and Herzegovina and the administrative center of the Republic of Srpska, does not differ from the above mentioned basic characteristics of urban settlements in the Western Balkans region.

3. BANJA LUKA - CITY STRUCTURE AND TRAFFIC CHARACTERISTICS

The term city means an organized human settlement that is the political, economic or cultural center of the area [9]. The role of urban traffic is to integrate city amenities, direct and synchronize activities and set the pace of city life. In addition, urban roads limit the space for the development of physical structures so that traffic is an inevitable factor in the spatial organization of the city. Therefore, the city and the traffic are unique planning and design complex with the same temporal and spatial dimensions.

As the planning and design of urban roads must be related to the land use, it is important to identify the basic units, i.e. to determine the main characteristics of the land use in the central city zone of Banja Luka. Typically (Figures 1 and 2), the inner city center is characterized mainly by business and administrative activities, although housing (single or multi-family) is also heavily represented in this part. In contrast, the rest of the central city area shows dominant housing characteristics with very few businesses.

The city center brings together various contents of higher and lower levels, imposes a high degree of social communication and connection of people into the essential community. The attractiveness of the center is a consequence of the structural elements and the services offered by the center with its contents. The basic precondition for the development of the center is its accessibility and connection with the gravity area. Significant functions of the center include the functions of supply and services, restaurants and accommodation, finance and business, communication and information, education and science, social and health care and social and political function.

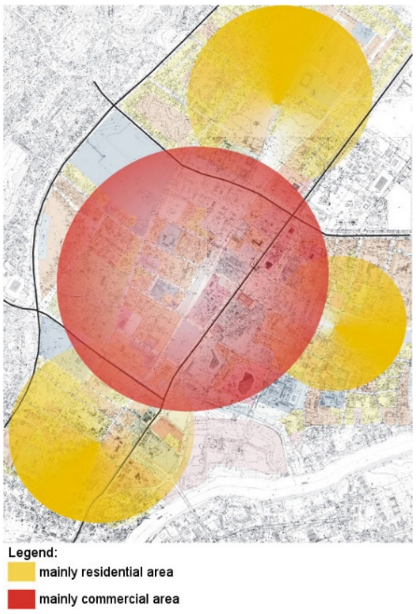


Figure 1. *Zoning of the central city area of Banja Luka [10]*

Figure 2. *Land use within the central city area of Banja Luka [10]*

In the last two decades, Banja Luka has witnessed a significant expansion of individual motorized traffic, accompanied by a high degree of urbanization and negligible correction of the capacity and/or organization of traffic areas. At this point, it is no longer questionable whether the city's road network will collapse, but only when it will happen. Over the last few years, it has been noticeable that morning and afternoon peak loads are being extended to more and more streets, and that in some parts of the central city area peak loads have a practically continuous duration from early morning to early evening.

Another important issue for Banja Luka is the absence of the updated urban planning documentation (currently valid is the one from 1975 [11]), as well as the outdated traffic analysis which was performed in 2007 [10]. At the moment, the only valid implementation planning documents, forming the basis for spatial planning, are regulation plans. However, they are all generally similar to one another, and the main focus is on the layout and design of structures (residential and administrative buildings), while at the same time missing to define the conditions for improvement and/or development of traffic infrastructure. Furthermore, the omission of the existing regulations (legislation, technical regulations and standards for design) in Bosnia and Herzegovina and the Republic of Srpska to address urban roads in general is also interesting - simply, such documentation does not exist. The regulatory gap is most often bridged by using certain professional literature and some experiences from outside the region that cannot be easily applied to domestic conditions.

The central city area (Figure 3) is confined with the so-called East (1) and West (2) transit (intercity roads in highly urbanized areas), on the North side with the Vuka Karadžića (3) and Aleja Svetog Save (4) streets, and on the South side with Bulevar vojvode Stepe Stepanovića (5), streets Teodora Kolokotronisa (6) and Cara Lazara (7) and Bulevar Cara Dušana (8). The aforementioned area is intersected with other urban roads, the most important being the streets of Gavre Vučkovića, Kralja Petra I Karađorđevića, Vidovdanska/Kninska, Vase Pelagića and Bulevar vojvode Živojina Mišića. There are also several significant resources and entities in the area, such as the Vrbas river, the Kastel fortress, and the old city center.

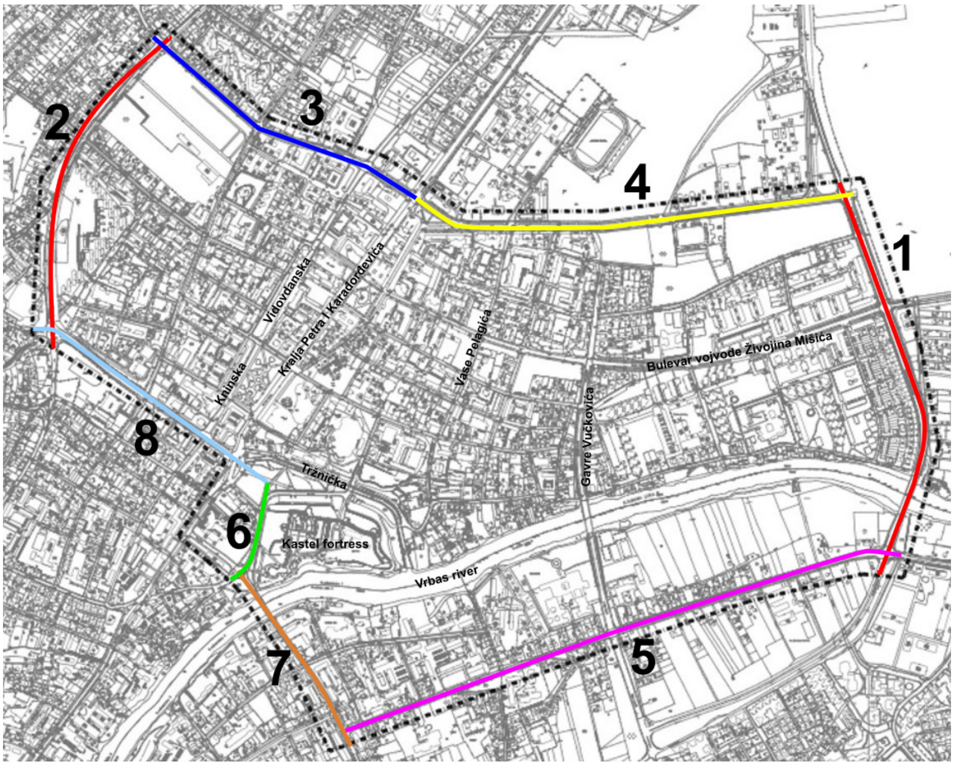


Figure 3. *Coverage of the observed area [authors]*

The urban street network, as dictated by theoretical basis and practical experiences, must be divided into primary (in the function of traffic connection) and secondary (in the function of supporting urban content), while the whole concept of a city as a whole is formed through intentional separation (segregation) and connection (integration) of different modes of traffic. Following these principles, the 1975 Urban Plan [11] further defined that West and East transit roads are primary urban roads - city's magistral roads interconnected into a ring by streets Ivana Gorana Kovačića in the North and

Gavrila Principa in the South (these two streets being outside the scope of the observed area in Figure 3). In the same direction, transverse connections were planned at the perimeter of the inner city center, namely Bulevar Cara Dušana - Cara Lazara Street (South) and Aleja Svetog Save - Vuka Karadžića Street (North). All other urban roads within the scope belong to the lower-level streets, i.e. to the feeder and access streets. Most of these streets were built with only two lanes and with poorly resolved space for pedestrians.

In order to improve the entire road network of the city, a great number of city streets should be reconstructed to achieve capacity expansion (i.e. final adaptation to a defined function for primary urban roads) or to carry out adaptation to a specific local conditions. In this regard, particular emphasis is placed on local network - first and second level access streets (with and without user segregation). Access streets of second level are particularly significant in relation to the possible implementation in residential areas.

The structure of the parking space in the central zone of Banja Luka reflects the specifics of current traffic relations and social attitudes about parking of passenger vehicles. In most of the central city area, passenger car parking has no time limits, but is subject to a charge system. Parking is mostly done on carriageways and sidewalks, making the conditions of movement of vehicles unbearable, while parking is also in direct conflict with urban functions. In addition, the toll system also includes several surface parking areas, with most of these areas in the city center - therefore, forcing the entry of passenger vehicles into the area limited by streets of Vidovdanska/Kninska, Bulevar cara Dušana/Tržnička, Vase Pelagića and Aleja Svetog Save.

4. STANDING TRAFFIC SOLVING CONCEPT

Since the highest densities of attractive urban contents are located in the inner central city zone, the highest concentration of parking demands occurs in this area, while at the same time this zone provides the least possibility to provide the required capacity. This should also take into account the fact that parking needs for the residents and visitors occur simultaneously in this area, without significant opportunities for combined use of the same parking facilities.

Therefore, the basic goal that should be achieved with proper movement organization and parking strategy is to discourage the use of passenger vehicles having the need for long-term parking at the city center. Only short-term parking periods that are in compliance with the operation of central urban roads can be accepted in the center. The problem of parking for city center residents should be solved by the construction of dedicated parking facilities in areas where the demands are high, as well as the possible combined use of all available parking spaces.

The street Kralja Petra I Karađorđevića is mentioned as an example of discouraging the passenger cars in the city center. As it stands, this urban road is of great capacity and runs through the center itself, generating significant motorized traffic. At the same time, significant housing and mainly service business capacities (trade, crafts, restaurants) are located around this urban road. The complete elimination of motorized traffic or the retention of public transport only on the route from Trg Krajine to the National Theatre would provide huge space for cyclists and improve the level of pedestrian service as proposed in Figure 4. A similar concept can be applied to other primary urban roads in the inner central area of the city. In case of this concept of streets, the reverse approach is applied - design decisions are not based on the parameters used in traditional design of urban roads (functional classification of the road, design speed and traffic volume), but on characteristics that more closely describe the road itself, as well as the hierarchical priority [12]. Pedestrians and cyclists come first. The aim is to provide safe access for all traffic participants. Addition to this concept of disincentives is the improvement of access street profiles through the full integration of users in common areas in order to calm traffic, raise the level of safety for “weaker” participants (pedestrians and cyclists), and prevent bypass traffic due to limited use of primary roads.

Following the previous paragraph and in order to support the complete concept of traffic organization in accordance with the postulates of sustainable urban mobility, the needs of amenities’ users in this zone, from the point of view of access to passenger cars, would be addressed by the construction of high capacity parking garages around the perimeter of the zone. So far, little has been done in Banja Luka to build vehicle parking facilities, but it is a fact that parking requirements could be significantly reduced by the construction of public multi-story parking facilities. To the contrary, the construction of surface parking lots and the provision of parking in street profiles, which is still a tendency, takes up a large part of the space and cannot have significant effect on solving the problem of standing traffic in the inner city area.

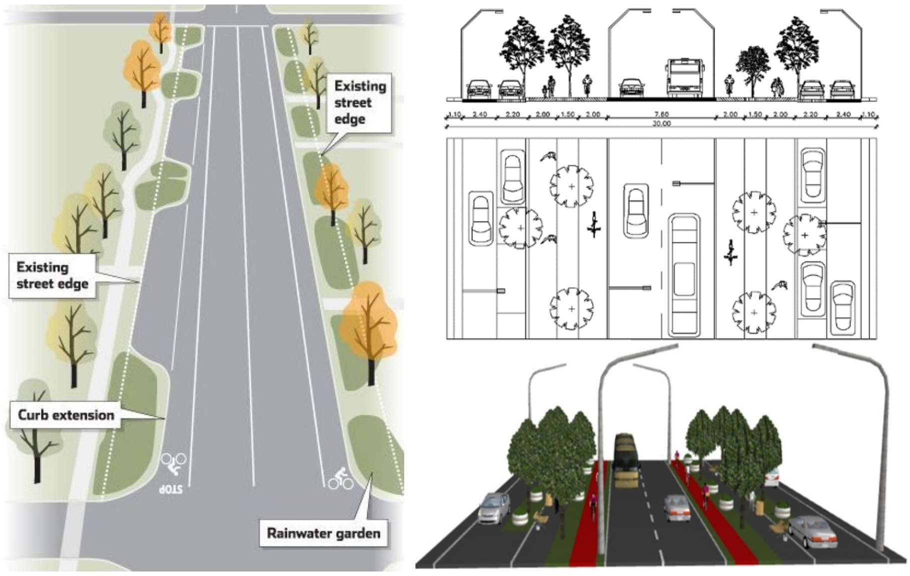


Figure 4. *Examples of possible solutions of cross section for Kralja Petra I Karađorđevića street [13, 14]*

Figure 5 shows the once planned locations of parking garages in the inner city center, as well as their possible capacities [10]. If these proposals were implemented as planned, the demands for parking in the inner city center would be significantly lower. As can be seen, the total number of parking lots in these five planned garages is 3,306 and by their construction, the total number of lacking parking space in the city center would be reduced by almost 50%, according to analyses at the time.

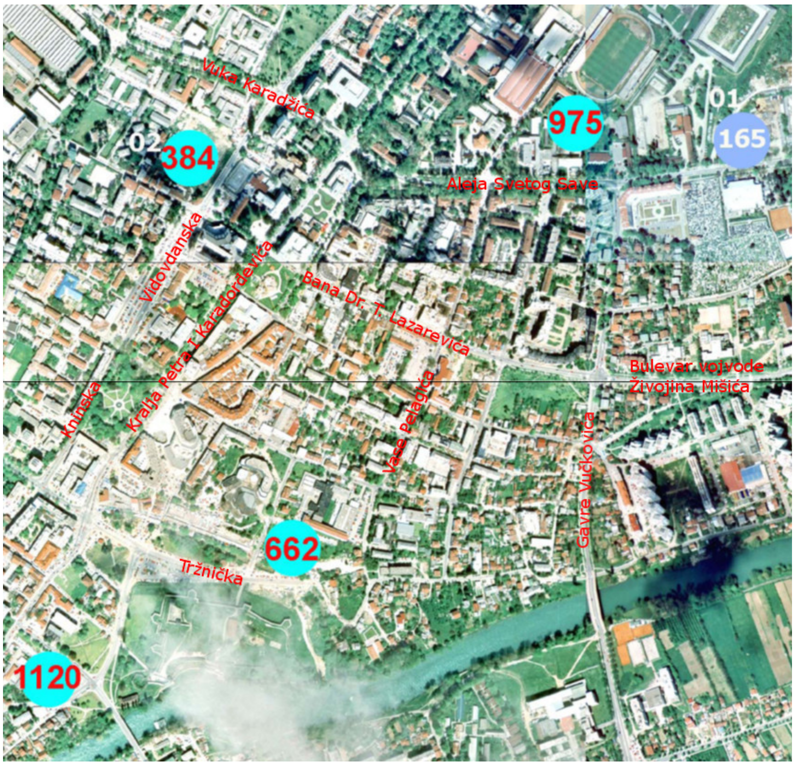


Figure 5. *Planning of the garages with number of parking lots [10]*

However, since these proposals have not been implemented, the problem of lacking parking space still remains, although in the meantime an attempt to overcome this issue by organizing the surface parking lots and the increasing engagement of street profiles for parking purposes was made. One of the positively applied solutions is the organization of combined parking in certain residential units where tenants have the apparent status of privileged users (in terms of price, but without a guaranteed parking space at the desired moment), while other users pay full tariff during occupancy. Currently, in this way, in the central city area, within the tariff system, about 5,000 parking lots have been provided. Considering only the minimal space required for the vehicle to stand (5.0 x 2.25 m), this represents an extremely high load for the urban road network (about 6 ha), with the stated amount increasing by at least 40-50% for communication purposes. A simple comparison with the previously planned parking garage capacities would indicate that significantly less engaged space would provide over 65% of current parking capacity, not to mention the access capacities, space freed for other purposes and the chances of adapting access streets to the concept of sustainable urban mobility.

Therefore, the only objectively possible solution for consideration is still the construction of high capacity parking garages. Bearing in mind that the acceptable length of pedestrian movements is 400-800 m [15], it is necessary to provide a motor traffic free area with a parking space. In this respect, the most rational solution is represented by the multi-story parking garages (with underground and above ground levels) in carefully selected locations around the perimeter of the central zone. Selection of the garages' locations depends, besides the acceptable length of pedestrian movement, on the available space around the perimeter of the zone without traffic. After considering the zones of attraction for the individual locations of the garages, as well as identifying the potentially available space for their location, the proposal for positioning multi-story garages is shown in Figure 6. The proposed locations are at the following positions:

- G1 - corner of Vase Pelagića and Bana Dr. Teodora Lazarevića streets;
- G2 - corner of Vuka Karadžića and Vidovdanska streets;
- G3 - Vidovdanska street (Contemporary Art Museum)
- G4 - corner of Tržnička and Đure Daničića streets;
- G5 - corner of Jovana Dučića and Bulevar cara Dušana streets;
- G6 - corner of Isaije Mitrovića, 22. aprila and Patre streets.

The quality access would be provided in this way to all amenities in the central city zone, while at the same time creating the preconditions for freeing this part of the city from the negative impact of passenger vehicles and, over time, becoming a "kingdom" of pedestrians and cyclists.

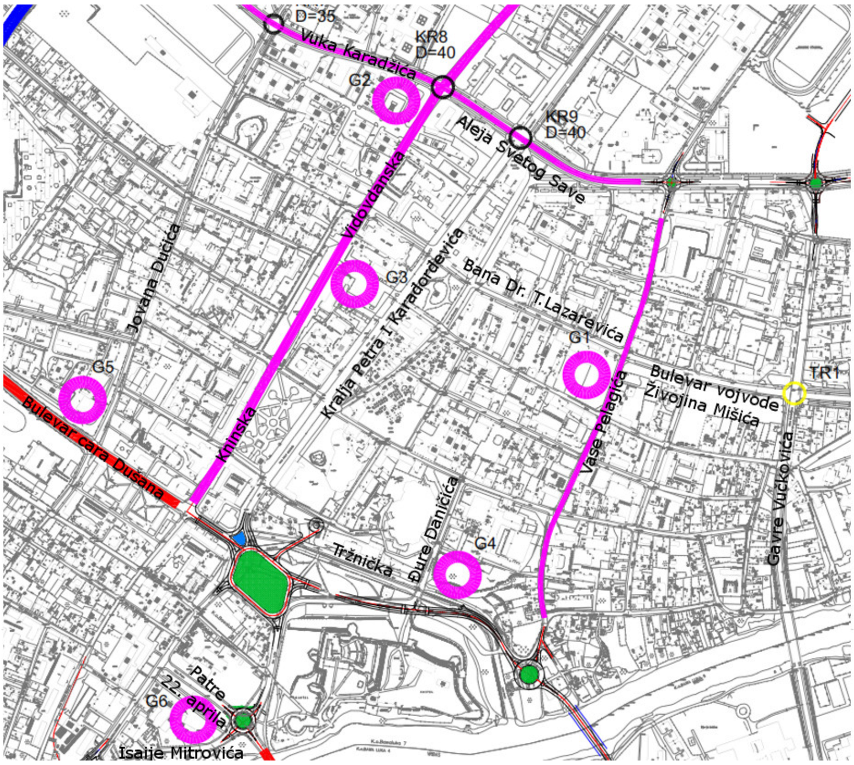


Figure 6. *Proposal of locations for parking garages [authors]*

In order to make the best use of the capacity of these sites, it is necessary to combine the proposal with appropriate solutions (corrections) on the primary network and on the network node points (intersections). For example, for good quality access to this zone, taking into account the consistency in solving intersections, it would be desirable to reconstruct the existing classical surface intersections along the streets of Vuka Karadžića into roundabouts, at the locations of crossroads with Jovana Dučića (KR7), Vidovdanska (KR8) and Kralja Petra I Karađorđevića (KR9) streets (Figure 7). Considering that there is intensive pedestrian and bicycle traffic around the inner city center zone, and given the intensive construction in the area immediately adjacent to this zone, it is necessary to further consider and analyze pedestrian flows and the way of cross-communication through street profiles.

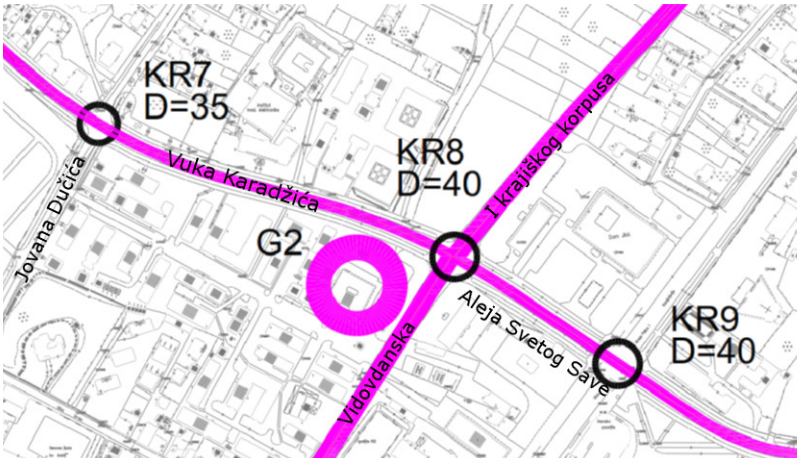


Figure 7. *Proposal for reconstruction of intersections along the street Vuka Karadžića in order to support access to the site of the garage G2 [authors]*

Also, for easier access to the parking garage in Vase Pelagića Street (which is under construction), it would be advantageous to realize the so called turbo-rotor (TR1) which would provide better access to the mentioned location for all vehicles aiming at the city center and central city contents, as well as more efficient distribution of flows towards the amenities at the edge of the central zone (Figure 7).

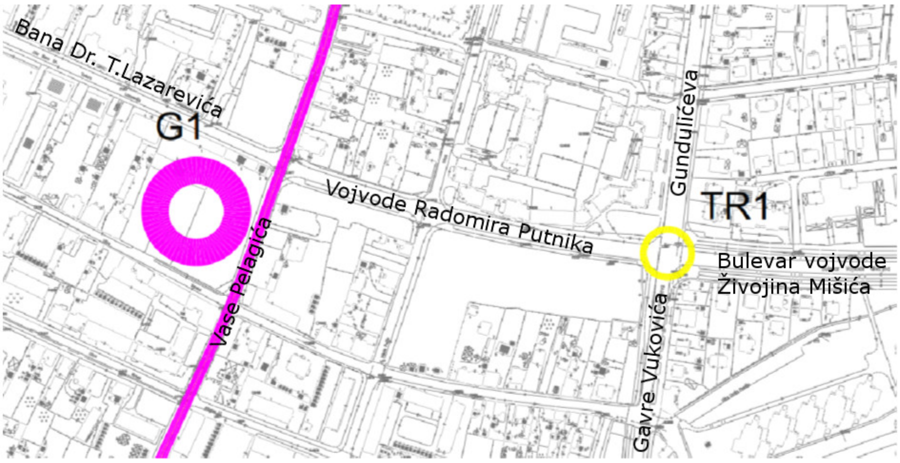


Figure 8. *Location of the garage G1 in Vase Pelagića street and position of turbo-rotor at the crossroads of Bulevar Živojina Mišića and streets Gundulićeva, Gavre Vučkovića and Vojvode Radomira Putnika [authors]*

The aforementioned discouraging and establishment of a parking garages system would also reduce the load on existing parking capacities within residential blocks, which could then be organized on the principle of restricted access, i.e. only for residents of those blocks.

On the other hand, the needs of new residents inside the central zone should be solved through the organized parking lots along the place of residence, as part of the apartment equipment. This would mean that investors, when performing new construction or reconstruction, are obliged to foresee and construct the required number of parking spaces within the facilities (underground garages or dedicating several first floors of the buildings for the purpose of parking), without planning to solve the problem within the street profile where these buildings are located. This practice should not only be a rule for the city center, but also for the entire territory of the city. The same principle must apply to all commercial buildings in the city, and especially in the central city area, which would address the parking demands of business cars and vans, visitors and a certain (smaller) volume of employees' vehicles.

Changing the way individual streets operate and changing the use of surfaces require an analysis of the redistribution of individual motorized traffic. For the proper consideration and justification of proposed locations and measures at certain intersections, it is also necessary to further determine the number of users that will spill over into public urban transport, as well as the part of traffic that would remain present on the new form of network after the intervention. According to the data obtained by such analysis, it would be necessary to check the functionality of the network and to compare the situation before and after to determine the feasibility of the intervention and the quality of the solution.

5. CONCLUSION

Spatial demands of passenger cars are the biggest drawback of the urban traffic system. The existing Banja Luka street network is very modest in size and capacity, which leads to traffic jams on a daily basis, while it is further complicated by the enormous need for standing traffic. The capacities of the existing parking places, especially in the central city zone, are not nearly enough to meet these demands, so it is necessary to find a solution for parking vehicles in the center of Banja Luka. The need to solve the problem of standing traffic is further emphasized in the light of meeting the requirements of sustainable development, i.e. establishing sustainable urban mobility.

The solution is to discourage the motorized traffic in the inner city center and the construction of a number of multi-story garages around the perimeter of the area, which with their capacities, suitable location and well-organized system of internal movement, could lead to significant progress in improving not only vehicle parking itself, but also the complete traffic system of the city. Also, one of the normative measures, which was lost in practice in turbulent times, is the obligation of all investors to solve the problem of standing traffic within the lot where they build their facilities. All these changes must first be analyzed through appropriate models of network usage and usage of individual modes of transport in order to arrive at the correct conclusion, to the contrary of the customary in current practice to solve problems in and ad-hoc manner, without analyzing the interaction with the rest of the network. Above all, the essential premise is to finally establish a hierarchical order in urban planning and traffic base of Banja Luka.

LITERATURE

[1] G.R. Marsden, "The evidence base for parking policies - a review", Transport Policy, vol. 13, No. 6, pp. 447-457, 2006. (DOI: 10.1016/j.tranpol.2006.05.009)

[2] D.C. Shoup, "Cruising for parking", Transport Policy, vol. 13, No. 6, pp. 479-486, 2006. (DOI: 10.1016/j.tranpol.2006.05.005)

[3] J. Simicević, S. Vukanović and N. Milosavljević, "The effect of parking charges and time limit to car usage and parking behaviour", Transport Policy, Vol. 30, pp. 125-131, 2013. (DOI: 10.1016/j.tranpol.2013.09.007)

[4] G. Scholefield, R. Bradley and A. Skinner, "Study of Parking and Traffic Demand: A Traffic Restraint Analysis Model (TRAM)", Transportation Planning Methods, Vol. P414, 1997.

[5] D. Higgins, "Parking taxes: Effectiveness, legality and implementation, some general considerations", Transportation, vol. 19, No. 3, pp. 221-230, 1992.

[6] D. Shoup, The High Cost of Free Parking, Chicago: Planers and Press, 2005.

[7] L. D'Acierno, M. Gallo and B. Montella, "Optimisation models for the urban parking pricing problem", Transport Policy, vol. 13, No. 1, pp. 34-48, 2006. (DOI: 10.1016/j.tranpol.2005. 08.001)

[8] I. Jokanović, M. Maksin and V. Ristić, "Saobraćaj i saobraćajna infrastruktura kao elementi strategije urbanog razvoja" in Proc. 10th Bosnia and Herzegovina Congress on Transport Infrastructure and Transport, Sarajevo, 2019, electronic proceedings, pp. 93-104, Book of Abstracts, pp. 18.

[9] M. Maletin, Planiranje i projektovanje saobraćajnica u gradovima, Belgrade: Orion art, 2019.

[10] Saobraćajna studija Banja Luke, Banja Luka: Urban Planning Institute, 2007.

[11] Banja Luka Urban Plan, Banja Luka: Urban Planning Institute of Banja Luka, 1975.

[12] Complete streets Chicago, Design guidelines, Chicago: Department of Transportation, 2013.

[13] Ž. Grujić, I. Jokanović, V. Đorđić and D. Topić, “Koncept drumske mreže u centralnoj zoni grada Banja Luka”, Put i saobraćaj/Journal of Road and Traffic Enginnering, vol. 65, No. 4, pp. 11-16, 2019. (DOI: 10.31075/PIS.65.04.02)

[14] N. Damnjanović, and I. Jokanović, “Kompletne ulice - ulice za sve”, Journal of the Faculty of Civil Engineering, vol. 34, pp. 67-78, 2018. (DOI: 10.14415/zbornikGFS34.05)

[15] M. Šimunović and Lj. Ćosić, Nemotorizirani promet, Zagreb: Faculty of Traffic Sciences, 2015.

38 | Professional paper | Стручни рад
ISSN 2566-4484 | Doi 10.7251/STP2014411K
pages 411-421

Mlađen Krndija, krndija.mladjen@gmail.com, "GIM-TEST" Ltd. Banja Luka

Marina Latinović, marina.latinovic@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

Gordana Broćeta, gordana.broceta@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

Gojko Savić, savic.gojko@yahoo.com, "GIM-TEST" Ltd. Banja Luka

MEASURING EQUIPMENT CALIBRATION AND DETERMINATION OF THE INITIAL CALIBRATION INTERVAL

Abstract:

To optimize measurement procedures in laboratories, in terms of the balance between economics and risk, determination of the optimal calibration interval for measuring equipment has significant importance. This paper will show an approximate, but effective method for determination of initial calibration interval, regarding "ILAC" guidelines and original recommendations based on authors' experience. The presented applied method is adapted for the equipment used in a laboratory for building materials and structural testing, and the results of its application are shown on the examples of several different instruments. Impact factors on calibration intervals are analyzed, and the basic recommendations for revision of the initial calibration intervals are given.

Keywords: calibration, measuring equipment, initial calibration interval, ILAC guidelines

КАЛИБРАЦИЈА МЈЕРНЕ ОПРЕМЕ И ОДРЕЂИВАЊЕ ПОЧЕТНОГ ИНТЕРВАЛА КАЛИБРАЦИЈЕ

Сажетак:

Да би се извршила оптимизација поступака мјерења у лабораторијима, у смислу баланса између трошкова и ризика, одређивање оптималног интервала калибрације мјерне опреме има велики значај. У овом раду, у циљу одређивања почетног интервала калибрације, приказана је приближна, али ефективна метода, која је у складу са "ILAC" смјерницама и оригиналним препорукама заснованим на искуству аутора. Презентована примјењена метода је прилагођена опреми која се користи у подручју испитивања материјала и конструкција, а резултати њене примјене приказани су на примјерима неколико различитих инструмената. Анализирани су фактори који утичу на интервале калибрације и дате су основне препоруке за ревизију почетног интервала.

Кључне ријечи: калибрација, мјерна опрема, почетни период калибрације, смјернице ILAC

1. INTRODUCTION

Every measurement is accompanied by errors, and the causes of these errors may be different. A common classification of measurement errors is: random, system and gross. Random errors are a result of imperfections of measuring instruments and imperfections of the senses of a person performing the measurements. They are always of a different sign and they are considered as inevitable. Gross errors are caused by an insufficient attention of a laborant and they must be excluded not to affect the test result. System errors, discussed in this paper, are the errors that occur as a result of the uncalibrated measuring instruments. In repeated measurements, such errors have the same sign and, approximately, the same intensity. It is important to note that, generally, their causes can be eliminated or reduced to a fair extent. Regarding this, this paper points out that the calibration and the determination of adequate calibration interval is of the utmost importance for the elimination of system errors.

During any scientific or commercial testing within accredited laboratories, to ensure the proper functioning of the equipment during its operation, its reliability and the required precision in the measurement and testing processes, laboratories should use only calibrated measuring equipment. This is strictly defined by the standards EN ISO/IEC 17025: *General requirements for the competence of testing and calibration laboratories,* and EN ISO 10012:2004 *Measurement management systems - Requirements for measurement processes and measuring equipment* [1], [2].

In addition to the status of calibration, i.e. determination of measurement traceability, standards [1], [2], require defining equipment management process, instructions for handling and maintenance, keeping servicing records and controlling measuring and environmental conditions. All mentioned needs to be defined in general and specific laboratory instructions for the equipment in use.

Based on the stated above, as well as on the experiential processes in the building material and structural testing laboratories, a schematic overview of the equipment management system within a testing laboratory is shown in Figure 1.

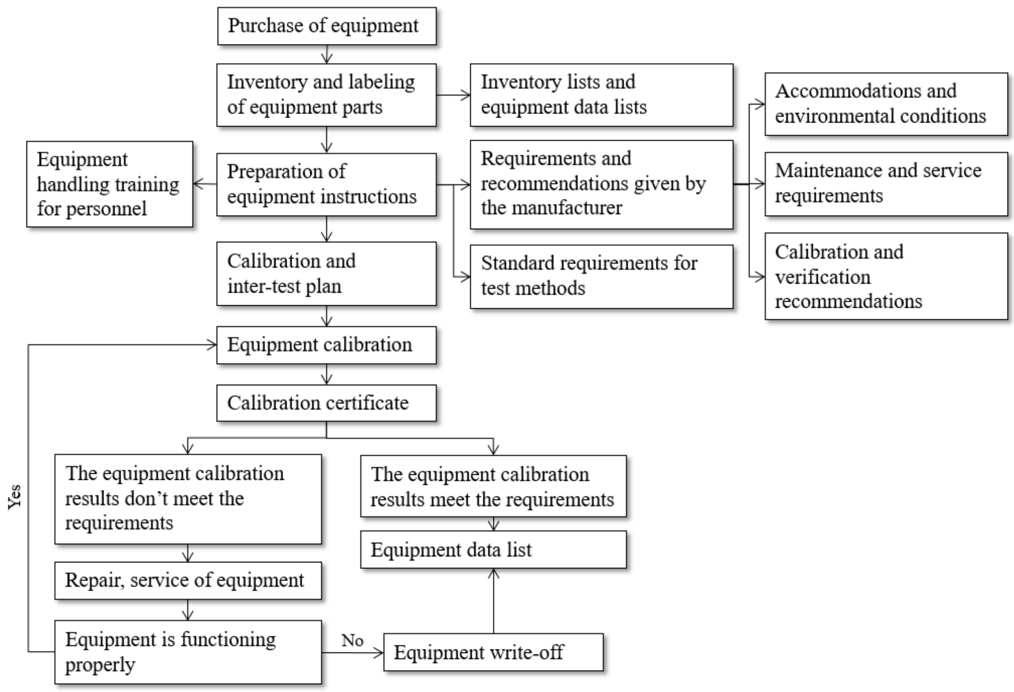


Figure 1. *Equipment management system scheme within a testing laboratory* [3]

Calibration ensures that in established intervals, measurements taken with a piece of equipment will remain in-tolerances, regarding defined measurement uncertainty between calibrations. Frequent calibration can ensure the quality of measurements, but if the interval is not optimal it leads to unnecessary costs. Factors to consider in calibration plan, as well as possible methods for determination of calibration intervals, are given in guidelines ILAC- G27:06 *Guidance on measurements performed as part of an inspection process* [4].

So, to reduce the risk of errors, but also the cost of calibration, it is in the interest of laboratories to determine the optimal calibration interval.

In this regard, in this paper, an orientational, but effective initial calibration interval calculation algorithm is presented. This algorithm for determining the initial calibration period was developed by the Brazilian Calibration Group (https://www.grupocalibracao.com.br/), and it is demonstrated on the example of the calibration period determination for the equipment used in the pharmaceutical industry [5] and for the equipment used for geodetic measurements [6]. Method is adapted for building materials and structural testing laboratories (mostly regarding defining wider scope of qualitative parameters) by the author of this paper, and following instructions given by ILAC [4].

Subject modified method, applied in document [3], was revised during the accreditations of the laboratory of the Public institution *Institute for urbanism, civil engineering and ecology of Republic of Srpska*, it's Business unit *Institute for materials and construction testing* and also "*GIM-TEST*" *ltd Banja Luka* laboratory.

The obtained results for the initial time intervals, according to the proposed model, are compared to the maximum initial intervals prescribed by the corresponding standards and/or manufacturer's recommendations for a specific group of laboratory equipment for testing of building materials and structures. Given the existence of the equipment for which there are no instructions or recommendations defined by the standards, or given by the manufacturer, it is of the utmost importance development and elaboration of such models. Also, recommendations for revision of calibration time interval are given.

2. CALIBRATION OF MEASURING EQUIPMENT

The standard EN ISO/IEC 17025: *General requirements for the competence of testing and calibration laboratories*, emphasizes establishing calibration programs for measuring equipment and/or parts of measuring equipment that have an impact on measurement results. For a valid measurement result, the measuring equipment must be calibrated using standards for which traceability to the Internacional System of Units can be shown, by the means of a documented unbroken chain of calibrations, each contributing to the measurement uncertainty [1].

To ensure traceability, equipment calibration is performed only in accredited calibration laboratories. In Figure 2. traceability pyramid scheme for the measuring equipment is given [7].

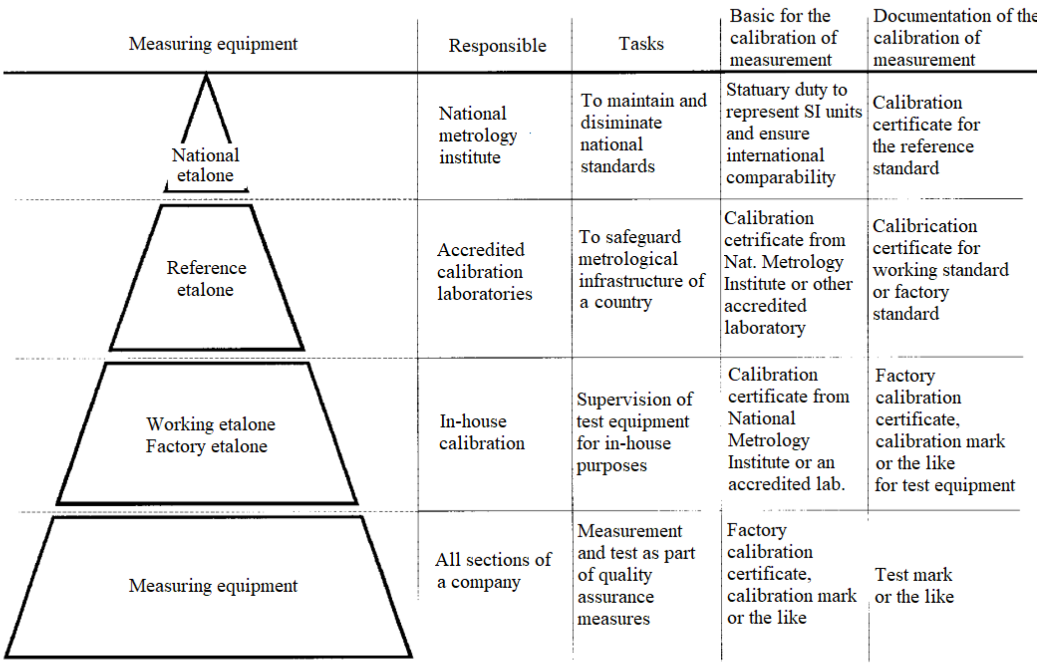


Figure 2. *The traceability pyramid with the basic characteristics of each pyramid stage* [7]

2.2. Measurement reliability

The purpose of a periodic calibration is to decrease deviation between a reference value and the value obtained using a measuring equipment, to define the uncertainty in this deviation, and also to indicate an eventual occurrence of some technical changes in the measuring equipment that would affect measurement results [4].

The calibration interval should be established by the analysis of instrument measurement reliability which changes in time, and the instrument needs to be calibrated before its measurement uncertainty reaches an unacceptable limit, for example concerning the requirement of a standard for a testing result [8]–[10].

Measurement reliability of measuring equipment can be calculated for individual equipment, using experimental data. At any given time since calibration, the probability that equipment measuring parameters are in tolerated limits can be checked by performing a number of calibrations n (t) at different time intervals. If the number of calibrations for which the parameter was found in-tolerance is represented by the variable g (t), then the sampled measurement reliability $\tilde{R}(t)$ for time t, as defined in [9], is:

$$\tilde{R}(t) = \frac{g(t)}{n(t)} \quad (1)$$

In experimental researches [9], [10], number of calibrations were performed at different time distances from the initial reference calibration and measurement results were arranged in ascending time interval to gain observed measurement reliability time series, as shown in the example on Figure 3.

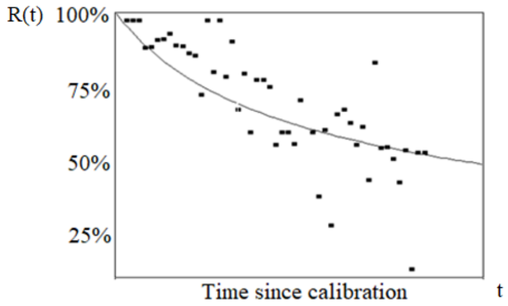


Figure 3. *Measurement reliability time series* [10]

2.3. Parameters affecting the calibration interval

Laboratories should take into account a large number of factors which influence the allowed time interval between calibrations, and according to [4], some of the most relevant ones are:

- measurement uncertainty required by the laboratory,
- risk of a measuring instrument exceeding the maximum permissible error when in use,
- risk of necessary correction measures costs if an instrument is not working with required measurement uncertainty,
- the instrument's type of and a tendency to wear and drift,
- extent of use,
- recommendation given by the manufacturer of the instrument,
- environmental conditions (temperature, humidity, vibration, etc.),
- data obtained from previous calibrations,
- frequency and quality of inter-tests against other reference standards or measuring devices,
- transportation arrangements and risk,
- training of personnel performing measurements.

3. DETERMINATION OF THE OPTIMAL CALIBRATION INTERVAL

Optimal calibration intervals are those which can be established to provide measurement reliability objectives in maximum periods between adjacent calibrations. The process for determination of optimal interval is a statistical process, requiring accurate and sufficient data taken during the monitoring of equipment behavior [9], [11]–[13].

There appears to be no universally applicable single best practice for establishing and adjusting the calibration intervals, which is why every laboratory needs to be familiar with its equipment measuring parameters and understand the calibration interval determination process. Also, for the range of measuring instruments, no single method is ideally suited [4], [11]–[13].

The equipment calibration time interval is determined in two phases, namely [4]:

- initial determination of the calibration interval and
- revision of the calibration interval.

Guided by the requirements of the standards [1], [2], every accredited laboratory should have a general equipment-related procedure, which includes a method for determining the initial and revised calibration interval.

Initial interval determination can be based on requests given in standards, recommendations in guidelines and manufacturer's instructions, if available. If not, a laboratory needs to develop or adopt own internal method. Initial interval is later modified after revising calibration certificates and eventual inter-tests and taking into account the changes in relevant impact factors used in defining the initial period.

3.1. Initial calibration interval

In the following, a method for determining the initial calibration interval (applied in the accredited testing laboratory "GIM-TEST" ltd Banja Luka) is presented, taking into account all parameters, according to the requirements of "ILAC" guidelines [4] and based on experience.

In the initial determination of calibration interval, it is important to consider particular instrument characteristics, measurement process, methods and standards used for measurements.

To determine the initial calibration interval (Pi), the following order of activity is suggested [3]:

- Review of the requirements in standards regarding all test methods in which the subject equipment is used. If the standard for the test method specifies the calibration interval for the equipment used, it is taken as the initial and no further analysis is necessary. In a case where one instrument is used for several different test methods, according to different standards, and if those standards prescribe different calibration intervals, then a more stringent requirement, i.e. shorter calibration interval, is adopted as the initial.
- If the calibration interval is not defined in the specific standard for the test methods in which the equipment is used, it is necessary to check the series of standards to whom the standard in question belongs. If there is a standard in the series that defines the correct calibration time interval, it is adopted and no further analysis is necessary.
- If referent standards do not define calibration intervals and they are given in the manufacturer's instructions, they shall be adopted as a starting point for further analysis, which shall include consideration of coefficients based on qualitative factors.
- If the referent document defining the calibration intervals does not exist, as in many testing methods, laboratory internal calibration interval is determined and defined in the laboratory instruction.

In this paper, the initial calibration interval method was applied for the equipment listed in Table 1, where, in addition to the name of the equipment, information is provided on the manufacturer, specific equipment model, measuring range and precision, referring the imperfection of measuring instruments.

Table 1. *Equipment list to which the proposed initial interval calculation model was applied*

No	Equipment	Manufacturer	Model	Measuring range	Precision
1	Digital scale 0-30kg	KERN	FKB30K1A	0-30000 g	1 g
2	Digital scale 0-6 kg	KERN	PCB 6000-1	0-6000 g	0.1 g
3	Position transducer	NovoTechnik	TR-0010 PIN	0-11 mm	0.001mm
4	Caliper	INSIZE	1108-300W	0-300 mm	0.01mm
5	Digital comparator	INSIZE	2314-10A	10 mm	0.01mm
6	Glass thermometer	TLOS Zagreb	100	-2 - +100ºC	0.2ºC

7	Hydrometer	UTEST	UTGP-1240	20 do 99 %	1.0 %
8	Digital stopwatch	UTEST	UTGT-1580	0-9999 s	0.01 s
9	Shear machine	UTEST	UTS-2060	100-400 kPa	0.01 kN
10	Compression testing machine	MATEST	C089-08	0-3000 kN	0.01 kN
11	Air-entrainment meter	HEMMER	LP-0017	0-100 %	0.1 %

Following the above-stated sequence of activities for determination of the initial calibration interval, an analysis of all applicable standards and documentation provided by the equipment manufacturer was carried out. So, as confirmed through the sample given in Table 1, not all measuring equipment in laboratories has prescribed calibration intervals in standards in use. For such equipment, it is important to have a calculation model for the interval determination.

For measuring equipment numbered 1-6 and 8 in Table 1, there are instructions given in reference standards regarding maximum calibration interval, while for the equipment numbered 7 and 9-11 that information is missing. Although, following the suggested order of activities, for determination of the initial period, the application of calculation model for instruments numbered 1-6 and 8, is not needed, it was performed, to compare the intervals obtained using the below described algorithm and those limited by the standard.

In the determination of an initial period of calibration, guided by the developed algorithm used in [5], [6], all quantitative and qualitative factors were defined [14] that affect the subject equipment. The algorithm considers general quantitative and qualitative influences, and more detail defining of these influences, such as the thermohygrometric conditions in which the equipment is used, the test field, the type of measured quantity, etc, which relate to the field of building materials and structural testing and the specific equipment, are suggested in the following sections.

3.1.2. Quantitative factors

According to the model for determination of Pi, presented in the paper, quantitative factors that influence the determination of the calibration interval, imply external influences which may cause physical damage to the measuring equipment and its parts.

The influence of quantitative factors on a determination of the initial calibration time interval is defined by a total factor TF, which is obtained from the following expression:

$$TF = F_t \times F_u \times F_e \qquad (2)$$

Where:

F_t – equipment transportation factor, with values:

- 9 - 10 when equipment is transported daily before the use,
- 6 - 8 when the equipment is transported once to three times a month,
- 3 - 5 when the equipment is transported once to three times a year,
- 1 - 2 when the equipment is transported only inside the laboratory or not at all;

F_u – equipment utilization factor, with values:

- 9 - 10 when equipment is used daily,
- 6 - 8 when the equipment is used once to five times a month,
- 3 - 5 when the equipment is used several times a year,
- 1 - 2 when the equipment is used once a year or not used at all;

F_e – a factor of external impact on equipment, with values:

- 9 - 10 when the impact on the equipment is very high (extreme thermohygrometric variations conditions, exposure to the possibility of physical damage ...),
- 6 - 8 when the impact on the equipment is moderate (moderate variation in thermohygrometric conditions, dust ...),
- 3 - 5 when the impact on the equipment is small (rare exposure to moderate variations in thermohygrometric conditions, less possibility of contact with dust…),

1 - 2 when the impact on the equipment is very small (controlled conditions).

After a determination of the value TF, an initial calibration interval is adopted, according to Table 2. Maximum period of 156 weeks, or 3 years, is given by the recommendations of the Brazilian Calibration Group [5], [6].

Table 2. *Times in weeks for different values of quantitative factor TF [5], [6]*

The range of TF	Initial time interval	The range of TF	Initial time interval
800 ≤ TF < 1000	4 weeks	**63 ≤ TF < 100**	65 weeks
525 ≤ TF < 800	13 weeks	**38 ≤ TF < 63**	78 weeks
320 ≤ TF < 525	26 weeks	**18 ≤ TF < 38**	91 week
160 ≤ TF < 320	39 weeks	**10 ≤ TF < 18**	104 weeks
100 ≤ TF < 160	52 weeks	**TF <10**	156 weeks

The adopted maximum period was retained herein, as it remains on the safe side, comparing to the proposals given in certain European standards for methods in the field of building materials and structural testings, regarding the maximum intervals for some instruments. For example, for calipers or thermometers in the group of standards for bitumen testing (according to EN 932) maximum calibration period defined is 5 years.

As can be seen, for the same type of equipment, quantitative factors can be different, thus the initial calibration period. Also, differences in values of these factors greatly affect the number of weeks taken as the initial time interval, so in a case of doubt, it is recommended to adopt values to be on the safe side.

For the equipment considered herein, the values of the quantitative factors, as well as the initial period in weeks, determined up to this point, are given in Table 3.

Table 3. *Quantitative factors and initial interval for a considered group of equipment*

No	Equipment	F_t	F_u	F_e	TF	Weeks	Days
1	Digital scale 0-30kg	1	10	1	10	104	728
2	Digital scale 0-6 kg	1	7	1	7	156	1092
3	Position transducer	2	7	2	28	91	637
4	Caliper	3	8	6	144	52	364
5	Digital comparator	1	8	1	40	78	1092
6	Glass thermometer	1	5	8	40	78	455
7	Hydrometer	2	10	2	40	78	546
8	Digital stopwatch	2	8	4	64	65	455
9	Shear machine	1	8	1	8	156	1092
10	Compression test. mach.	1	10	2	20	91	637
11	Air-entrainment meter	6	4	4	96	65	455

3.1.3. Qualitative factors

Qualitative factors refer to the parameters that directly affect the process of measurements, i.e. processes that lead to the weakening of the measuring equipment. Their intensity affects the calibration interval in terms of the correction of the interval based on the quantitative factors.

Qualitative factors are defined by the factor Q, which may extend or shorten the calibration interval obtained by quantitative factors, or the period adopted based on the recommendations of the equipment manufacturer.

Factor Q represents a scope of all defined effects on the calibration interval, expressed by the coefficients q, by the expression:

$$Q = q_1 \text{ x } q_2 \text{ x } q_3 \text{ x} ... q_n \quad (3)$$

Where:

q_1 – the impact proportional to the ratio of the required precision according to the standard and the precision of the instrument with the measurement uncertainty included,

q_2 – the impact of the equipment based result on the overall result,

q_3 – possibility of the influence of equipment loading,

q_4 – the impact of the time weakening of the equipment characteristics,

q_5 – operator influence impact, if the equipment operator can influence the measurement result,

q_n – other possible impacts.

The values of the coefficients q are determined based on impact intensity, so if the factor does not affect the calibration interval, it extends the calibration interval and vice versa:

- 0.80 for critical impact,
- 0.90 for great impact,
- 1.00 for normal impact,
- 1.10 for low impact,
- 1.20 no impact.

Regarding stated, practical examples for the values of particular coefficients q_i are given, namely:

- a value for q1 of 0.8 is taken if the precision of the instrument is the same as required by the standard, and if the precision of the instrument is higher, the coefficient increases proportionally,
- for q2, on the example of a compression testing machine, which has a critical impact on the final result, adopted value is 0.80, while for a stopwatch used indirectly for certain methods, a value of 1.00 is taken,
- value of 0.80 for q3 is taken if a force measuring equipment is used up to the maximum measuring range, which is a critical influence, whereas, in the case of using a thermometer for measuring ambient temperature in the laboratory, this value can be taken at 1.20.
- data needed for the determination of the factor q4 are given by the manufacturer's recommendations, and can also be determined by an experience with a related instrument, eg constant use of some types of comparators can affect their precision, so the recommended value is 0.80, for scales or presses of modern manufacturers, this influence is moderate and the coefficients of 0.90-1.10 can be assigned, whereas this is not the case for a rulers or thermometres where a factor of 1.10-1.20 is normally taken,
- a value of 1.20 is defined for the factor q5, for the compression or shear machine, which are not susceptible to the operator's influence, while during a dimension measurement with a caliper, the operator's influence is large, and thus a coefficient of 0.80 is to be assigned,
- qn - during the development of the calibration plan, other possible influences, not listed herein, may affect the equipment and should be taken into account through a detailed analysis of the characteristics of specific equipment, manufacturer's recommendations and available literature for the same or similar equipment.

Table 4. *Qualitative factors for initial interval correction for the considered set of equipment*

No	**Equipment**	**q_1**	**q_2**	**q_3**	**q_4**	**q_5**	**Q**
1	Digital scale 0-30kg	0.9	0.8	1.2	0.9	1.2	0.9331
2	Digital scale 0-6 kg	0.8	0.8	1.2	0.9	1.2	0.8294
3	Position transducer	0.8	0.8	1.2	1	1.2	0.9216
4	Caliper	0.9	0.8	1.2	1	0.8	0.6912
5	Digital comparator	0.8	0.8	1.2	1	1	0.7680

6	Glass thermometer	0.8	0.8	1.2	1.1	1	0.8448
7	Hydrometer	1.2	0.8	1.2	0.9	1.2	1.2442
8	Digital stopwatch	1.2	1	1.2	1.2	1.2	2.0736
9	Shear machine	1	0.8	0.9	1	1.2	0.8640
10	Compression test. mach.	0.8	0.8	1.2	0.9	1.2	0.8294
11	Air-entrainment meter	1	0.8	1.2	0.9	1	0.8640

According to [5] and [6], only 3 qualitative characteristics are defined, but herein, regarding requirements needed for accreditation [1], and guided by "ILAC" [4], qualitative influences are elaborated in much more detail.

3.1.4. Estimated calibration initial interval

Final initial calibration interval Pi, is obtained from the expression:

$$Pi = TF \times Q \quad (3)$$

Table 5 shows initial calibration intervals obtained using the algorithm presented.

Table 5. *Final initial calibration period obtained for the considered set of equipment*

No	**Equipment**	**TF**	**Days**	**Q**	**Pi** (days)	**Requirements given in standards**
1	Digital scale 0-30kg	10	728	0.933	679	<730
2	Digital scale 0-6 kg	7	1092	0.829	906	<730
3	Position transducer	28	637	0.922	587	<365
4	Caliper	144	364	0.691	252	<365
5	Digital comparator	40	1092	0.768	419	<365
6	Glass thermometer	40	455	0.845	384	<1825
7	Hydrometer	40	546	1.244	679	-
8	Digital stopwatch	64	455	2.074	943	<365
9	Shear machine	8	1092	0.864	943	-
10	Compression test. mach.	20	637	0.829	528	-
11	Air-entrainment meter	96	455	0.864	393	-

Most of the initial calibration intervals obtained using the algorithm are shorter than the maximum intervals defined by the standards, but that there are also some with longer intervals obtained. This is understandable because each laboratory has its specific conditions of use, workload, transportation, and similar, that must be taken into account.

The biggest difference is seen for the glass thermometer. This is because the maximum calibration interval, according to Table 2 is 3 years, and, as mentioned, in a group of standards for the methods which apply this instrument, the maximum defined interval is 5 years.

3.2. Revision of the calibration interval

Once the initial calibration interval has been established, which relied on the adequate impact factors, but also on “engineering intuition”, to optimize the balance of risks and costs, this interval must be adjusted in later use, taking into the account monitored instrument behavior [9]–[11].

It is expected that the intervals initially selected do not give the desired optimal results in long term, since the instruments can be less reliable than expected, the usage may not be as anticipated, or any other factor can differ from the expected factor that affected initial interval determination, or can change after a certain period.

The revision of the equipment calibration interval is performed based on the equipment characteristics, considering the results of previous calibrations and the results of inter-tests.

For reviewing and precise determination of calibration interval impact factors, and modification of initial interval, several methods are described and recommended by “ILAC” guidelines [4]:

- automatic adjustment or “staircase” ,
- control chart,
- “in-use” time,
- in service checking, or “black-box” testing,
- other statistical approaches.
- The methods chosen differ according to several factors, for example, their suitability for different types of equipment. The overview is given in Table 6.

Table 6. *Comparison of methods for reviewing calibration interval [4]*

	“Staircase”	Control chart	“In-use” time	“Black box”	Other approaches
Reliability	*Medium*	*High*	*Medium*	*High*	*Medium*
Effort of application	*Low*	*High*	*Medium*	*Low*	*High*
Work-load balances	*Medium*	*Medium*	*Bad*	*Medium*	*Bad*
Applicability for particular devices	*Medium*	*Low*	*High*	*High*	*Low*
Availability of equipment	*Medium*	*Medium*	*Medium*	*High*	*Medium*

As a method that responds to the problems in testing laboratories in the field of building materials and structures, an easily applicable, the “staircase” method is discussed herein. The revision of the intervals, using this method, performed on the basis of the calibration results, is carried out by monitoring the constancy of the equipment regarding its accuracy. If the calibration results, obtained in equipment calibration certificates, deviate within the limits of 80% of the maximum allowed measurement error (for example, given in standards for methods), the initial calibration interval Pi can be multiplied by a factor > 1.0. Otherwise, the adopted calibration initial interval is divided by a factor > 1.0 [4]. This system treats the instruments individually and they are sent for recalibration at different periods.

The risk of a measuring instrument exceeding the maximum permissible error when in use is reduced using defined procedures for ensuring the proper functioning and calibration status of the measuring instruments between calibrations. Between calibrations, it is necessary to monitor the changes in measurements through an inter-tests, using certified reference materials and/or calibrated standards. The revision of the calibration intervals based on the results of the inter-tests should be carried out only if a constant decrease in the characteristics of the equipment is shown. It is suggested that, if the results show a constant drop, beyond the 60% limit of the maximum permissible error required for measurement, the equipment should be sent for extraordinary calibration. Inter-tests time intervals are determined within the laboratory, based on the adopted calibration time interval, in such a way that they are allocated at regular time intervals, and the minimum time interval is determined according to the utilization factor of the equipment F_u.

4. CONCLUSIONS

To gain a reliable measurement results, and to ensure measurement traceability, measurements must be carried out using reliable equipment. Regarding this, measuring equipment must be monitored and calibrated regularly.

Calibration intervals are established to meet measurement reliability objectives, but to reduce unnecessary calibrations, and thereby costs, an optimal calibration interval should be implemented.

Knowledge in the functioning of laboratory equipment and monitoring its operation are key factors in determining the optimal interval. To manage these intervals, many probabilistic methods have been developed. These methods depend on the type of equipment and measuring conditions.

This paper presents an application of the algorithm for the approximate optimal initial calibration interval determination. Used algorithm is modified, considering all relevant factors which meet the recommendations given by the "ILAC" guidelines, and based on the authors' experience. The contribution stated in this paper is an elaboration of parameters considered, which is not covered by the standards defining the calibration periods, by the technical data sheets of the manufacturers of the measuring devices, or by the guiding algorithm. They are based on specific problems in the field of using equipment for building material and structural testing.

The determination of the initial period is described in the example of a set of measuring devices from a laboratory for building materials and structural testing. To determine the initial calibration period, quantitative and qualitative parameters that affect this period are elaborated and defined, and examples are given for determining their values. In terms of defining qualitative factors, a more detailed classification is given, compared to the existing in guiding algorithm.

Also, methods for determination of the revised calibration interval are discussed, which is performed based on all previous calibrations of the equipment and monitoring its consistency. The methods for revision of the calibration period differ according to several factors, for example, their suitability for different types of instruments.

LITERATURE

[1] EN ISO/IEC 17025 General requirements for the competence of testing and calibration laboratories, pp. 1–53, 2018.

[2] EN ISO 10012 Measurement management systems - Requirements for measurement processes and measuring equipment, pp. 1–38, 2003.

[3] M. Krndija, "Procedura za korištenje laboratorijske opreme", GIM-LAB ltd, 2019.

[4] ILAC, "ILAC- G27:06/2017 Guidance on measurements performed as part of an inspection process," pp. 1–16, 2017.

[5] W. Portella and M. N. Frota, "Frequency of Calibration: A critical issue for quality control in the pharmaceutical industry," 18th IMEKO World Congr. 2006 Metrol. a Sustain. Dev., vol. 3, pp. 1897–1899, 2006.

[6] A. Milinković, S. Tuckešić and K. Ristić, "Fekventnost kalibracije u procesu kontrole kvaliteta geodetske mjerne opreme," Proceedings: 40th International Scientific Conference: Maintenance of machinery and equipment, pp 52-64, 2015.

[7] EAL-G12 Traceability of Measuring and testing equipment to national standards, no. November, pp. 1–16, 1995.

[8] A. Charki and F. Pavese, "Data comparisons and uncertainty: A roadmap for gaining in competence and improving the reliability of results," Int. J. Metrol. Qual. Eng., vol. 10, no. 9, pp. 1–10, 2019.

[9] D. W. Wyatt and H. T. Castrup, "Managing Calibration Intervals," Ncsli, pp. 1–20, 1991.

[10] H. T. Castrup and K. M. Johnson, "Techniques for Optimizing Calibration Intervals," ASNE Test Calibration Symp., no. December, pp. 1–6, 1994.

[11] N. Natalinova, N. Ilina, and E. Frantcuzskaia, "Calibration Interval Adjustment of a Measuring Instrument in Industries during Long-term Use," IOP Conf. Ser. Mater. Sci. Eng., vol. 132, no. 1, 2016.

[12] O. Velychko and T. Gordiyenko, "The implementation of general international guides and standards on regional level in the field of metrology," J. Phys. Conf. Ser., vol. 238, September, 2010.

[13] C. De Capua, S. De Falco, A. Liccardo, and R. Morello, "A virtual instrument for estimation of optimal calibration intervals by a decision reliability approach," VECIMS 2005 - IEEE Int. Conf. onVirtual Environ. Human-Computer Interfaces, Meas. Syst., pp. 16–20, 2005.

[14] D. C. Montgomery, Introduction to statistical quality control, 7th ed, 2013.

39 | Professional paper | Стручни рад
ISSN 2566-4484 | Doi 10.7251/STP2014422J
pages 422-433

Ivana Janković, ivana.jankovic@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

Mladen Amović, mladen.amovic@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

HARMONISATION MODEL OF ADMINISTRATIVE UNITS OF THE REPUBLIC OF SRPSKA ACCORDING TO INSPIRE DIRECTIVE

Abstract:

The INSPIRE Directive establishes a framework for the creation of a spatial data infrastructure (SDI), which will enable the exchange of spatial information between public sector organizations and better access to spatial information in general across the Europe. This paper describes the harmonization of the INSPIRE theme Administrative Units. Data harmonization was carried out within the framework of the IMPULS project implemented by the Republic Geodetic and Property Administration of Republika Srpska with the support of the Swedish Agency for Cadastre and Cartography. Implementation involves the development of a GML scheme with mapping of existing data in accordance with that structure, development and testing of INSPIRE services, and preparation of metadata for data and services. The model was verified by the Joint Research Center in Ispra, established by the European Commission (Joint Research Center).

Keywords: Inspire, Administrative Units, Data harmonisation, GML

МОДЕЛ ХАРМОНИЗАЦИЈЕ АДМИНИСТРАТИВНИХ ЈЕДИНИЦА РЕПУБЛИКЕ СРПСКЕ У СКЛАДУ СА INSPIRE ДИРЕКТИВОМ

Сажетак:

INSPIRE директива успоставља оквир за стварање инфраструктуре просторних података (SDI), који ће омогућити размјену просторних информација између организација јавног сектора и бољи приступ уопште, просторним информацијама широм Европе. У раду је описана хармонизација INSPIRE теме административне јединице. Хармонизација података је извршена у оквиру IMPULS пројекта који спроводи Републичка управа за геодетске и имовинско – правне послове Републике Српске уз подршку шведске агенције за катастар и картографију. Имплементација подразумијева развој GML шеме са мапирањем постојећих података у складу са том структуром, развој и тестирање INSPIRE сервиса и припрема метаподатака за податке и сервисе. Модел је верификован од стране Заједничког истраживачког центра у Испри, основаног од стране Европске комисије (Joint Research Centre).

Кључне ријечи: Inspire, административне јединице, хармонизација података, GML

1. УВОД

INSPIRE директива успоставља оквир за стварање Европске инфраструктуре просторних података (ESDI), који ће омогућити размјену просторних информација између организација јавног сектора и бољи приступ уопште просторним информацијама широм Европе. Да би се то обезбиједило, развијене су спецификације које се односе на податке, метаподатке и мрежне услуге. Један од најважнијих задатака INSPIRE директиве је усклађивање стварних модела података широм Европе са уобичајеним INSPIRE моделима. Задатак хармонизације у складу са овим правилима није важан због количине података која је укључена у процес хармонизације, већ и због врло различитих модела изворних података и различитих произвођача података који су укључени у различитим фазама хармонизације и успостављања оквира инфраструктуре геопросторних података (Spatial daa infrastructure - SDI), а који кроз међусобне споразуме и сарадњу требају направити јединствен оквир сарадње на Европском нивоу.

Као јединствен начин на који ће бити успостављен тај оквир, још 2001. године покренут је програм INSPIRE, а у мају 2007. године INSPIRE директива је ступила на снагу као Европска директива, усвојена од стране Европске комисије, за које су све земље чланице ЕУ везане. INSPIRE би требало да се примењује у различитим фазама, а потпуна примјена је предвиђена до 2020. године. Директива утврђује општи оквир за Европску инфраструктуру просторних података (ESDI). Бернард и остали 4.[1] наводе да у контексту INSPIRE, термин Инфраструктура просторних података (SDI) прати дефиницију SDI Cookbook. Стандарди су основни дио савременог друштва и организован начин за обезбјеђивање најбоље праксе, заједничког дизајна, безбједности и многих других користи у свим областима индустрије и науке. Значајну улогу у успостављању оквира за стандардизацију геопросторних информација играју International Organisation for Standardisation (ISO), European Committee for Standardisation (CEN) и Open Geospatial Consortium (OGC). Са становишта интегрисаности и интероперабилности, стандарди се користе за обезбјеђивање синтаксне, прагматичне и семантичке интероперабилности геопросторних података. INSPIRE дефинише административне јединице као "јединице управе, подјелу на којима државе чланице имају и / или остварују јурисдикцијска права, локалну, регионалну и националну управу, одвојене административним границама" 4.[4]. Дефиниција је интерпретирана тако да не укључује административне јединице као што су пописни округ, поштански региони и други региони специфични за друге секторе 4.[3]. Тема Административних јединица садржи референцу на номенклатуру територијалних јединица за статистику (Nomenclature of Territorial Units for Statistics - NUTS). NUTS је ЕУ геокод стандард за референцирање подјела земаља у статистичке сврхе на европском нивоу, а на националном нивоу постоје локалне административне јединице (Local Administrative Units - LAU) 4.[6]. NUTS и LAU дефинисани су за све државе чланице, па се може закључити да административни нивои у контексту INSPIRE имају јединствену дефиницију на нивоу цијеле Европске Уније и земаља потписница INSPIRE директиве.

1.1. Досадашња истраживања (Related works)

Европска Унија кроз посебан низ докумената последњих година указала је на значај употребе просторних података у свим областима људског дјеловања. Подручја примјене попут пољопривреде, регионалног развоја, управљања животном средином, транспорта и енергетике су посебно обрађена различитим политикама и директивама Европске Уније 4.[1]. Владине, комерцијалне и истраживачке институције развијају све већи број гео-апликација како би олакшале свакодневне активности. На нивоу Европске уније постоји стални пораст броја пројеката прекограничне сарадње и потребе за прекограничним географским анализама у прекограничним регионима. Међутим, успјех и ефикасност таквих пројеката и сарадње се у великој мери ослања на доступност и употребљивост хетерогених геоподатака 4.[2]. У таквим случајевима пуна корист и успјех ових пројеката, постићи ће се само ако су геопросторни подаци „потпуно интероперабилни, употребљиви и разумљиви од стране глобалне интердисциплинарне заједнице" 4.[8]. То подразумијева да је обезбијеђен стандардизовани приступ подацима који потичу из различитих извора. У европском контексту већина, ако не и све државе чланице Европске Уније имају локалне стандарде, законске и подзаконске акте који отежавају, а понекад и онемогућују дијељење геопросторних података. Дефиниција интероперабилности се у већини случајева заснива на подацима, посебно у случају географских информационих система где је главни циљ омогућити дијељење просторних података. Стога се интероперабилност просторних података може дефинисати као способност приступа, размјене и манипулације просторним подацима сачуваним у хетерогеним дистрибуираним каталозима 4.[8]. Према Östman 4.[9], усклађивање података може се примјенити када је потребно спајати податке из различитих извора, када постоји иницијатива да се подаци доставе према одређеном стандарду или када се нестандардизовани подаци морају увести у циљану апликацију. У том смислу се наводи да постоје и различите дефиниције или погледи на усклађивање података:

- Одређивање заједничких карактеристика скупова података.
- Усклађивање скупа података са одређеним карактеристикама.
- Уклањање разлика између два или више скупова података.

1.2. Подручје истраживања (Study area)

Административно-територијална организација Републике Српске прописана је Законом о територијалној организацији Републике Српске. Према овом Закону, територију Републике Српске чине општине и градови, чији назив се утврђује законом, те насељена мјеста (Табела 1). Подручје јединице локалне самоуправе чине насељена мјеста односно катастарске општине које улазе у њен састав. Границе подручја јединице локалне самоуправе подударају се са границама насељених мјеста и са границама катастарских општина са њеног подручја. Сједиште јединице локалне самоуправе утврђује се њеним статутом. Општине представљају територијалне јединице локалне самоуправе, које се формирају за дио насељеног мјеста, за једно насељено мјесто или за више насељених мјеста. Република Српска у свом саставу има 57 општина.

Градови представљају територијалне јединице које представљају кохерентну географску, историјску, административну, социјалну, економску цјелину са одговарајућим нивоом развоја. Град који у свом саставу нема општина има карактер основне јединице локалне самоуправе. Градови у Републици Српској су Бања Лука, Бијељина, Добој, Зворник, Источно Сарајево, Приједор, и Требиње. При чему само Источно Сарајево у свом саставу има општине. Насељено мјесто је дио подручја јединице локалне самоуправе које има изграђене објекте за становање, основну комуналну инфраструктуру и друге објекте неопходне за задовољавање потреба становника настањених на његовом подручју. Насељено мјесто може бити у саставу само једне јединице локалне самоуправе. На подручју једне јединице локалне самоуправе, два или више насељених мјеста не могу имати исти назив. Према међународно усвојеном систему дефинисања кодова кроз директиву Европске Уније, Inspire, код државе за Босну и Херцеговину је BA (http://publications.europa.eu/code/en/en-5000600.htm).

Табела 1. Категоризација административно – територијалне организације Републике Српске

Ниво	**Назив**	**Примјер**
1	Држава	Босна и Херцеговина
2	Ентитет	Република Српска
3	Град	Бања Лука, Бијељина, Приједор, ...
	Општина	Прњавор, Челинац, ...
4	Насељено мјесто	

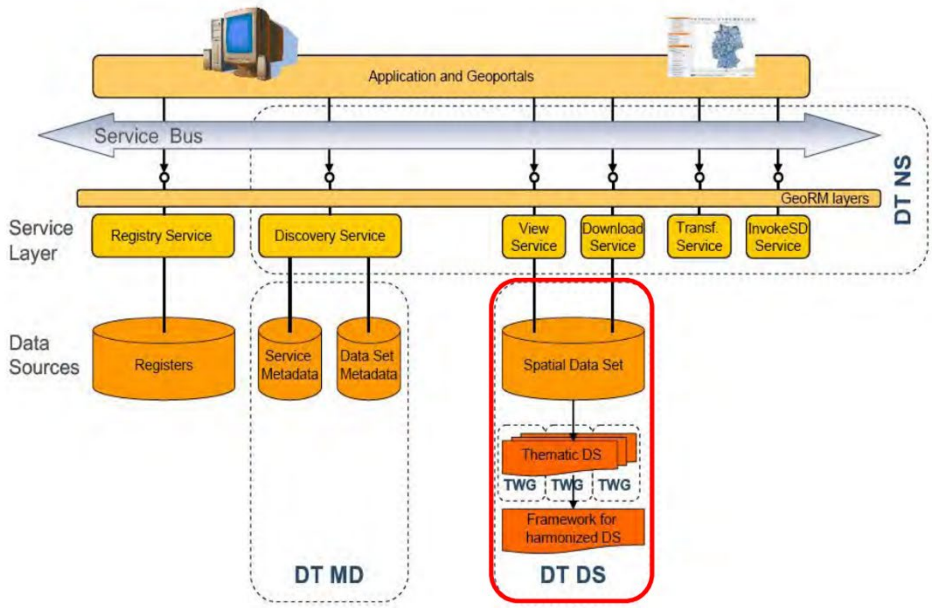
1.3. Инфраструктура геопросторних података Републике Српске

Републичка управа за геодетско и имовинско правне послове Републике Српске и Федерална геодетска управа учествују у IMPULS пројекту кроз који је потребно убрзати развој иновативних INSPIRE услуга и успоставити интероперабилност података и сервиса. Посебан значај пројекта огледа се у професионалној и финансијској помоћи геодетским и картографским властима у процесу успостављања и примјене инфраструктуре геопросторних података (ИПП). У оквиру IMPULS пројекта, дају се годишње анализе и извјештаји који се односе на тренутно стање и побољшања питања ИПП-а у Републици Српској и Федерацији Босне и Херцеговине, како у правном тако и у техничком и организационом погледу. Циљ овог пројекта је успостављање модерног и функционалног оквира за размјену просторних података у складу са регионалним и међународним стандардима. (https://www.lantmateriet.se/sv/Om-Lantmateriet/Samverkan-med-andra/impuls/about-the-impuls-project/). У оквиру наведених извештаја у пројекту IMPULS могу се извући следеће важне чињенице 4.[7]:

- У Босни и Херцеговини постоје дјелимично посебни закони и правни акти који регулишу ИПП (Република Српска (РС) кроз једно поглавље уређује питања ИПП-а, што није посебан акт, а у Федерацији Босне и Херцеговине (ФБиХ) постоји Уредба о ИПП, која има снагу законског акта, док не буде усвојен закон)
- Постоје стратешки документи: ФБиХ је усвојила Стратегију развоја ИПП-а, а Вијеће ИПП-а ФБиХ усвојило је трогодишњи план који се ослања на ову стратегију као дио својих краткорочних, средњорочних и дугорочних циљева; у РС се припрема нацрт ове стратегије и оснива се Вијеће за развој ИПП-а.
- Одређени су координатори за успостављање, имплементацију и одржавање ИПП-а на нивоу оба ентитета.
- Како не постоје посебни закони који би се бавили овом облашћу, законски механизми још нису дефинисани између контактних тачака, појединих учесника / оператора и свих осталих субјеката који су укључени у развој и употребу ИПП-а у РС, док је у ФБиХ ово питање регулисано Уредбом о ИПП-у. .
- У ФБиХ и РС постоје скупови података који су усклађени у складу с INSPIRE правилима. У ФБиХ је хармонизовано седам скупова података: административне јединице, изохипсе, географски називи, ортофото, густина насељености, хидрологија и геологија (посљедња три нису објављена у каталогу метаподатака). У РС је у току хармонизација 8 скупова података, у складу са INSPIRE правилима, до 31.12.2019. године. То су: административне јединице и насељена мјеста, географски називи, ортофото, хидрографија, саобраћајнице, дигитални модел висина, статистичке јединице и теоријска мрежа).
- ФГУ је развила каталог метаподатака. у складу са INSPIRE директивом и регионалним пројектом IMPULS. РУГИПП је развила каталог метаподатака на основном *GEONETWORK* рјешењу.
- ФБиХ тренутно развија апликацију којом ИПП ентитети могу самостално ући у ентитетски регистар и уписати своје збирне податке у регистар извора просторних података.
- ФБиХ тренутно развија апликацију за уређивање метаподатака, при чему ће ИПП ентитети моћи уносити метаподатке о својим скуповима података путем интернета, а који су усаглашени са INSPIRE.
- Објављене су техничке смјернице за Регионални профил метаподатака. У складу с тим, метаподаци за хармонизоване скупове података (преглед и преузимање) су објављени у оквиру IMPULS пројекта.

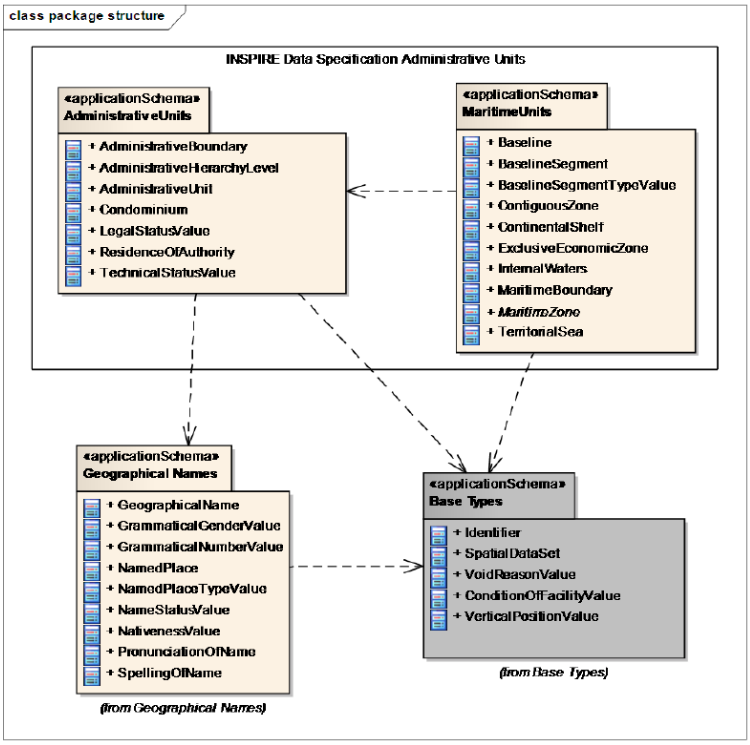
2. ИЗРАДА МОДЕЛА ПОДАТАКА АДМИНСТРАТИВНИХ ЈЕДИНИЦА РЕПУБЛИКЕ СРПСКЕ

Административне јединице су јединце управе, које су подијељене административним границама, гдје држава има и/или остварује надлежности над локалним, регионалним и националним носиоцима власти. На слици 1. је приказан преглед кључних елемената техничког оквира INSPIRE директиве. Основна компонента дијаграма су подаци који су под јурисдикцијом ‘Drafting Team Data Specifications’ (DT DS). Сви остали ресурси као што су метаподаци, мрежне услуге и слично су потребни за проналажење, приступање и визуелизацију или коришћење просторних објеката који су саставни дио инфраструктуре (Drafting Teams ‘Data Specifications’, ‘Metadata’, ‘Network Services’, 2007). Тема административне јединице у INSPIRE спецификацији садржи административне јединице на копну и административне јединице или подручја на мору. Тиме су дефинисане и двије апликационе шеме, са истим називима.

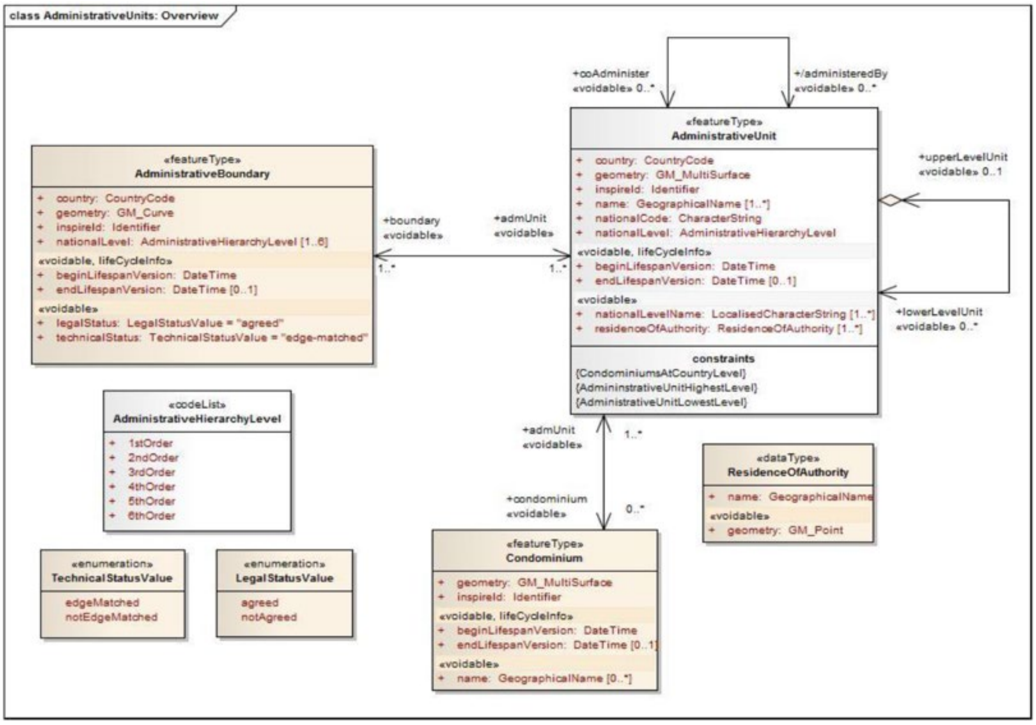


Слика 1. Кључни елементи техничког оквира по Inspire Directive

Територија сваке државе подијељена је на административне јединице, са различитим административним нивоима, у складу са важећом националном законском регулативом. Административне јединице су подијељене административним границама. Дефиниција је представљена тако да не укључује административне јединице као што су: пописни округи, поштанске регије, статистички окрузи и остале специфичне регије. Тиме су дефинисане и двије апликационе шеме, са истим називима.



Слика 2. Адмнистративне јединице – структура теме

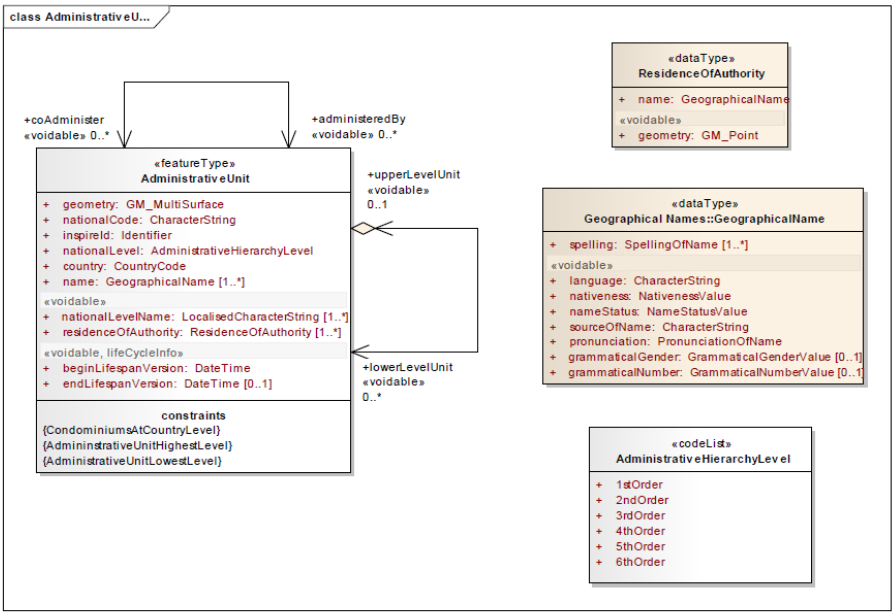


Слика 3. Модел апликационе шеме админстративне јединице

Апликациона шема административне јединице дефинише три типа просторних објеката. AdministrativeUnit, тип административне јединице, AdministrativeBoundary, линија разграничења између административних јединица, Condominium, административно подручје успостављено независно од службене националне подјеле и администрирано од стране двије или више држава.

2.2. Типови административних јединица

Тип административне јединице је основни тип просторног објекта за представљање јединица подјеле на свим нивоима административне хијерархије. Сваки тип административне јединице одговара тачно једном нивоу одговарајуће националне хијерархије.



Слика 4. Тип административне јединице

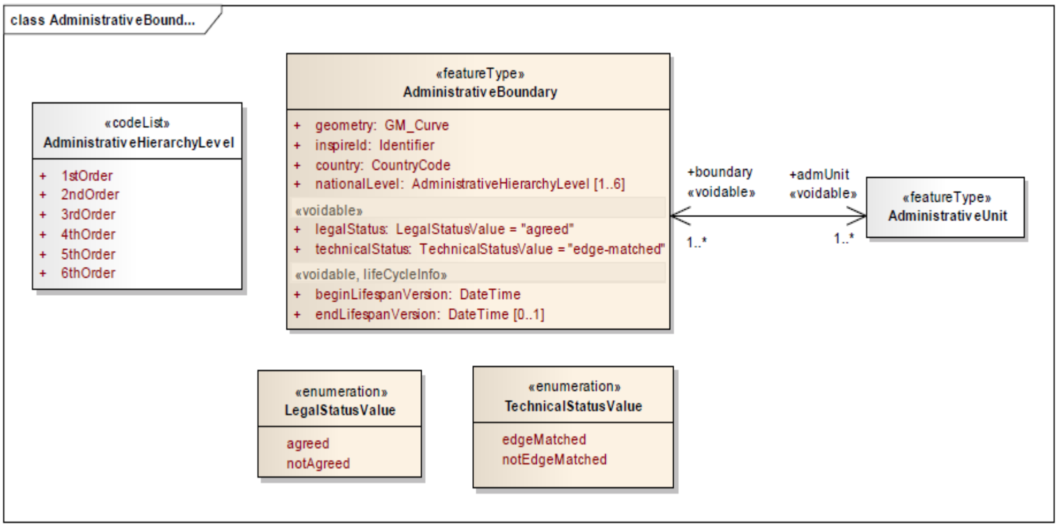
Иако је најчешће случај да административне јединице вишег нивоа садрже административне јединице нижег нивоа, то није увијек случај. Из тог разлога у INSPIRE теми уведене су семантичке везе између административних јединица вишег и нижег нивоа. Број нивоа административних јединица разликује се од државе до државе, па се према томе дефинише као кодна листа. Међусобна повезаност између нивоа ријешена је додавањем повратне везе на тип административне јединице, с тим да се за административну јединицу нижег нивоа дефинише само једна јединица вишег нивоа. Тип административне јединице користи тип географски називи (енгл. GeographicName type) из теме Географски називи. За сваку административну јединицу може се дефинисати сједиште јединице локалне самоуправе (ResidenceOfAuthority), које се дефинише као географски назив. Административне јединице нижег нивоа требају бити описане и садржавати податке у оквиру класе lowerLevelUnit, док административне јединице вишег нивоа требају имати ознаку upperLevelUnit. Уколико једном административном јединицом управљају двије административне јединице истог нивоа, користе се асоцијацијске улоге administredBy и coAdminister. Административне јединице на истом нивоу не би требале дијелити иста заједничка подручја. Свака административна јединица има атрибут националне шифре (nationalCode), који би требао бити јединствен на територији једне државе.

Административна граница

Други тип просторног објекта у апликационој шеми је тип административна граница, који представља границе између сусједних административних јединица, укључујући атрибуте специфичне за њихове границе.

Класа административна граница дефинише два индикатора: legalStatus и techicalStatus, па пружа важне информације за административну подјелу (Слика 5.). Иако не морају бити дефинисани, препорука је да се оба индикатора дефинишу. Ова правила су остварена кроз тополошку конзистентност података:

- сусједне административне јединице се не преклапају, односно њихове границе се не сијеку ни у једној тачки,
- не би требало бити рупа између сусједних административних јединица,
- границе сусједних административних јединица би требале имати исте координате, како би се избјегле непланиране рупе између територија због неконзистентности геометрије,
- гранична линија која ограничава административне јединице треба одговарати геометрији која представља границе административне јединице,
- границе не смију имати истурене крајеве (енгл. dangles), границе увијек раздвајају различите административне јединице.

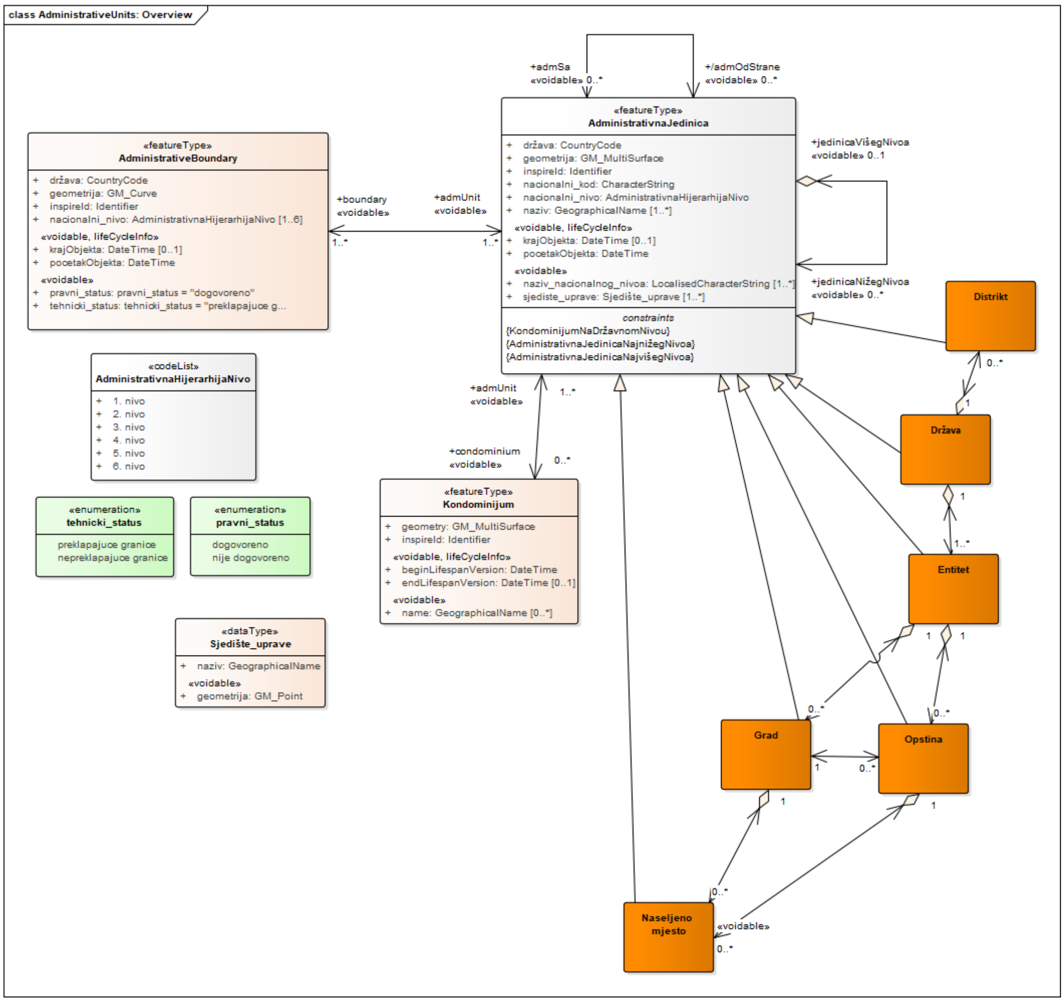


Слика 5. Класа административна граница

2.3. Проширење модела Адмистративних јединица Републике Српске

Као што је напоменуто у претходним поглављима, административно-територијална организација Републике Српске прописана је Законом о територијалној организацији Републике Српске. У складу са тим, територија је оргнизована као структура, градова и општина, са подручјем јединица локалне самоуправе коју чине насељена мјеста, односно катастарске општине које улазе у њен састав. На основу тога, основна класа AdministrativeUnit проширена је са класама: држава, ентитет, дистрикт, град, општина и насељено мјесто. Према важећим законским прописима општине могу да буду самосталне јединице или саставни дио градова (нпр. Источно Сарајево). Заједно су подорганизациона структура ентитета. Класа држава је састављена од ентитета и дистрикта (Брчко дистрикт). Градови и општине као основне градивне административне јединице имају нижу јединицу насељена мјеста. Заједно све новодефинисане класе наслијеђују основне атрибуте класе Административне јединице.

Имплементација модела је извршена превођењем структуре класа у структуру релационог модела у Postgis окружењу. На овакав начин је остварено успостављање слоја базе података у процесу успостављања сервисно – оријентисане архитектуре.



Слика 6. Проширени модел теме Административне јединице

3. ХАРМОНИЗАЦИЈА ПОДАТАКА

Просторни ETL алати омогућавају обраду података традиционалног ETL софтвера, али с примарним фокусом на способност управљања просторним подацима. Просторни подаци обично се састоје од географског елемента који физички поставља различите карактеристике земљине површине и повезаних атрибутних података. Просторне ETL трансформације често се описују као геометријске трансформације (трансформације географског елемента) или трансформације атрибута (трансформације повезаних података атрибута). Уобичајене геометријске трансформације које би требале бити присутне у било којем просторном ETL -у односе се на:

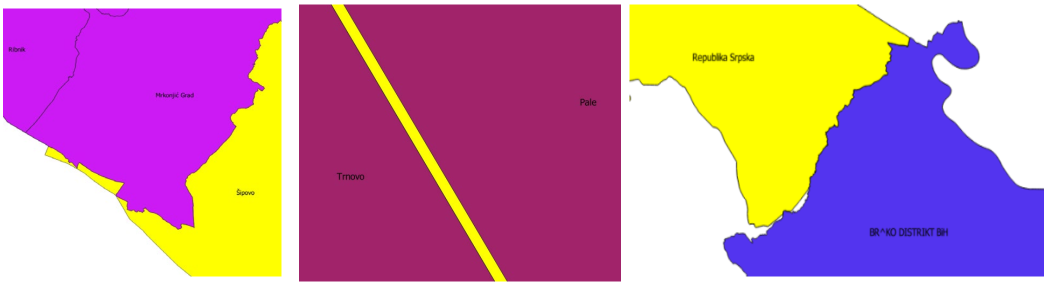
- Репројекцију - способност претварања просторних података из једног координатног система у други.
- Просторна трансформација - способност моделовања просторних интеракција.
- Тополошке трансформације - способност стварања тополошких односа између различитих скупова података.
- Чишћење података - уклањање грешака из скупа података.
- Спајање података - процес спајања више скупова података у заједнички оквир.
- Процјена квалитета - поређење више скупова података у сврху верификације и осигурања квалитета.
- Превод података - конверзија између различитих формата података и модела података.

3.1. Тополошке анализе над изворним подацима

У поступку успостављања јединствених података, извршена је хармонизација сетова податка из Адресног регистра и Регистра просторних јединица. Поступак хармонизације подразумијева геометријске и тополошке корекције постојећих података из два наведена сета података (Табела 2.). Валидацијом геометрије установљено је да су све геометрије успостављене у складу са ISO 19107 стандардом. Над подацима су вршене тополошке анализе које су подразумијевале идентификацију тзв. multypart геометрија. Установљено је да административна јединица општине Шипово у веома неповољном положају, са чак 6 одвојених цјелина, са насељеним мјестом Хатковци које је само састављено од пет независних цјелина (Слика 7.а). Анализом преклапања и прекида између полигона истог нивоа утврђено је 296 преклапања и 405 прекида између полигона насељених мјеста (Слика 7.б). Анализом преклапања и прекида између полигона различитог нивоа, највећи број преклапања и прекида установљен је између територије Града Бијељина и границе Републике Српске у износу од 233 (Слика 7.в). Последња анализа која је вршена подразумијевала је проналажење различитих података са истим матичним бројем административне јединице што је предложеним системом ријешено кроз успостављање кодних листи.

Табела 2. Тополошке анализе над изворним подацима

Полигони из више дијелова		Број преклапања и прекида између полигона				Различити подаци са истим матичним бројем
		На истом нивоу		*На различитим нивоима*		
Граница Републике Српске	**1**	Градови	0	Република	Градови	4
Градови	**2**	Општине	3	611		
Општина	**9**	Насељена мјеста	701	Република	Општине	
Насељена мјеста	**33**			4241		
Дистрикт	**0**			Република	Насељена мјеста	
				2393		
				Градови	Насељена мјеста	
				282		
				Општине	Насељена мјеста	
				4892		



(а) (б) (в)

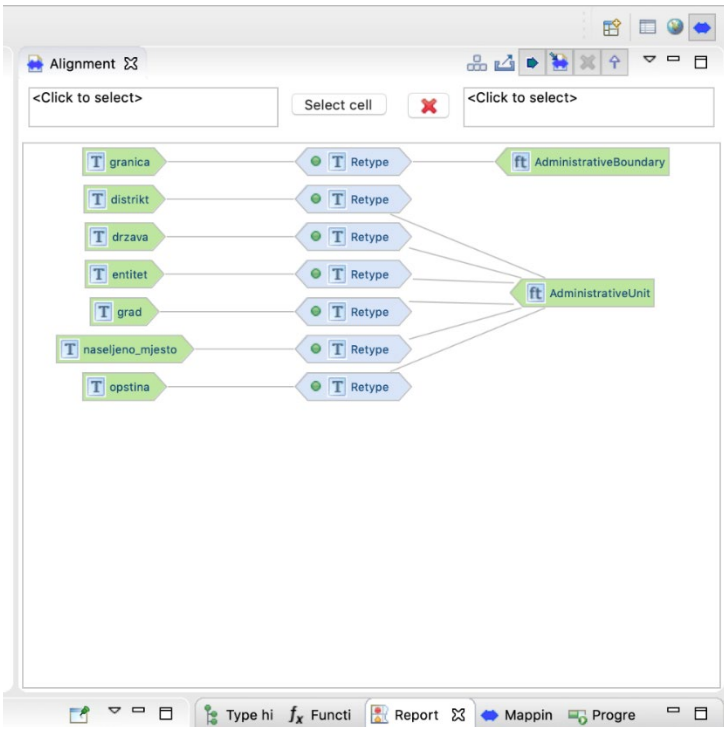
Слика 7. . Графички прикази тополошких грешака

3.2. Израда GML са мапирањем података

Према Östman 4.[10], трансформација података подразумијева превођење изворне шеме (INSPIRE server) у циљану шему (креирану апликациону шему). Шема у овом контексту може се дефинисати као формални опис модела, а постоје различите врсте / нивои шема. У концептуалној шеми, модел се састоји од структура података, листа кодова итд. Описана је помоћу UML (Unified Modelling Language). Логичка и / или физичка шема је повезана са физичком структуром скупова података, које имају везу на датотеке за пренос које су кодиране у XML/GML формату. Превод шеме обрађује се кроз три главна корака:

- Усклађивање шеме - поступак проналажења семантички повезаних објеката (тј. класа, атрибута који одговарају један другом). То се постиже путем онтологија, рјечника итд.
- Мапирање шеме - процес проналажења правила трансформације. То може укључивати различите операције као што су рекласификација, конверзија типова података итд.

Трансформација шеме - процес превођења података из изворне базе података, трансформација према правилима утврђеним у мапирању шема и учитавање података у циљану базу података или апликацију. Овај корак се такође назива и Extract-TransformLoad (ETL) процес.



Слика 8. Модел мапирања података у софтверу HUMBOLDT Hale Studio

У складу са горе наведеном процедуром, мапирање података је извршено поређењем изворне шеме која је учитана са репозиторијума INSPIRE-а и мапирањем одговарајућих класа са њиховим атрибутима у наведену структуру (Слика 8.). Трансформација података је извршена за цијели сет података и записана као GML (WFS 2.0 Feature Collection), у државном координатном систему. Као модел верификације података, извршена је валидација на Inspire Validatoru за GML апликациону шему и GML feature колекције.

4. ЗАКЉУЧАК

INSPIRE директивом је успостављен јединствен оквир, који треба да обезбиједи већу употребуи дијељење података међу различитим учесницима изградње инфраструктуре геопросторних података. Успостављањем инфраструктуре геопросторних података, засноване на сервисно – оријентисаној архитектури система, уз учешће свих релевантних институција, пружа се оквир који ће омогућити лакше и ефикасније планирање свих привредних процеса. На овакав начин је обезбијеђено избјегавање редудантности података, могућност провођења нових промјена у реалном времену и слично. У техничком смислу, успостављење инфраструктуре геопросторних података подразумијева формирање каталога метаподатака, формирање основних скупова података, дефинисње архитектуре која подржава интеграцију података и сервиса са великим бројем корисника и произвођача геопросторних информација, усвајање одговарајућег законског и институционалног оквира.

У оквиру истраживања констатовано је постојање више извора података административних јединица (Адресни регистар РС, РУГИПП, јединице локалне самоуправе), који су имали различиту структуру у геометријском и атрибутном смислу. Успоствањем јединственог оквира са минималним сетом метаподатака који се воде за административне јединице, добијен је оквир који је у сагласности са INSPIRE директивом. Описана проширења модела представљају техничку имплементацију за важеће законске прописе, а који пружају испуњавање међународно дефинисаних правила, прописаних INSPIRE директивом као и националних прописа. Модел дефинисан на овакав начин пружа могућност јасног дефинисања надлежности над креирањем, модификацијом и коришћењем података административних јединица, у оквиру система инфраструктуре геопросторних података Републике Српске.

Напомена: Резултати презентовани у овом истраживању су дио сарадње између Републичке – управе за геодетске и имовинско – правне послове Републике Српске и ангажованих консултаната.

ЛИТЕРАТУРА

[1] Bernard L., Kanellopoulos I., Annoni A., & Smits P., (2005), The European geoportal—one step towards the establishment of a European Spatial Data Infrastructure. Computers, Environment and Urban Systems, 29(1), pp. 15-31.

[2] De Vries M., Di Donato P., Ledoux H., Zlatanova S. & Laurent D., (2010), Concept of ApplicationSpecific Harmonised Data Models, HUMBOLDT Project Deliverable A7.1-D2, 44 p. Available at http://www.esdi-humboldt.eu/files/1102-a7_1-d2_concept_of_application-specific_- harmonised-tud-002-final.pdf.

[3] Drafting Team ‘Data Specifications’, (2010a), D2.7: Guidelines for the Encoding of Spatial Data – Version 3.2. Available at http://inspire.jrc.ec.europa.eu/documents/Data_ Specifications/- D2.7_v3.2.pdf.

[4] European Commission, (2007), Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE). Available at http://eur-lex.europa.eu/Notice.do?val=447703:- cs&lang=en&list=447703:cs,&pos=1&page=1&nbl=1&pgs=10&hwords=.

[5] INSPIRE Thematic Working Group Coordinate Reference Systems and Geographical Grid Systems, (2010), D2.8.I.1 INSPIRE Specification on Coordinate Reference Systems – Guidelines (v3.1). Available at http://inspire.jrc.ec.europa.eu/documents/Data_Specifications/ INSPIRE_- Specification_CRS_v3.1.pdf.

[6] INSPIRE Thematic Working Group Administrative Units, (2010), D2.8.I.4 INSPIRE Data Specifications on Administrative Units – Version 3.0.1. Available

at http://inspire.jrc.ec.europa.eu- /documents/Data_Specifications/INSPIRE_DataSpecification_AU_v3.0.1.pdf.

[7] Амовић, М., (2019), Трећи национални извјештај о стању инфраструктуре геопросторних података у Републици Српској и Федерацији Босне и Херцеговине у оквиру BESTSDI пројекта.

[8] Nowak J., Nogueras-Iso J. & Peedell S., (2005), Issues of Multiliguality in Creating a European SDI – The Perspective for Spatial Data Interoperability. Paper presented at the 11th EC-GI & GIS Workshop ‘ESDI: Setting the Framework’ (29th June – 1st July), Alghero, Sardinia, Italy.

[9] Östman A., Abugessaisa I., Tanzilli S., He X. & El-Mekawy M., (2009), GeoTest: A Testing Environment for Swedish Geodata. Paper presented at the GSDI 11 World Conference, Rotterdam, 2009. Available at http://www.gsdi.org/gsdiconf/gsdi11/papers/pdf/234.pdf.

[10] Östman A., (2010), Data Harmonisation Concepts. Presentation in the HUMBOLDT Training Framework, Level 1 – HUMBOLDT Knowledge. Available at http://www.gisig.it- / humboldt/training/index.php?option=com_content&view=article&id=58&It

40 | Professional paper | Стручни рад
ISSN 2566-4484 | Doi 10.7251/STP2014434T
pages 434-442

Dajana Todorović, dajanat24@gmail.com, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

Tanja Fržović, tanja.frzovic@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

Branko Božić, bozic@grf.bg.ac.rs, Faculty of Civil Engineering, University of Belgrade

APPLICATION OF PBL MODEL ON STUDY PROGRAM OF GEODESY AT THE FACULTY OF ARCHITECTURE, CIVIL ENGINEERING AND GEODESY AT THE UNIVERSITY OF BANJALUKA

Abstract:

The subject of this paper is the application of the PBL model in the teaching process of the first cycle of studies at the Faculty of Architecture, Civil Engineering and Geodesy. The meaning of the term PBL model and its basic characteristics as well as its historical development are described. The application of PBL to SP Geodesy and evaluation of its implementation on the example of a current subject are presented.

Keywords: PBL, geodesy, higher education

ПРИМЈЕНА PBL МОДЕЛА НА СТУДИЈСКОМ ПРОГРАМУ ГЕОДЕЗИЈА НА АРХИТЕКТОНСКО-ГРАЂЕВИНСКО-ГЕОДЕТСКОМ ФАКУЛТЕТУ УНИВЕРЗИТЕТА У БАЊАЛУЦИ

Сажетак:

Предмет овог рада је примјена PBL модела у наставном процесу првог циклуса студија на Архитектонско-грађевинско-геодетском факултету. Описано је значење појма PBL модела и његове основне карактеристике као и историјски развој. Приказана је примјена PBL-а на СП Геодезија и процјена његове имплементације на примјеру актуелног предмета.

Кључне ријечи: PBL, геодезија, високо образовање

1. УВОДНЕ НАПОМЕНЕ

PBL (*eng.**P**roblem **B**ased **L**earning)* је проблемски оријентисана настава то јест активна педагогија код које су студенти у центру процеса учења (student centered), [2] Код PBL, студенти уче о одређеној теми кроз рјешавање актулног и реалног проблема. Ово укључује стицање знања, унапријеђену групну сарадњу и комуникацију. Процес PBL -а развијен је за медицинско образовање, а касније се проширио и на друге програме учења. Процес омогућава ученицима да развију вјештине које ће се користити у њиховој будућој пракси. ПБЛ мотивише критичко оцјењивање, проналажење литературе и подстиче стално учење у тимском окружењу. Подстакнути тенденцијама свјетских универзитета, тачније, њиховим наставним процесом, предметни наставници (тутори) су у сарадњи са студентима треће године студијском програма Геодезија на Архитектонско-грађевинско-геодетском факултету иновирали наставни процес предмета „Геодетски премјер 3“ на Архитектонско-грађевинско-геодетском факултету, увођењем PBL модела у наставни процес. Увођење иновација у наставном процесу подстакло је студенте на студиозно бављење тематиком: „Глобални навигациони сателитски системи“. PBL модел красе свеобухватност техничког и умног рада те новитети у наставном процесу . Циљ примјене оваквог модела на техничком факултету је формирање нових модела учења у раду будућих инжењера који су, с обзир на процес напретка технологије и појаву све тежих инжењерских задатака, изузетно потребни. Примјена PBL модела у наставном процесу СП Геодезија, Архитектонско-грађевинско-геодетског факултета на предмету „Геодетски премјер 3“ је једна од неколико иновација наставног процеса на СП Геодезија. Студенти треће године СП Геодезија подијељени су у четири групе по 5 чланова и свака група је креирала сценарио која се односи на глобалне навигационе сателитске системе. Тутори су студентима објаснили срж PBL модела. Након добијених инструкција, свака група је приступила имплементацији PBL модела и постизању крајњег циља, а то је стицање знања и вјештина у контексту задате теме са елаборатом који представља само један од резултата PBL процеса.

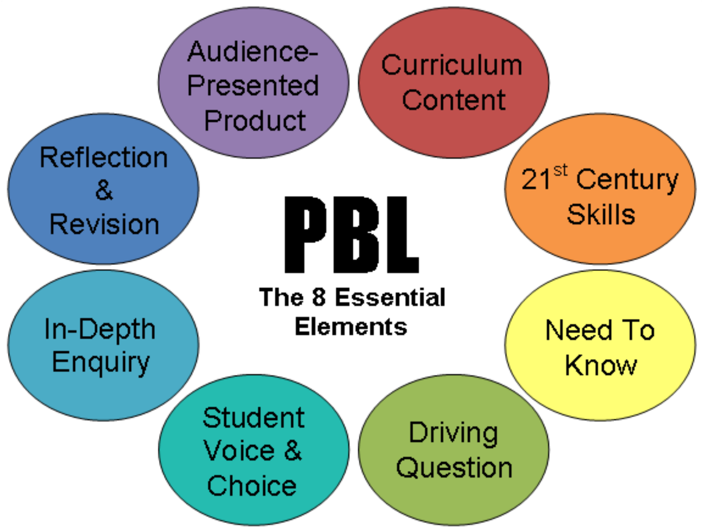
2. ИСТОРИЈСКИ РАЗВОЈ PBL-A

Проблемски оријентисана настава (PBL) настала је почетком 70-тих година XX вијека на *Mc Master* Универзитету у Онтарију, од стране љекара Barrows-a и Tamblyn-a, који су сматрали да наставни процес може боље да се организује, с циљем развоја дијагностичких вјештина студената медицине кроз анализу недовољно прецизно описаних проблема пацијената. [1]

Узрок настанка PBL-a је обесхрабљеност студената традиционалним медицинским образовањем. Студенти су схватили да је велика количина материјала представљеног у прве три године факултета мало везана за медицинску праксу и клинички засновану медицину. Циљ настанка PBL-a је подстицање учења код студената омогућавајући им да виде важност и примјену њихове струке за будуће улоге. PBL одржава виши ниво мотивације за учење и показује важност одговорних, професионалних ставова са вриједностима тимског рада.

Мотивација, која је један од кључних фактора успјеха XX и XXI вијека, буди интересовање студената за њихову струку и тематику коју обрађују, док им у истом тренутку омогућава рјешавање проблема чију примјену виде у стварном свијету.

Успјех нове парадигме охрабрио је остале универзитете те се оваква метода учења ширила поприлично брзо и за неколико година од њене концепције направљени су наставни програми PBL-a у Холандији, Аустралији, Израелу и Сједињеним Америчким Државама. За разлику од традиционалног образовања, које је усмјерено на професоре и фокусирано је на дискретни предмет, PBL модел образовања је усмјерен на студенте, њихову креативност и индивидуалност у тимском раду на рјешавању одређеног проблема. [2]



Слика 1. PBL модел и његови основни елементи(Group of authors:"Problem-based-learning", Stanford University Newsletter on Teaching, 1.стр. [5])

3. ОСНОВНЕ КАРАКТЕРИСТИКЕ PBL МОДЕЛА

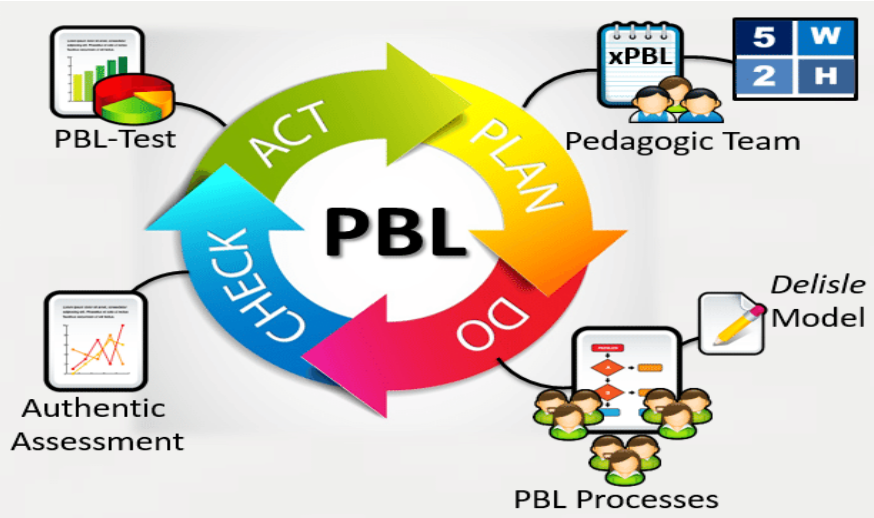
PBL је модерна педагогија, чија је срж усредсређеност на студенте те развијање вјештина код студената кроз рјешавање проблема одређене тематике. Оваква педагогија не фокусира се искључиво на рјешавање проблема, већ омогућава развој других вјештина и својстава, укључујући стицање знања, развијену групну сарадњу и комуникацију. Индивидуалност је изузетно важна код PBL-а јер студент на основу своје индивидуалности стиче способност да стечено знање пренесе својим колегама и тиме допринесе раду тима односно групе.

Учествујући у оваквим програмима студенти развијају вјештине које су им потребне у пракси на студију и на будућем послу након завршеног студија. Осим тога у свијести студента долази до изражаја критичко оцјењивање и смањење субјективних утицаја.

Начин проналаска литературе у оваквим моделима подстиче стално учење и сналажљивост у тимском окружење. Успјех тима је изражен кроз успјех рада сваког појединог члана тима.

Основне карактеристике PBL модела биле би следеће:

- Тимски рад;
- Индивидуалност као услов за успјех тимског рада;
- Развој нових особина;
- Способност дефинисања циља пројекта;
- Креативност у идејама;
- Сагледавање потребних знања;
- Сагледавање постојећег знања;
- Креирање исхода учења;
- Одговорност према обавезама;
- Комуникација и размјена знања и вјештина међу члановима тима;
- Способност лидерства;
- Квалитет презентовања резултата;
- Улога професора-организатор који подстиче и усмјерава процес учења;
- Нема одсуства са сесија, изражена одговорност појединца тиму; и
- Активно учешће и допринос раду сваког члана тима.



Слика 2. Основне карактеристике PBL-a(A.Rodrigues, S.C. dos Santos:"Students creation of PBL", Federal University of Pernambuco, creation of the authors, 4.стр. [6])

4. ФАЗЕ PBL-A

У оквиру предмета, PBL је реализован кроз осам следећих фаза:

- Идентификовање и разјашњење појединих израза и термина садржаних у сценарију;
- Дефинисање проблема;
- Анализирање појединих пројектних захтјева на основу претходног знања и искустава;
- Дефинисање неопходних нових знања у складу са пројектним захтевом;
- Формулисање циљева и исхода учења;
- Независно индивидуално учење;
- Размјена знања и идеја;
- Излагање рјешења и вредновање PBL модела .[3]

Прва фаза посвећује се презентовању проблема студентима и појашњењу нејасних појмова. Улога наставника је кључна у овој сесији јер наставник у овој фази предочава реалност проблема и објашњава нејасне појмове.

Основни циљ друге фазе је дискусија о захтјевима датог проблема. Све мора бити јасно свима и објашњено до краја. Послије завршене друге фазе не смију постојати недоумице око проблема и његових законитости.

Од великог је значаја сагледавање постојећег знања сваког члана тима и то се утвђује у трећој фази PBL-a. Након тога је погребно створити идеје о потребном знању. Сваки члан даје допринос резултату ове фазе кроз своје идеје о начинима рјешавања проблема. Студенти заједнички дискутују о идејама и обједињавају их сагласно пројектним захтјевима.

Четврта фаза посвећује се анализи проблема. Студенти износе своје идеје на основу стечених знања и прикупљених информација те на тај начин едукују колеге о свом дијелу задатка. Остали чланови и наставник постављају питања и допуњују неопходан садржај који треба конституисати. Процес је интерактиван и укључује све присутне чланове што доприноси креативности и комплетности закључака.

Веома је важно да исходи буду фокусирани на проблем те да су одговарајући и доступни. Тутор обезбјеђује адекватност исхода. Систематски приступ захтјева да се они дефинишу након неколико итерација кроз одређена објашњења везана за проблем.

У петој фази долази до јако „осјетљиве" дискусије о потребном знању. Понекад може доћи и до недоумица и конфликта између чланова групе. Студенти уочавају одређене аспекте који нису описани или објашњени у дискусији. PBL очекује да студент издвоји исте и дефинише их као циљ који треба реализовати. Та врста недоумице између тога „шта знају", а „шта им недостаје" или „шта треба да науче" је есенција PBL. Питања и дилеме у овој сесији се претачу у исходе које треба достићи (реализовати, остварити). Пажњу треба усмјерити на дијелове проблема који захтијевају нова знања.

Шеста фаза је фаза у којој индивидуалност и сналажљивост студента долази до изражаја. Студенти проналазе одговоре на постављена питања из претходне фазе, сагласно распореду обавеза дефинисаних кроз активности и исходе из претходне фазе (види Табелу 2). Информације се прикупљају из литературе као и свих других извора до којих студенти могу индивидуално доћи. Наставник припрема материјале (туторијале) и указује на изворе информација. Укупно вријеме за ову активност је од два до неколико дана. Рад може бити индивидуалан, у паровима или групно.

У седмој фази се синтетизује новостечено знање. Процјењује се потпуност и квалитет рјешења. Процјена методологије се испитује да би се дошло до процјене колико су студенти схватили свој задатак. Студенти размјењују знања и образлажу резултате рада и остварење исхода (у Табели 2 дат је примјер активности и исхода). У овом се кораку вреднује индивидуалан рад, комуникативност, одговорност, способност доношења одлука и заснованост донијетих одлука.

Излагање и вредновање се требају институционализовати. Вредновање се односи на све студенте, наставника (тутора) и PBL процес. Намјера вредновања је унапређење процеса учења и оцјене појединачних доприноса. Веома је важно да се студенти изјасне о ефектима PBL приступа учењу и дају своје мишљење о квалитету сценарија, квалитету тимског рада, литератури и улози тутора. Након завршеног вредновања потребна је анализа резултата и доношење закључка о иновираном наставном процесу. Квалитетна анализа повратних информација је кључна за побољшање PBL модела у новом циклусу наставе. PBL без повратних информација губи смисао, а кључна улога студената би у том случају била потпуно дезавуисана.

5. ПРИМЈЕНА PBL-A НА СП ГЕОДЕЗИЈА

Реализација примјена PBL-а у наставном процесу СП Геодезија на предмету „Геодетски премјер 3“, који се изучава на трећој години Факултета, започета је првом сесијом студената и тутора. Након уводног часа и објашњења сржи PBL-а формиране су четири групе од по пет чланова. Тематику „Глобални навигациони сателитски системи“ су задали тутори, док је свака група (тим) изабрала одређен сателитски систем као тему свог семинарског рада. Семинарски рад (елаборат, решење) на који је примијењен PBL модел требало је да садржи теоријски дио о заданој тематици и конкретној теми одређене групе те рачунски дио, који је подразумијевао обраду података ГНСС мјерења у неком од софтверских пакета и изравнање мреже. Тимски рад је организован око задатог сценарија по динамици у сесијама пратећи основну методологију PBL-а. Садржај учења је дефинисан кроз тимски рад, заједно са туторима, а сагласно задатом сценарију. Текст сценарија је садржао сљедеће дијелове:

- GNSS системи;
- Опис једног GNSS система којег је изабрао тим (GPS, GLONASS, GALILEO, BeiDou,...);
- Координатни системи;
- Технике опажања GNSS-om;
- Технике GNSS премјера;
- Мрежа перманентних ГНСС станица Републике Српске;
- Прописи;
- Координатне трансформације; и
- Изравнање мреже.

Табела 1. Динамика реализације PBL фаза (Dn = Дан, n је број дана од почетка), [1]

Сесија	Активност	Вријеме
1	Формирање групе, увод у PBL, објашњавање значења појединих израза и термина у оквиру задатог сценарија (постављање питања, разјашњавање појмова, сви чланови тима морају разумјети захтјеве)	D0
2	Дефинисање проблема (издвојити релевантне захтјеве кључне за рјешавање проблема)	D8
3	Анализа раније стеченог знања у контексту проблема (изношење идеја, повезивање с раније стеченим знањима, шта је познато, а шта је ново)	D8
4	Структуирање нових садржаја неопходних за рјешавање проблема и постављање хипотеза	D19
5	Дефинисање циљева и исхода процеса учења	D19
6	Реализација постављених циљева и исхода, учење, прикупљање информација, појединачно учење или у паровима (читање литературе, коришћење различитих извора, реализација задатих исхода)	D35
7	Дискусија и синтетизација прикупљених информација и знања, израда завршне форме, облика презентације	D35
8	Презентација резултата	D62

Текст сценарија је обухватао највећи дио садржаја и није детаљно струкруиран. Сесијама су присуствовали сви студенти. Сваку сесију је водио други члан тима и послије сваке сесије су креирани кратки записници о садржају дискусије и плану рада наредне сесије. Првој и петој сесији су присуствовали тутори те дали свој допринос анализи рада студената и дефинисању исхода појединих активности. [3]

Табела 2. Садржај рада са очекиваним исходима[1]

Основне активности	Посебни циљеви и активности	Очекивани исход
Дефинисање дизајна и датума основне ГНСС мреже	Облик основне мреже прилагодити задатом објекту у погледу геометрије. Датум мреже дефинисати са минималним трагом	Дефинисан положај тачака у основној мрежи. Дефинисан геодетски датум основне мреже.
Избор плана опажања	Планом опажања одабрати мјерене величине, број мјерених величина и дефинисати тачности планираних мјерења	Урађен план опажања. Дефинисаа тачност мјерења
Предходна анализа (валидација изабраног плана опажања)	За предходно усвојени план опажања извршити прорачун прецизности и поузданости и добијене вриједности упоредити са задатом толеранцијом дефинисаном пројектним задатком	Урађен план тачности и поузданости. Показатељи квалитета и поузданости се налазе у очекиваним границама.
Провјера дефинисаних техничких услова	У складу са изабраним планом опажања и захтјевима задатих толеранција,	Дефинисани услови при мјерењу и услови

реализованих (симулираних) мјерења	дефинисани захтјеви при реализацији мјерења на терену	тачности су испоштовани. Услови за контролу мјерења су извршени.
Дата мјерења реализована (симулирана) методом GNSS премјера	Дата мјерења су у складу са планом и прорачуном тачности симулирана GNSS методом (GPS, GLONASS)	Извршена симулација мјерења.
Обрада и анализа датих резултата мјерења	Изравнати мјерења по методи најмањих квадрата. Извршти оцјену тачности, тестирати на адекватност модела и тестирати мјерења на присуство грубих грешака.	Мјерења изравната. Тест адекватности модела задовољен. Мјерења не садрже грубе грешке. Хипотеза о сагласности са претпостављеном вриједношћу испуњена. Квалитет мреже испуњава услове пројектног задатка.
Извјештај	Описати захтјеве пројектног задатка. Навести постојеће прописе у вези израде мреже објекта. Описати пројектно рјешење са претходном анализом. Описати поступак симулације мјерења. Описати и документовати поступак изравнања са оцјеном тачности. У закључку анализирати постигнуте резултате сагласно захтевима из пројектног задатака	Извјештај о реализацији пројекта завршен. Презентација садржаја урађена.

6. ВРЕДНОВАЊЕ PBL-A

Након завршене синтетизације прикупљених информација и знања те израде завршне форме рада услиједила је презентација резултата. Свака група имала је задатак да након излагања свог рада вреднује PBL процес и резултате. Процјена је извршена на основу три основа: вредновање личног ангажовања, вредновање ангажовања других чланова тима и вредновање методологије учења, квалитета литературе и улоге наставника, [1]

Табела 3. Вредновање властитог доприноса PBL тима, [1]

РБ	Питања
Вредновање властитог доприноса	
1	Креативност у идејама, сагледавање потребних знања и креирање исхода учења
2	Допринос стицању нових знања и способности/остварењу исхода учења
3	Допринос укупним резултатима рада тима/одговорност према обавезама
4	Комуникација и размјена знања и вјештина међу члановима тима
5	Способности лидерства
6	Квалитет презентовања резултата
Вредновање доприноса других чланова PBL тима	
1	Укупан допринос у комуникацији

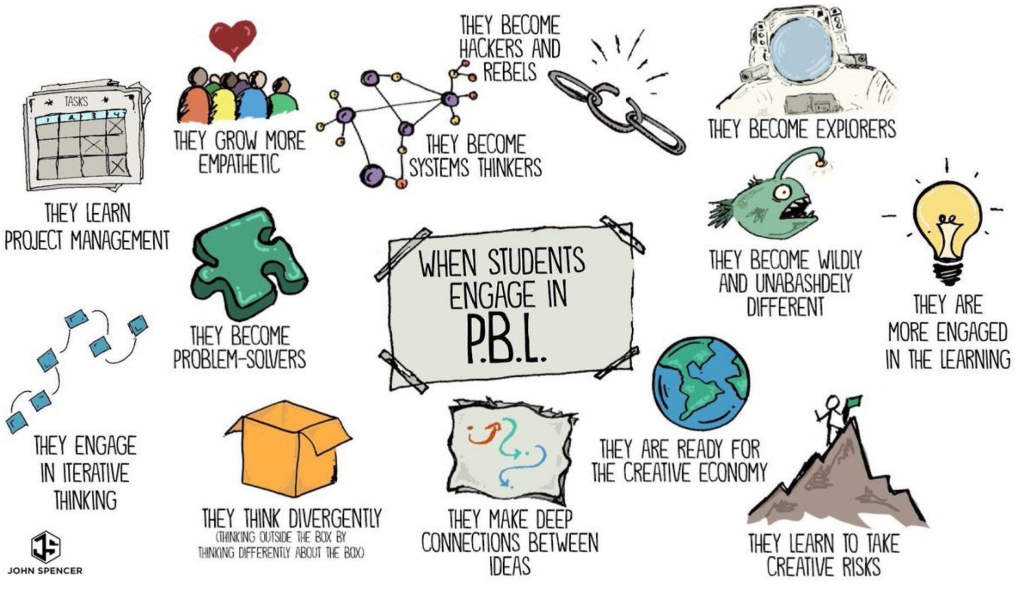
2	Допринос у изргадњи и унапређењу знања и способности тима/остварењу исхода учења
3	Учешће у размјени знања и вјештина међу члановима тима
4	Способности лидерства
5	Квалитет презентовања резултата
Вредновање PBL процеса	
1	Квалитет PBL сценарија (задатка)
2	Заступљеност и квалитет литературе
3	Улога наставника
4	Квалитет PBL учења у односу на класичан модел
5	PBL доприноси развоју тимског рада
6	PBL допринос вјештини презентовања резултата
7	PBL допринос мотивацији у раду
8	PBL допринос припреми за професионални рад у струци

Након завршене процјене PBL модела тутори су добили мишљење студената о PBL моделу.

Анализом процјене имплементације PBL модела изведено је свеобухватно студентско мишљење о иновираном наставном процесу.

На основу мишљења студената долази се до следећих предности ПБЛ модела:

- Нов начин извођења наставног процеса, који је занимљивији од традиционалног наставног процеса;
- PBL модел је утицао на развој креативности, одговорности, тимског учешћа и способности лидерства код студената;
- Сваки члан групе учествовао је активно пратећи сценарио, који је квалитетно осмишљен;
- Сви студенти су присуствовали сесијама;
- Литература је била веома квалитетна и доступна студентима;
- Учешће тутора било је присутно у свим фазама сценарија;
- Консултације са туторима много су помогле студентима у сагледавању концепата PBL-а .



Слика 3. Ангажованост студената у PBL-и (Koen Timmers:"When students engage in PBL" creation of the author [7])

7. ЗАКЉУЧАК

PBL пружа студентима могућност стицања вјештина кроз расправу и примјену нове стратегије учења и интегрисањем различитих знања. PBL образовна стратегија приказала је врло добар ниво перформанси у погледу интерпретације и информација и постизања циљева учења тима. Ученици су потврдили да су стекли тимске радне вјештине. Већина учесника се сложило да је PBL бољи од традиционалног система и да помаже у побољшању вјештина ученика, углавном вјештина рјешавања проблема и помаже у развијању аналитичких вјештина. Такође пружа студентима вјештине проналажења, процјене и интерпретације доказа, рјешавања проблема као и способност да открију сопствени таленат. Ови резултати су показали побољшање способности ученика у самосталном учењу, критичком размишљању, независном истраживању, групној интеракцији и активном учешћу. Вршњачка евалуација подстиче студенте да развију вјештине критичког расуђивања и омогућава им да уче једни од других. Међутим једна студија у Кини потврдила је да се студенти који су упознати са традиционалном наставом могу осјећати непријатно у улогама PBL-a у којима се морају координирати са вршњацима, бити самостални и стварати сопствене материјале за учење. Ово је било у супротности са тренутном студијом у којој се већина студената који су били упознати са традиционалном наставом чврсто сложила да је PBL ефикаснији од предавања. Квалитет реализације PBL модела зависи од активности наставника, квалитета чланова тима, који морају бити добро освијешћени о начину правилног приступања PBL моделу. Сценарио и сесије су кључне ствари за реализацију модела, зато је од велике важности било да студенти присуствју сесијама и активно учествују у истима.

ЛИТЕРАТУРА

[1] Б.Божић, М.Пејић, С.Туцикешић: „Пројктно оријентисан проблемски заснован модел учења-прва искуства у примени модела у оквиру студијског програма Геодезија и Геоинформатика“, Техника, pp. 1-7, 2020.

[2] H.S. Barrows, R.M. Tamblyn, Problem-Based Learning: An Approach to Medical Education. Springer Publishing Company, CA: New York, 1980, pp. 20-215.

[3] A. Walsh, The tutor in problem based learning:a novice's guide. Hamilton, ON Canada: Mc Master University, Faculty of health science, 2005, pp. 2-22

[4] J. Barell, Problem-based learning: An inquiry approach. March 2007; (2nd ed.). Thousand Oaks, CA: Corwin Press, Inc, pp. 177-197

[5] Group of authors: Problem-based-learning, Stanford University Newsletter on Teaching, April 2001. pp. 1-4

[6] A.Rodrigues, S.C. dos Santos: “A Framework for Applying Problem-Based Learning to Computing Education“, Federal University of Pernambuco, October 2016, pp. 1-7

[7] Koen Timmers:”When students engage in PBL”, creation of the author, March 2019

This article was prepared under the Erasmus+ project “Business driven problem-based learning for academic excellence in geoinformatics - GEOBIZ ". The project has been funded with support from the European Commission. This publication reflects the views only of the authorc, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

41 | Professional paper I Стручни рад
ISSN 2566-4484 I Doi 10.7251/STP2014443M
pages 443-451

Maja Milić Aleksić, maja.milic-aleksic@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

Marina Radulj, marina.radulj@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

CONCEPT OF METAPHOR IN THE MEMORIAL ARCHITECTURE. CASE STUDY MEMORIAL CENTER "DONJA GRADINA"

Abstract:

This paper discusses the phenomenon of metaphor as an instrument of significance and expression in the memorial architecture. The metaphor enables an indirect transfer of meaning via analogy. In the wider sense it represents expression of meaning via something else. The original linguistic form, the metaphor in architecture deeply permeates creative thought process, understanding and structure of perception alongside the end reception of the work. The metaphor as the type of architectural communication initially appears as the conceptual system in the creation process and then in the reception phase i.e. conceptual interpretation of the sense and meaning through its expressive attributes. This research shall be divided in two basic parts. The first part of the paper shall present the theoretical framework of metaphor considerations as an architecture concept. The second part shall be designed as qualitative research through case study

Keywords: metaphor, material architecture, concept, knowledge

КОНЦЕПТ МЕТАФОРЕ У МЕМОРИЈАЛНОЈ АРХИТЕКТУРИ. СТУДИЈА СЛУЧАЈА МЕМОРИЈАЛНИ ЦЕНТАР „ДОЊА ГРАДИНА“

Резиме:

Овај рад разматра феномен метафоре као инструмента значења и изражајности у меморијалној архитектури. Метафора омогућава посредно преношења значења путем аналогије. У ширем смислу она представља исказивање значења путем нечег другог. Изворно лингвистички фигура, метафора у области архитектуре дубоко задире у креативни мисаони процес, разумијевање, структуру перцепције, те крајње рецепције дјела. Метафора као облик архитектонске комуникације првобитно се јавља као концептуални систем у процесу стварања, а затим у фази рецепције тј. појмовног тумачења смисла и значења кроз своје изражајне карактеристике. Ово истраживање ће бити подијељено на двије основне цјелине. У првом дијелу рада ће бити постављен теоријски оквир разматрања матафоре као архитектонског концепта, док ће други дио рада бити конципран као квалитативно истраживање кроз студију случаја.

Кључне ријечи: метафора, меморијална архитектура, концепт, значење

1. INTRODUCTION

This paper aims to discuss the theory and thereafter, with the qualitative research method through case study, bring points of view closer together and better understand the concept of metaphor as a model of architectural thought and creation. Further to this, the paper aims to explain the significance of the concept of metaphor in the design process of creating memorial architecture; the primary goal of such an architecture being to achieve interaction and establish a communication process with the observer/participator. Discussing the communication process in architecture means talking about architecture through semantic information through which the idea, the state of the spirit, the thought of emotions are transferred. [1] In this communication model it is necessary to consider two moments, the first one - in the creative process of forming, i.e. input of the sense and meaning, and the second - in the reception phase, when architecture is a sensual framework for the one observing, experiencing and interpreting the meaning. This communication process is especially emphasised in the area of memorial architecture, when it is necessary to develop the experience of the mnemonic with the metaphoricality of space structures of the visitor.

The idea of mnemonic refers to the skill of memorising, i.e. the skill of having the possibility of remembrance supported by certain aids and it primarily consists of that what needs to be remembered through association brought by something else. [2]

In wider terms, the memorial architecture (and monuments) has the role of keeping alive the memory, carrying the message, commemoration of the memory on historical events. They are part of the collective and personal memory. In the traditional sense, the monument implies an architectural or sculptural composition, or a combination of these two, which are dedicated to a personality, an event, and is primarily meant as a visual marker. The memorial, on the other hand, is seen as an architectural construct, determined by the use of space, rather than representation. Memorials form the space which implies the engagement of the visitors at several levels starting from the visual perception, i.e. the visitor is exposed to the mnemonic nature of the space, being both an audience and a performer at the same time. [3] The memorial as defined in the area of transitional justice “designed to provoke a reaction, or a set of reactions, including the public awareness of the event or the people it represents; start a personal reflection of regret, pride, anger or sorrow about something that has happened; or knowledge and curiosity about a period in the past”. Aspiration of contemporary memorials is to include a contemporary moment, i.e. the existence of the past in the present. [4]

2. BASIC TERMS AND THEORY

2.1. Metaphor as a model of architectural thought

In the wider terms the concept of metaphor may be discussed as the model of architectural communication. Specifically, the role of metaphor is emphasised as an instrument in the construction of significance and expression of the architectural work, which is of great importance when talking about memorial architecture.

Metaphor (deriving from the Greek word, 'transfer') is a figure of speech for change, transfer of name or word from one to another term based on an obvious or hidden analogy, shortened comparison. [5]

Originally the metaphor was a comparison, but in an implicit way, implying cognitive processes of analogy in the emergence of metaphor. "Metaphor implies an expressive means of conveying meaning, and it literally also includes either additional sense or a surplus of meaning." [6]

The Italian semiotician Umberto Eco is of the opinion that the logic of metaphor belongs to the semantic mechanism, appearing in every system of signs, thus metaphor is not characteristic only for the language. In other words, the mechanism of metaphor is present in different discourses, and it allows the meaning to be conveyed in a creative manner through analogy: "What is illustrated is that the relation of analogy, which is primarily based on the visual similarity of the presentation and the original, may be formulated as a compositional rule that no longer has a direct and literal relation with the starting object, but with the concept of presenting the object, i.e. the knowledge of presenting and perceiving the object."[7]

It is precisely owing to the semantic and creative potential that the metaphor constitutes a creative instrument by which we form the meaning and expression in the area of architecture: "Our architectural gnosis deprives us of the need to operate with literal terms and categories in our profession. We will always better explain ourselves with our actions, if we remain with the metaphors and allegories, and it teaches us to be careful about the literal, about the monosemic."[8]

Pointing to the meaning and sense of a work, the metaphor refers to the category of symbols. It is analysed as a form of communication at the symbolic/semantic level. Within the domain of communication characteristics of architecture, the concept of metaphor enables interaction at the symbolic level, it carries the content, message, emotion. This is the key aspect in the use of metaphor with the memorial architecture. The structure of symbols is formed by two elements: the formal phenomenon and experience of space, on the one hand, and the sense and meaning, on the other hand, both of which arise from the experience of space phenomenon. Symbolically, as well as metaphorically, in architecture it enables that certain space experiences, observations, events and experiences are constituted and named in a symbolic way. [9]

In the area of architectural communication, the phenomenon of metaphor is naturally present in the creative and contemplated process of the creator, as well as in the structure of perception, and finally in the reception and understanding of the work with the observer/participator. Apart from the dominant function of the metaphor - as the instrument for carrying the message, it is also a significant figure in building the recognisability and uniqueness of memorial architecture. In this sense, the concept of metaphor can be a key design strategy in the entire design process - from the setting of spatial disposition, formal and functional characteristics of architecture, to the use of materials.

We can observe the metaphor in the wider system of the mimetic process. [10] Here we will emphasise the contemporary interpretation of the term mimesis in the field of art, without going into detail about the origin and definition of this term. The impulse of mimesis, as the German philosopher Theodor Adorno explains [11], refers to the natural desire of the creator to by multilevel observation absorb the environment, to through the creative process then process its content, and finally articulate and incorporate it in a symbolic way in its own (artistic) work. He is of the opinion that mimetic processes are present in the creative process in the early intuitive phase even before the creator engages in conscious stimulation and rational actions. This thesis supports the understanding of the design process which does not exclusively rely on rational thinking but is imbued with intuition and imagination in the understanding and creating of things (the world) surrounding us. On the other hand, the mimetic process is also present in the reading of the work, where the recipient in the semiotic apparatus decodes the meanings by identifying similarities, rearticulated in the creative expression. [12]

According to this view, in the designing of the mimetic mechanism the architect absorbs the material and immaterial characteristics/values of the context, and then incorporates them through the symbolic articulation and expresses them metaphorically in a new value. As for the observer /participator, in this mechanism it is exactly through the metaphorical expression that they recognise and adopt the recognised values with which they identify themselves. In this sense, the metaphor is, inter alia, based on the interpretation of the contextuality and is in tandem with the conceptual, esthetical and creative intention of the author. Hence, metaphorical expression in the mimetic system may be observed as a way of expressing - emotionally, ideationally, conceptually and symbolically - characteristics of the contexts formed in the creative expression.

3. CASE STUDY- COMPETITION PROPOSAL

3.1. Spatial-time context

The awarded competition[6] work shall be taken as a case study -the idea of urban and architectural presentation of the memorial center in the site of conscience "Donja Gradina".

Until nineties of the 20th century, memorial center (site of conscience) Donja Gradina was the part of the unique memorial complex "Jasenovac- Donja Gradina". Disintegration of the Federative Republic of Yugoslavia caused splitting of the memorial complex between the two states: Jasenovac site which was the concentration camp site under the Independent Croatian State during the WWII and today situated in the Croatia and Donja Gradina site, the biggest burial site within the concentration camp Jasenovac, and today situated in the Republika Srpska,. The main memorial buildings were built in the 1960s with the central monument "Flower" of the architect Bogdan Bogdanović and the museum Jasenovac on the territory of the former camp. Donja Gradina, established on the conceptual proposal from 1977, acquires the character of the Open-Air Museum,

[6] The autors of the first awarded work are Marina Radulj, Maja Milic Aleksic, Milana Nedmovic and Slobodan Peulic

which is conceptually called Silence, as based on the Una River rudder. The open-air museum follows natural Posavina landscape with emblematic tombs in the landscape and slip articulated pedestrian paths.

In the new geopolitical circumstances, the Republika Srpska Government in 1996 proclaimed the area of Donja Gradina as a prominent place and immovable cultural property of exceptional significance. In this context, on the basis of the 2009 public competition solution, the preparation of the Regulatory Plan for the wider area was approved, and it was adopted in 2011 along with the Program for the Site of Conscience organization at the Donja Gradina area. The public competition was published in 2015, and repeated competition in 2017/2018 for the best urban and architectural solution of the Memorial Center of Donja Gradina. In fact, all these activities in the broader sense represent the basic program idea of the interruption of Silence. In the text to follow we shall explain the method of building of basic spatial elements of the Memorial center in the work that was rewarded in the latest competition. They will be viewed in the context of realization of the communicational aspect of architecture which is important for memorials.

3.2. Design approach

How to build in a sensitive area? How to build and at the same time express our contemporary attitude towards the area of suffering from 70 years ago? It is important to note that the design process was rather intuitive, guided by the long-term experience of the author (the list all the participants in the footage) and the impression and knowledge of the area - Donje Gradine and the event - the Holocaust.

In the creative thinking, the two key goals were crystallized: the first, to achieve a relationship with the infinite Posavina landscape and the established memorial and the second, to build new spatial and metaphorical values of the memorial character.

In this way, this paper attempts to illuminate in a certain way and, once again, re-examine the competitive solution by bringing it into connection with definitions and philosophy in the interpretation of the set of metaphors and symbols. The reasoning behind was to design, build and establish better quality interaction with the future generations that will come to pay their respect.

The author clearly expresses the attitude in the introduction of the paper as well as in the interpretation of the term "memorial" that Donja Gradina memorial as well as events that happened there and the echo of those events in the contemporary moment should not remain only as the representation of the visual and monumental. Quite the opposite, they should be determined by the use of the space hence each visitor will build and carry authentic memories as a part of the wider collective memory. For precisely: "Forgetting extermination is part of extermination, because it is also the extermination of memory, of history, of the social... "[13]

Under this paper, a program segment will be considered that includes a monumental unit within the Field of Sighs without the accompanying contents of the complex located on the edge of this Field. Within the open-air museum, two places of intervention are identified: in the physical and mental center of the Silence Filed and along the Sava River, towards Jasenovac, at the historical site which represents the chronology of the events - bringing prisoners to Gradina, and their path to death.

Exposed to the specific context of the space, the authors unconsciously initiate mimetic system of layered observation and absorption of the surroundings and „ (...) transfer and report to others the same truthful messages. How? *Through metaphors*. The topic of the suffering, according to the philosopher Živanović, is at the same time the topic of overcoming life. "From the overshoot horizon and we speak (...) in the only possible way - precisely metaphors." [14] With the help of friend - philosopher, two basic metaphors are being defined i.e. a **whirlwind of silence** and **scaffolds of fear**, stretching through the space as two-folds monumental and memorial space interventions.

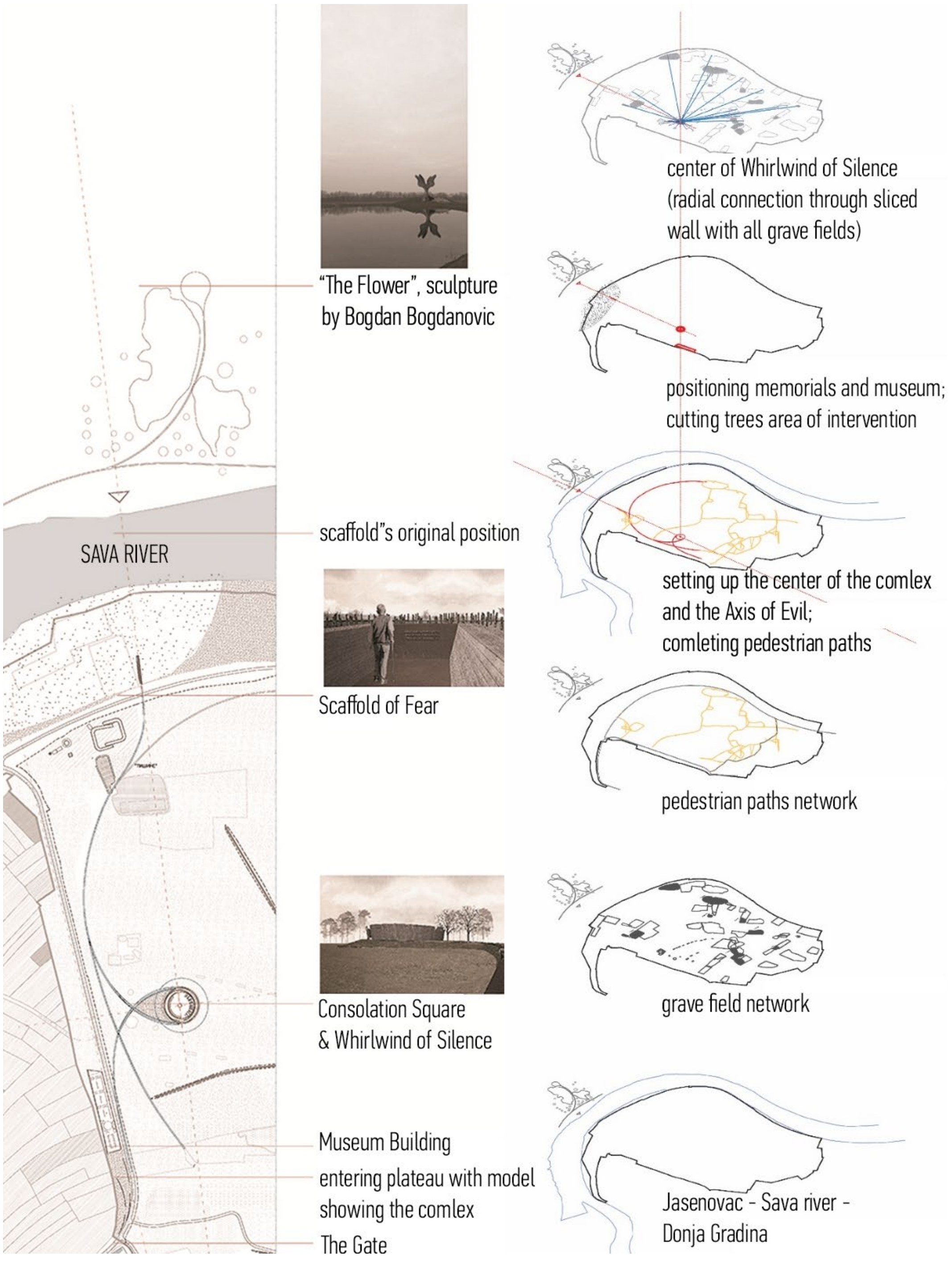


Figure 1. *Design plan of the complex Donja Graina with Jasenovac on the other side of river Sava (competition proposal) with Jasenovac central memorial by Bogdan Bogdanovic*

3.3. Memorial center: whirlwind of silence and scaffold of fear

Memorial Whirlwind of Silence represents the central element of the Memorial park and it is in the center of the complex. Its appearance is marked by its detachment in the field and in the grass layered mound from which it appears as a fort - representing the metaphor of the city. "Gradina" is augmentative of the town, and represents city inhabited by many people. And we can in a way say, that one whole city of people disappeared in Donja Gradina.

Figure 2. *Memorial Whirlwind of Silence (competition proposal), 3D visualization*

“Gradina", site, is the term in architecture describing difficult to access fortified site of bigger or smaller dimensions; it may be applied to almost all high settlements and often to fortifications on the swamp land and in the plains. At the same time, the mound is being built and in order to drain the ubiquitous water in the field during the high water level of the groundwater.

The area of Gradina is marked by tragic historical events - the Holocaust; time is infinite, separated from every day, whole and unique. Guided by this thinking, the WHIRLWIND OF SILENCE, in the geometry of the base, is built from the circle. The circle and geometry that builds from it are symbolically layered and multifaceted, and in this sense, metaphorically open to complex interpretations.

Whereby, the circle "(...) symbolizes the individual self, manifestly, infinitely. (...) The circle removes time and space and indicates repetition. It is the symbol of heavenly unity. "[15]

The three circles in the geometric setting of the Whirlwind walls were formed as a formal analogy to the three peoples who were singled out as "others" and whose members were in the largest numbers killed here. With that: "The three concentric circles are a symbol of the past, the present and the future."[15]

In the formal sense, the Whirlwind is built of walls from the geometry of concentric circles whose center is slightly shifted along a line. It is positioned so that its center is located on the north-south line called the Axis of Evil, which connects the direction of providing another monumental element of SCAFFOLD OF FEAR and monuments in Jasenovac.

The vortex theme through spatial design characteristics is experienced through movement and time from the very entrance into the field. "A rotten man is spinning." [14] The movement in the vortex presupposes the effect of space over time. It is a dramaturgy of movement that should cause a variety of different feelings to the visitor: a certain discomfort, fear, anxiety, tension in movement, curiosity. What is behind the high walls of the gates?! Concentric walls with a pronounced height and at a slight distance create a sense of movement in the maze to the visitor. The entrances are not emphasized, they are searched along the concentric path, along which vertical flanks occur towards the center of the Whirlwind, and, on the contrary, when going out, towards the field, which, with fragmentary opening, is curious, but also builds uncertainty. There are also "blind" spaces. One single path leads right into the center and out again According to some hypotheses, the labyrinth is a symbol of the world, of all things, of incompetence, of movement. "Its uninterrupted line is eternity, infinite duration, and immortality. (...) At the same time, the permission and the prohibition, he excludes, because it makes the road more difficult and fails, makes the exit more difficult. "[14]

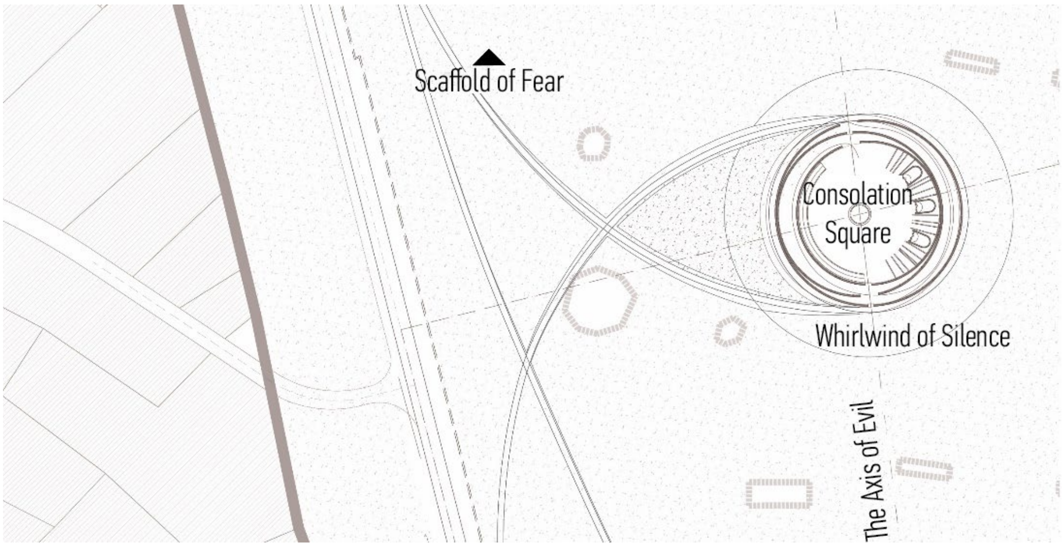


Figure 3. *Memorial Whirlwind of Silence (competition proposal), plan*

Whirlwind connotes the "Survival of life and death, signifies a state in which one neither can live nor die ... It can only be turned into a circle or vortex." The etymology of the word vortex indicates the verb spin, which connects with the spindle word. This etymological series suggests that the whirlwind, in addition to bringing fear and leading to death, simultaneously points to the source of life, on weaving and creation; therefore, the theme of the vellum is also the cyclical movement of life, where life ends and it reappears. [14]

The second axis is perpendicular to the axis of evil and lies towards the east - west where memorial religious objects are positioned as a place of purification, comfort and faith in life. The square within the vortex is intended for gatherings, manifestations and worship. The interior of the vortex is a protected place, a limited and defined space, forms a place, a spacious whole open to the infinite sky.

The vortex center is a place that calls, arouses memory, recognition and identity. This is also the place where a visual vertical connection with the crypt is realized. From the square we are moving towards the depths, the vortex narrowing, anxiety, uncertainty, pressure intensify, so that one single point that does not rotate on the bottom itself, stands as a fact, as an eternal truth. It is a place of sculpture for all victims. "Rake, funeral caves and maze-shaped maze were protecting the dead, but also preventing their return."[15] Mating into the labyrinth is a symbol of death, and a birth-giving birth. The Vortex is turning. His power is unequal, somewhere stronger, somewhat weaker, but continuous. Whirlwind leads us to our center, in order to ultimately drag us to the bottom, in the essence of the truth about this place. The Whirlwind is emphasized by geometric separation - a circle in the field. They symbolize an independent self, manifestly, infinitely.

The second part of the memory comes from the need to factually reconstruct the historical facts related to the former Jasenovac death camp. During the WWII, there was a river scaffolding at the place where the Sava River was narrowest. It was used for the transport of inmates, path without return. On the other hand, as a mimetic stimulus, we have a lush wildflower forest towards the Sava River all the way to the dam that protects the Gradina from the flood.

As it is impossible to expose the chronology of events linearly, due to state borders, it is possible to create an end-of-life experience. The scaffold of fear is projected as a narrow bridge that has no end, it does not merge to the other shore, which goes to some point towards the Sava and the stables. The seized forest is shed so that only the trunks below the Scaffold, many of them, in the numbers of Jasenovac victims, remain. The bridge is creaky. It is possible to establish a visual connection with Jasenovac on the Scaffold.

At the end of the Scaffold there are just a few verses:

"Darkness is not the worst place,

The end is not the worst place,

The Fear is the worst place. "[16]

Figure 4. *Memorial Scaffold of Fear (competition proposal), 3D visualization*

4. CONCLUSION

The purpose of this paper was to show the phenomenon of metaphors as an instrument of meaning and expression in memorial architecture. In the conceptual setting, the metaphorically expressed urban and architectural elements create the overall message and the meaning to be transmitted to the observer / visitor. All together: the internal structure of the elements, their forms, materialization and spatial dispositions, create the morphology of the overall memorial through multi-layered symbolic meanings.

The construction of symbolic speech through the instrument of metaphors was directly conditioned byspatial and physical characteristics and historical facts as a kind of framework for interpretation and experience. Through the characteristics of the form and function, the site of conscience builds and expresses the meaning, in a unique spatial framework with the idea of conveying a message of memorial architecture.

LITERATURE

[1] Umberto Eko, Kultura, informacija, komunikacija. Beograd: Nolit, 1973, pp. 207-270.

[2] Riječnik stranih riječi: tuđice, pouđenice, izrazi, kratice i fraze. Beograd: Evro, 2001.

[3] S. Tanović, Designing Memory.Technische Universiteit Delft, The Netherlands: Cambridge University Press

[4] Brett, S., Bickford, L., Ševčenko, L., Rios, M. Memorialization and Democracy:State Policy and Civic Action, Report International Coalition of Sites of Conscience. 2007.

[5] http://www.sitesofconscience.org/wpcontent/uploads/2012/10/Members_member-Benefits_004.pdf

[6] I. Klajn,M. Šipka M. Veliki rečnik stranih reči i izraza. Novi Sad: Prometej, 2007.

[7] Miško Šuvaković, Pojmovnik teorije umetnosti. Beograd: Orion Art, 2011, , pp. 367.

[8] Miško Šuvaković,Pojmovnik suvremene umjetnosti. Zagreb: Horetzky, 2005.

[9] Богдан Богдановић, Архитектонска теорија, наука или гноза.

[10] Predavanje održano na Arhitektonskom fakultetu održano na Arhitektonskom fakultetu jula 1987. godine, Snimak: RTB Radiotelevizija Beograd

[11] https://www.youtube.com/watch?v=jgJCBM-lZNw

[12] Umberto Eko, Simbol Beograd: Narodna knjiga, 1995. pp. 5-33.

[13] M. Milić Aleksić, Komunikacijska svojstva arhitekture na primjeru djela Zlatka Ugljena. Doktorska disertacija. Beograd,2017.

[14] .Neil Leach, Camouflage. Cambridge Mass: MIT Press, 2006 pp.44.See more in Teodor Adorno, Estetička teorija, Beograd: Nolit, 1979.

[15] Benjamin, Walter. “On the Mimetic faculty”, in: Camouflage,NeilLeach, Cambridge Mass: MIT Press, 2006, pp. 18–22.

[16] Жан Бодријар, Симулакруми и симулација. Нови Сад: Светови, 1991, pp. 50.

[17] Миодраг Живановић, Филозофија у метафоричком кључу. Бањалука: Библиотека Посебна издања, 2014. pp.. 71-79.

[18] Мали речник традиционалних симбола.Београд: Libertto, 1999.

[19] Милена Марковић, фрагмент пјесме „Мрак“, књиза поезије „Песме за живе и мртве“, Београд: ЛОМ, 2014.

42 | Professional paper | Стручни рад
ISSN 2566-4484 | Doi 10.7251/STP2014452C
pages 452-459

Marina Carević Tomić, marinac@uns.ac.rs, Faculty of Technical Sciences, University of Novi Sad

Ranka Medenica Todorović, ranka.medenica@uns.ac.rs, Faculty of Technical Sciences, University of Novi Sad

Milica Vračarić, kostresm@uns.ac.rs, Faculty of Technical Sciences, University of Novi Sad

UNIVERSITY CAMPUS AS A SECONDARY CITY CENTER – A CASE STUDY OF NOVI SAD IN SERBIA

Abstract:

The presence of the university within the city triggers competitive advantages together with the various spatial and socio-economic challenges of the urban area. Introducing the historic perspective of the symbiotic relationship between the city and the university, the paper explores the interaction between the campus of the University of Novi Sad and its urban neighborhoods. It is supposed that the university campus can have a more prominent role in the system of centers in Novi Sad through the integration of its functions and open public spaces with the surrounding area and within the limits of the campus itself. The presented analysis supports the idea of the policentricity of the city of Novi Sad.

Keywords: campus, city centers, town-gown relationship, policentricity, University of Novi Sad

УНИВЕРЗИТЕТСКИ КАМПУС КАО СЕКУНДАРНИ ЦЕНТАР ГРАДА – СТУДИЈА СЛУЧАЈА НОВОГ САДА У СРБИЈИ

Сажетак:

Присуство универзитета у граду покреће конкурентске предности заједно са различитим просторним и друштвено-економским изазовима у урбаној средини. Кроз приказ историјске перспективе симбиотског односа града и универзитета, у раду се истражује интеракција између кампуса Универзитета у Новом Саду и његовог градског окружења. Испитана је претпоставка о могућности истакнутије улоге универзитетског кампуса у систему центара у Новом Саду кроз интеграцију функција и отворених јавних простора са околином, као и у оквиру граница самог кампуса. Представљена анализа подржава идеју о полицентричности града Новог Сада.

Кључне речи: кампус, градски центри, однос града и универзитета, полицентричност, Универзитет у Новом Саду

1. INTRODUCTION

The transition to the knowledge society imposed the growing need for synergy between economic development and universities, creating a unique competitive position of the university towns. Considering heterogeneous missions and strong impacts of the higher education institutions, they are recognized as important catalysts of social transformations and a stimulus to the dynamics of regional and city development, going beyond the traditional goals of education and research **Invalid source specified.**.

During the current period of population decline in Serbia, the city of Novi Sad is counting enlargement of population, which is to a large extent a result of the existence of the university. It is not rare to hear that Novi Sad is a "university city" that attracts students from all over the Autonomous Province of Vojvodina, as well as from other parts of Serbia and the wider region. Taking into account the changing dynamics of the functioning of the university and the city itself, the relationships between the campus and its urban surrounding is changing as well. Considering that a large number of people, mostly young, gravitate to the university campus daily, this case study examines how the University of Novi Sad and its campus interact with the wider urban context highlighting the relationships and functional composition of the bordering zones around the campus. The paper posts a question if the university campus can be treated as an extension of the city center in a manner that both entities benefit, particularly in response to the unique circumstances – opportunities and restraints – that the city provides. It is supposed that the campus can have a more prominent role in the system of centers in Novi Sad, considering the significance and specificities of the University and favorable location of its campus.

The paper discusses the significance of the University and the campus as its spatial frame, and analyzes the system of centers in Novi Sad by means of site surveys and planning documents reading, with an intention to elaborate the opportunities for better recognition of the University of Novi Sad through the improved spatial conditions in the city. The focus of the paper is on the integration of functions and open public spaces of the campus with the surrounding neighborhoods and within the limits of the campus itself.

2. GENERAL SIGNIFICANCE OF THE UNIVERSITY AND THE CAMPUS

The origins of the university in the western society are rooted in the newly formed cities of the 12th and 13th century medieval Europe. They appeared in accordance with the social conditions and emerging urban society of the time. Based on the model of guilds – professional associations of craftsmen or merchants, universities were established as associations of students and/or masters (teachers). Striving for the autonomy and academic freedom since the inception, they were an important factor of social life, but equally dependent on municipal and public authorities for financial support and legal rights and privileges **Invalid source specified.**.

This symbiotic relationship between the city and the university has continued to evolve throughout history. The19th-century European universities were grounded on the value of universal, pure knowledge and freedom of learning and research "for their own sake" **Invalid source specified.**. Its social role has been metaphorically articulated as the "ivory tower" phrase, which points to the irresponsiveness to socio-economic demands and real-world problem-solving. Spatial expression of such academy-society relations was the suburban or isolated greenfield campus development in the 1960s and 1970s, which separated students from other civic structures and public life **Invalid source specified.Invalid source specified.**.

Contrary to the European university tradition, North American universities emerged much later, mostly as a result of private initiatives and therefore sensitive to the effects of the market and the demands of the social environment. It is stated that American universities have achieved a significant relationship with community needs, providing excellent professionals, expert knowledge and continual advancing in science, and forming the basis for sustained economic growth and prosperity **Invalid source specified.**.

On the turn of the new millennium, globalization and neo-liberal ideology imposed new challenges and demands on higher education worldwide. Universities have been assigned with the third mission (besides two essential roles of teaching and scientific research), implying to their economic role as a force of development in the knowledge society. Studies on the heterogeneous mission of the university point to diverse modes of their engagement in the contemporary society based on the knowledge spill-overs, innovation and technology transfer in collaboration with industry and private sector; support in the entrepreneurial engagement through intermediary structures like technology transfer offices, science-technology parks, R&D centers and start-ups **Invalid source specified.**.

Nowadays, the type of suburban university structure does not provide the right environment for the modern knowledge society to flourish **Invalid source specified.**. The university campus itself should represent an urban area that forms an integral part of the city. Its physical settlement, the quality of design and the definition of its functional program might influence specific relationships with the city which certainly vary according to the context **Invalid source specified.**. The relationships between cities and universities have started to shift as a result of the reconfiguration of the socio-spatial organization of economic activity. The major social and economic transformations over the course of the twentieth century reflected on universities' degree of engagement with communities outside their campuses. O'Mara states that "the historical transformations of university and city since the mid-twentieth century have been closely intertwined and interdependent" **Invalid source specified.**, which is especially relevant for the urban neighborhoods with the large physical and political presence of higher education institutions. The universities are nowadays exhibiting a significant capacity to affect the social, spatial and symbolic structures of the urban area. The concept of the "town-gown relationship" explains the relations between the universities and the communities that surround them. The boundary between town and gown entities is declared to have real and lasting consequences, particularly in terms of land use and policy issues **Invalid source specified.**. At the same time, the social component of this relationship has growing importance. Gehl and Gemzoe **Invalid source specified.** stress the influence of university and especially students on the vitality of the city center, giving the examples of famous university cities and districts well known for their vitality and interesting atmosphere. As the economic and social purpose of the university has changed, so did the degree of the university's engagement with communities outside their campuses. It is stated that "nowadays the university has been transformed from a closed space for communicating knowledge into an open space aimed at active engagement in the social life of cities and regions" **Invalid source specified.**. Greater socio-economic incorporation of the university into its urban structure seeks the way for its spatial reflection – the need for rethinking the role of the campus within the spatial organization of the city and its central functions.

3. SYSTEM OF CENTERS IN NOVI SAD

The traditional center of Novi Sad consists of a great variety of uses due to the fact that it is the oldest part of the city which has always been a place of a dynamic urban life. Contemporary socio-economic context and processes have further contributed to the richness of programs of the neighborhood in terms of the rise of a share of non-residential uses. The most important city institutions are located here (local administration, culture, education, business, etc.), but the center is also traditionally related to the trade, which became the prevalent use together with cafés and restaurants **Invalid source specified.**. Apart from the old city center, General urban plan suggests the system of primary centers along main city streets, such as the linear center between old core and main boulevard –Bulevar oslobođenja, as well as the Fortress of Petrovaradin, as a tourist attraction, and Mišeluk, foreseen for decades as the future center on the right bank of the Danube. This layout of central zones should create conditions for the development of secondary centers, usually parallel to busiest streets, and make a system of connected central functions. All those centers ought to be mixed-use zones adjusted to different catchment areas. The focus points of current and future development also include a wide range of specialized public institutions in the city, since Novi Sad is a provincial and macro-regional center. Specific programs of science and higher education, health care, culture, trade, and sport are usually developed concentrated in so-called specialized centers – university campus, clinical center, sport and business centers, fair, etc. Those institutions, attracting people from the wider region and even from abroad, are among strategic priorities for the development of the city as a whole **Invalid source specified.**. Contemporary global and local circumstances have caused the emergence of a new focal point – the shopping mall Promenada, recently being one of the main places of interest. With its inner-city location, Promenada attracts various groups of people from the city, as well as from other areas – competing with the traditional urban center and reflecting a number of issues connected with contemporary consumerism.

The study of the specialized centers and focal points as the elements of the spatial structure emphasizes the importance of the diversity of their forms for the proper functioning of the space, urban identity and social integrity, and especially for the diversity and the number of their users. It also reveals the increasing significance of the areas that offer a variety of facilities, enclosing vacant spaces, micro-spaces or smaller squares, among which the student campus stands out as an example

Invalid source specified.. University campus in Novi Sad has the most convenient location among specialized centers, with a share of housing facilities and a large number of visitors who spend time there on a regular basis. This creates favorable conditions for the development of accompanying central functions in and around university grounds and gives the opportunity for the opening campus to all citizens, especially young people. Dispersion of the population and economic power from the traditional centers could, therefore, produce new decentralized and interdependent cores that often mimic the patterns of traditional centers but also lead to new qualities of urban densification **Invalid source specified.**.

4. CASE STUDY OF UNIVERSITY CAMPUS IN NOVI SAD

The first faculties in Novi Sad were established in 1954 and the creation of the university campus started in 1956 along with the construction of the Faculty of Agriculture. At the time of the establishment of the University of Novi Sad, there was no master plan for the campus – there was just a piece of vacant land where faculty buildings were built as needed. Yet, the position of the university on such an important location – close to the city center and river waterfront (Figure 1) – shows that the site has not been chosen simply due to chance and proves the significance of this institution for the city as a whole. The university campus has one of the best locations in Novi Sad and shouldn't be an isolated monofunctional zone, but an integral part of the city.

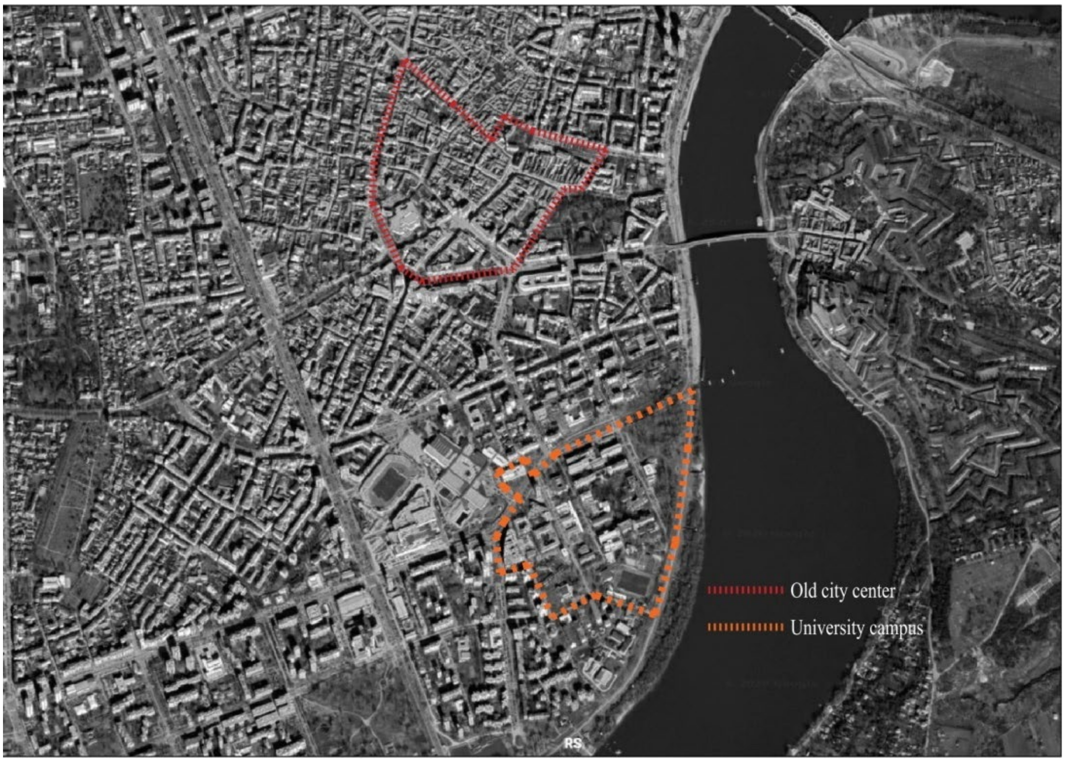


Figure 1. *Location of the university campus in Novi Sad (source: authors)*

Today, the campus is the location for seven faculties, central building of the university, two student restaurants, medical center, and a sports complex, but there is very little housing for students and teaching staff, even less commercial offerings, no cultural and leisure facilities. The whole university counts around 50.000 students and 5.000 employees **Invalid source specified.**, the majority of which study on campus, as the main core, and the rest at faculties in other parts of Novi Sad or in some of three other university enclaves in Subotica, Sombor and Zrenjanin. Because of the disproportion in the number of people visiting campus and those who live there (a little bit more than 1.000), daily migrations, as well as traffic crowds, are significant. The majority of students study and eat on campus but live all over the city. Living outside the campus gives the opportunity to students to mingle with other social groups, but the consequence is the unbalanced activity on campus: the campus life is very vivid during the lessons, unlike in the evenings or during summer break.

Because of the functional composition of the campus, students here attend classes and use student canteen services, but student life does not take place only in classrooms. An important part of socializing and leisure activities almost exclusively happens outside the campus, even on weekdays, so the academic community plays an important part of urban life in Novi Sad. The exceptions are short gatherings of students in the main square on campus that usually take place during the breaks between lessons, as well as gatherings on the small unnamed plaza between dormitories and student canteen, which emphasize the significance of this kind of uses of space on campus.

Like many other inner-city campuses, the university campus in Novi Sad is prevailingly a monofunctional zone, compensating this disadvantage by its favorable location and the proximity of the city center. It is placed very close to the traditional urban core, where cultural and leisure activities are concentrated, while on the other side it is bordered by the river embankment, which is the favorite recreational path for the citizens. Because of the high concentration of primary uses in the campus and lack of secondary at the same time, the university imposes a strong influence on the surrounding urban neighborhood, especially on territory of Mali Liman, around the axis that connects the campus and the old city center – Stražilovska Street and along Boulevard cara Lazara, which is one of the main traffic arteries and the edge of the campus. In the past, old railway tracks stretched here dividing central urban tissue from the undeveloped area, later founded as the university campus. The relocation of the railway enabled the more intensive spread of the city toward the south and opened the opportunity to connect the campus with the city center. Although tracing of the new boulevard (Boulevard cara Lazara) resulted in high traffic load and the creation of a new kind of a barrier between the university and the city, this new axis also enabled the flourish of commercial premises on the ground floors of buildings facing the campus, substituting, in a way, mixed-uses shortage on campus itself. These primarily include cafés, small shops, stationary stores, restaurants, etc. Similar situation is seen in Stražilovska Street, once mainly built up with low-rise houses, and today being a hectic mixed-use corridor with various kinds of businesses (Figure 2). The intersection of these two streets is also the busiest entrance to the campus, crowded with people coming by bus or on foot, which are the most common modes of transportation among the student population.

Figure 2. *Left: View of Stražilovska Street and the University in Novi Sad (1968) (source: http://vgis.nsurbanizam.rs/gis/fotoarhiva/). Right: View of Stražilovska Street (2020) (source: authors)*

Even though the campus has an inner-city location, morphologically it is more of a greenfield type, with freestanding structures surrounded by green areas creating pleasant microclimatic conditions. Nowadays, the university complex is almost fully completed as a whole, but the open plan of the university grounds offers some spaces still to be built. There are also some older structures which can be demolished and replaced by new ones with larger volumes and capacities, in order to fulfill ever-rising demands for space enlargement of contemporary educational and scientific activities as well as development plans of the University of Novi Sad.

The western outskirt of the campus was the construction site for the past few years, where the new building of the Science-Technology Park is erected as a joint project of the governments of the Republic of Serbia and Autonomous Province of Vojvodina (APV). The program itself reflects a fairly new process of expansion of the socio-economic mission of higher education through the clustering of research and technology-based organizations on or near a university campus **Invalid source specified.**. Science and technology parks are real-estate developments in which land and buildings are used to house public and private R&D facilities, high-technology and science-based companies, and support services. Inner-city universities have begun to apply the research park concept not only to provide needed R&D space for academics and their industry collaborators but also to stimulate the redevelopment of surrounding neighborhoods. The building within the campus of the University of Novi Sad with a total of 30.000 square meters will be used by the Faculty of Technical Sciences, start-ups and IT companies, and scientific institutes founded by the Government of APV. Its importance is multifaceted, primarily in the domain of the university-industry linkage. The building is located at the junction of the Boulevard cara Lazara and Fruškogorska Street, which form the south-west edge of the campus. It is assessed that the position and the program of the building have the potential to represent a new landmark of the university campus and to act as a strong and direct link between the campus and the city **Invalid source specified.**. The future introduction of the start-ups and IT companies on campus is expected to contribute to the functional diversity through mixed-use campus expansion, together with the diversification of the users.

5. HOW TO STRENGTHEN THE ROLE OF THE CAMPUS IN THE SYSTEM OF CENTERS IN NOVI SAD?

Given that the university can be considered one of the major factors of urban infrastructure, its implications are obvious because it occupies an important social and economic space within the dynamics of the city. In other words, universities have an effect by the mere fact of their presence **Invalid source specified.**. Taking into account the high mobility of the academic population and the fact that in Novi Sad a large majority of students live outside the campus, they play a significant role in the dynamics of urban life. Practical recognition of this fact is confirmed by the recent implementation of a new line of public transport that passes directly through the campus. This improved the connections between the university and distant parts of the city, but further steps have to be made in order to diminish the negative effects of motorized traffic on campus.

Bordering zone linking the university and the neighborhood north to the campus, called Mali Liman, is of special importance and indicates that the holistic approach is needed in the creation of balanced relationships between the university and the city. Contact zones, where university meets the city are essential parts where the synergy between two entities could be developed. In other words, even though this is a prevailingly residential zone, because of the proximity of university and other important programs such as the business and sports center (SPENS) and the court, accompanying uses emerge. Nowadays the only large lot near the campus suitable for new construction is the neglected area north of the university park. This area could be developed having in mind spatial closeness of the university, especially since many companies specializing in innovative research and production choose to settle in and around universities in order to profit from the proximity of scientific research and resources **Invalid source specified.**. Proper integration in those edge areas in terms of programs and spatial links as well, should be among priorities regarding that Boulevard cara Lazara with high traffic intensity creates a barrier and an obstacle in connecting campus with the surrounding urban tissue.

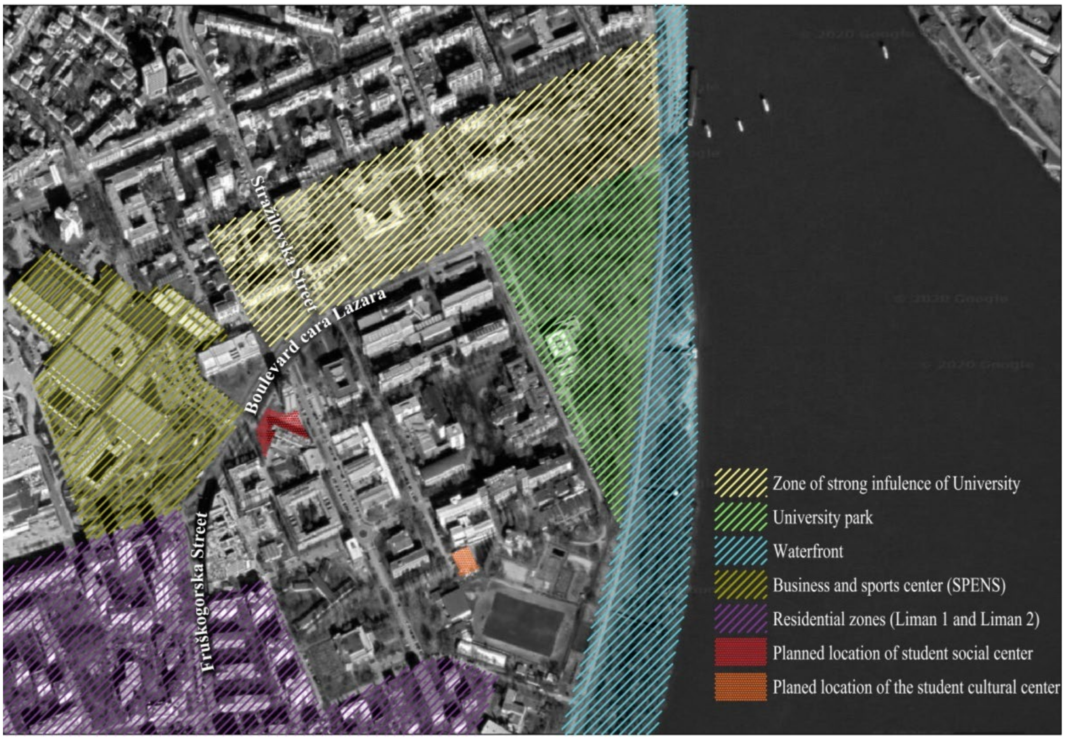


Figure 3. *Surrounding of the university campus*

To a lesser extent, the influence of the proximity of the university is also visible west and south of the campus in residential zones of Liman 1 and Liman 2. A great opportunity could also be achieved by better integration of the campus and the waterfront since the nearness of the river is currently not exploited. Despite the fact that the campus is located on the very bank on the Danube River, its link to the embankment does not exist. Walking path along the Danube attracts a large number of people during the day and especially in the summer evenings and for the last few years it became a place for a gathering of youth. Landscaping of the park, as a contact zone, would improve conditions for students, and other citizens of Novi Sad – better connection between the river bank and the campus would mean better city-river connection, too.

The important aspect of making the campus more inviting to the wider population of citizens is diversification of functions. Majority of campuses in North America with their concert halls, museums, sports stadiums, landscaped grounds, and busy calendar of events, operate as a hub of activities that serves not only students and staff, but the larger population of a town and region, being both an environment for learning and a public space **Invalid source specified.**. The introduction of similar programs on the university campus in Novi Sad would enrich the academic and civic life, at the same time. It would enable a longer period of activity and more rational usage of buildings and open spaces among students and citizens as well, but considering a lack of space for new construction, this is feasible only to a certain extent. The realization of additional staff housing and a student social center with a restaurant adjacent to existing structures, as envisioned by the Plan of detailed regulation **Invalid source specified.**, could create a new social core of the campus and additionally strengthen the role of the plaza between dormitories. This could contribute to community building among students, and at the same time attract other young people. On the other hand, the planned position of the student cultural center, which is a program that should be open to the general public, not only to students, is secluded from other non-academic functions. This raises a question of better integration of programs in the campus itself with the intention to strengthen the recognition of the university grounds among the wider community, which could also lead to the reinforcement of its competitiveness among other higher education institutions through the improvement of students' everyday experiences. Public spaces may not be the most important, but certainly are a relevant factor when it comes to creating the general image of the University and making it more student-friendly. Open spaces inside the campus are public spaces, and, as such, are open for all the citizens – students and others alike. Regarding obstacles, in terms of little vacant spaces for building on campus and around it, the focus should be on the improvement of the existing open spaces, especially in terms of their landscaping, which is a potential that has not yet been fully exploited.

6. CONCLUSIONS

Having in mind the general significance of the higher education institutions and specific circumstances of the University of Novi Sad and the location of its campus within the city, we could conclude that the university campus should gain more attention in the range of specialized centers. As one of the accelerators of urban dynamics of the city, and especially in the neighboring areas, the campus gives rise to the opportunity of the emergence of accompanying uses in spaces that surround it. A lack of space for all necessary structures on campus has caused the flourish of commercial services in the vicinity. A high density of activities in those zones, coexisting with the university campus, strengthens its role in the system of centers in Novi Sad. Further steps should be directed toward reinforcement of connections between campus and its surroundings, but also toward better integration within the campus itself. The addition of new amenities and high-quality public spaces on campus and in the contact zones of the surrounding neighborhoods would contribute to the idea of policentricity of the city of Novi Sad. This could create a new network of well-used structures – buildings and open spaces alike – and create a vivid center that would reflect both dimensions of policentricity: a morphological and a more “functional” one **Invalid source specified.**. From the morphological perspective, it would represent a space of concentration of mixed land uses and employment, while its functional dimension would supply the rest of the city with new functions, diverse programs and flows that could shape the territorial hierarchies in a more sustainable and citizen-friendly way. Enhancement of the relations between the city and the campus would also emphasize the importance of the University as an institution and improve students' everyday life. Together with the highest standard of education, this could develop the identity, recognition, and competitiveness of the University of Novi Sad as a good environment for studying and student life.

ACKNOWLEDGMENT

The paper was done within the project “Optimization of architectural and urban planning and design in function of sustainable development in Serbia” (TR36042), funded by the Ministry of Education and Science, Republic of Serbia.

LITERATURE

[1] M. Fernandez-Esquinas and H. Pinto, "The Role of Universities in Urban Regeneration: Reframing the Analytical Approach," European Planning Studies Vol. 22, No. 7,, p. 1462–1483, 2014.

[2] J. Le Goff, Intelektualci u srednjem veku, Zagreb: Grafički zavod Hrvatske, 1982.

[3] D. Bok, Beyond the Ivory Tower: Social Responsibilities of the Modern University, Cambridge, MA: Harvard University Press, 1982.

[4] K. Hoeger, "Campus and the City - A Joint Venture?," in Campus and the City - Urban Design for the Knowledge Society, gta Verlag, 2007, pp. 13-22.

[5] J.-P. D. Addie, R. Keil and K. Olds, "Beyond Town and Gown: Universities, Territoriality and the Mobilization of New Urban Structures in Canada," Territory, Politics, Governance, pp. 27-50, 2015.

[6] D. Bok, Univerzitet na tržištu, Beograd: Clio, 2005.

[7] F. Curvelo Magdaniel, "The university campus and its urban development in the context of the knowledge economy," 2013. [Online].

[8] M. P. O’Mara, "Beyond town and gown: university economic engagement and the legacy of the urban crisis," J Technol Transf, p. 234–250, 2012.

[9] S. M. Gavazzi, M. Fox and J. Martin, "Understanding Campus and Community Relationships through Marriage and Family Metaphors: A Town-Gown Typology," Innovative Higher Education, p. 361–374, 2014.

[10] J. Gehl and L. Gemzoe, Public Space - Public Life, Copenhagen: The Danish Architectural Press, 1996.

[11] R. V. Oplakanskaia, L. A. Osmuk, A. Pogorelskaya and I. Pomorina, "Post-industrial university towns and the triple helix concept: case studies of Bristol, Sheffield, Novosibirsk and Tomsk," Bulletin of Geography. Socio-economic Series, pp. 39-46, 2019.

[12] M. Carević Tomić, M. Kostreš and D. Reba, "Primary and Secondary Uses in Cities – Principles, Patterns and Interdependence," in International Academic Conference on Places and Technologies, Belgrade, 2018.

[13] Generalni plan grada Novog Sada do 2021. godine, Novi Sad, 2006.

[14] A. Milinković, "Reperne i Žižne tačke kao elementi fizičke strukture vojvođanskih naselja", doktorska disertacija, Fakultet tehničkih nauka, Novi Sad, 2019.

[15] UNS, "Osnovne informacija," 2020. [Online]. Available: http://www.uns.ac.rs/index.php/univerzitet/c-o-univerzitetu/informacije. [Accessed 14 02 2020].

[16] A. Link and J. Scott, "Geographic Proximity and Science Parks".UNCG Economics Working Papers No 18-4, University of North Carolina at Greensboro, Department of Economics.

[17] J. Bugarski Vujović and M. Carević, "Creating sustainable university through development of a science technology park," in INDIS 2012 Scientific conference on planning, design, construction and building renewal, Novi Sad, 2012.

[18] B. Gumprecht, "The campus as a public space in the American college town," Journal of Historical Geography 33 (2007, pp. 72-103, 2005.

[19] Plan detaljne regulacije Univerzitetskog kompleksa u Novom Sadu, 2017.

[20] M. Brezzi and P. Veneri, "Assessing Polycentric Urban Systems in the OECD: Country, Regional and Metropolitan Perspectives," European Planning Studies, vol. 23, no. 6, p. 1128–1145, 2015.

43 | Professional paper | Стручни рад
ISSN 2566-4484 | Doi 10.7251/STP2014460S
pages 460-471

Ljiljana Stošić Mihajlović, stosicmihajlovicljiljana@gmail.com, Academy of Technical and Educational Studies, Niš

STRATEGY FOR THE DEVELOPMENT OF 'SMART' CITIES WITH A LOOK AT THE REPUBLIC OF SERBIA

Abstract:

Cities are the main pillars of human and economic activities and have the capacity to create positive synergies that create opportunities for development for their residents. However, they also generate a large range of problems that are increasingly complex and more difficult to solve as the city grows. The "smart" city is a newer concept introduced into urban theory, and is increasingly the subject of analysis in scientific and professional circles. For the city to be "smart", it needs a cultural transformation, and for the vision to become a reality, it is necessary to have a unique strategy that will unite all individual efforts and ensure the sustainability of the whole concept, otherwise individual smart projects will only be lonely sparks.

Keywords: Smart city, urbanization, development strategy

СТРАТЕГИЈА РАЗВОЈА „ПАМЕТНИХ“ ГРАДОВА СА ОСВРТОМ НА РЕПУБЛИКУ СРБИЈУ

Сажетак:

Градови су главни стубови људских и привредних активности и имају капацитет да створе позитивну синергију која ствара могућност развоја својим становницима. Међутим, они такође генеришу велики дијапазон проблема који су све комплекснији и све теже могу бити решени како град расте. „Паметни“ град је новији концепт који је уведен у урбану теорију, и све више је предмет анализе у научним и стручним круговима. Да би град био „паметан“, потребан је културолошки преображај, а да би визија постала стварност, неопходно је да постоји јединствена стратегија која ће објединити сва појединачна настојања и осигурати одрживост целокупног концепта, у противном ће појединачни паметни пројекти бити тек усамљене искре.

Кључне ријечи: Паметни град, урбанизација, стратегија развоја

1. УВОД

Нема нити једног универзалног оквира по којем се може дати дефиниција појма „паметни град“. Ипак, према својим карактериситкама „паметан“ град је високо технолошки интензиван и напредан град који повезује људе, информације и градске елементе помоћу нових технологија како би се створио одржив, зеленији град, конкурентна и иновативна трговина, и повећан квалитет живота становника. [1]

Једна од дефиниција паметног града потенцира да је "Паметан град јесте град који има успешних шест карактеристика (економија, становништво, власт (управа), мобилност, средина и услови живота), изгранен на паметној комбинацији подстицаја и активности одлучних, независних и самосвесних гранана. Међутим, израз паметан град се не користи у холистичком смислу, али се у већини случајева наглашавају специфичне карактеристике различитих поља урбаног развоја, па чак и свест и партиципација гранана о специјалним питањима урбаног развоја. У складу са поменутим, паметно указује на имплицитну или експлицитну амбицију или намеру да се побољшају перформансе које се тичу специфичних карактеристика урбаног развоја." [2]

Од око 260 милиона Европљана, који живе у градским регионима са више од 100.000 становника (према подацима пројекта Еспон 1.4.3, 2006), 20% живи у градским регионима са преко 2,5 милиона људи, док готово половина (око 44%) свих урбаних становника живи у градским регионима са мање од 500.000 становника. [3] Ова последња категорија градова, може се сматрати градовима "средње величине" на европској скали док у домаћим оквирима, осим Београда, сва остала насеља са статусом града у ствари могу да се сврстају у градове средње величине.

Капело (Capello) и Камањи (Camagni) у прилог градова средње величине наводе следеће: "Постоје разлози за оправдану претпоставку да градови средње величине имају специфични потенцијал у конкуренцији са већим градовима. На првом месту, агломерација има недостатке као што је гужва у саобраћају, високе цене некретнина, социјална сегрегација, криминал и заганење животне средине, који имају тенденцију прогресије са увећањем величине града, што наводи на закључак да се наведене појаве лакше контролишу у градовима средње величине. На другом месту, величина града као таква није довољно добро објашњење за конкурентну позицију града. У реалном свету, величина града не одренује увек и функцију коју тај град има. Постоје примери мањих градова у којима су утемељене специфичне специјализоване функције које се нормално могу наћи у великим градовима. Изгледа да просторна организација града фундаментално утиче на његову ефикасност, раст, продуктивност, а понекад и на специјализацију." [4]

Градови средње величине се сусрећу са различитим изазовима развоја. Према документима ЕУ који се баве овом проблематиком, а и према Стратегији просторног развоја Републике Србије (СПРРС), поменути градови би требало да буду "мотори развоја" региона, па самим тим и државе којој припадају. Иако при помињању развоја, већина теоретичара и лаика помисли на економске параметре, социолошко тумачење је подједнако важно. Један од основних принципа европске територијалне Агенде јесте принцип територијалне кохезије, која је описана и у Стратегији просторног развоја Републике Србије: територијалну кохезију би требало посматрати као резултат активирања територијалног капитала. [5]

Конкурентни урбани развој, менутим, изгледа да није само производ ефеката агломерације. Други фактори попут историјског искуства, вероватније је да на много ефикаснији начин одређују могућности за конкурентност и одрживи развој у будућности. Наредни чиниоци јесу паметне технологије Internet-of-Things(IoT), вештачка интелигенција, друштвени медији, нови и обновљиви извори енергије многе друге повезане нове технологије.

Осим тога, термини који се често помињу у описивању појма социјалне кохезије су јачина социјалних веза и односа, дељење заједничких вредности, осећај заједничког идентитета и припадања истој заједници, поверење мену члановима заједнице, као и екстензивност економских и просторних неједнакости. Канадски истраживачи су идентификовали пет димензија овог појма: припадништво (belonging), инклузија, партиципација, признавање (recognition), легитимност. [6]

Према савременом поимању града, може се рећи и да је град "инкубатор културе, иновација, спремиште научних и уметничких достигнућа, центар стратешког одлучивања и мотор економског развоја". [7]

Сваки град има неку својственост [8], креативност, специфичност - градови су специфични друштвени ентитети чије се основне карактеристике рефлектују у простору и делимично бивају одренене просторним структурама. Простор је друштвено произведен/ социјално обликован, али је истовремено и "историјски реалитет који је подложан променама зависно од одредница поменутог реалитета". [9]

У Србији, нема још увек "паметних" градова у пуном смислу овог концепта, али има зачетака или потенцијала за развој. Наиме, у Републици Србији данас постоје 24 града, од чега се сем Београда, три града издвајају као градови који се могу сврстати у веће градове средње величине - Ниш, Нови Сад и Крагујевац, али који се дефинитивно у великој мери разликују од преосталих градова и општина, који би, посматрано на нивоу целе државе, заиста спадали у категорију средњих градова. Поменута три града, таконе, предњаче у развоју и у величини. Менутим, позиција свих градова у Србији сем главног града је подложна променама. Како Нови Сад, Ниш и Крагујевац теже да достигну Београд или барем цифру од 500.000 становника, тако и остали градови теже да остваре своје специфичности како би били конкурентни управо у односу на поменута три града. Такође, политика многих великих градова у свету данас је да смањи притисак становништва у својој урбаној метрополи или агломерацији, док се у Србији још увек недовољно ради на спречавању ширења београдског метрополитенског подручја и равномерном развоју других градова. Овде је настављена "урбоцентрична политика" бивше СФРЈ, која води даљој централизацији од стране државе, београдизацији и неравномерном развоју других градова и региона. [10] Да је наведено стање потребно мењати сведоче и Стратегија просторног развоја РС 2009-2013-2020 и Закон о регионалном развоју из 2010. године, који афирмишу принципе на којима почива једна "паметна" регионализација и просторна организација државе: субсидијарност, полицентризам, децентрализација, равномернији развој, развој средњих градова као "мотора развоја"

2. УРБАНА ПОЛИТИКА И СТРАТЕГИЈА РАЗВОЈА „ПАМЕТНИХ“ ГРАДОВА

Урбана политика је неизоставни елемент целокупног концепта који је предмет овог рада, дефинисана је као збир интереса оних који креирају или утичу на политику једног града, затим самих актера, као и њихових акција. Урбана политика се, као и политика генерално, реализује на три нивоа: глобалном, регионалном и локалном. Овај »политички ланац« је природно стање сваког друштва, али је његово функционисање, менутим, резултат низа специфичних околности, а пре свега генералног друштвеног профила и степена друштвеног развоја једне средине. [11]

Уопште узев, урбана политика се може посматрати из два правца: теоријског и емпиријског. У овом раду је нагласак на оба аспекта, а емпиријски представља утврђивање начина за боље функционисање локалне средине на свакодневној бази. У градовима то подразумева испитивање услова и начина функционисања друштвеног живота у свим његовим сегментима, тј. испитивање урбаног карактера. Важан одговор на урбану загонетку је однос три сегмента: урбане моћи (ко има моћ), интереса гранана и интереса политике која је на власти [11]

На пример, Мајкл Голдсмит (Michael Goldsmith) указује на неке проблем управљања у великим урбаним подручјима. Може се рећи да се ти проблеми, као и стратегије функционисања таквих система, могу видети и у мањим срединама. Стога, указивање на Голдсмитову анализу може појаснити концепт модерног управљања локалном заједницом. Према Голдсмиту, метрополитенска подручја функционишу најбоље по принципу децентрализације. Наиме, упркос општем тренду светског управљања многе функције, које треба да обавља државна власт, се преносе на широк спектар јавних тела, која у сарадњи са приватним сектором, стварају предуслов за успешну имплементацију урбане политике. [12]

Први корак према постанку паметног града предузет је на стратешком нивоу а главна подручја деловања у том контексту су енергија, мобилност, окружење, привреда, друштво, политика, управа и квалитет живота. Ова подручја су испреплетена и све више умрежена уз подршку ИТ-а. При томе, Техничке, економске и социјалне иновације пружџају основу за такве активности. Паметни градови граде се на принципима одрживости, али и на отпорности у смислу да су такви градови отпорнији и прилагодљиви утицајима који долазе како изнутра тако и споља. [13] Паметни градови имају високу продуктивност јер имају релативно висок удео високообразовани људи, у свом пословању интензивно се користе знањем, оријентисани су на систем планирања, креативне активности и иницијативе усмерене на одрживост. Коначни циљ паметног града је да пружити нови приступ урбаном управљању у коме се сви аспекти третирају повезивањем које се одвија у стварном животу града. Побољшање само једног дела урбаног екосистема значи да се проблеми целине решавају. Комплексни проблеми урбанизације, који су истовремено инфраструктурни, социјални и институционални, све су то разлози због којег се стратегије развијају у смеру паметног града јер тај концепт подразумева свеобухватан приступ управљању и развоју града. Он ствара равнотежу технолошких, економских и друштвених фактора укључених у урбани екосистем. [14]

Појам "паметан град" такође се користи у литератури у контексту разматрања образовања становника. Паметан град има паметне становнике у смислу њихове образовне оцене. Интелигентни системи представљају важан део будућег образовног процеса. Интелигентни системи утичи на начин на који корисници примају, користе, разумеју и размењују научне информације. Ако се становници образују, онда се предпоставља да ће знати да раде на развоју града, а при томе ће имати у виду границе природних ресурса. Интелигентни образовни систем темељи се на три елемента: међусобно повезивање (образовање технологије дељења ресурса), инструментализација (акумулација потребних података) и интелигенција (доношење одлука које побољшавају процес учења). [15]

Концепт паметног града често се сужава на паметну употребу и коришћење информационе и комуникационе технологије. Шири концепт паметног града обухвата више компоненти и у вези је са интегративним приступом побољшању ефикасности свих градских функција, квалитета живота грађана и раста локалное привреде. Развој стратегије обухвата различита подручја и активности: индустрију и производњу роба и услуга, образовање, партиципацију и учешће грађана, техничку инфраструктуру, разноврсне “софт чиниоце”. [16] Развој стратегије паметних градова повезује се са следећим елементима: [17]

- снажно увођење ИКТ технологије у све поре пословних и приватних процеса
- примена тзв. паметне мреже у којој су на интелигентан и енергетски ефикасан начин повезани сви елементи тог сложеног система
- интернетско повезивање свих објеката (Internet of Things – IoT) применом M2M (Machine to Machine) комуникација
- смањење загађења околине увођењем интелигентних транспортних система
- повећање енергетске ефикасности применом тзв. паметног мерења, али и увођењем иновативних решења у грађевинарству.

3. КОРАЦИ У РАЗВОЈУ СТРАТЕГИЈЕ ПАМЕТНОГ ГРАДА

На темељу искуства оних земаља које су имплементирале паметне градове, у целом свету, не само у Европи, могу да се идентификују три различита корака или нивоа: [18]

Први ниво или корак ка паметном граду утемељен је на физиĉкој телекомуникационој мрежној инфраструктури, која се састоји од бежичне мреже, заједно са свим смерницама потребним за управљање инфраструктуром;

Други корак представљају апликације које олакшавају пословање у граду, попут контроле трговине и промета итд. Такве апликације ће обезбедити многи добављачи, користећи предвиђену инфраструктуру;

Трећи корак је заснован на свеприсутности или повезаности свих.

Паметни град као концепт који је намјењен побољшању квалитета живота грађана стекао је све већи утиецај код креирања урбане политике на дуге стазе. Међутим, не постоји заједничка дефиниција паметног града и тешко је идентификовати заједниĉке универзалне трендове. С огромним бројем међусобно повезаних грађана, предузећа и различитих превозних средстава, комуникационих мрежа, услуга и комуналних услуга, градови постају сложенији него икад пре. [19]

То доводи до раста становништва с урбанизацијом, што такође повећава разноликост и усложњава проблеме, као што су технички, социјални, економски и и организациони. Са друге стране, потреба за одрживијим градом расте.

4. КАРАКТЕРИСТИКЕ ПАМЕТНОГ ГРАДА

Паметни градови су дугорочни, прогресивни и са ефикасним ресурсима, тако да пружају истовремено и висок квалитет живота становника. Они примењују друштвене и технолошке иновације и повезују постојеће инфраструцтуре; затим, уграђују нове енергетске, трговинске, транспортне концепте који утичу на околину. Њихов фокус је на новим облицима управљања и учешћи јавности. Интелигентне одлуке се предузимају на стратешком нивоу, ако град жели да постане паметан. Потребно је више од појединачних пројеката, али и пажљивих одлука са дугорочном имплементацијом. Њихов циљ је да се осигура конкурентност економије и квалитет живота за градске популације, уз обезбеђење континуираног развоја.

Пројект који спроводи Центар регионалних наука на Техничком факултету у Бечу препознаје шест главних "оса" (димензија) на којима је спроведено рангирање 70 европских градова средње величине. Те осе/димензије су: паметна економија, паметна мобилност, паметна околина, паметни људи, паметно живљење и паметно управљање. Ових шест оса повезују се с традиционалним регионалним и неокласичним теоријама урбаног раста и развоја. Посебно се димензије заснивају у односу на теорије регионалне конкурентности, трговине и ИЦТ економије, природних ресурса, људског и друштвеног капитала, квалитета живота и учешћа чланова друштва у градовима.

Табела 1. Димензије паметног града

Димензије паметног града	Повезани аспект урбаног ţивота
паметно господарство паметни људи паметно управљање паметна мобилност паметно окруţење паметно ţивљење	индустрија образовање е-демократија логистика и инфраструктура уĉинковитост и одрţивост сигурност и квалитета

Извор: Pardo, T., & Taewoo, N. Conceptualizing smart city with dimensions of technology, people, and institutions. Proceedings of the 12th Annual International Conference on Digital Government Research, ACM, New York, 2011., p. 282–291 [20]

Рангирање градова ће бити уранено према Гифингеровој методологији на основу шест димензија "паметних" градова - квантитативна анализа. Концепт "паметног града", као што је већ напоменуто, идентификује шест карактеристика за које се сматра да су релевантне за паметан град: економија, становништво, власт (управа), мобилност, средина и услови живота. Према Гифингеровој методологији, ових 6 карактеристика је представљено 31 релевантним фактором (табела 2), који рефлектују најважније аспекте сваке од паметних карактеристика. На крају, сваки фактор паметне карактеристике је емпиријски дефинисан групом одговарајућих индикатора, при чему је дефинисано укупно 74 индикатора, који су потом употребљени за операционализацију.

Табела 2. Опис карактеристика и фактора паметног града (Giffinger, 2010:14)[2]

ПАМЕТНА ЕКОНОМИЈА (конкурентност)	ПАМЕТНИ ЉУДИ (социјални и хумани капитал).
- Иновативни дух - Предузетништво - Економски имиџ и заштитни знак (бренд) - Продуктивност - Флексибилност тржишта рада - Интернационална укорењеност - Способност трансформације	Степен квалификације - Афинитет ка доживотном учењу - Друштвени и етнички плуралитет - Флексибилност - Креативност - Космополитизам/отвореност (ширина) - Учешће у јавном животу
ПАМЕТНО УПРАВЉАЊЕ (партиципација)	ПАМЕТНА МОБИЛНОСТ (транспорт и ИТ сектор)
- Партиципација у доношењу одлука - Јавни и друштвени сервиси - Транспарентно управљање - Политичке стратегије и перспецтиве	- Локална приступачност - (Интер-)национална приступачност - Доступност ИТ инфраструктуре -Одрживи, иновативни и безбедносни транспортни систем
ПАМЕТНА ОКОЛИНА (природни ресурси)	ПАМЕТАН ЖИВОТ (квалитет живота)
- Природни услови - Загађеност - Заштита животне средине - Одрживи менаџмент ресурса	- Културне установе - Здравствени услови - Индивидуална безбедност - Квалитет становања - Установе образовања

Пет социјалних поља је од битног значаја за економски и социјални развој индивидуе и квалитет њеног живота", то јест, за постизање социјалне кохезије одренене области. "То су:

- образовање,
- здравствена заштита,
- социјална заштита,
- рањивост/осетљивост друштвене групе, и
- становање.

У сваком социјалном пољу дефинисане су димензије, односно сегменти/области, за које се утврнују индикатори на основу којих се процењује степен остварености одрененог права или потреба становиштва, односно одрененог функционалног, старосног или полног контингента" (СПРРС, 2007:124).[5]

Перцепција технологије у паметним градским иницијативама наглашава интеграцију система, инфраструктуру и услугу посредовања технологијама које омогућују већи квалитет живота. Технолошке иновације су средство за паметан град, а не крај. ИТ је само фацилитатор за стварање нове врсте иновативног окружења, што захтиева свеобухватан и уравнотежен развој креативних вештина, иновативних институција, широкопојасних мрежа и виртуелних сарадничких простора. [21]

5. ПРИМЕРИ ПАМЕТНИХ ГРАДОВА

У Европи, Беч се може назвати паметним градом. Паметна решења у свакодневном животу чине Беч градом са највећим квалитетом живота у свету. Беч је идеално место за живот и рад. Град расте, а паралелно са њим расту и његове могућности. Раст је утемељен на неколико снажних полуга, почевши од градске структуре предузећа и образовног сектора и укључујући нетакнуто окружење и довољно зелених површина. На међународном нивоу, Беч даје велике резултате са својом мрежом јавног превоза, опсежним социјално стамбеним активностима и социјалним услугама које су доступне и приступачне за све. Велика иницијатива Смарт Циту Беч покренута је 2011. године под вођством градоначелника Мицхаела Хäупла. На основу широког процеса, много учесника и многобројних приступа изведених из различитих подручја деловања Беча и Градске управе, започео је развој ове стратегије 2013. године. Све групе извршне политике као и бројни стручњаци су томе придонели и пружили свој допринос. Истовремено, постоји интензивна размена искуства с другим европским градовима који исто тако настоје да иду у смјеру постизања паметних циљева града.

Беч као паметни град чине следеће ставке:

- Грађевинска стамбена изградња - општинска и непрофитна –произведено је више од 400.000 висококвалитетних станова у целом граду. То значајно доприноси доброј друштвеној мешавини и приступачним трошковима становања за све.
- Јавни превоз је врло развијен и омогућује брзо стизање до свих делова града. Јефтине цене и изврсна поузданост и квалитет омогућавају и висок ниво прихватања од стране корисника услуга.
- Вода у Беу је је врхунског квалитета за метрополу. Изванредна сигурност снабдевања и висока ефикасност дистрибуције воде за пиће су исходи напорног рада и одрживих улагања коју је Град Беч израдио пред већ више од једног века. Годишње се у Бечу улаже 30 милиона еура у водоводне мреже.
- Уређаји за одлагање отпада града, укључујући прочишћавање отпадних вода, поступање с отпадом, одвајање отпада или когенерација, тј. комбиновано спаљивање отпада и производња топлоте су модели добре праксе многих других градова.
- Беч је густо насељени град – али истовремено успева да задржати свој удео зелених површина на 50%. Велике структурне одлуке као што је очување Бечких шума и стварање вештачких острва, јесте добра комбинација окружења са атрактивним могућностима за забаву, али и заштиту од поплава.

Приступ Бечу као паметном граду заснован је на дугорочној тенденцији овог града на спречавању коришћења ресурса како би се масовно смањиле емисије ЦО2 и смањила зависност у вези са оскудним или коначним ресурсима. Истовремено, развијање даље стратегије паметног града Беча, значи подстицај и даље повећање високог квалитета живота и друштвено учешће. На крају, Беч као паметни град, представља промену засновану на иновацијама, активној организацији и где је то потребно, развоју нових облика јавних и друштвених пружања услуга

Едмонтон је пример паметног града у Канади, и лидер је у коришћењу иновација за побољшање комуналних услуга, од јавне сигурности до јавних радова и транзита. Едмонтон, као „Смарт Циту", представља више од усвајања нових технологија и подстицања иновација. Заједно стварају и његују еластичну, живљиву и радну заједницу која се надовезује на изазове с којима се суочавају данас, пружају грађанима позитивно искуство и обухватају низ могућности у будућности. Године 2017. Едмонтонова „Open City" Иницијатива добила је Златну награду Градској категорији награда „WeGo Smart Sustainable City", која препознаје и промовише изванредне информације и комуникационе технологије, е-владу и иновације паметног града. Град је такође проглашен 2017. године, за интелигентну заједницу године коју додељује Форум интелигентне заједнице, делом због снажних односа с локалним предузећима и непрофитним организацијама.

Едмонтон је креативна заједница друштвених иноватора - где се грађани ангажују са својом заједницом и иду у смеру боље будућности. Град Едмонтон решава данашње изазове и ствара могућности за будућност кроз сарадњу грађана, индустрију, образовање и владу. Овај отворени екосистем пружа креативност, ангажман и партнерство, док иде у смеру интелигентне заједнице. Оно што чини Едмонтон паметних градом је:

- Ефикасно одлучивање, сарадња, смањење трошкова и еластичне јавне услуге
- Боља комуникацијска повезаност, побољшана социјална једнакост, повећана запосленост, бољи квалитет живота
- Промоција иновација, убрзање стварање и покретања знања и подстицање талената

Барселона, град у Шпанији, показала се изузетно ефикасном градском средином у паметном управљању захваљујући имплементацији технологије Internet of Things. На пример, технологија сензора имплементирана је у систем наводњавања у Parc del Centre de Poblenou, где се у реалном времену запослени преносе информације о количини воде која је потребна биљкама у парку. У Барселони је такођр пројектиована и нова аутобуска мрежа на основу анализе података о најчешћим саобраћајним токовима у Барцелони. Током 2018. године Барселона је спровела 22 главна програма и 83 засебна пројекта који тај град претварају у паметни град. Неки од њих су паметна расвета, паметни паркинг, паметно управљање водом, одрживо господарење отпадом.

Иако је технологија увек била у средишту модерних процеса, значајан напор је уложен у развој из фокуса е-владе на фокус паметних градова и жељу за јачањем Барселона као паметног града и као промотора нове економије градских услуга. Циљ је био да се Барселона промовише као битна референца за све градове који желе да преусмере своју привреду и да створе имиџ следећи ту парадигму. Smart City Expo и Свјетски конгрес, први пут одржани 2011. године, помогли су да се покренеи и промовисали су ову политику.

Барцелона се широм света рангира као водећи паметни град, са неколико студија које га рангирају међу најпаметнијим у Шпанији, Европи и на међународном нивоу. Поред тога, Европска комисија је у 2014. доделила награду Европски главни град иновација и награда "e-Capital" за увођење нових технологија како би се боље повезали грађани. Ово признање помогло је тако да је Барцелона проглашена "Мобилним светским капиталом" до 2023. године. У међувремену, Уједињене нације су успоставие своју међународуи канцеларију sa урбану еластичност у Барцелони, уз ИЕСЕ Business School, Центар изврсности за ЈПП (јавно-приватна партнерства) у Смарт градовима. Светска банка је такође идентификовала Барселону као средиште знања за истраживање коришћења ИКТ у управљању градом. [22]

6. СТАЊЕ У СРБИЈИ

За успешност једног града, кључни су, дакле, актери који њиме управљају, тзв. урбани менаџери (Петровић, 2009: 85) [23] Процесима у градовима управљају различити актери, од којих неки доиста управљају, док се други томе опиру, што говори о веома конфликтној природи урбане стварности. Идеја сарадње измену актера на основу потреба и/или интереса потиче од Мишела Басана (Michel Bassand): "Урбани развој проистиче из структуре моћи, што значи из система актера од којих су неки надренени а други подренени; заједно, они структуришу урбани феномен" [24](Басан, 2001: 351). Актери на основу поменутих интереса граде хоризонталне и вертикалне савезе.

Између политичара и привредника је најчешћи хоризонтални савез, који је карактеристичан за тзв. политички капитализам. Може се рећи да је Србија друштво у коме влада политички капитализам. Са друге стране, најчешћи вид савеза између грађана и политике је вертикални - однос хијерархије, вође и вођених, те као што је већ напоменуто, Србија је и бирократизована држава у којој влада слаба синергија измену државе и друштва.

Пошто урбани актери структуришу урбани феномен, то исто тако значи да су урбани актери и њихови сукоби од фундаменталне важности за развој града. У многим градовима, па и у пост-социјалистичким, можемо разликовати четири типа актера: стручњаке за простор - архитекте, урбанисте, инжењере, итд; економске актере - разна индустријска предузећа и сервисе, власнике градског земљишта, банке, и слично; политичке актере - политичке лидере, њихове партије, покрете, итд; становнике, кориснике/гранане, који се диференцирају према друштвеној позицији, животном стилу, старости, образовању, НВО, итд [25](Вујовић, 2004:153).

Европске интеграције, процес глобализације и слично, воде ка променама градског предузетништва у смислу утицаја како на мање градове, тако и на шире регионе у чијем су они саставу. Развојни проблеми Србије су:

- проблем екстремно неравномерног регионалног развоја,
- проблем веома слабе територијалне кохезије,
- проблем неискоришћеног, слабо коришћеног или погрешно коришћеног ТК и
- проблем конкурентности у заостајању [26] (Стојков, 2006:12-13).

Ово су све питања којима би требало да се приступа мултидисциплинарно, при чему урбанизам има свој угао посматрања. Србија и даље пролази кроз процес пост-социјалистичке трансформације и то на националном, регионалном и локалном нивоу. Трансформација пост-социјалистичких градова ка тржишном моделу условљава њихово истовремено суочавање са изазовима деконструкције социјалистичког града и регулационе трансформације капиталистичког урбаног система. На путу интеграције у глобалне мреже пост-социјалистички градови се суочавају са препрекама које их стављају у полу-периферијски положај. Наиме, такви градови могу бити од локалног и регионалног, али не и од глобалног значаја, јер им наслеђена подурбанизованост (примарност инвестиција у индустрију и тиме спорији раст инфраструктуре) умањује потребну конкурентност [23].

Као и велики део источне Европе, Србија није довољно урбанизована. "У Србији преовладава урбано-индустријски тип развојне структуре региона, који обухвата скоро 60% популације која живи на 1/4 укупне територије земље. Већи број насеља у овој категорији су у најмању руку креирала радна места која углавном служе становништву које ту живи. Друга карактеристика овог урбано-индустријског типа је богат спектар активности које су смештене измену градова и њихових одговарајућих предграна/окружења, и физичка трансформација насеља као резултат социјалног реструктурирања становништва. Присутан је јак демографски притисак на широко окружење градова и на квалитетна рурална подручја.

Урбанизација се раширила и на простор измену насеља, а карактерише је расипничко коришћење земљишта, уз нејасно дефинисане границе насеља, сиромашне комуналне инфраструктуре и имиџ проблематичног земљишта који је у контексту сиромашне регионалне организације и регионалног просторног планирања. Претходни полицентрични развој ишао је ка порасту улоге општинских центара што је често водило дуплирању активности и смањењу ефикасности коришћења земљишта. Уочена је тенденција оснивања нових, недовољно развијених општина као резултат постојећег система финансирања општина, уместо да се подупире, у складу са принципима одрживог развоја, оснивање таквих општина које би зависиле у што мањој мери од државних субвенција, а више од развоја самоиницијативности и повезаности" (СПРРС, 2007:186).

Степен урбанизованости у општинама у Србији је око 55%, а у Војводини нешто више. Наравно, кључни проблем је доминација Београда и још неколико већих градова, што је створило некохерентан и асиметричан урбани систем који није компатибилан са циљевима формирања европског урбаног система. [27]

Већи степен доступности инфраструктури, службама и информацијама свим становницима, усклaненост и одрживост социо-економског развоја, заустављени негативни демографски трендови и равномернији просторни размештај становништва у балансираном и полицентричном систему са посебном улогом градова и њихових функционалних подручја, означавају предуслове унапренења територијалне кохезије на регионалном и државном нивоу" (СПРРС, 2007:43).

У поменутој стратегији се инсистира на полицентризму као једном од основних принципа равномерног регионалног развоја Србије: "Полицентричност, као веома значајан критеријум за оцену реалних резултата успешности просторног развоја Србије, захтева доследно спровођење политике полицентризма односно подршке Републике јачању развојне улоге градова и мањих урбаних центара. Основни циљ је интеграција Србије у шире окружење и постизање одрживог развоја дефинисањем, подстицањем и усклађивањем модалитета међународне/регионалне сарадње и применом одредби међународних стратешких докумената..." (СПРРС, 2007:187, 189, 190).

Улога Града Београда и његовог метрополитенског подручја у том систему је доминантна имајући у виду његову величину, позицију, титулу главног града као и хумани, економски и културни потенцијал. Улога функционалних урбаних подручја међународног значаја коју имају Нови Сад и Ниш, као и функционалног урбаног подручја националног значаја коју има Крагујевац, је изузетна са становишта формирања развојне осовине на правцу север-југ, док уз то функционална урбана подручја Ужица и, у мањој мери, Зајечара имају регионални значај, отварајући перспективу развоја на западу и истоку Србије. Остали градови Србије, поред своје морфолошке распорености, имају потенцијал развојних центара активирањем и адекватном организацијом својих функционалних подручја, повезивањем са руралним окружењем, бољом дистрибуцијом економских и социјалних активности и одговарајућим повезивањем саобраћајном и другом техничком инфраструктуром, повећањем степена приступачности знању и информацијама и јачањем локалног и регионалног идентитета заснованог на културном и природном наслену, економској препознатљивости (бренд) и одликама биолошког и културног диверзитета" (СПРРС, 2009:50).

По питању развоја паметних градова, Србији стоји на располагању више опција, при чему би требало водити рачуна о оквиру поменутог европског концепта који се у последњих петнаестак година.

7. ЗАКЉУЧАК

Концепт паметног града користи се како би се истакла важност информационих и комуникационих технологија (ИКТ) задњих 20-так година. У литератури се појам паметан град користи за одређивање способности града да што брже одговори захтевима и потребама грађана. Квалитет живота и градског развоја дубоко су под утицајем основних система града, као што су: промет, државне службе, образовања, јавна сигурност заштита здравља. У литератури се истиче да се у вези са условима паметног града спомињу разни аспекти који се односе на побољшање живота у граду, као што су: превоз, образовање, јавна управа, здравствена заштита, сигурност, зелена, ефикасна и одржива, енергија.

Паметни град је развијено урбано подручје које ствара одрживи привредни развој и висок квалитет живота у више кључних подручја; привреди, мобилности, окружењу, свакодневном живљењу и владе. Напредак и развитак у овим кључним подручјима може се постићи јаким људским капиталом, друштвеним капиталом и/или ИЦТ инфраструктуром. Главна компонента која неки град чини паметним је укључивање информационе и комуникационе технологије у јавне службе. У паметном граду коришћење технолошких платформи мора бити лако доступно кроз различите уређаје, а везе морају бити брзе. Ефикасне јавне услуге су друга тачка у овом новом урбаном концепту. Одговарајуће управљање отпадом, једноставност рециклирања, управљање обновљивом енергијом, између осталог су минималне услуге с којима се мора рачунати да буду карактеристике паметног града. Заштита и сигурност грађана је још један важан аспект. У паметном граду кључни захтеви су везани са саобраћајем у граду, уличном расветом, интензивним праћењем и брзим одзивимаа за хитне позиве. Финансијска независност представља још један значајан чинилац. Паметни градови имају стратешко планирање свих својих извора прихода: порези, плаћања, градски буџет и имају друштвену инфраструктуру прилагођену њиховим захтевима. То значи да су њихове школе, болнице, рекреацијска подручја и комуникацијски путеви довољни и ефикасни. Планирање саобраћајног промета је, готово по дефиницији, још једна карактеристика ове врсте града. Ефикасна јавна превозна мрежа која смањује потрошњу енергије и омогућавање бициклистиčких стаза су међу параметрима које треба испунити. Стога се у паметним градовима смањује употреба приватног превоза. Када се говори о стратегији развоја паметног града, она се може посматрати с обзиром на подручја у којем сегменту се овакав град развија. Приступи стратегији с обзиром на елементе који чине град паметним су информацијско комуникацијска технологија, паметна мрежа, енергетска ефикасност, паметна мерила, интелигентни транспортни системи и саобраћајна инфраструктура и квалитет окружења. Приликом развоја стратегије паметног града важно је узети и обзир детаљне кораке које је потребно предузети како би се стратегија успешно имплементирала. Ти кораци морају да укључе анализу постојећег стања, а након тога, дефинисање визије и мисије одрживости града уз успостављање комуникацијске платформе. Циљеви одрживости града морају бити мерљиви, како би се идентификовали пројекти. Након тога следи израда инвестиционог плана и идентификација финансијских механизама и покретање пилот пројеката и размена искустава с другим градовима. На крају се пројект спроводи и врши се едукација грађана, затим следи праћење и евалуација резултата. Добар пример успешног развоја стратегије паметног града је град Беч у Аустрији. Овај град гради снажна партнерства кроз пројекте уз активно укључивање грађана. Иницијатива паметног града Беча покренута је 2011. године и до данас је постигла значајан напредак у развијању квалитета живота својих грађана. Тим путем овај град иде и даље и има развијену Оквирну стратегију која је дугорочна кровна стратегија за раздобље до 2050. и обухватаа сва подручја опшинске управе и урбану политику у Бечу. Едмонтон у Канади је још један добар пример паметног града. Према " Financial Times" има "најбољи економски потенцијал било којег града у Северној Америци". Његова инфраструктура, људски ресурси, економичност, високи стандарди живљења и забринутост за одрживо окружење препознају се кроз повољне позиције на страна директна улагања. Барселона као паметни град је један од најнапреднијих градова у смислу дигиталне трансформације. Искуство Градског већа у Барселони пружа важан увид и спознају о начину на који би паметна градска политика требала бити осмишљена и имплементирана.

ЛИТЕРАТУРА

[1] Bakıcı, T. E. Almirall, and J. Wareham(2012), “A Smart City Initiative: The Case of Barcelona,” Journal of the Knowledge Economy 2: 1 p. 1–14.

[2] Giffinger, R. and Haindlmaier, G. (2010), »Smart Cities Ranking: An Effective Instrument for the Positioning of Cities?«, *Architecture, City and Environment*, No 12, p.p. 7-25.

[3] *ESPON project 1.4.3*. (2006), »Study on Urban Functions«, First Interim Report.

[4] Capello R., Camagni R. P. (2000), »Beyond Optimal City Size: An Evaluation of Alternative Urban Growth Pattern«, *Urban Studies*, vol. 37, n°9, pp. 1479-1496.

[5] www.apps.org.rs/wpcontent/uploads/strategije/Strategija_PROSTORNI%20RAZVOJ%20Republike%20Srbije.pdf

[6] Berger-Schmitt, R. (2000), »Social Cohesion as an Aspect of the Quality of Societies: Concept and Measurment«, EU Reporting Working Paper, No.14.

[7] Стојков, Б. (2006), »Статус града, децентрализација и полицентричност Србије«, у: Дамјановић, Д. и Миленковић, Д. (ур.), У сусрет новом статусу градова у Србији реалност и потребе, ПАЛГО центар, Београд, стр.17

[8] Лефевр, А. (1980), »Теорија простора«, Трећи програм Радио Београда, бр. 45, ИИ, стр. 557-651.

[9] Чалдаровић, О. (1985), Урбана социологија - социјална теорија и урбано питање, Глобус, Загреб, стр. 193-217.

[10] Петовар, К. (2006), »О критеријумима дефиниције града«, у: Дамјановић, Д. и Миленковић, Д. (ур.), У сусрет новом статусу градова у Србији- реалност и потребе, ПАЛГО центар, Београд.

[11] Пушић, Љ. (2007), »Урбана политика«, у: Социолошки речник, Мимица, А. и Богдановић, М. (пр.), Завод за уџбенике и наставна средства, Београд.

[12] Goldsmith, M. (2001), »Urban Governance«, in: Paddison, R. (ed.), Handbook of Urban Studies, SAGE Publications, p.p. 325-335.

[13] Eremia, M., Toma, L., Sanduleac, M.(2016). The smart city concept in the 21 Century, 10th International Conference Interdisciplinarity in Engineering, INTER-ENG9

[14] Oberg, C. (2015). Smart cities: A literature review and business network approach discussion on the management of organisations, Emerald Publishing Limited, USA, p.44

[15] Pardo, T., & Taewoo, N. (2011). Conceptualizing smart city with dimensions of technology, people, and institutions. Proceedings of the 12th Annual International Conference on Digital Government Research, ACM, New York, 2011., p. 282–291

[16] Чаврак, В. (2018). Развој метрополских полицентричних регија и концепт паметног града,https://www.researchgate.net/publication/303413058_RAZVOJ_METROPOLSKIH_POLICENTRICNIH_REG IJA_I_KONCEPT_PAMETNOG_GRADA, (25.8..2018)

[17] Burazer, B. (2012). Normizacija u procesu kreiranja „pametnih gradova“, Zagreb: Hrvatski zavod za norme,str.1

[18] Caragliu, A., Del Bo, C., & Nijkamp, P. (2011). Smart cities in Europe. Journal of Urban Technology, 18:2, p.65–82.

[19] Neirotti, P., Marco, A., Cagliano, A., Mangano, G., & Scorrano, F. (2014). Current trends in Smart City initiatives: Some stylized facts. Elsevier.

[20] Pardo, T., & Taewoo, N. Conceptualizing smart city with dimensions of technology, people, and institutions. Proceedings of the 12th Annual International Conference on Digital Government Research, ACM, New York, 2011., p. 282–291

[21] Albino, V., Berardi, U., Dangelico, R.M. (2015).Smart cities: definitions, dimensions, and performance, Journal of Urban Technology, 2015, 22:1, p. 3-21

[22] Gascó-Hernandez, M (2018). Building a Smart City: Lessons from Barcelona, Communications of the ACM, April , Vol. 61 No. 4, p.53-54

[23] Петровић, М. (2009), Трансформација градова: ка деполитизацији урбаног питања, ИСИ ФФ, Београд.

[24] Басан, М. (2001), »За обнову урбане социологије - једанаест теза« (прев. Вујовић, С.), Социологија, Вол. ХЛИИИ, Но. 4.

[25] Вујовић, С. (2004), »Актери урбаних промена у Србији«, у: Аннелка Милић (ур.), Друштвена трансформација и стратегије друштвених група- свакодневица Србије на почетку трећег миленијума, ИСИ ФФ, Београд.

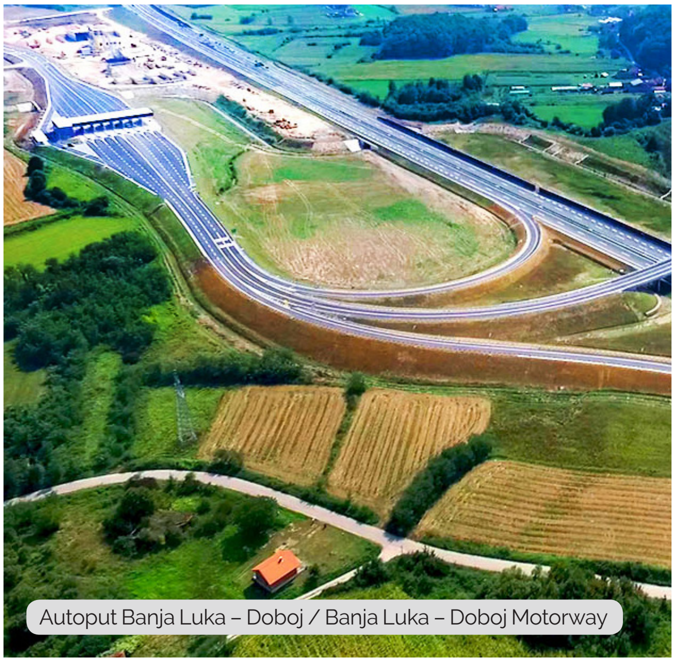
[26] Стојков, Б. (2006), »Статус града, децентрализација и полицентричност Србије«, у: Дамјановић, Д. и Миленковић, Д. (ур.), У сусрет новом статусу градова у Србијиреалност и потребе, ПАЛГО центар, Београд.

[27] Tošić, D. i Maksin- Mićić, M. (2009), »Functional Urban Regions as an Instrument for Balanced Development of the Republic of Serbia«, In: *Regional Development, Spatial Planing and Strategic Governance*, Institute of Architecture and Urban & Spatial Planing of Serbia, Belgrade, p.p. 155-178.

Sa ostvarenom ukupnim godišnim prihodom od 222,7 milion KM (113,8 milion evra) u 2019. godini Integral je najveća građevinska kompanija u Bosni i Hercegovini, te jedan od lidera u regionu.

Integral raspolaže sa modernom i fleksibilno koncipiranom mehanizacijom, koja uključuje više od 300 jedinica građevinske mehanizacije i stacionarne opreme.

U toku je puštanje u proizvodnju stacionarnog drobilišnog postrojenja za dijabaz u okolini Gradiške (Republika Srpska, Bosna i Hercegovina), čiji kapacitet je 170 t/h. Vrijednost investicije je više od 2 miliona evra.



Autoput Banja Luka – Doboj / Banja Luka – Doboj Motorway

Neki od najvažnijih projekata koje je izveo Integral inženjering:

» projektovanje i izgradnja autoputa Banja Luka - Doboj u dužini od 71,9 kilometara, dionice: Banja Luka (petlja Mahovljani) - Prnjavor i Prnjavor-Doboj (Johovac),
» projektovanje i izgradnja poddionice autoputa E75 (Koridor 10) u Republici Srbiji, koja se u dužini od 6,75 km, nalazi između Caričine doline i tunela Manajle,
» izgradnja autoputa E661, dionica: Gradiška – Banja Luka (petlja Mahovljani),
» trajno rješenje klizišta Čemerno na magistralnom putu M-20 Gacko-Foča,
» izgradnja kompleksa Vlade Republike Srpske i zgrada ministarstava u Vladi,
» izgradnja sjevernog i južnog kraka sistema za vodosnabdijevanje crnogorskog primorja.

With a total annual revenue of 222.7 million BAM (113.8 million €) in 2019, Integral inženjering is the largest construction company in Bosnia and Herzegovina, and one of the leaders in the region.

Integral inženjering has modern and flexibly selected machinery, which includes more than 300 units of construction machines and stationary equipment.

The commissioning of a stationary crushing plant for diabase in the vicinity of Gradiška (the Republic of Srpska, Bosnia and Herzegovina), with a capacity of 170 t / h, is in progress. The value of the investment is more than 2 million euros.

Some of the most important projects that Integral inženjering has completed:

» design and construction of Banja Luka-Doboj Motorway in total length L= 71,9 km, sections: Banja Luka (intersection Mahovljani)-Prnjavor and Prnjavor-Doboj (Johovac),
» design and construction of the subsection on the E75 Motorway (Corridor X) in Serbia - Grdelica Canyon,
» construction of the E661 Motorway, section: Gradiška – Banja Luka (intersection Mahovljani),
» permanent stabilization of Čemerno landslide on the trunk road M-20 Gacko-Foča,
» construction of the Government of the Republic of Srpska business premises
» construction of the northern and southern branch of the regional water supply system along the coast of Montenegro

Autoput na Koridoru 10 u Srbiji (Grdelička klisura)
Motorway on the Corridor 10 in Serbia (Grdelica Canyon)

Najvažniji aktuelni radovi Integral inženjeringa:

» projektovanje i izgradnja autoputa na Koridoru 5c, dionica: Johovac – Rudanka,
» izgradnja mosta preko rijeke Save (Gradiška), dionica: Okučani – granica Bosne i Hercegovine,
» iskop dovodnog tunela za hidroelektranu “Dabar” (Nevesinje) dužine 12,5 km,
» sanacija usjeka br.2, 3, 4 i 5 na dionici autoputa E-75 u Srbiji (Grdelica - Predejane),
» radovi pojačanog održavanja (rekonstrukcije) autoputa u Srbiji, dionica: Sremska Mitrovica – Ruma,
» radovi na rekonstrukciji postojećeg i izgradnji novog kolosjeka željezničke pruge u Hrvatskoj (Dugo Selo-Križevci) za projektovane brzine do 160 km.

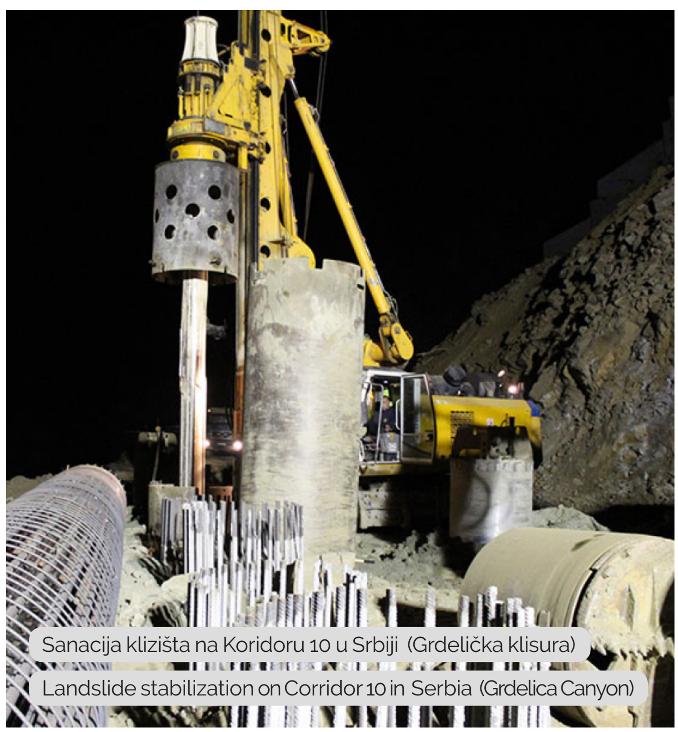
Autoput na Koridoru 5c, dionica: Johovac – Rudanka

Corridor 5c Motorway, section: Johovac – Rudanka

Most na Savi (Gradiška) / Bridge over the Sava River (Gradiška)

Sanacija klizišta na Koridoru 10 u Srbiji (Grdelička klisura)

Landslide stabilization on Corridor 10 in Serbia (Grdelica Canyon)



Sanacija klizišta na Koridoru 10 u Srbiji (Grdelička klisura)

Landslide stabilization on Corridor 10 in Serbia (Grdelica Canyon)

Željeznička pruga u Hrvatskoj, sekcija: Dugo Selo – Križevci

Railway track in Croatia, section: Dugo Selo – Križevci

Dovodni tunel za HE Dabar (Nevesinje)

Headrace tunnel for Dabar HPP (Nevesinje)

The most important ongoing projects of Integral inženjering:

» design and construction of the motorway on the Corridor 5c , section: Johovac – Rudanka
» construction of the bridge over the Sava River (Gradiška), section: Okučani (Croatia) – border with Bosnia and Herzegovina,
» investigation, design and construction of the headrace tunnel for the Dabar Hydro Power Plant (Nevesinje) in total length L= 12,5 km,
» landslide stabilization in the zone od the cut no. 2, 3, 4 and 5 on E75 Motorway (Corridor X) in Serbia – Grdelica Canyon;
» heavy maintenance (upgrading) of the state road IA3 (Serbia), section: intersection Sremska Mitrovica – intersection Ruma,
» reconstruction of exiting and construction of new railway track in Croatia (projected speed of 160 km/h): section Dugo Selo – Križevci.

Kompleks Vlade Republike Srpske (Banja Luka)

Government of the Republic of Srpska premises (Banja Luka)


Mi gradimo
BUDUĆNOST!
30
GODINA SA VAMA
1989
2019