ISSN 2217-8139 (Print)
ISSN 2334-0229 (Online)
UDK: 06.055.2:62-03+620.1+624.001.5(497.1)=861

DIMK

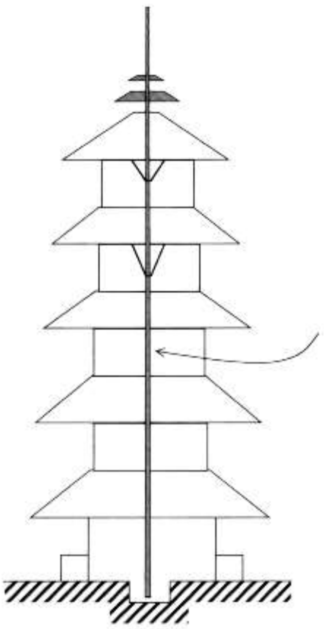
2020.
GODINA
LXIII

GRAĐEVINSKI MATERIJALI I KONSTRUKCIJE

2

BUILDING MATERIALS AND STRUCTURES

ČASOPIS ZA ISTRAŽIVANJA U OBLASTI MATERIJALA I KONSTRUKCIJA
JOURNAL FOR RESEARCH OF MATERIALS AND STRUCTURES



DRUŠTVO ZA ISPITIVANJE I ISTRAŽIVANJE MATERIJALA I KONSTRUKCIJA SRBIJE
SOCIETY FOR MATERIALS AND STRUCTURES TESTING OF SERBIA

DRUŠTVO ZA ISPITIVANJE I ISTRAŽIVANJE MATERIJALA I KONSTRUKCIJA SRBIJE
SOCIETY FOR MATERIALS AND STRUCTURES TESTING OF SERBIA

GRAĐEVINSKI MATERIJALI I KONSTRUKCIJE

BUILDING MATERIALS AND STRUCTURES

ČASOPIS ZA ISTRAŽIVANJA U OBLASTI MATERIJALA I KONSTRUKCIJA
JOURNAL FOR RESEARCH IN THE FIELD OF MATERIALS AND STRUCTURES

PUBLISHER

Society for Materials and Structures Testing of Serbia, 11000 Belgrade, Kneza Milosa 9
Telephone: 381 11/3242-589; e-mail:dimk@ptt.rs, veb sajt: www.dimk.rs

REVIEWERS: All papers were peer reviewed

KORICE: Shema višespratne pagode i Velika pagoda u Nari
COVER: Diagram of the multi-storey pagoda and the Great pagoda in Nara

Štampa/Print: Razvojno istraživački centar grafičkog inženjerstva, Beograd

Publikacija: tromesečno
Edition: quarterly

Financial supports: Ministry of Scientific and Technological Development of the Republic of Serbia

ISSN 2217-8139 (Print)
ISSN 2334-0229 (Online)

GODINA LXIII - 2020.

DRUŠTVO ZA ISPITIVANJE I ISTRAŽIVANJE MATERIJALA I KONSTRUKCIJA SRBIJE
SOCIETY FOR MATERIALS AND STRUCTURES TESTING OF SERBIA

GRAĐEVINSKI MATERIJALI I KONSTRUKCIJE

BUILDING MATERIALS AND STRUCTURES

ČASOPIS ZA ISTRAŽIVANJA U OBLASTI MATERIJALA I KONSTRUKCIJA
JOURNAL FOR RESEARCH IN THE FIELD OF MATERIALS AND STRUCTURES

SADRŽAJ

CONTENTS

CIP - Каталогизација у публикацији
Народна библиотека Србије, Београд

620.1

GRAĐEVINSKI materijali i konstrukcije : časopis za istraživanja u oblasti materijala i konstrukcija = Building materials and structures : journal for research of materials and structures / editor-in-chief Radomir Folić. - God. 54, br. 3 (2011)- . - Belgrade : Društvo za ispitivanje i istraživanje materijala i konstrukcija Srbije = Society for Materials and Structures Testing of Serbia, 2011- (Beograd : Razvojno istraživački centar grafičkog inženjerstva). - 30 cm

Dostupno i na:
http://www.dimk.rs/stg/website/filemanager/files/Casopis_1_2011.pdf. - Tromesečno. - Tekst na srp. i engl. jeziku. -
Je nastavak: Materijali i konstrukcije = ISSN 0543-0798. -
Drugo izdanje na drugom medijumu: Građevinski materijali i konstrukcije (Online) = ISSN 2335-0229
ISSN 2217-8139 = Građevinski materijali i konstrukcije
COBISS.SR-ID 188695820

A CURRENT PROBLEM FOR STEEL BRIDGES: FATIGUE ASSESSMENT OF SEAMS REPAIR

TEKUĆI PROBLEMI ČELIČNIH MOSTOVA: PROCENA ZAMORA SANIRANIH ŠAVOVA

H. PASTERNAK
A. CHWASTEK

ORIGINALNI NAUČNI RAD
ORIGINAL SCIENTIFIC PAPER
UDK:624.21.014.2
doi:10.5937/GRMK2002003P

1 INTRODUCTION

In dynamically loaded components, weld transitions are often the reasons for cracking with subsequent crack growth. In many cases they restrict the life of the components and structures. There are also deviations that could not be taken into account in the design of the construction, for example, larger loads and the desire for prolonged use.

To the best of the authors knowledge no design concept for the load capacity of the weld after the repair is known to this day. In a research project [Nitschke 2015, Pasternak 2015], in which not only the Department of Steel Construction of the BTU but also the Institute of Joining and Welding Technology at the TU Braunschweig (both Germany) and the Institute of Engineering and Materials Science of the University Innsbruck Austria took part, FAT classes for renovated welds are developed for the first time.

2 RESEARCH SCHEDULE

Since fillet welds contain significant higher stress concentration than in butt ones, in the following paper the experimental investigations were carried out indeed using specimens with fillet welds under tensile stresses. The fatigue strength of whole structure decisively depends on details, which are mostly welded joints. Weld transitions are the most critical locations where fatigue cracks are more likely to occur and later grow. Quite often it comes to fatigue failure even at non-load carrying details e.g. transverse attachment of a bridge girder. It was a reason for the choice of specimens in this research. The examined specimen in this paper are transverse non-load carrying attachment with fillet welds manufactured from steel grade S355J2N (Figure 1).

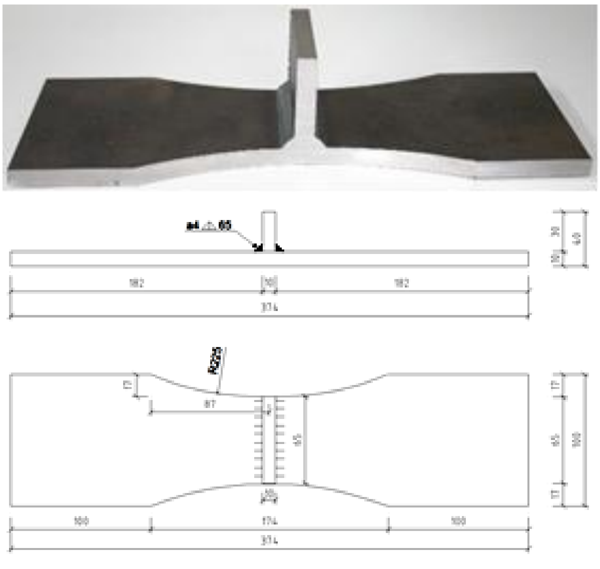


Figure 1. Geometry of specimen

For such geometry of specimen, a fatigue crack is expected to occur at weld toe and is mostly caused by concentration of notch stresses (Figure 2). To make possible a comparison the results of fatigue strength for the welds after seams repair and additionally seams' re-working methods the fatigue strength test analyses were divided into three groups.

- Group I: fatigue strength tests for defect-free weld seams;

H. Pasternak, Brandenburg University of Technology, Cottbus, Germany
A. Chwastek, Brandenburg University of Technology, Cottbus, Germany

• Group II: fatigue strength tests for seams' repair scenario, i.e. flawed weld seams renovated by grinding the existed crack and re-welding;

• Group III: fatigue strength tests for analogous to group II but supplemented by post-weld treatment methods.

The test schedule is given in Table 1, whereas the Table 2 shows parameter of welding.

Table 1. Investigation schedule

Test schedule – seams repair with the existed crack (prior damage)	
Group I original state	1. with MAG (135) welded; 2. each pieces were separately cut; 3. fatigue strength test.
Group II seams 'repair	1. with MAG (135) welded; 2. each pieces were separately cut; 3. grinding the existed cracks till 30% of plate thickness; 4. E-welding (3 layers); 5. fatigue strength test.
Group III seams 're-working	1. analogous to group II but with supplemented by weld-seam reworking methods (high frequency hammer treatment).

Table 2. Welding parameters of specimens during manufacturing

I [ampere]	320	process of welding	135
U [volt]	30,8	position of welding	PB
v_S -welding speed [cm/min]	40	wire electrode	G4Si1
v_D - wire feed speed [m/min]	11	-	-

3 MANUFACTURING OF TEST SPECIMENS

3.1 Original State

The original state is given on Figure 1 and Table 2.

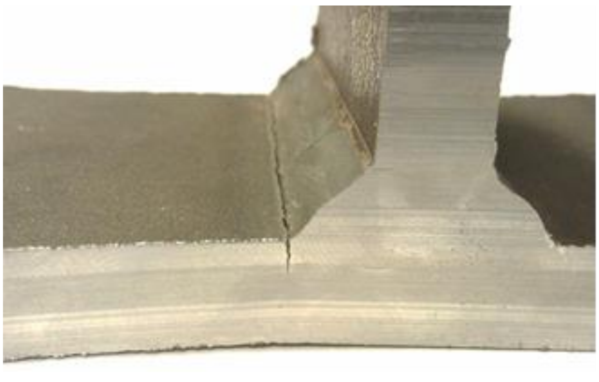


Figure 2. Crack at weld toe

3.2 Seams 'repair

In repair state the potentially existing cracks were removed by grinding of weld toe area. It was proceeded using a milling machine. In order to get an adequate fusion in the HAZ the excavated groove of the flawed material was performed in V-shape (Figure 3). A stage of re-welding was carried out using arc welding and supplemented in 3 welding layers (Figure 4). These weld seams characterize much flatter shape in comparison to the ones in original state.

3.3 Seams re-working method

In order to explore the effects of mechanically treated weld toes on the fatigue strength the high frequency hammer treatment with frequency of 230 Hz was applied.

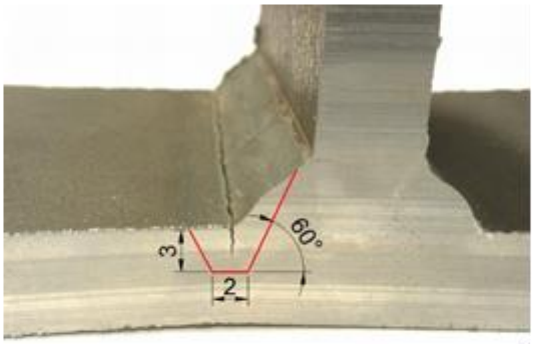


Figure 3. Grinding of crack

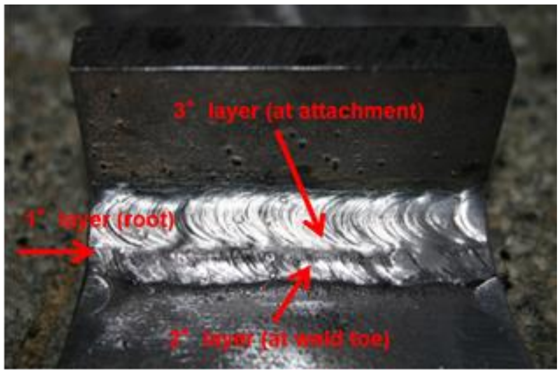


Figure 4. Repair welding layers

4 EXPERIMENTAL INVESTIGATION AND RESULTS

The fatigue tests were carried out with frequency of loading 30 Hz using a servo hydraulic fatigue test machine (Figure 5). According to recommendation for fatigue tests the specimens were loaded in five different load levels. To determine a *Wöhler* curve just specimens with the crack at weld toe were taken into consideration. The run-out samples were indicated on diagrams by data points with arrow marks. The fatigue loading was alternating axial tensile with assumption of stress radio R = 0,1 and fixed slope of *Wöhler* curve m = -3.

The following numbers of specimens were investigated: 29 for group I (original state), 13 for group

II (after seams repair) as well as 13 for group III (with post-weld treatment). The data points were presented in *Wöhler* diagram (Figure 6). For the group I the fatigue strength has a value of 104 N/mm^2, for the group II 124,5 N/mm^2 and accordingly for group III 116,5 N/mm^2. It concerns a probability of survival of 50 %, i.e. regression line. The results show that the weld seams after repairing process could easily achieve the fatigue strength of those in initial state. In some cases, is being observed even the considerable enhancement of fatigue life. But it should be mentioned that such repair procedures can lead to the increase of misalignments of specimen geometry. The post weld treatment i.e. the high frequency hammer delivered in this case negligible effects on the fatigue strength to compare with the original ones.

Figure 5. Hydraulic fatigue test machine

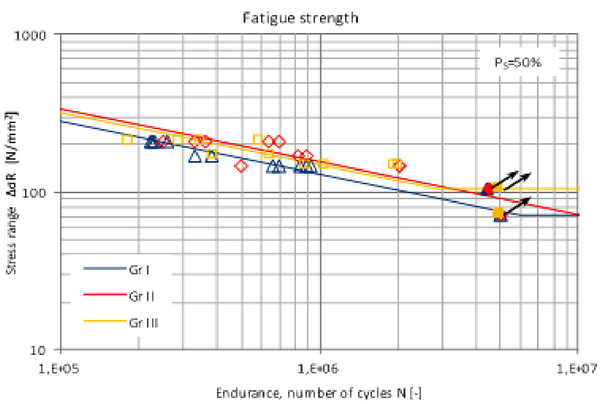


Figure 6. Comparison of results from three states

5 NUMERICAL INVESTIGATION

5.1 Welding simulation

The welding simulation should be carried out as realistically as possible. In order to realize this, the structure transformation of material, material properties as well as temperature dependence of the material were taken into account in analyses. The residual stresses of the specimens were calculated using the software package SYSWELD [Nitschke 2015]. For this simulation matter especially thermo-mechanical coupling in the material and the geometric preparation of the seam itself. Therefore, the temperature field and macrosection were experimentally measured. It was necessary to calibrate accordingly the moving heat source of the welding simulation. To meet the test conditions as closely as possible, these analyses considered in advance simulation of welding the transverse attachment to the base plate (Figure 7, left) and afterwards cutting out every sample separately (Figure 7, right).

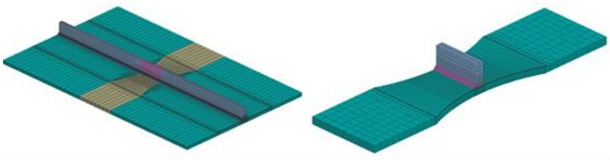


Figure 7. Base plate with transverse attachment (left) and separate specimen (right) [Nitschke 2015]

The modelling of the repair process was also quite realistic. A flawed part of fillet weld and material was "numerically" removed and re-welded (Figure 8).

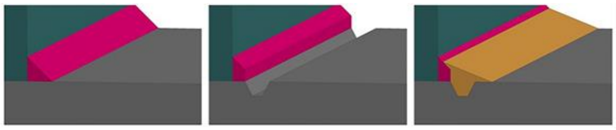


Figure 8. Schematic drawing of seams repair. Fillet weld (left), milled part (center) repaired seam (right)

5.2 Fatigue strength assessment concepts

Beside a purely experimental determination the fatigue resistance can be verified according to three analytical concepts. They are based on nominal, structural and notch stresses. Particular attention is paid to local approaches (i.e. structural and notch stress approach) since they are recommended due to better efficiency for welded joints [Hobbacher 2008, Morgenstern 2006].

The nominal stress approach concerns stresses calculated in the sectional area of potential crack initiation region using simple beam theory. The local stress concentrations of the welded joints are disregarded. The fatigue verification occurs in form of relation of stress ranges towards FAT classes, which generally were delivered from fatigue tests. The local stress peak is covered on the resistance side.

The structural stresses include both nominal stresses and the effects of structural discontinuities due to structural detail of welded joint, but excluding the notch effects of the weld profile itself. These fictive stresses are calculated through extrapolation to the weld toe stresses from two or three reference points taken from certain distances from the weld toe.

The basics of the notch stress concept relate to the principle of Neuber at location of potential crack initiation (either at the weld toe or the root). This concerns a theory of macro- and micro-support, with basic assumption that the full notch stress at the weld toe affects fatigue failure. According to this approach all edges at weld toe were rounded with the fictitious radius r_t= 1 mm and for such geometry the effective notch stresses were calculated. A master S-N curve for this concept has a value of FAT 225. The FE calculations are required to determine the effective notch stress.

5.3 FAT classes according to structure and notch stress concept

The structure stress was determined using 20-nodes volume elements of type C3D20R. Table 3 contains various models with calculated stress concentration factors. The value of this factor for original state was k_t = 1,15 and after seams repair k_t = 1,21 [Chwastek 2019].

The notch stress for original state was analysed both with shell and solid elements. The 8-nodes elements of type S8R were used for the shell model and the same elements like in the structural stress concept for the volume model. Table 4 shows a comparison of the calculated stress concentration factors for the original state. The values of this factor are a little higher by model using volume elements. For this reason, just volume model was analysed in the case of seams repair. The value of stress concentration factor for original state was K_t = 2,3 and after seams repair K_t = 2,2 [Chwastek 2019]. The lower value by repaired welds results from considerably flatter seams shape after repairing.

Table 3. Comparison of the FE calculations of structural stress

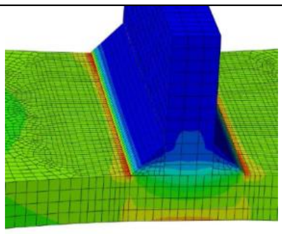
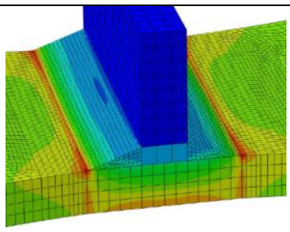
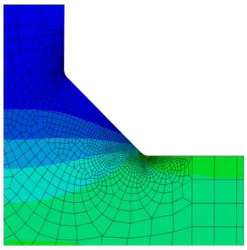
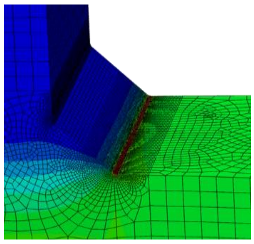
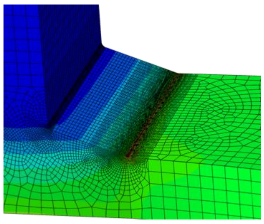
model	Volume elements C3D20R	Calculated k_t
Original state (group I)		**k_t=1,15**
Seams repair (group II)		**k_t=1,21**

Figure 9 shows determined FAT classes for three assessment concepts. For each approach the value of calculated FAT notch detail is considerably higher than in the currently valid standards [DIN EN 1993-1-9 2010] or guidelines [Hobbacher 2008]. Additionally, the results confirm a conservatism of notch class according to EC3 [DIN EN 1993-1-9 2010] for detail of transverse attachment with fillet welds. This applies in particular to nominal and structural stress concept, whereby value of improvement reach even till 20 %.

Table 4. FE calculation of notch stress for seams repair

model	Calculated k_t	
Original state (group I)	 K_t=2,17	**K_t=2,3**
	 K_t=2,36	
Seams repair (group II)	 K_t=2,24	**K_t=2,2**

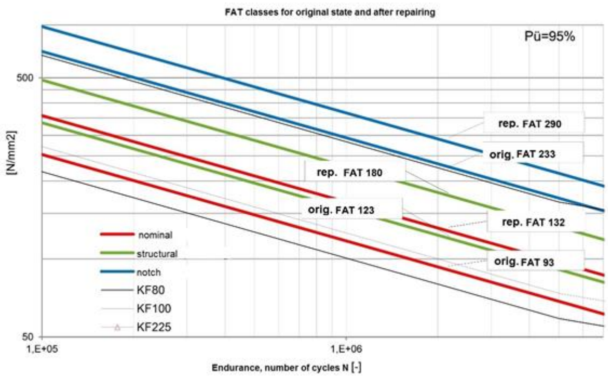


Figure 9. FAT categories of original state and after seams repair

6 CONCLUSIONS

As it was shown in experimental and numerical investigations of steel plates with welded transverse attachment, these repair procedures can lead to considerable improvement of fatigue strength in comparison to original state. In this case, using the post treatment methods with the high frequency hammer is rather no advisable.

The following procedure of cracks repairing by steel bridges is recommended: At first the flawed part of weld seam and material should be removed. It was assumed that grinding reaches till maximal 30 % of plate thickness. The prepared form is afterwards re-welded using arc welding method. Since the excavated groove is relatively large, it is recommended to use the 3-layers welding. In that case such repaired weld seam fails to match the dimensions of seam from original state.

The following conditions must be noticed: stress ratio R=0,1, assumption of imperfection according to IIW-Recommendations; T-joints detail geometry; steel grade S355, seam thickness 5 mm and plate thickness 10 mm.

7 ACKNOWLEDGMENT

The authors would like to thank the German Federation of Industrial Research Associations (AiF) for its financial support on the research project IGF-no. 54 EBG. This project was carried out under the auspices of AiF and financed within the budget of the Federal Ministry of Economics and Technology (BMWi) as part of the program to support Industrial Community Research and Development (IGF).

8 REFERENCES

[1] Nitschke-Pagel T., Pasternak H., Lener G. et al.: Bemessungskonzepte für Trag- und Dauer-festigkeitsberechnungen von Reparatursschweißungen- Repair Welding of Structures, Research Project IGF-No. 54EBG, 2015

[2] Pasternak H., Chwastek A.: Zur Entwicklung eines Bemessungskonzeptes für die Lebensdauer von Reparaturschweißungen. Bauingenieur Vol. 90(2015) pp.47-54 and pp. 272-277

[3] Hobbacher A.: Recommendations for fatigue design of welded joints and components. Doc.IIW XIII-1539-96/XV845-96, Paris, October 2008

[4] Morgenstern C. et al.: Fatigue design of aluminium welded joints by the local stress concept with fictitious notch radius of r_t = 1mm. International Journal of Fatigue Vol. 28(2006), pp.881-890

[5] Chwastek A.: Beitrag zur Entwicklung von Bemessungskonzepte für Dauerfestigkeits-berechnungen von Reparaturschweißungen, basierend auf kleinen Musterbauteilen, Dissertation, BTU, Cottbus. Germany 2019

[6] DIN EN1993-1-9:2010, Eurocode 3: Bemessung und Konstruktion von Stahlbauten –Teil 1-9: Ermüdung, Dezember 2010

ABSTRACT

A CURRENT PROBLEM FOR STEEL BRIDGES: FATIGUE ASSESSMENT OF SEAMS REPAIR

H. PASTERNAK
A. CHWASTEK

The paper describes the results from a research project about repair of welds. The repair was carried out by grinding the flawed seams and re-welding them. The main task was to determine the FAT classes of original state and after repair of seams according to the assessment procedures, such as nominal, structural and effective notch stress approach. The first part shows the results of the tests, the second part encloses numerical analysis and evaluation of results to determine the fatigue strength classes according to three assessment procedures.

Key words: Steel bridges, repair of welds, fatigue stress, fatigue assessment

APSTRAKT

TEKUĆI PROBLEMI ČELIČNIH MOSTOVA: PROCENA ZAMORA SANIRANIH ŠAVOVA

H. PASTERNAK
A. CHWASTEK

U radu su predstavljeni rezultati naučnog projekta koji se bavi ispitivanjem saniranih šavova zavarenih spojeva. Postupak sanacije se sastojao od mehaničkog uklanjanja oštećenog šava i ponovnog zavarivanja. Glavni zadatak projekta je bio određivanje klase otpornosti na zamor u prvobitnom stanju i nakon sanacije šavova, primenom pristupa nominalnog, efektivnog i "hot-spot" napona. U prvom delu rada su prikazani rezultati eksperimentalnih ispitivanja, dok su u drugom delu predstavljeni rezultati numerički analiza i određivanja klase otpornosti na zamor primenom tri pomenuta pristupka.

Ključne reči: Čelični mostovi, sanacija šavova, napon zamora, zamor zavarenih spojeva, procena zamora

ANALIZA OŠTEĆENJA FASADA ZGRADA LAKOG MONTAŽNOG SISTEMA NAKON DUGOGODIŠNJE EKSPLOATACIJE

ANALYSIS OF FACADE DAMAGE OF LIGHTWEIGHT PREFABRICATED HOUSES AFTER LONG LASTING USE

Predrag PETRONIJEVIĆ
Ana MOMČILOVIĆ PETRONIJEVIĆ

ORIGINALNI NAUČNI RAD
ORIGINAL SCIENTIFIC PAPER
UDK:691.23.059.22
doi:10.5937/GRMK2002009P

1 UVOD

U ovom radu analizirana su oštećenja fasada individualnih i kolektivnih stambenih objekata u naseljima u Apelovcu i Rasadniku u Nišu, građenih početkom 60-tih godina XX veka u lakomontažnom sistemu. U ovom periodu, s naglom industrijalizacijom grada paralelno je došlo do brze izgradnje čitavih naselja na periferiji grada Niša. Razmatrani objekti izgrađeni su po fazama, od 1958. do 1964. godine, u sistemu fabrike Krivaja iz Zavidovića iz Bosne u tadašnjoj SFRJ. U tom periodu, nisu postojale tehničke norme i standardi za izgradnju objekata tog tipa, tako da podaci pokazuju da kvalitet omotača tada izgrađenih objekata ne zadovoljava današnje zahteve, naročito u pogledu termoizolacije [25. Poseban problem predstavlja značajan fond izgrađenih višespratnih zgrada u drugoj polovini XX veka, poznatoj kao u periodu intenzivne stambene izgradnje. Tada izgrađene fizičke strukture poseduju zadovoljavajuće performanse u konstruktivnom smislu, ali usled brzine gradnje, malo pažnje je posvećeno kreiranju omotača zgrade [17]. Standardni tipovi fasada lakomontažnih objekata građenih u tom periodu bili su: malterisane fasade, fasade od azbestnih ploča, objekti sa oblogom od lima, od iverice, prirodnog drveta i panela od lakog betona (slika 1).

Docent dr Predrag Petronijević, Univerzitet u Nišu, Građevinsko-arhitektonski fakultet, Aleksandra Medvedeva 14, 18000 Niš, predrag.petronijevic@gaf.ni.ac.rs
Docent dr Ana Momčilović-Petronijević, Univerzitet u Nišu, Građevinsko-arhitektonski fakultet, Aleksandra Medvedeva 14, 18000 Niš, ana.momcilovic.petronijevic@gaf.ni.ac.rs

1 INTRODUCTION

This paper analyzes the damage of facades of individual and collective housing buildings in lightweight prefabricated neighborhoods on Apelovac hill and Rasadnik in Nis, built in the early 1960s. In this period, with the rapid industrialization of the city, there was an accelerated construction of entire neighborhoods on the outskirts of the city of Niš. The considered buildings were built in phases in the period from 1958 to 1964 using the system of the Krivaja factory from Zavidovići, Bosnia in Former Yugoslavia. At the time there were no technical norms and standards for construction of buildings of this type, so the data show that the quality of cladding of the buildings constructed in that period fails to meet the present day standards, especially in terms of thermal insulation [25]. A special problem is a sizeable stock of built multi-storey buildings constructed in the second half of the 20^{th} century, which is known as a period of intensive housing construction activity. Physical structures built in this period have satisfactory performances in structural sense, but due to the rapid construction process, little attention was paid to creation of building cladding [17]. The standard types of lightweight building facades built in this period were: plastered facades, asbestos panel facades, sheet-metal clad facades, plywood facades, natural timber and light concrete panel facades (Figure 1).

Predrag Petronijević, PhD, Assistant Professor, Faculty of Civil Engineering and Architecture, University of Nis, Aleksandra Medvedeva 14, 18000 Nis, predrag.petronijevic@gaf.ni.ac.rs
Ana Momčilović Petronijević, PhD, Assistant Professor, Faculty of Civil Engineering and Architecture, University of Nis, Aleksandra Medvedeva 14, 18000 Nis, ana.momcilovic.petronijevic@gaf.ni.ac.rs

Slika 1. Tipovifasadalakihmontažnihobjekata: a) malterisanafasada, b) azbestneploče, c) limenaobloga, d) paneliodiverice, e) drvenaobloga, f) paneliodlakogbetona

Figure 1. Types of facades of light prefabricated buildings: a) plastered façade, b) asbestos plates, c) metal sheet, d) plywood façade panel, e) timber cladding, f) lightweight concrete. panel

Koncept objekata bio je u minimalizovanju troškova izgradnje što je kasnije uslovljavalo visoke troškove održavanja [4,10,12]. Na raznovrsnom stambenom tržištu ovo je značilo da su početkom 60-ih godina jedino siromašni stanari i pripadnici etničkih manjina bili voljni ili bili prinuđeni da žive u takvim naseljima, dok srednje klase nije bilo u ovom tipu stanova. U tom tipu naselja jasno je izražena socioekonomska pripadnost njenih stanovnika [26]. Socijalni problemi kao rezultat masovnog doseljavanja stanovništva iz ruralnih krajeva, kao i etničkih manjina, onemogućili su izgradnju stabilne društvene zajednice. To je bio trajni problem ovih naselja koja su postala stecište ekonomski neaktivne potklase. Ta naselja postala su zapuštena urbana područja, s problemom primene zagađujućih građevinskih materijala kao što je azbest [3,7] i loših mera zaštite od požara [19]. Problem lošeg imidža i društvenih nevolja u ovim naseljima, doveo je do veoma negativne slike o ovoj vrsti smeštaja među širom populacijom. To je rezultiralo ambivalentnim stavom javnosti prema ovoj vrsti stanovanja počev od ranih 70-ih godina XX veka.

Temeljna analiza naselja pokazala je nezadovoljavajuće stanje u kome se nalazi većina zgrada koje su, iako prvobitno zamišljene kao privremene (rok trajanja je od dvadeset do trideset godina), sada postale trajne. Za većinu objekata je iznenađujuće što su, s predviđenim rokom trajanja od dvadeset godina, uopšte trajali šezdeset godina [27]. Problem ovih, kao i mnogih drugih naselja, jeste u njihovom neadekvatnom održavanju [5]. Ljudi lošeg materijalnog stanja vremenom su postali privatni vlasnici socijalnih stanova, bez dovoljno sredstava za njihovu obnovu i adekvatno održavanje [2]. Stanari su samoinicijativno i bez projekata menjali fasade, uništavajući ih, iako to ne bi smeli, jer je fasada zajednička, a za radove bilo koje vrste neophodna je saglasnost većine stanara. U višestambenim zgradama u analiziranim naseljima trenutno živi više stotina ljudi.

The concept of the buildings was to minimize construction costs, which later caused high maintenance costs [4,10,12]. In the diverse housing market at the beginning of 60's, this meant that only the poor tenants and ethnical minorities were willing or compelled to live in such neighborhoods, while the middle class did not live in such type of housing.This type of neighborhoods clearly reflects the socio-economical stratum of its residents [26]. Social problems, as a result of mass influx of population from rural areas and ethnic minorities, prevented building of a stable social community. This became a durable problem of such neighborhoods, which became residences of economically inactive subclass. These neighborhoods became derelict urban areas, plagued by the polluting building materials such as asbestos [3,7] and poor fire prevention measures [19]. The problem of bad image and social problems in these neighborhoods resulted in a very negative picture of this type of housing among the wider population. This resulted in a very ambivalent public opinion of this kind of housing since the early 70's of 20th century.

A thorough analysis of the neighborhood revealed a sorry state of most of the buildings which were originally conceived as temporary (service life from 20 to 30 years), and which now became permanent. Through the lack of maintenance, many of the buildings are now in very poor repair, and it is unbelievable how they survived for 60 years, at all [27]. The problem with this, as with many other neighborhoods is that they are inadequately maintained[5]. People became private owners of social apartments, but nowadays they have no resources to restore them [2]. The residents change the facades according to their own fashion, and destroy them, even though they should not do it because the façade is a common property, and for any kind of repair works, consent of majority of residents is required. Several hundred people currently live in the multi-family buildings in the mentioned neighborhood.

Ovaj rad ima za cilj dobijanje osnovih podataka o tehničkom stanju primenjenih tehnologija montažne gradnje višeporodičnih stambenih zgrada u lakomontažnom sistemu [1].

This paper strives to obtain the basic data on the technical condition of implemented technologies of lightweight prefabricated construction of multi-family buildings [1].

2 NAČIN ODABIRA UZORKA I PRIKUPLJANJE PODATAKA

Predmetni objekti se nalaze u: ul. Mokranjčeva 35–37, ul. Mokranjčeva, prilazi II i III i u naselju Rasadnik (slika 2). Analizirano je: šest trospratnih zgrada, dve dvospratne, sedamnaest prizemnih kuća sa po četiri stana u osnovi, deset dvojnih kuća i pet individualnih kuća. Na određenom broju objekata izvršena je dogradnja, što je bitno uticalo na stanje fasada u smislu popravki, dok je na mnogim objektima izvršena sanacija ili potpuna rekonstrukcija u vidu kontaktnih fasada.

2 SAMPLING METHOD AND DATA COLLECTION

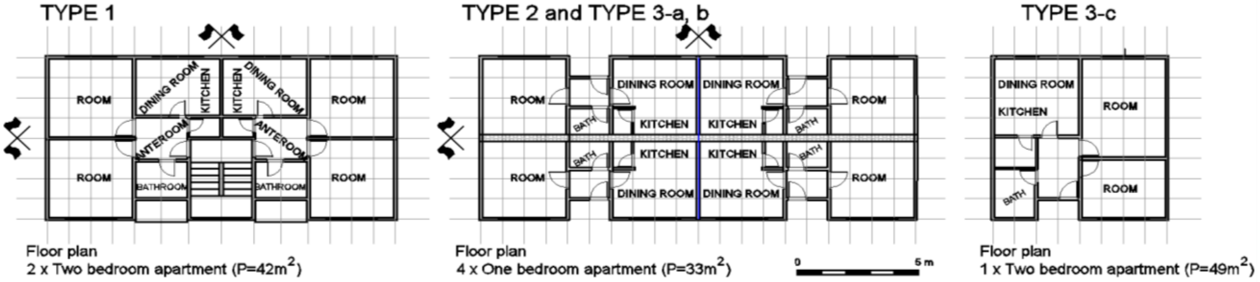
The buildings in question are in: Mokranjčeva street, no. 35-37, Mokranjčeva street, access roads II and III and in Rasadnik neighborhood (Figure 2). The subjects of consideration were: six three-storey buildings, two two-storey buildings, seventeen ground level buildings having four apartments, ten buildings with two apartments and five individual houses. Many buildings were extended, which affected the status of facades (in terms of repairs), while many buildings were remediated or fully reconstructed using contact facades.

Slika 2.Dispozicijamontažnihnaseljaiizgledtipskihobjekata

Figure 2. Disposition of prefabricated neighborhoods and appearance of standardized buildings

Tipske višespratnice (uzorci Tip 1 i 2) izgrađene su sa čeličnom nosećom konstrukcijom, unutrašnjom oblogom od drvenih panela, ispunom od drvolita (heraklit) i fasadom od ravnih azbestcementnih ploča ili od maltera (Tabela 1). Prizemni objekti (Tip 3-a, b, c) izrađeni su s drvenim skeletom, drvenom oblogom sa unutrašnje strane i malterom sa spoljne. Krovni pokrivač svih objekata jesu salonit-ploče. Podrumski zidovi i tavanice podruma svih uzoraka od armiranog su betona. U svim objektima su stanovi male kvadrature, a struktura stanova je jednosobna i dvosobna (slika 3).

Standardized multi-storey buildings (Specimen Type 1 and 2) were constructed using steel supporting structure, with interior lining of timber panels, with heraklit infill and a façade of flat asbestos-cement panels or mortar (Table 1). Ground level buildings (Type 3-a,b ,c) were constructed using timber frame, interior timber lining, and they are plastered from the outside. The roof covering of all buildings is everite. Basement and basement ceiling of all buildings is made of reinforced concrete. All buildings contain small apartments, having one or two rooms (Figure 3).



Slika 3. Šeme osnove uzoraka
Figure 3. Specimen floor plans

U periodu nakon Drugog svetskog rata uporedo s naglom ekspanzijom montažne gradnje kreće se u intenzivnu upotrebu azbestnih mineralnih vlakana na prostoru bivše SFRJ. Azbest zbog svoje strukture otporne na mehanička dejstva, vlagu, visoke temperature, agresivne hemikalije a dobre termičke izolacije i athezije s cementnim vezivima, našao je široku primenu. Salonitne fasadne i krovne ploče koje sadrže kancerogena azbestna vlakna i nakon više od pet decenija nalaze se na ovim objektima.

In the period after WWII, simultaneously with the booming prefabricated building construction, asbestos mineral fibers were intensively used in former SFRY. Asbestos became widely used due its structure resistant to mechanical action, damp, high temperatures, and aggressive chemicals, while exhibiting good thermal insulation properties and adhesion with cement binders. Façade and roof panels containing carcinogenic asbestos fibers are still found on these buildings after five decades.

Tabela 1. Karakteristike noseće konstrukcije analiziranih objekata
Table 1. Building structure characteristics of analysed prefabricated buildings

	Karakteristike noseće konstrukcije Building structure characteristics			
	Noseća konstrukcija *Load bearing structure*	Fasadni zidovi *Facade walls*	Pregradni zidovi *Partition walls*	Krovna konstrukcija *Roof structure*
Apelovac P+3	Čelični okviri *Steel frames*	Drveni paneli sa termo izolacijom+azbestni paneli *Timber panels with thermo insulation+asbestos panels*	Drveni paneli *Timber panels*	Dvovodni krov, drvena konstrukcija pokrivena azbestnim panelima *Double-pitched roof, timber construction covered with asbestos plates*
Apelovac P+1	Čelični okviri *Steel frames*	Drveni paneli sa termo izolacijom+malter *Timber panels with thermo insulation+mortar*	Zidani zidovi 25cm i drveni paneli *Brick walls 25cm and timber panels*	
Apelovac P	Drveni okviri i paneli, zidani zidovi *Timber frames and panels, brick walls*			

3 DEFINISANJE METODOLOGIJE

Izbor uzorka konkretnih objekata izvršen je na osnovu približnog perioda izgradnje (1958–1962). Starost objekata je oko šezdeset godina i upotrebni vek im je odavno istekao. Podaci su dobijeni opservacijom, odnosno posmatranjem, uočavanjem, registracijom i mapiranjem uočenih defekata. Zbog male spratnosti opserviran je celokupan fasadni omotač. Za svaki posmatrani objekat je, u okviru posmatranog uzorka, izvršena identifikacija vrste fasadne obloge kao i prebrojavanje zastupljenih oštećenja. Svi uočeni defekti na fasadama odabranih objekata precizno su opisani i razvrstani [18]. Sabiranjem ukupnog broja defekata na svim fasadama (u okviru jednog uzorka) dobijen je ukupan broj oštećenih fasada po uzorku. Oštećenja su zasebno evidentirana i klasifikovana za: fasadne zidove, temeljne zidove, strehe i ivice krova.

Prebrojavanje klasifikovanih defekata radi se za svaki uzorak, posmatrajući fasadnu površinu jednog trakta kao primerak, odnosno od šest do trideset šest taktvih primeraka po uzorku. Konfiguracije fasada posmatranih objekata su gotovo identične bez obzira na veličinu i spratnost objekta. Defekti svakog pojedinačnog elementa evidentirani su po vrsti i nivou oštećenja konkretnog elementa prema [17]. Nivo oštećenja fasade pojedinačnog trakta u odnosu na njegovu ukupnu površinu klasifikovan je kao: manji (oštećena površina iznosi manje od 30% ukupne površine trakta), srednji (oštećena površina iznosi od 30% do 60% ukupne

3 DEFINING OF METHODOLOGY

The selection of specific buildings was performed based on the approximate construction period (1958-1962). The age of the structure is around 60 years, and their service life expired long ago. The data were obtained by observation, monitoring, registering and mapping of the observed defects. Since the buildings were low, entire façade cladding was observed. Façade cladding and counting of damage was performed for each observed building, within the observed sample. Classification of the type of façade cladding and counting of the found damage was performed for each observed building, within the observed sample. All the observed defects on the facades of the selected buildings have been described in detail and classified [18]. By summing up the total number of defects on all the facades (within one sample) a total number of damaged facades per sample was obtained. The damage was separately recorded and classified for: façade walls, foundation walls, eaves and roof edges.

Counting of classified defects is performed for each sample, observing the façade surface of tract as a specimen, i.e. 6 to 36 such specimens per sample. Façade configurations of the observed structures are almost identical, regardless of the size and height of the buildings. Defects of each individual element are recorded by type and level of damage of the specific element according to [17]. The level of damage of individual tracts in comparison to its total surface area is površine trakta) i značajan (oštećena površina iznosi preko 60% ukupne površine trakta) (Tabela 2).

classified as: small (damaged surface is less than 30% of total tract surface area), medium (the damaged surface is 30% to 60% of total tract surface area) and significant (the damaged surface is exceeding 60% of the total tract surface area) (Table 2).

Tabela 2. Evidentiranje defekata na fasadama zgrada Tip 1, Mokranjčeva i Rasadnik, 2014. god.
Table 2. Recording of defects on the facades of buildings Type 1, Mokranjceva and Rasadnik, 2014 year

	Opis oštećenja *Description of damage*	Nivo oštećenja (2014. godine) *Demage level (2014. year)* mali <30% *small <30%*	30%< srednji < 60% *30%< medium< 60%*	60%< značajan *60%< significantly*
Malterisane fasade *Plastered facade*	prsline - pukotine *cracks – fissures*	32	37	19
	odlomljene ivice *broken edgese*	17	5	4
	prsline u malteru usled skupljanja *shrinkage cracks in mortar*	23	6	0
	odvajanje završnog sloja *separation of the final layer*	36	15	4
	oštećenja soklenog zida *plinth wall damages*	42	23	3
	iscvetavanje *efflorescence*	4	9	2
Obloga od azbestnih ploča *Asbestos-tiles cladding*	krivljenje panela *panel bending*	12	2	0
	lom panela *panel fracture*	17	4	0
	otpadanje panela *panel falling off*	5	0	0

Fasadne obloge u razmatranom uzorku mogu da se podele na fasade od maltera i fasade od azbest-cementnih ploča. Dalja podela izvršena je na pune fasade (bez otvora) i one sa otvorom. Za svaki posmatrani objekat u okviru posmatranog uzorka fasadne površine izvršena je identifikacija vrste fasade i oštećenja na njima. Usvojena je klasifikacija defekata prema [17] i prilagođena – dopunjena je oštećenjima primećenim tokom opservacije konkretnih primera. Klasifikacija koja se primenjuje u ovom istraživanju data je u (Tabela 2). Zbog ograničenog prostora rezultati analizirani u ovom radu dati su zbirno za presek stanja oštećenja opserviran 2014. godine.

Defekti malterisanih fasada [16] u ovom istraživanju klasifikovani su kao: dezintegracija sloja maltera, totalno odvajanje fasade od potkonstrukcije, otpadanje maltera i korozija rabic-pletiva, otpadanje završnog sloja maltera, ljuskanje završnog sloja fasade, mrežaste prsline od skupljanja, pojava mahovine i lišajeva, bujanje flore, prsline-pukotine, prsline-pukotine predisponirane geometrijom potkonstrukcije, otpadanje delova fasade (slika 4).

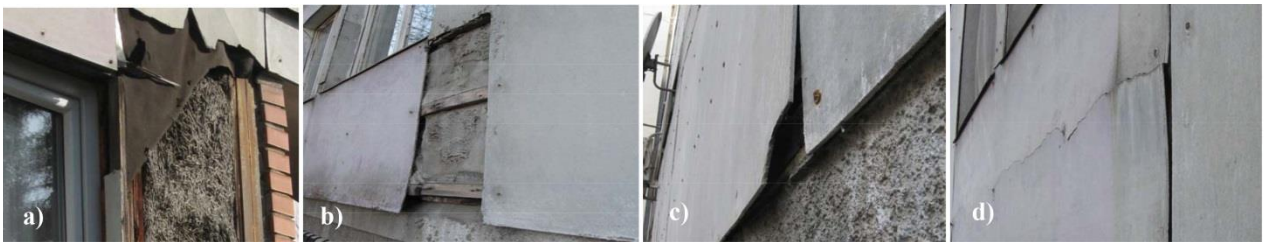
Façade cladding in the observed sample can be classified into the mortar facades and asbestos-cement facades. Further classification comprises monolithic facades (without openings) and those with openings. Façade type and damage on them was performed for each observed structure within the observed sample of façade surface. Classification of defects according to [17] was adopted and adapted – amended with damage perceived during the observation of specific examples. The classification implemented in this research is provided in (Table 2). Because of the limited space results analyzed in this paper are presented as summation for the damage status observation of 2014.

Defects of the plastered facades [16] in this research were classified as: disintegration of the mortar layer, total separation of the façade from substructure, falling off of the mortar and corrosion of the wire mesh, falling off of the finish mortal layer, flaking of the façade finish layer, network of cracks from shrinkage, occurrence of moss and lichen, flora development, cracks and crevices resulting from the geometry of substructure, falling off of façade parts (Figure 4).

Slika 4. Karakteristična oštećenja malterisanih fasada (slika: P. Petronijević)
Figure 4. Characteristic damage of plastered facades (photo: P. Petronijević)

Karakteristična oštećenja fasada od azbestcementnih panela klasifikovana su kao: potpuna dezintegracija zida, otpadanje panela, lom krajeva panela, uvrtanje i krivljenje panela, pukotine i prsline panela, odvajanje panela od drvene potkonstrukcije, oštećenja ter-hartije (slika 5).

Characteristic damage of asbestos panel façade are classified as : complete disintegration of the wall, falling off of panels, panel edge breaking, warping of panels, cracks and crevices of panels, separation of panels from the substructure, roofing paper damage (Figure 5).



Slika 5. Karakteristična oštećenja fasadnih panela od azbesta (slika: P. Petronijević)
Figure 5. Characteristic damage to the asbestos panels (photo: P. Petronijević)

Strukturalne pukotine u temeljnim zidovima evidentirane su kod većeg broja uzoraka. Podužne pukotine u visini tavanice podruma i vertikalne pukotine ćoškova objekata posledica su neadekvatnog armiranja podrumskih zidova (slika 6-a). Kose pukotine evidentirane su kod objekata fundiranih na kosom terenu i posledica su nejednakog sleganja. S obzirom na malu masu ovog tipa objekata, nejednako sleganje je uzrokovano različitim stepenom zbijenosti tla na različitim dubinama fundiranja. Na postojanost završnog sloja sokle dominantan uticaj imali su mraz i pojava vlage usled propadanja vertikalne hidroizolacije u temeljnim zidovima. Najčešće evidentirana oštećenja su: otpadanje sokle, kristalizacija soli, karbonatizacija, biodegradacija, oštećenja završnog dekorativnog premaza i druga.

Structural cracks in the foundation walls were recorded in a number of samples. Longitudinal cracks at the level of the basement ceiling and vertical cracks of the corners of the buildings are the result of the inadequate reinforcing of basement walls (Figure 6-1). Diagonal cracks are identified in the structures founded on an inclined ground as the consequence of irregular settling. Regarding small mass of this type of buildings, irregular settling was caused by the different ground compaction degree at various depths of founding. The durability of the finish layer of the plinth was affected by the frost and damp due to dilapidation of vertical waterproofing in the foundation walls. Most often recorded damage was: falling off of the plinth, salt crystallization, carbonation, biodegradation, damage of the finish decorative coating.

Slika 6. Oštećenja temeljnog zida: a) strukturalne pukotine, b) otpadanje obloge, c) iscvetavanje, d) karbonatizacija
Figure 6. Plinth wall damages: a) structural cracks, b) wall cover falling off, c) salt crystallization, d) carbonation

Oštećenja kalkanskih zidova, dimnjaka, ventilacionih kanala, streha i oluka svedoče o totalnom zanemarivanju objekata od strane njihovih vlasnika. Na svim objektima izuzev Tip 3-c i posle 60 godina nalaze se izvorno ugrađeni elementi. Evidentirana su oštećenja opšiva krova bez obzira na primenjenu vrstu materijala (slika 7-b,c). Na mnogim objektima nedostaju: delovi kalkanskih zidova, limeni opšiv krova, delovi oluka, ploče krovnog pokrivača i drugo.

Damage to gable walls, chimneys, ventilation ducts, eaves, downpipes give evidence of the total neglect of the buildings by their owners. On all the buildings, except Type 3-c there are original elements after 60 years. The roof flashing damage was recorded, irrespective of the used type of material (Figure 7-b,c). Many buildings lack: parts of galble walls, sheet-metal flashing of the roof, parts of gutters, roofing panels etc.

Slika 7.Oštećenja strehe (slika: P. Petronijević)
Figure 7.Damage to the eaves (photo: P. Petronijević)

Tokom više decenija od kada su izrađene, u najvećem broju uzoraka stambenih zgrada pojavila se realna potreba za njihovom adaptacijom, renoviranjem ili rekonstrukcijom [6,15]. S obzirom na specifičnost tehnologije izrade spoljnih zidova montažnih kuća, tada važećim propisima o termičkoj zaštiti objekata i primenjivanim materijalima, javio se problem adekvatnog saniranja dotrajalih fasada. Osnovni nedostatak ovog tipa montažnih zgrada jeste nizak stepen stambene ugodnosti unutrašnjih prostorija koji je posledica loše izolacije, loše zaptivenosti i paronepropustljivosti spoljašnjih zidova.

Nedovoljno poznavanje fenomena građevinske fizike uzrokovalo je postavljanje parne brane (paronepropusne lepenke Sd=40–50m) na pogrešnom mestu. Na ispitanim uzorcima izgrađenim u periodu od 1958. do 1962. godine, ter-hartija je postavljana na spoljnoj strani heraklit-ploča bez ikakvog dodatnog termoizolacionog sloja, što je na velikim fasadnim površinama bez otvora prouzrokovalo umerena do značajna oštećenja (slika 8-a,b). Ovim je izazvana pojava kondenzata u sloju heraklit-ploča, značajan porast koeficijenta prolaska toplote i pojava površinske kondenzacije na unutrašnjoj strani zida. Usled povećanja vlažnosti, bubrili su drveni

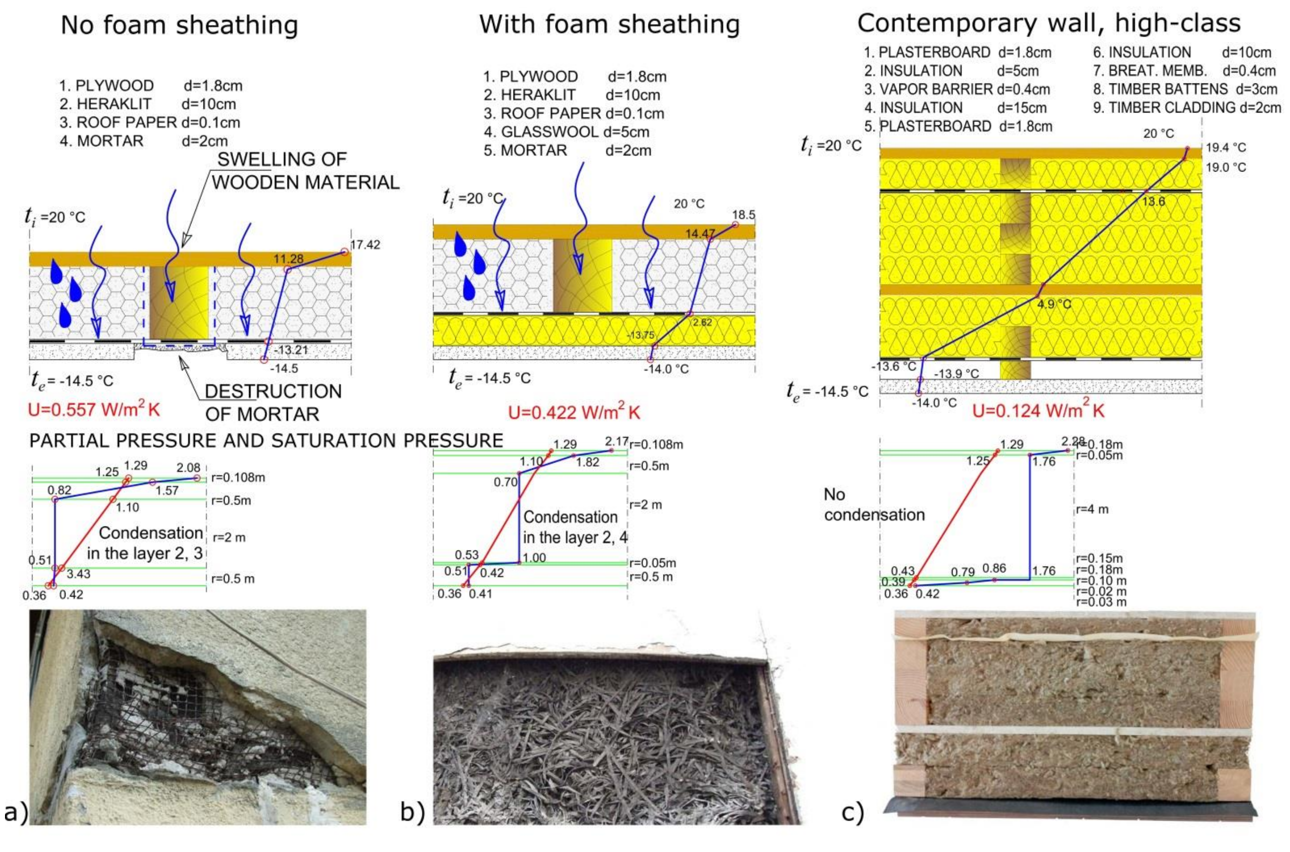
In the course of decades that passed since the buildings were built, a real need arose to adapt, renovate or reconstruct the majority of housing building samples [6,15]. Regarding the specific technology of construction of external walls of prefabricated houses suited to the regulations of thermal insulation of buildings and materials available at the time, there arose the problem of adequate remediation of decrepit facades. The fundamental shortcoming of this type of prefabricated buildings is the low indoor living comfort level which is the consequence of poor insulation, sealing and vapor impermeability of external walls.

Lack of understanding of building physics phenomena resulted in construction of the vapor barrier (vapor impermeable plywood Sd=40-50m) in a wrong position. On the observed samples, built in the period 1958-1962 the roofing paper was placed on the external side of heraklit panels without any additional thermal insulation layer, which caused moderate to considerable damage to the large façade areas without openings (Figure. 8-a,b). This caused condensation in the layer of heraklit panels, considerable increase of passage of heat and onset of surface condensation on the interior side of the wall. Due to the increase of dampness, the timber elementi u sastavu noseće konstrukcije zida. Povećanje zapremine drvenih stubova i greda uticalo je na dezintegraciju maltera fasade (slika 9-a,b). Kod uzorka Tip 1 sa čeličnom nosećom konstrukcijom, oštećenja ovog tipa nisu registrovana osim vizuelnih nedostataka fasadnih zidova (slika 9-b,c). Ovaj tip objekata imao je značajno nepovoljnije termičke karakteristike u vidu izraženih termičkih mostova [24]. Povećanje vlažnosti fasadnog roštilja i heraklit-ispune stvorilo je uslove za pojavu buđi i plesni na unutrašnjoj strani zida [28,30].

Postupak nastavljanja ter-hartije je na preklop bez zaptivanja tako da je u kombinaciji s loše ugrađenom stolarijom stvorena mogućnost za izvestan protok vodene pare. Na fasadama s velikim brojem otvora, oštećenja usled bubrenja drvene građe su evidentirana ali u znatno manjoj meri. Oštećenja fasada su intenzivnija na mestu prostorija s povećanom vlažnošću vazduha (kuhinje i mokri čvorovi). Uzorci izgrađeni nakon 1962. godine na spoljnim zidovima imali su dodatni sloj termoizolacije sa ispravnim položajem parozaptivnog sloja tj. s tople strane termoizolacionog sloja. Ter-hartija je uslovno rečeno preuzela ulogu parne brane sprečavajući prodor vodene pare u zonu termoizolacionog sloja. Time je ostvarena povoljnija raspodela parcijalnog pritiska i pritiska zasićenja u slojevima sklopa zida (slika 8-a,b) [20].

elements within the bearing structure of the wall swelled. Increase of volume of the timber posts and beams had effects on disintegration of the façade mortar (Figure 9-a,b). In the Type 1 samples with the steel supporting structure, damage of this type were not registered except the visual defects of façade walls (Figure 9-b,c). This type of buildings had considerably more unfavorable thermal characteristics demonstrated by the evident thermal bridges [24]. The increase of dampness of façade bearing sub-structure and heraklit infill created conditions for onset of mould on the interior side of the wall [28,30].

The roofing paper was installed with overlapping without sealing, so in combination with the poorly fitted joinery, there occurred potential for a certain water vapor flow. Damage was found also on those façades with a large number of openings, but to a much lesser degree. Façade damage is more intensive where the rooms have increased air humidity (kitchens and bathrooms). Those samples constructed after 1962 had an additional layer of thermal insulation on the external walls, with a correct position of vapor barrier layer, on the warm side of thermal insulating layer. Roofing paper assumed the role of a vapor barrier preventing penetration of water vapor into the zone of thermal insulation layer. This created a better distribution of partial pressure and saturation pressure in the wall layers (Figure. 8-a,b) [20].



Slika 8. Nastanak oštećenja fasadnog maltera usled bubrenja drvene građe (slika: P. Petronijević)
Figure 8. The appearance of damage to the facade mortar due to swelling of timber (photo: P. Petronijević)

Delimično poboljšani poprečni presek spoljašnjeg zida s dodatnom izolacijom od 5 cm i dalje je bio loš zbog loše zaptivenosti. Koeficijenti prolaska toplote, temperaturnog kašnjenja i faktor gušenja temperature višestruko su ispod danas zahtevanih vrednosti. Subjektivan ugođaj boravka u ovim stanovima jako je loš zbog slabe izolovanosti, kratkog faznog pomeranja i odsustva značajnijeg faktora prigušenja temperature [29]. Koeficijent prolaska toplote smanjen je povećanjem sloja termoizolacije, dok su koeficijent temperaturnog kašnjenja i faktor gušenja temperature i u savremenoj montažnoj gradnji teško ostvarivi. Veće temperaturno kašnjenje može se postići dodatnom masom materijala i rasporedom slojeva (Slika 8-c), što u slučaju montažne gradnje značajno povećava cenu fasadnih panela [22,23]. Spoljna temperatura vazduha i temperatura spoljne površine zida osciluje tokom dana. Amplituda temperaturnog talasa prodire kroz slojeve zida i pri tome se smanjuje – guši. Gušenje temperature je karakteristična vrednost kojom se opisuje toplotna stabilnost konstrukcije. Faktor gušenja je odnos amplitude temperaturne oscilacije spoljašnjeg vazduha i amplitude unutrašnje površine zida [8].

Partially improved cross section of the external wall with additional insulation of 5 cm was still bad because of poor sealing. Heat passage coefficients, temperature retardation and temperature damping factor are many times below the values required nowadays. Subjective feel of living in such apartments if very low because of poor insulation, short phase shift and absence of any considerable temperature damping factor [29]. Heat passage coefficient is reduced by the increase of thermal insulation layer thickens. Whereas, the temperature retardation coefficient and temperature damping factor are hard to achieve even in the contemporary prefabricated construction. A higher temperature retardation can be achieved with additional mass of material and arrangement of layers (Figure8-c). In case of prefabricated construction this considerably increases the cost of façade panels [22,23]. The external air temperature of the external wall surface oscillates during daytime. The amplitude of the temperature wave penetrates through the wall layers and gets decreased – damped. Temperature damping is a characteristic parameter used to describe heat stability of the structure. Damping factor is the ratio of amplitude of temperature oscillation of outside air and amplitude of interior wall surface [8].

Slika 9. Oštećenja fasadnog maltera usled bubrenja drvene građe, mrlje na mestima termičkih mostova (slika: P. Petronijević), Efeka ttermičkog mosta na mestima čeličnih profila kod zidova lakih montažnih konstrukcija [24]

Figure 9. The damage to the facade mortar due to swelling of timber, stains at thermal bridge sites (photo: P. Petronijević), Thermal bridge's effect due to vertical steel studs in a light steel framed walls [24]

4 ANALIZA PRIKUPLJENIH PODATAKA

Sabiranjem ukupnog broja defekata na svim primercima (u okviru jednog uzorka), dobija se ukupan broj oštećenja fasadnih traktova po uzorku. Deleći ukupan broj oštećenja s brojem posmatranih primeraka, dobija se broj oštećenja po jednom fasadnom traktu, tj. po primerku. Rezultati su prikazani primenom u-kontrolne karte za atribute. Podaci su grupisani prema pojedinačnim objektima i prema vrsti fasade, kako bi kontrolne karte imale smisla (Tabela 3).

4 ANALYSIS OF ACQUIRED DATA

By adding up the total number of defects on all specimens (within one sample), a total number of damage of façade tracts per sample is obtained, and by dividing the obtained number with the number of the observed samples, the number of damage per one façade tract, i.e. specimen is obtained. The results are displayed using in the u- control chart for attributes. The data are grouped according to the individual structures and type of the façade, so that the control charts would make sense (Table 3).

Tabela 3. Broj defekata na malterisanim fasadama (2014 god.)
Table 3. Number of defects on plastered facades (2014 year)

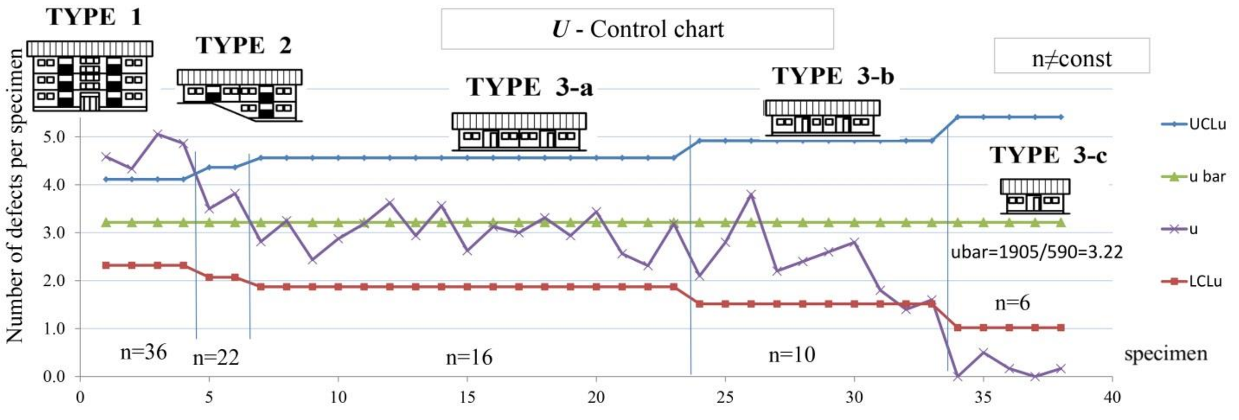
Uzorak *Specimen* (zgrada i tip) *(building and type)*	veličina uzorka *number of specimen* (broj rastera) **n** *(facade pattern)* ***n***	ukupan broj defekata u uzorku **c** *the total number of defects in the specimen* ***c***	broj defekata po primerku **u=c/n** *number of defects per specimen* ***u=c/n***
1-4 (Tip 1) malter 1-4 (*Type 1*) *mortar*	4x36	165 156 182 175	4.58 4.33 5.06 4.86
5, 6 (Tip 1) azbest 5, 6 (*Type 1*) *asbestos*	-	-	-
7-8 (Tip 2) 7-8 (*Type 2*)	2x22	77 84	3.50 3.82
9-26 (Tip 3-a) 9-26 (*Type 3-a*)	17x16	45 52 39 46 51 58 47 57 42 50 48 53 47 55 41 37 51	2.81 3.25 2.44 2.88 3.19 3.63 2.94 3.56 2.63 3.13 3.01 3.31 2.94 3.44 2.56 2.31 3.19
27-37 (Tip 3-b) 27-37 (*Type 3-b*)	10x10	21 28 38 22 24 26 28 18 14 16	2.10 2.80 3.80 2.20 2.40 2.60 2.80 1.80 1.40 1.60
38-42 (Tip 3-c) 38-42 (*Type 3-c*)	5x6	0 3 1 0 1	0.0 0.50 0.17 0.0 0.17
		∑ = 1898	∑ = 101.67 (ŭ=3.22)

Kontrolna karta je urađena po uzoru na istraživanje [17]. Na kontrolnim kartama je neophodno utvrditi centralnu liniju i kontrolne granice. Centralna linija kontrolne karte definiše standard kvaliteta za posmatrane uzorke – zgrade, u pogledu oštećenja posmatranih fasadnih elemenata. Kontrolne granice definišu granice tolerancije kvaliteta, a vrednosti koje prelaze gornju granicu ukazuju na broj oštećenja po primerku (jednom modularnom fasadnom rasteru), odnosno po uzorku (objektu), koji nije posledica normalne standardne eksploatacije zgrade i uobičajenih spoljašnjih uticaja. Razlozi koji su doveli do takvog stanja zahtevaju posebne postupke ispitivanja i analize.

Stabilnost kvaliteta izvedenih radova fasade nakon isteka određenog vremenskog perioda, ocenjuje se pomoću ovako formiranih kontrolnih karata, utvrđivanjem broja tačaka koje se nalaze van kontrolnih granica (slika 10).

The control chart was made using the research as a model[17]. It is necessary to determine the central line and control boundaries on the control charts. The central line of the control chart defines the quality standard for the observed samples – buildings; in terms of damage of façade elements. Control boundaries define the boundaries of quality tolerance, and the values exceeding the upper limit indicate the number of damages per specimen (one modular façade pattern), i.e. per sample (building), which is not the result of normal and standard use of the building and usual external impacts. The reasons causing such state require special research procedures and analyses.

Stability of quality of executed works on the façade after the lapse of a specified time period is assessed using such control charts, by finding the number of points outside the control boundaries (Figure 10).



Slika 10. U kontrolna karta
Figure 10. U control chart

S obzirom na to što je za uzorak konstatovan broj grešaka po primerku i da je broj primeraka po uzorku promenljiv, sračunat je udeo defekata po uzorku i upotrebljena je u-kontrolna karta. Primena *u*-kontrolne karte skoro je identična primeni *c*-kontrolne karte, s tim što se ova karta može koristiti i za praćenje broja defekata po jedinici mere uzorka. *U*-kontrolna karta primenjuje se na primercima koji nemaju za jedinicu komad. Uslovi za primenu u-kontrolnih karti su: $n \neq const$ i $k \geq 15$, a kontrolne granice variraju.

U je količnik između ukupnog broja defekata u uzorku i ukupnog broja primeraka u uzorku.

Regarding that for a sample, a number of errors per specimen has been specified, and that the number of specimens per sample is variable, the share of defects per sample was calculated and used in the research. Use of an*u*- control chart is almost identical to the use of a *c*- control chart, but this chart can be used for monitoring the number of defects per sample measurement unit. *U*-control chart is used for the specimens which are not measured in pieces. Conditions for use of the u-control chart are: $n \neq const$ and $k \geq 15$, and the control limits are variable.

*U i*s the quotient of the total number of defects in the sample and the total number of specimens in a sample.

$$u = \frac{c}{n} = \frac{number\ of\ defects\ found\ in\ the\ subgroup}{subgroup\ size} \tag{1}$$

$$ubar = \sum_{1}^{k} c_i \Big/ \sum_{1}^{k} n_i = \frac{1898}{590} = 3.22 \tag{2}$$

Gornja kontrolna granica UCLu i donja kontrolna granica LCLu date su formulama 3 i 4. Važno je istaći da ukoliko se promeni veličina podgrupe, menjaju se i kontrolne granice.

The upper control limit UCLu and the lower control limit LCLu are given by formulas 3 and 4. It is important to note that if the subgroup size changes from subgroup to subgroup, the control limits will change.

$$UCLu = ubar + 3\sqrt{(ubar/n)} \tag{3}$$

$$LCLu = ubar - 3\sqrt{(ubar/n)} \tag{4}$$

Stabilnost kvaliteta fasadnih površina kod objekata Tip 1 i Tip 3-c van statističke je kontrole. U ovim slučajevima stanje fasada je izvan specifikacionih granica. Uzrok varijacije je stepen kolektivizacije stanovanja. Stanje fasada objekata Tip 1 pokazuje oštećenja iznad uobičajenog nivoa oštećenja. Sa u-kontrolne karte uočava se da smanjenje broja stanova u okviru jednog objekta direktno utiče na poboljšanje opšteg stanja fasade objekta. Adekvatno održavanje i najveća materijalna ulaganja imali su objekti sa samo jednim vlasnikom.

The Stability of the quality of façade surfaces in the Type 1 and Type 3-c buildings is outside the statistic control. In these cases the condition of the facades is outside the specified limits. The cause to this variation is the degree of collectivization of the housing. The Type 1 façade condition shows damage above the usual damage level. From the U-chart, it can be observed that reduction of a number of apartments within one building directly causes improvement of the general condition of the building façade. Adequate maintenance and highest investments was recorded in the buildings with only one owner.

5 DISKUSIJA REZULTATA ISTRAŽIVANJA

Evidentirani defekti na fasadama su statistički podaci dobijeni istraživanjem. Prikazani su u Tabeli 2 i 3. Veličina uzorka je ukupan broj objekata (zgrada). Prosečan broj defekata po tipu objekata dobija se deljenjem ukupnog broja defekata s brojem ispitanih primeraka. Kvalitet fasadnih površina razmatranih uzoraka montažnih objekata ocenjen je analizom dobijenih u-kontrolnih karti. Ustanovljeno je da je potrebno odrediti meru oštećenja, do koje je moguće izvršiti popravke, tako da se dobiju optimalni rezultati u pogledu troškova i trajnosti izvršenih radova. Istraživanje je rađeno s ciljem doprinosa mogućnosti eventualnog otklanjanja oštećenja nastalih na fasadnim površinama nakon više od šezdeset godina eksploatacije objekata. Totalna rekonstrukcija fasadnih zidova neophodna je zbog nedovoljne termičke izolovanosti [11].

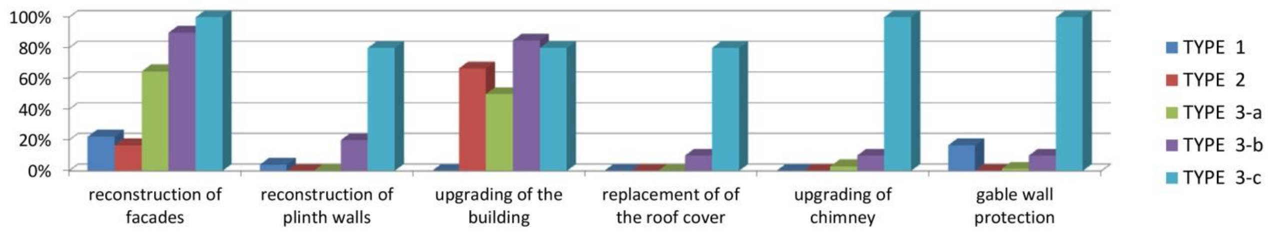
Primećeno je da su neke intervencije urađene prekasno jer je nakon kratke stabilizacije stanja izazvalo

5 RESEARCH RESULTS DISCUSSION

The recorded data – defects on the facades are statistical data obtained by the research. They are presented in Tables 2 and 3. The size of the sample is the total number of structures (buildings). The average number of defects per type of structure is obtained by dividing the total number of defects with the number of researched specimens. The quality of façade surfaces of the observed samples of prefabricated structures is evaluated by analyzing the obtained u- control charts. It was established that it is necessary to determine the degree of damage up to which it is possible to perform repairs, so that optimum results in terms of costs and durability of executed works are obtained. The research was performed with the goal of contributing to potential repair of damage occurring on the façade surfaces after more than 60 years of building service. The total reconstruction of façade walls is necessary for the reasons of inadequate thermal insulation [11].

ubrzanu devastaciju fasada. Klasifikovani su izgrađeni objekti i ustanovljena je tipologija fasadnih zidova, zasnovana na konstrukciji i materijalizaciji fasade. Istraženi su uzroci defekata i dati su tipični primeri oštećenja na betonskim (soklenim) zidovima i fasadnim zidovima. Posebno je analiziran uticaj neadekvatno saniranih fasada i nadograđenih delova objekata na loš vizuelni identitet naselja.

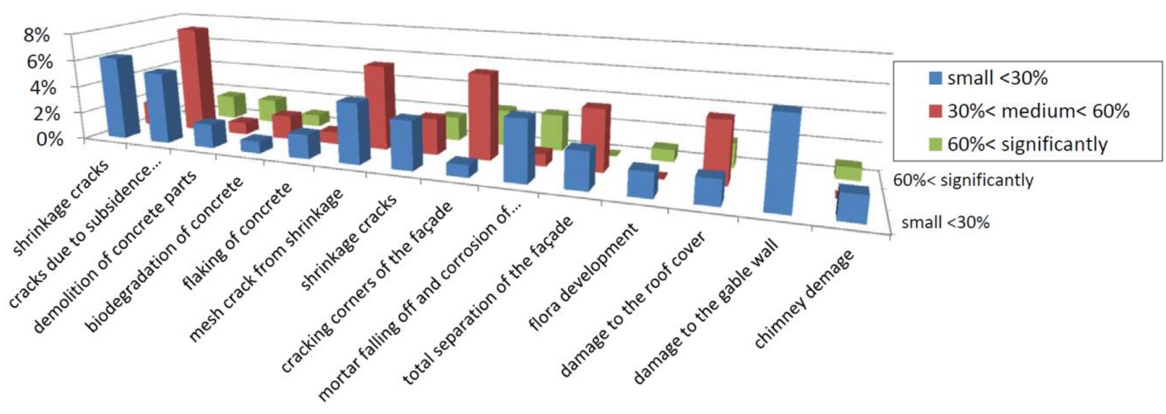
It was noticed that some interventions were made too late, because after a short stabilization, they caused an accelerated devastation of facades. The built structures are classified and the typology of façade walls based on the structure and materialization of facades was established. The causes of defects were explored and typical examples of damage on the concrete (plinth) walls and clad facades were provided. The detrimental impact of inadequately remediated facades and extended sections of structures on the visual identity of the neighborhood was separately analyzed.



Slika 11. Aktivnosti na održavanju zgrada
Figure 11. Building maintenance activities

Tipska grupa fasada podeljena je na zidove obložene malterom i azbestcementnim pločama. Za obe vrste fasadnih zidova data je klasifikacija defekata (pukotine, pukotine usled skupljanja, krivljenje elemenata, razdvajanje azbestnih ploča, korozija armature, ljuskanje, prodiranje vlage, pucanje maltera na mestu nosećih elemenata, oštećenje termoizolacije, biokorozija,...) po ustanovljenim fizičkim, hemijskim, mehaničkim ili biološkim uzrocima oštećenja [13,21].

The standardized group of facades is classified into the walls clad with mortar and with asbestos-cement panels. For both types of façade walls, classification of defects is provided (cracks, shrinkage cracks, bending of elements, delaminating of asbestos panels, reinforcement corrosion, flaking, dampness penetration, cracking of mortar where the structural elements are located, thermal insulation damage, biocorrosion…) according to the established physical, chemical, mechanical or biological damage causes [13,21].



Slika 12. Tipična oštećenja i njihov relativni udeo na omalterisanim fasadama (Apelovac, 2014)
Figure 12. Typical defects and their relative share in plastered façade (Apelovac, 2014)

Defekti fasada podeljeni su u dve grupe: one koje su nastale usled grešaka pri izvođenju i one koje su nastale kao posledica neadekvatnog održavanja ili prekomernog naprezanja. Uzroci karakterističnih oštećenja fasada su identifikovani kao sledeći: neadekvatna termoizolacija, otpadanje maltera na mestu drvenih stubova noseće konstrukcije, mrežaste pukotine usled skupljanja, oštećenja maltera usled prodora vode u termoizolacioni sloj. Na osnovu sprovedenih istraživanja oštećenja montažnih objekata u naselju Apelovac u Nišu, može se

Façade defects are divided into two groups: those occurring due to the construction errors and those occurring as a consequence of inadequate maintenance or overloading. Causes of characteristic façade damage are identified as: inadequate thermal insulation, falling off of mortar at the location of timber posts of the bearing structure, mesh crack resulting from shrinking, mortar damage due to the water penetration into the thermal insulation layer. On the basis of the conducted research of prefabricated buildings damage in the neighborhood zaključiti da su osnovni uzroci oštećenja veoma slični, mada su strukture fasada različite.

Stabilnost kvaliteta fasadnih površina ocenjena je analizom dobijenih grafika u-kontrolnih karti za atribute. Kako ne postoji podatak koji bi ukazivao na očekivana ili uobičajena oštećenja fasadnih površina montažnih objekata nakon višedecenijske eksploatacije, početni podatak predstavljaju centralne linije kontrolnih karata [17].

Prosečna vrednost oštećenja usvojena je kao očekivana. Fasadne površine uzoraka Tip 3-c imaju oštećenja znatno ispod uobičajenog nivoa. Analizom gornjeg nivoa oštećenja zaključuje se da su fasade na zgradama Tip 1 oštećene preko uobičajenog nivoa oštećenja i svi uzorci prelaze gornju kontrolnu granicu. Ovakvo grupisanje podataka pokazuje da postoji više aritmetičkih sredina, koje su posledica neujednačenog kvaliteta tehničkog stanja fasada za ove tri grupe uzoraka. Za dalju analizu, neophodno je stanje fasada razmatrati u zavisnosti od stepena kolektivizacija stanovanja. Evidentno je da je isti tip fasade na objektima veće spratnosti i s većim brojem stambenih jedinica u značajno lošijem stanju u odnosu na pojedinačne i dvojne kuće. Uzrok ove pojave je nemogućnost usaglašavanja svih stanara oko radova na održavanju i saniranju fasada.

of Apelovac in Niš, it can be concluded that the basic causes of damage are very similar, although the façade structures are different.

The stability of quality of façade surfaces is assessed through the analysis of the obtained graphs u– control charts for attributes. Since there are no data indicating the expected or common damage of façade surfaces of prefabricated buildings after a service lasting several decades, the baseline data are the central lines of control charts [17].

The average value of damage is adopted as expected. Façade surfaces of Type 3-c samples have damage considerably below the usual level. By analyzing the upper level of damage, it is concluded that the façades on the Type 1 buildings are damaged past the usual damage level and that all the samples exceed the upper control limit. Such grouping of data indicates that there are multiple arithmetic means which are the consequence of the uneven quality of technical condition of façades of these three groups of samples. For further analysis, it is necessary to consider the façade condition in dependence of the degree of collectivization of housing. It is evident that the same type of façade on the higher buildings with a large number of housing units is in a considerable poorer state of repair in comparison with individual and semi-detached houses. The cause of this is that the tenants could not reach the agreement about necessary maintenance and repair works on the facades.

Slika 13. Intervencije na fasadama objekti Tip 1 (Apelovac, 2014-2019)
Figure 13. Facade interventions on Type 1 structures (Apelovac, 2014-2019)

Upoređenjem stanja omalterisanih fasada u odnosu na prefabrikovane montažne elemenate, zaključujemo da je devastacija fasadnih elemenata od azbestcementa izraženija. Direktna izloženost fasadnog sloja od azbestcementnih ploča atmosferskim i drugim uticajima tokom eksploatacije objekata dovela je do masivnih oštećenja elemenata, pukotina, krivljenja ploča, odlamanja delova, propadanja drvene potkonstrukcije i odvajanja ploča od potkonstrukcije usled korozije zavrtnjeva. Malterisane fasade u zgradi s parnom branom i dodatnom termoizolacijom, prosečno pokazuju za trećinu manje oštećenja od preostalih njoj identičnih zgrada.

S obzirom na to što je ovaj tip fasade koji je analiziran u istraživanju najzastupljeniji u objektima

By comparing the condition of plastered facades with prefabricated elements, it can be concluded that deterioration of façade elements made of asbestos-cement is more pronounced. Direct exposure of the façade layer made of asbestos-cement panels to atmospheric and other impacts during building service led to massive damage of elements, to onset of cracks, panel bending, chipping of parts, decay of timber substructure, separation of panels from the substructure due to the corrosion of bolts. Plastered facades in buildings with vapor barrier and additional thermal insulation, demonstrate on average a third less damage than the other buildings identical to it.

Considering that this type of façade analyzed in the research is most widely present in the lightweight lakog montažnog tipa, realizovanim u drugoj polovini dvadesetog veka, na osnovu posmatranih uzoraka i dobijenih rezultata, može se zaključiti da su generalno potrebne investicije u vidu popravke, obnove i termičke sanacije fasada.

Danas je već uveliko razvijena metodologija reparacije fasada koja donosi trajne rezultate. Razvijeni su modeli analiza koje kombinuju uticaje toplote, vlage i drugih merodavnih faktora, koji omogućavaju valorizaciju kvaliteta fasadnih zidova s funkcionalnog aspekta, pre i posle izvršenih radova [14].

Dosadašnje mere, preduzete u tom pravcu, obuhvataju više arhitektonskih rešenja kao što je dogradnja, dok se u mere poboljšanja kvaliteta omotača zgrade mogu ubrojati razni vidovi zamene ili dodavanja slojeva [9]. Najmanje intervencija primenjeno je na krovnom pokrivaču od salonit-ploča, koji je i nakon šest decenija zadržao skoro sve svoje karakteristike, osim estetskih.

prefabricated buildings built in the second half of the 20th century, based on the observed samples and obtained results, it can be concluded that in general it is necessary to invest in repairs, renovations and thermal renovations of facades.

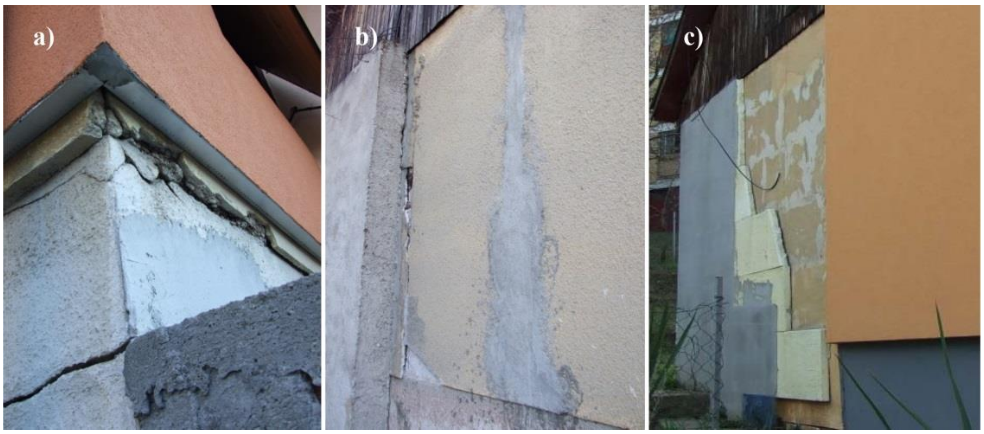
Nowadays, the façade repair methodology with durable results is well developed. The models of analyses which combine the effects of heat, damp and other relevant factors are developed as well which facilitate assessment of the quality of façade walls from the aspect of function, prior and after the performed works [14].

The current measures, to this end, include multiple architectonic designs such as extensions, while the measures of improvement of building cladding quality may include various forms of replacement or addition of layers [9]. There were the least interventions on the roofing cover made of everite panels. After six decades, it retained all its characteristics, except esthetic appearance.

Slika 14. Dogradnja objekata Tip 3-b (Apelovac, 2019)
Figure 14. Upgrades of buildings Type 3-b (Apelovac, 2019)

S obzirom na to što se analizirana naselja nalaze na rubnim delovima grada, poslednjih dvadeset godina su izložena intenzivnoj nelegalnoj gradnji. Dogradnje su izgrađene u potpunom neskladu s postojećim objektima, bez ikakve međusobne usaglašenosti i tipizacije. Novoizgrađeni delovi po gabaritima prevazilaze i nekoliko puta postojeće objekte (Slika 14). Bespravnim nadziđivanjem i doziđivanjem preko postojećih gabarita objekta u potpunosti je naružen izgled i vizuelni identitet naselja.

Regarding that the analyzed districts are on the periphery of the city, they have been exposed to intensive illicit building in the last 20 years. Upgrades were constructed in a total disharmony with the existing buildings, without any mutual coordination and typifying. Newly constructed sections exceed the existing buildings for several times, in terms of their size (Figure 14). Illicit extensions and additions of floors over the existing building dimensions entirely marred the visual identity of the district.



Slika 15. Neadekvatne intervencije na fasadi Type 3-b (Apelovac, 2019)
Figure 15. Inadequate interventions on the façade Type 3-b (Apelovac, 2019)

Na osnovu analiziranih rezultata sprovedenog istraživanja može se zaključiti da su radovi na sanaciji fasada mahom odrađeni nesistematično, od slučaja do slučaja i da su se pokazali kao nezadovoljavajući zbog nedovoljnih prethodnih saznanja o uzrocima i vrstama oštećenja fasada. Dominantan vid saniranja fasada bio je dodavanje kontaktne fasade bez ikakvih prethodnih radova na saniranju oštećenja postojećeg fasadnog omotača (Slika 15). Time su problemi samo sakriveni, ali ne i rešeni [31].

6 ZAKLJUČAK

Nakon kratkog perioda euforije tokom šezdesetih godina, postali su jasni negativni aspekti ove forme montažnih objekata namenjenih kolektivnom stanovanju. Fizički i ekološki problemi, upotreba zagađujućih i materijala za građenje koji nisu trajni, problemi sa održavanjem, prerano propadanje zgrada nakon veoma kratkog perioda – sve ovo je vodilo rastućoj sumnji u kvalitet montažnih objekata. Jedna od posledica slabih karakteristika i lošeg održavanja jeste nezadovoljavajući kvalitet fasada po današnjim merilima. Bitan faktor koji se ne sme izostaviti prilikom analiza jeste relativno nizak socioekonomski položaj stanara. Slab materijalni status stanara je uslovio odabir montažnog tipa objekta u odnosu na klasičnu gradnju koja je skuplja. Ovo je takođe imalo uticaja na kasnije loše održavanje i izostanak periodičnog obnavljanja fasade. Iz grafika 10 nedvosmisleno se može zaključiti da i stepen kolektivizacije ima direktan uticaj na pad održavanja objekata. S povećanjem broja stambenih jednica u okviru jednog objekta znatno se pogoršava trenutno stanje fasada a stepen oštećenja raste. Ova pojava se objašnjava težim dogovorom većeg broja stanara. Uticaj razlike u spratnosti je mali jer su svi objekti s malom spratnošću a tehnološki proces sanacije fasada i cena radova je međusobno približna (jedina razlika je u ceni skele).

U današnjoj savremenoj montažnoj gradnji većina nedostataka je korigovana striktnim poštovanjem pravila građevinske fizike. Najbitnije razlike su primena gipskarton ploča umesto drvenih, pravilna upotreba parnih brana tj. sprečavanja difuzije vodene pare, azbestcementni paneli su u potpunosti izbačeni zbog svoje kancerogenosti a značajna su i poboljšanja hidro i termoizolacionih svojstava savremenih fasadnih obloga.

Based on the analyzed results of the conducted research, it can be concluded that the facade remediation works were mostly performed unsystematically, in a case-by-case fashion, and they proved to be unsatisfactory due to insufficient preliminary knowledge about the causes and types of facade damage. The prevalent form of remediation of facades was adding a contact facade without any previous work on remediating the damage on the existing facade cladding (Figure 15). This only concealed the problems, and failed to solve them [31].

6 CONCLUSION

After a short period of euphoria during the 60's the negative aspects of this form of prefabricated buildings intended to collective housing became evident. Physical and environmental problems, usage of polluting and non-durable building materials, problems with maintenance, excessively early deterioration of buildings after a very short period – all this led to a growing distrust in the quality of prefabricated buildings. One of the consequences of weak characteristics and poor maintenance are unsatisfactory quality of facades by the contemporary standards. An important factor which should be included in the analysis is a relatively low socio-economic position of the tenants. The low financial status of the tenants necessitated the selection of the prefabricated type of buildings as opposed to the classical construction which is more expensive. This also had effects on the later poor maintenance and lack of periodical renovation of the façade. In reference to the chart 10 it can undoubtedly be concluded that the degree of collectivization has a direct impact on the low level of building maintenance. Increased number of housing units in a single building considerably aggravates the current condition of facades, and the degree of damage increases. This phenomenon is explained by the failure of a large number of tenants to reach an agreement on maintenance works. The number of floors makes a small difference, because all the buildings have few floors and the technological process of remediation of facades and works cost is approximately the same (the only difference being in the cost of scaffolding).

In the contemporary prefabricated construction most of the defects is corrected by strict observation of the building physics rules. The most prominent differences are usage of gypsum-cardboard panels instead of timber ones, correct utilization of vapor dams, i.e. prevention of water vapor diffusion; asbestos-cement panels are completely cancelled because of their carcinogenic properties, and considerable improvements of water and thermal insulation properties of contemporary façade claddings have been made.

7 LITERATAURA REFERENCES:

[1] American Society for Testing of Materials International, ASTM Standard E2270-05 Standard Practice for Periodic Inspection of Building Facades for Unsafe Conditions

[2] Bartiaux, F. et al., Socio-technical factors influencing residential energy consumption (Serec), Part 1: Sustainable production and consumption patterns, Scientific support plan for a sustainable development policy (SPSD II), UCL, VITO and Danish Building Research Institute, January 2006.

[3] Curwell, S. et.al.,(2008), Hazardous Building Materials, Spoon Press, New York, USA.

[4] Folić, R., (2002) Održavanje konstrukcija pregled stanja i izveštaj o prispelim radovima. Građevinskim aterijali i konstrukcije, 45(3-4), 41-53.

[5] Folić, R., Kurtović - Folić, N., "Pouzdanost i održavanje stambenih zgrada" Tehnika – Naše građevinarstvo 49 (1995) 9-10, str. NG1-NG11

[6] Folić, R., Laban, M., Milanko, V., Analiza pouzdanosti i održivosti krupno panelnih stambenih blokova u Sofiji, Skoplju i Novom Sadu, Factauniversitatis - series: Architecture and Civil Engineering, 9(1), 161-176. (2011)

[7] Godish, T., Sick Buildings: definition, diagnosis and mitigation, Lewis Publ. Boca Raton, USA, (1995)

[8] Grabovski, B., Klasična ili montažna gradnja, Građevinar, 60 (1), pp. 81-84, (2008)

[9] Guidance: Securing parapets and facades on unreinforced masonry buildings, Advice for building owners, councils and engineers. Ministry of Business, Innovation and Employment,. New Zealand, 85 p., (2018)

[10] Hasan, A., (1999) Optimizing insulation thickness for buildings using life cycle cost, Appl Energy 63, pp. 115–24

[11] Hens, H., Ali Mohammed F., (1993) Thermal insulation quality and energy use in existing housing stock. CIB W64 Energy efficient energy symposium, Stuttgart

[12] Hens, H., Parijs, W. &Deurinck, M. (2009): Energy consumption for heating and rebound effects. Energy and Buildings, 42, 105-110

[13] Henshell Justin, (2015), FAIA, FASTM, Analyzing Building Failures: Tools and Methodologies, pp 28-34

[14] Huovinen, S., Bergman, J., Hakkarainen, H., Development of a new methodology to analyse the durability of fasade repair and retrofitting systems, Deterioration defects and repair methods of fasades, Final report, Laboratory of structural engineering and buildin physics, Helsinki University of Technology, Finland, (1998)

[15] Itard, L, Meijer, F., Vrins, E., Hoiting, H., Building Renovation and Modernisation in Europe: State of the art review (2008) ERABUILD final report, OTB TU Delft, January 2008.

[16] Kimball, J., Beasley, P.E., and Mark K. Schmidt, S. E. Building Facades, (chapter 8), pp. 207-233.

[17] Laban, M. (2006). Kontrola kvaliteta prefabrikovanih betonskih fasadnih elemenata nakon višegodišnje eksploatacije. Građevinski materijali i konstrukcije, 49(1-2), 3-19.

[18] Martinez A, Patterson M, Carlson A et al (2015) Fundamentals in façade retrofit practice. Procedia Eng 118:, pp. 934–941

[19] Milanko V., Laban M., Karabasil, D., (2006) Fire safety problems of residential towers, 2nd international scientific conference FIRE ENGINEERING, Lučenec, Slovakia, Proceedings, pp. 255.-261

[20] Moghtadernejad, S., Design, inspection, maintenance, life cycle performance and integrity of building facades, Department of Civil Engineering and Applied Mechanics McGill University Montreal, Quebec, Canada Apr. 15, 2013

[21] Petronijević, P., Momčilović-Petronijević, A., (2019) Analysis of façade damage of prefabricated houses after long lasting use, 11th international conference Assessment, maintenance and rehabilitation of structures and settlements, Zlatibor, Serbia, 19-21. jun 2019. Conference proceedings, pp 73-82.

[22] Peuhkuri, R., Vares, S., Pulakka, S., et al., (2012), Sustainable refurbishment of exterior walls and building facades, Final report, Part C – Specific refurbishment concepts, Espoo 2012. VTT Technology 35. 198 p. + app. 1 p.

[23] Romila, C. (2013), General principles for the design and construction of ventilated facades, buletinulinstitutuluipolitehnic Din Iaşi, Publicat de UniversitateaTehnică "Gheorghe Asachi" din Iaşi, Tomul LIX (LXIII), Fasc. 3, 2013, SecţiaConstrucţii. Arhitectură, pp. 161-169.

[24] Santos, P.; Lemes, G.; Mateus, D. Thermal Transmittance of Internal Partition and External Facade LSF Walls: A Parametric Study. *Energies* 2019, 12, 2671.

[25] Saussay, A., Saheb, Y. &Quirion, P., (2012): The Impact of Building Energy Codes on the Energy Efficiency of Residential Space Heating in European Countries - A Stochastic Frontier Approach. International Energy Program Evaluation Conference. Rom

[26] Savov, R., Beloeva, V., Refurbishment of Social Buildings in Bulgaria – Specific problems and Solutions, The CRES conference proceedings "Retrofitting of Social Housing-Financing and Policy Options", 7-8 November 2006, Thessaloniki, Greece

[27] Schiessl, P., et al., (2003), Prediction of service Life of Existing Structures by Applying Probabilistic Service Life Design (SLD) Procedures, presented at the Proceedings of the International Conference ICACS 2003, China.

[28] Surface condition and mouldgrowth in traditionally-built dwellings (1990), BRE Digest 297.

[29] Ucar, A., Balo, F., (2010), Determination of the energy savings and the optimum insulation thickness in the four different insulated exterior walls Renew Energy 35, pp. 88–94.

[30] Viitanen, H. &Ritschkoff, A. 1991. Mould growth in pine and spruce sapwood in relation to air humidity and temperature. Uppsala. The Swedish University of Agricultural Sciences, Department of Forest Products. Report no 221. 40 p + app 9 p

[31] Waldum A. M. Restoration of masonry facades. Renders and final coats in a severe climate. pp. 1128- 1135

REZIME

ANALIZA OŠTEĆENJA FASADA ZGRADA LAKOG MONTAŽNOG SISTEMA NAKON DUGOGODIŠNJE EKSPLOATACIJE

Predrag PETRONIJEVIĆ
Ana MOMČILOVIĆ PETRONIJEVIĆ

U ovom radu analizirana su oštećenja fasada individualnih i kolektivnih stambenih objekata u montažnom naselju Apelovac u Nišu. Sprovedena je evaluacija tehničkih i konstruktivnih karakteristika fasadnih zidova prema kriterijumima trajnosti i održivosti. Nakon više od pedeset godina eksploatacije, ovi objekti u većini slučajeva i dalje ispunjavaju svoju osnovnu namenu, ali njihove fasade više ne zadovoljavaju zahteve kvaliteta, što je u jednoj meri posledica oštećenja tokom vremena ali i strožih zahteva u pogledu tehničkih karakteristika i izgleda zgrada. Fasadni zidovi, urađeni po tadašnjoj građevinskoj praksi, u potpunosti su izgubili svoje fizičko-tehničke i likovno-estetske funkcije.

Ključne reči: Oštećenje fasada, montažne kuće, trajnost, održivost, obnova

ABSTRACT

ANALYSIS OF FACADE DAMAGE OF LIGHTWEIGHT PREFABRICATED HOUSES AFTER LONG LASTING USE

Predrag PETRONIJEVIC
Ana MOMCILOVIC PETRONIJEVIC

This paper analyzed the damage of facades of individual and collective housing buildings in pre-fabricated neighborhoods on Apelovac hill in Nis. An evaluation of technical and structural characteristics of facade walls according to the durability and sustainability criteria has been conducted. After over 50 years of service, these buildings, in most cases are still fit for their primary purpose, but their facades fail to meet the quality standards any longer. It is in part the result of damage sustained in time, but also of more stringent requirements regarding technical characteristics and building appearance. Facade walls constructed according to the building practice of the day completely lost their physical-technical and visual-esthetic functions.

Key words: Façade damage, prefabricated houses, durability, sustainability, restoration

PROŠLOST I NEKI AKTUELNI PROBLEMI ZAŠTITE GRADITELJSKOG NASLEĐA OD ZEMLJOTRESA

PAST AND SOME TOPICAL PROBLEMS OF BUILT HERITAGE PROTECTION FROM EARTHQUAKES

Nađa KURTOVIĆ-FOLIĆ
Radomir FOLIĆ

PREGLEDNI RAD
REVIEW PAPER
UDK:624.042.7:699.841
doi:10.5937/GRMK2002027K

1 UVOD

Tokom cele istorije graditeljstva, građevine su bile izložene brojnim devastacijama prouzrokovanim prirodnim i ljudskim faktorima. Savremeni teoretičari arhitekture često raspravljaju o tome kakve bi bile potencijalne mogućnosti graditeljskog razvoja da povremeno nije dolazilo do njegovog diskontinuiteta izazvanog nepogodama. Vremenske i prostorne praznine (cezure) u istoriji graditeljstva bile su, povremeno, izazvane upravo katastrofalnim zemljotresima, koji su prekidali razvojnu nit graditeljstva mnogih generacija. Velike prirodne nepogode često su bile uzrok razaranja, ne samo pojedinačnih građevina već i čitavih naselja. Među najrazornije sile koje deluju, nesumnjivo, ubrajaju se zemljotresi. Suočeni s tom opasnošću, ljudi su na tim područjima prvo i počeli da stvaraju oblike konstrukcija koje su bile najpogodnije da "prežive" ili bar ublaže posledice zemljotresa. Posle takvih nesreća, pojedina rešenja su usavršavana ili su stvarani potpuno novi graditeljski oblici, da bi se gubici ublažili. O tome postoji niz dokaza, a savremena proučavanja pronalaze stalno nove podatke o izboru materijala i tehnikama građenja. To je od posebnog značaja za do danas očuvano graditeljsko nasleđe.

Posle zemljotresnih dejstava i oštećenja koja ona izazivaju, društva su različito reagovala, opredeljujući se za uklanjanje svih građevina i to u celosti ili za njihovu obnovu u obliku koji su imale pre zemljotresa. Savremena

Dr Nađa Kurtović-Folić, redovni profesor Univerziteta u Novom Sadu, FTN, Dpartman za arhitekturu
Dr Radomir Folić, profesor emeritus Univerziteta u Novom Sadu, FTN, Dpartman za građevinarstvo i geodeziju

1 INTRODUCTION

Throughout the history of building, structures have been exposed to numerous devastations caused by natural and human factors. Contemporary theorists of architecture often discuss what the potential possibilities of architectural development would be if there were no occasional discontinuities caused by disasters. Temporal and spatial gaps (caesuras) in the history of construction were, occasionally, caused by catastrophic earthquakes, which interrupted the thread of construction development for many generations. Major natural disasters were often the cause of destruction, not only of individual buildings but also of entire settlements. Undoubtedly, earthquakes are among the most destructive forces at work. Faced with this danger, the people in these areas first began to create the forms of structures that were most suitable to "survive" or at least mitigate the effects of the earthquakes. After such accidents, certain designs were improved or completely new forms of construction were created, in order to mitigate the losses. There is a body of evidence about that, and contemporary research studies are constantly finding new data on the choice of materials and construction techniques. It is particularly important for the built heritage preserved to this day.

Human societies had different reactions after the earthquakes and the damage they caused, opting either for the complete removal of all buildings or for their reconstruction in the distinctive shape they had had

Dr Nadja Kurtovic-Folic, full professor, University of Novi Sad, Faculty of Technical Sciences, Dpartment of Architecture
Dr Radomir Folic, profesor emeritus, University of Novi Sad, Faculty of Technical Sciences, Department of Civil Engineering and Geodesy

praksa zaštite graditeljskog nasleđa predviđa blagovremeno ojačanje konstruktivnog sklopa, koji po svojim tehničkim rešenjima nije bio predviđen da izdrži jake seizmičke udare. S druge strane, nekoliko snažnih zemljotresa u našem okruženju opominje da treba ozbiljnije pristupiti istraživanju zemljotresa kroz istoriju područja i formiranju baze podataka za pojedinačne spomenike kulture. Tokom istraživačkih radova na građevinama nailazi se na starije intervencije, od kojih su se neke, verovatno, odnosile na ojačanja i popravke oštećenja izazvanih zemljotresom.

Na osnovu različitih statističkih podataka koji potiču iz zemalja Evropske unije, zemalja Azije, Južne i Severne Amerike, sačinjen je savremeni popis prirodnih katastrofa koje su rangirane prema relativnoj učestalosti i obimu štete koju nanose kulturnom nasleđu [4], [9], [15–18], [22], [49], [55], [59] i [66–67]. U tom popisu, prvo mesto dodeljeno je zemljotresima, a potom slede poplave, uragani, tajfuni i cikloni (koji se međusobno objedinjuju), dalje slede klizišta, oluje, tornada, cunamiji i, na kraju, erupcije vulkana [3] i [19]. Danas se ovi klasični obrasci prirodnih katastrofa u mnogim zemljama često dopunjavaju i klimatskim promenama, kao globalnim oblikom agresivnih prirodnih efekata.

Nepredvidljivost zemljotresa uticala je na to da su ljudi od najranijih vremena bili svesni da se, na neki način, treba obezbediti od stihije. Oblikovanje građevina koje je trebalo da budu što sigurnije bilo je tako, s jedne strane, povezano s mitovima, legendama i strahovima koje je zemljotres izazivao kod ljudi, a s druge strane intuitivno osiguravano, tako da se toj nesreći građevine odupru i da se izbegnu posledice razaranja. U borbi da se odbranimo od zemljotresa od posebnog je značaja proces postepenog uočavanja i razumevanja porekla zemljotresa i efekata koje on proizvodi. Teorija konstrukcija omogućila je formulisanje matematičkih modela za predviđanje ponašanja različitih tipova konstrukcijskih elemenata i/ili sistema pod zemljotresima. Pre njihovog formiranja postojali su različiti načini za kodifikaciju iskustva koje se postepeno sticalo prilikom gradnje, a trebalo je da služi kao vodič za projektovanje i izvođenje sve kvalitetnijih i na zemljotres otpornijih građevina.

Da bi se razumeli napori starih graditelja pri stvaranju seizmički otpornih građevina, treba imati na umu da se njihova polazišta znatno razlikuju od današnjih. Dok savremeni graditelji, na osnovu proračuna i modela, unapred tačno znaju šta na građevini treba da bude pojačano kako bi se prihvatila seizmička dejstva, stari graditelji su seizmički otpornu građevinu stvarali tako što su pravilno obrađivali svaki njen deo, od pripreme terena, izvođenja temelja, sve do oblikovanja svih detalja do krova. Promišljeno su birani i ugrađivani materijali na mesta uslovljena njihovim oblikom i strukturom da bi se obezbedila seizmička stabilnost. To je predmet zemljotresnog inženjerstva čiji tragovi se nalaze i u dalekoj prošlosti.

U celoj istoriji građenja mogu se izdvojiti tri potpuno različita pristupa pri stvaranju seizmički otpornih građevina [9] i [59]:

before the earthquake. The contemporary practice of protection of architectural heritage focuses on the timely strengthening of the structural systems, whose technical design solutions were not intended to withstand strong seismic shocks. On the other hand, several strong earthquakes in our close surroundings warn us that earthquake research through the history of the area and the formation of a database for individual cultural monuments should be approached more seriously. During the research works on the buildings, older interventions were encountered, some of which were probably related to the strengthening and repair of damage caused by the earthquake.

Based on various statistical data originating from the countries of the European Union, Asia, South and North America, a modern list of natural disasters has been made, ranked according to the relative frequency and extent of damage to cultural heritage [4], [9], [15-6]. [22], [49], [55], and [66-67] In that list, the first place has been assigned to earthquakes, followed by floods, hurricanes, typhoons and cyclones (which unite with each other), followed by landslides, storms, tornadoes, tsunamis and, finally, volcanic eruptions [3] and[19]. Today, these classic patterns of natural disasters in many countries are often supplemented by the climate change, as a global form of aggressive natural effects.

The unpredictability of earthquakes made people from the earliest times become more aware of the need to protect themselves from the elements. The design of buildings that were supposed to be as safe as possible, was, on one hand, related to the myths, legends and fears caused by the earthquake in people, and on the other hand intuitive, in the sense that buildings could resist the disaster and avoid the destructive effects. In the struggle to tame the nature, the process of gradual observation and understanding of the earthquake origin and the effects it produces is of special importance. Structural theory has made it possible to formulate mathematical models for predicting the behaviour of different types of structural elements and/or systems in earthquakes. Prior to their emergence, there were various ways to codify the experience that was gradually gained during construction, and it was to serve as a guide for the design and construction of increasingly high-quality and earthquake-resistant buildings.

In order to understand the efforts of ancient builders in creating seismically resistant structures, it should be borne in mind that their starting points were significantly different from the present day ones. While modern builders, based on calculations and models, know in advance exactly what should be reinforced on a building so that it could resist seismic effects, builders in the past created a seismically resistant building by properly treating every part of it, from site preparation, construction of the foundations, to shaping all the details up to the roof. Materials were carefully selected and installed in place, depending on their shape and structure, and seismic stability was ensured. It is the subject of earthquake engineering, traces of which can be found in the distant past.

Throughout the history of construction, three completely different approaches to the creation of seismically resistant structures can be distinguished [9] and [59]:

• Najčešći pristup sastoji se u podizanju građevine s nosivošću koja omogućuje da podnese zemljotres bez značajnijih oštećenja. Ovaj način građenja primenjivao se na svim područjima za koja je od davnina poznato da su trusna.

• Drugi pristup zasniva se na sprečavanju čvrste veze između tla i građevine, jer je poznato da čvrsta veza između građevine i trusnog zemljišta, povećava efekte seizmičkih pokreta/dejstva na zgradi, a slabija veza ih smanjuje. Kod istorijskih građevina, slabljenje ove veze postizalo se različitim načinima, od nabacivanja slojeva peska u najstarijim vremenima, preko glinenih jastuka do utežućih pojaseva i drugih klizećih elemenata. Danas se ovaj način takođe primenjuje i mnogi ga nazivaju pasivnom zaštitom od zemljotresa.

• Treći pristup je upravo suprotan prethodnom, jer zahteva određena rešenja koja mogu promeniti dinamičke karakteristike građevine, da bi se izbeglo da uđe u rezonantno područje. Smatra se da je to i najstariji metod zaštite od zemljotresa, jer svaka građevina može izmeniti svoju krutost čime se modifikuje njena konstrukcija, a time i perioda njenih prirodnih vibracija. Pomerajući se izvan periodâ vibracija očekivanog seizmičkog dejstva, građevina se izvlači iz tog opasnog stanja [59].

O značaju organizovane utemeljene zaštite graditeljskog nasleđa svedoči i formiranje istraživačkih projekata u Evropi, npr. NIKER [84] i PERPETUARE [70]. Opšti aspekti kulturnog nasleđa i prirodne nepogode analizirani su u [22] i [97] i uz analizu oštećenja nasleđa u seizmičkim područjima u [15–16], [27] i [116]. Iskustva seizmičke zaštite objekata kulturnog nasleđa nakon zemljotresa u Kraljevu prezentirana su u [42]. Ublaženje oštećenja razmatrano je u [114] i [116]. Zaštita u zemljama u razvoju razmatrana je u [58]. Seizmički rizik kulturnog nasleđa razmatran je u [93]. Analiza metoda primenjivanih u zemljotresnom inženjerstvu i mogućnosti njihove zaštite prikazani su u [34]. Metode pregleda objekata kulturnog nasleđa u Italiji prikazane su u [1], u Novom Zelandu [3], u Brazilu [13], u Kini [116] i u Rumuniji [81]. Procena kamenih istorijskih zgrada prikazana je u [105]. Procena i povredljivost predmet su radova [10], [17], [28], [86], [108], [111] i [112], a postupci dijagnoze stanja predmet su rada [10]. Procena i pojačavanje razmatrani su u [2] i [41] u Švajcarskoj [40], a prilagodljivost kulturnog nasleđa u [24]. Povredljivost zidanih istorijskih objekata razmatrana je u [4], [6] i [91], a monumentalnih zgrada u Švajcarskoj u [28]. Informacije za vlasnike tretirane su u [31]. Integritet je razmatran u [71]. Značajan doprinos eksperimentalnim ispitivanjima graditeljskog naleđa dali su istraživači Instituta za zemljotresno inženjerstvo i inženjersku seizmologiju (IZIIS) iz Skoplja, na vibro-platformi [60]. Projektovanje seizmički otpornih zgrada razmatrano je u [82] i [98], sanacija i pojačavanja u [99], a *retrofitting* u [87]. Procena rizika kulturnog nasleđa tretirana je u [100]. Seizmičke performanse istorijskih i monumentalnih građevina razmatrane su u [103].

• The most common approach is to erect a building with a load-bearing capacity that allows it to withstand an earthquake without significant damage. This method of construction was implemented in all areas that had been known as seismic since the ancient times.

• The second approach is based on preventing a strong connection between the ground and the building, because it is known that a strong connection between the building and seismic ground increases the effects of seismic movements/actions on the building, and a weaker connection reduces them. In historical buildings, the weakening of this connection was achieved in various ways, throwing layers of send in the earliest times, through clay beds to weighting belts and other sliding elements. Nowadays, this method is also used and it is called by many the passive earthquake protection.

• The third approach is exactly the opposite of the previous one, because it requires certain designs that can change the dynamic characteristics of the building, in order to avoid entering the resonant area. It is considered to be the oldest method of earthquake protection, because each building can change its rigidity, which modifies its structure, and thus the period of its natural vibrations. By displacing outside the vibration periods of the expected seismic action, the building is pulled out of that dangerous state [59].

The importance of organized protection of architectural heritage is evidenced by the formation of research projects in Europe NIKER [84] and PERPETUARE [70]. General aspects of cultural heritage and natural disasters were analyzed in [22] and [97] and with the analysis of heritage damage in seismic areas in [15-16], [27] and [116]. Experiences of seismic protection of cultural heritage buildings after the earthquake in Kraljevo are presented in [42]. Damage mitigation was discussed in [114] and [116]. Protection in developing countries is discussed in [58]. The seismic risk of cultural heritage is discussed in [93]. An analysis of the methods applied in earthquake engineering and the possibilities of their protection are presented in [34]. Methods of inspecting Cultural Heritage sites in Italy are presented in [1], in New Zealand in [3], and in Brazil in [13], in China [116] and in Romania [81]. An assessment of stone historic buildings is presented in [105]. Assessment and vulnerability are the subject of papers [10], [17], [28], [86], [108], and [111-112], and procedures for diagnosing the condition of [10]. Assessment and reinforcement were discussed in [2] and [41] in Switzerland [40], and cultural heritage resilience in [24]. The vulnerability of masonry historic buildings was discussed in [4], [6] and [91], and of monumental buildings in Switzerland in [28]. Information for owners is treated in [31]. Integrity was discussed in [71]. A significant contribution to the experimental research of architectural heritage was made by IZIIS from Skopje, especially on the vibro-platform (Shaking Table Testing) [60]. The design of seismically resistant buildings was discussed in [82] and [98], rehabilitation and strengthening in [99], and retrofitting in [87]. The seismic performance of historic and monumental buildings is discussed in [103].

Za zaštitu graditeljskog nasleđa od posebnog značaja su zidani objekti čija su analiza i ostali aspekti projektovanja šire tretirani u mnoštvu referenci, naročito u [19], [47], [90] i [110], a stari zidani objekti su šire tretirani u [52] i na Seminaru [2]. Odgovor starih zidova u ravni razmatran je u [121]. Prikaz i analiza geometrijskih karakteristika zidanih spomenika kulture u Santjagu–Čile predmet je rada [56], a prikaz kriterijuma seizmičke analize Crkve u Sv. Domingu, dat je u radu [57]. Priprema za ublažavanje posledica zemljotresa u Istočnoj Aziji i Pacifiku opisana je u [55], redukcija gubitaka u [15], a redukcija povredljivosti i pojačavanje istorijskih zgrada u [73]. Egipatske piramide, sa spuštanjem težišta što niže čime se povećava seizmička otpornost, razmatrane su u [37] i [53]. Pojačavanje kontraforima predmet je rada [80]. Šira razmatranja zaštite starih objekata arhitekture predmet su radova [9], [59] i [66], a spomenika u Jermeniji u [48]. Vremenom su razvijene i metode zaštite uvođenjem bazne izolacije [25], [44], [46], [88] i [105], a zaštita i restauracija dati su u [49]. Razvoj zaštite u Japanu opisan je u [85]. Prioritizacija za pojačavanje kulturnog nasleđa opisana je u [7]. Pouke iz dogođenih zemljotresa razmatrane su u [74]. Studije slučaja sa detaljnim analizama, za različite objekte: kulturno nasleđe grada Mendelej [87], minaret [79], Crkva Sv. Sofije [75], zamak [76], crkva u Meksiku [92], zamena kamena pri konzervaciji istorijskih zgrada. Konzervacija je razmatrana u [7], [20], [63] i [114], a njoj je posvećena Konferencija [107]. Problemi procene ponašanja zidanih zgrada i njihove restauracije prema Preporukama Međunarodnog saveta za spomenike i spomeničke celine (ICOMOS) su detaljno prikazani u [17]. Veza prirodnih nepogoda nasleđa u turističke svrha opisana je u [61].

U ovom radu sažeto je prikazan razvoj zemljotresnog inženjerstva, od najstarijih vremena do današnjih dana. Prikazani su neki objekti i mehanizmi koji obezbeđuju otpornost i/ili ublažavanje (mitigaciju) dejstva zemljotresa. Izlaganja su propraćena i osvrtom na naše i internacionalne tehničke propise koji su korišćeni ili se koriste za projektovanje seizmički otpornih konstrukcija. O tome je sačinjen širi popis literature kojom su obuhvaćeni očuvanje, konzervacija, stabilizacija, i mnogi aspekti u vezi s pregledom objekata posle zemljotresa, procenom oštećenja, povredljivošću i procenom ponašanja graditeljskog nasleđa pod seizmičkim dejstvima. Komentarisani su i neki reprezentativni objekti koji su opisani u citiranoj literaturi, uglavnom zidani objekti. Pomenuti su neki materijali i tehnike zaštite graditeljskog nasleđa. U radu nisu obuhvaćeni novi materijali, veće popravke, restauracije, rekonstrukcije, pojačavanja, adaptacije i niz drugih mera nakon zemljotresa, koje će biti predmet drugog rada.

Masonry buildings are especially important for the protection of the built heritage whose analysis and other aspects of design are more widely treated in many references, especially in [19], [47], [90] and [110], and old masonry buildings are more widely treated in [52], and at the Seminar [2]. The response of the old walls in the plane is discussed in [121]. The review and analysis of the geometric characteristics of the masonry cultural monuments in Santiago-Chile is the subject of the paper [56], and the review of the criteria for the seismic analysis of the Church in St. Domingo of [57]. Preparations for earthquake mitigation in East Asia and the Pacific are described in [55], loss reduction in [15], and vulnerability reduction and strengthening of historic buildings in [73]. The Egyptian pyramids, with the centre of gravity lowered as low as possible, which increases seismic resistance, were considered in [37] and [53].Strengthening with buttresses is the subject of the paper [80]. A broader consideration of the protection of old architectural structures is the subject of papers [9], [59] and [66], and monuments in Armenia in [48]. Over time, protection methods have been developed by introducing the base insulation [25], [44], [46], [88], and [105], and protection and restoration in [49]. The development of protection in Japan is described in [85]. Prioritization of cultural heritage reinforcement is described in [7]. Lessons from the earthquakes were discussed in [74]. Case studies with detailed analyzes of different structures: the cultural heritage of the city of Mandalay [87], the minaret [79], for the Church of St. Sophia [75], Castle [76], Churches in Mexico [92], stone replacement in the conservation of historic buildings [106]. Conservation is discussed in [7], [20], [63], [114] and the Conference [107] was dedicated to it. Problems of assessing the behaviour of masonry buildings and their restoration according to the ICOMOS Recommendations are described in detail in [17]. The connection between natural disasters and heritage tourism is described in [61].

This paper summarizes the development of earthquake engineering since ancient times to the present day. Some structures and mechanisms that provide resistance and/or mitigation of earthquake effects are presented. The presentation has been accompanied by a review of our and international technical regulations that have been used or are being used for the design of seismic structures. A broader list of references has been prepared on this topic, which includes preservation, conservation, stabilization, and many aspects related to the inspection of buildings after the earthquake, assessment of damage, vulnerability and assessment of the behaviour of architectural heritage structures under seismic action. Some representative buildings described in the cited literature were also commented upon, mostly masonry buildings. New materials and techniques for the protection of architectural heritage are also included. The paper fails to include some materials, repairs, restorations, reconstructions, reinforcements, adaptations and other measures that will be the subject of another paper.

2 NAJSTARIJA ISKUSTVA U BORBI PROTIV ZEMLJOTRESA

Najstarije, praistorijske konstrukcije svakako nisu smišljane s namerom da budu zemljotresno otporne, pa ipak izbor teških, kamenih blokova koji su formirali praistorijske megalitske grobne komore, dolmene, uglavnom zadovoljava principe seizmički otpornih građevina. Ove džinovske strukture istovremeno ukazuju na način razmišljanja praistorijskih ljudi, uglavnom iz doba neolita, koji je, bez obzira na geografski položaj gde su ti ljudi živeli, bio skoro identičan. Svest da je potrebno upotrebiti što teže opterećenje da bi se stabilizovali vertikalni elementi uočljiva je kod svih očuvanih dolmena, a pojedine pokrivne ploče bile su teške preko 86 tona (slika 1a), (slika 1b). Slični su i dolmen u Portugaliji (slika 2a), i u Južnoj Koreji (slika 2b).

2 THE EARLIEST EXPERIENCES IN THE PROTECTION AGAINST EARTHQUAKE

The earliest, prehistoric structures were certainly not designed to be earthquake-resistant, and yet the choice of heavy, stone blocks that formed the prehistoric megalithic burial chambers, dolmens, generally satisfies the principles of seismically resistant structures. At the same time, these giant structures indicate the way of thinking of prehistoric people, mainly from the Neolithic era, which, regardless of the geographical position where these people lived, was almost identical. The awareness that it is necessary to use as heavy a load as possible to stabilize the vertical elements is noticeable in all preserved dolmens, and some cover slabs weighed over 86 tons (Figure 1a), and (Figure 1b). The dolmens are similar in many parts of the world such as in Portugal (Figure 2a), and in South Korea (Figure 2b).


Slika 1. Dolmen Madlen, Francuska; Dolmen Pentru Ivan, Velika Britanija [122] i [123]
Figure 1. Dolmen de la Madeleine, France (a); PentreIfan Dolmen, Great Britain (b), after [122] and [123]

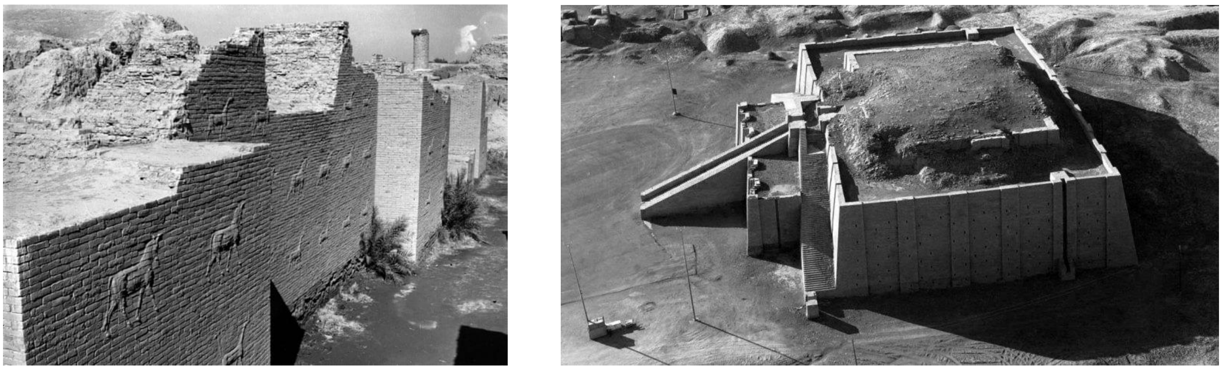

Slika 2. Dolmen Anta da Pedra da Orka, Portugalija; Dolmen Gočang, Južna Koreja, prema [124] i [125]
Figure 2. Dolmen Anta da Pedra da Orca, Portugal (a); Dolmen Gochang, South Korea (b), after [124] and [125]

Hronološki, prva upotreba zidova kruće obloge i mekog unutrašnjeg jezgra zabeležena je u Mesopotamiji i datira iz perioda stvaranja ove civilizacije, oko 3.700 p. n. e. Gradske zidine od kamena počele su da se formiraju i ranije, ali su njihove dimenzije bile tako velike, a kameni blokovi se oslanjali jedan na drugi, a pod silama pritiska i trenjem (formira se prirodni zglob), slično praistorijskim zidinama (slika 3). Zidovi zgrada i utvrđenja su i u kasnijim periodima bili značajne debljine, u rasponu od 4 do 20 m. Spoljna obloga je bila od nepečene opeke, a jezgro od trpanca različitog sastava. Hramovi tipa zigurata bili su obloženi, takođe, nepečenom opekom, retko kamenom, ali ispuna je bila od nasute zemlje ili nepečene opeke i svojom ogromnom težinom i oblikom bila je otporna na zemljotres.

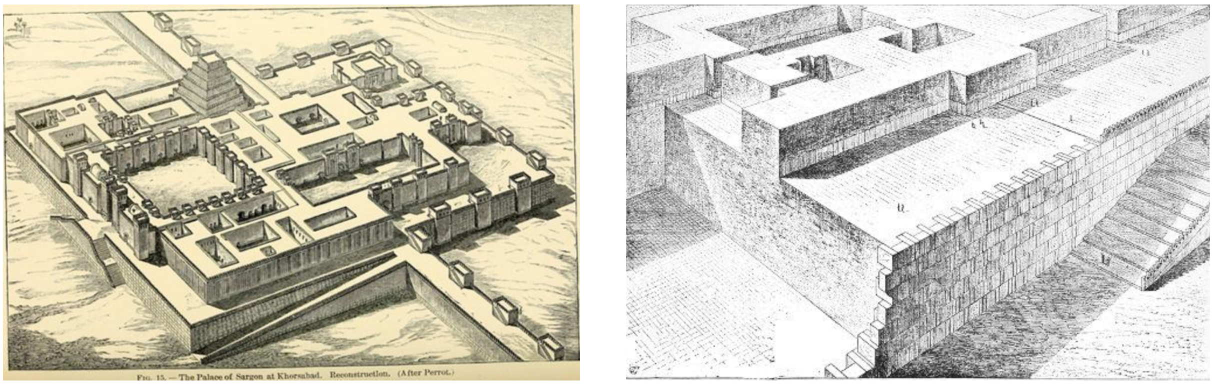
Chronologically, the first use of walls with a rigid cladding and a soft inner core was recorded in Mesopotamia and it dates back to the period when this civilization was created, around 3,700 BC. The stone city walls began to form earlier, but their dimensions were so large, and the stone blocks leaned on each other, and under the forces of pressure and friction (a natural joint is formed), similar to prehistoric walls (Figure 3). The walls of buildings and fortifications were of considerable thickness in later periods, in the range of 4 - 20 m. The outer lining was made of unfired brick, and the core was made of riprap of different composition. Ziggurat-type temples were also lined with unfired brick, rarely with stone, but the filling was made of loose earth or unfired brick, and with its enormous weight and shape, it was resistant to earthquakes.

Iznuđene kao odbrana od velikih poplava bujičnih reka, osmišljene su visoke platforme na kojima su bile izgrađene palate i hramovi. Bile su izvedene od jednoobrazne i simetrično postavljene mase, a time su i značajno spuštale težište cele strukture i tako istovremeno predstavljale odbrambeni sistem od zemljotresa. Dimenzije površinskog zemljotresnog talasa bile su srazmerne dimenzijama platforme, tako da je zadatak velike, krute platforme bio da ublaži taj talas. Građevina na platformi bila je podvrgnuta samo prosečnom pomeranju tla usled zemljotresa, bez nepredvidljivih pikova (slika 4).

High platforms on which palaces and temples were built were a forced solution as a defence against large floods of torrential rivers. They were made of a uniform and symmetrically placed mass, and thus at the same time significantly lowered the centre of gravity of the entire structure and simultaneously represented the earthquake resistant system. The dimensions of the surface earthquake wave were proportional to the dimensions of the platform, so the task of the large, rigid platform was to mitigate that wave. The building on the platform was subjected to only average ground movement due to the earthquake, without unpredictable peaks (Figure 4).



Slika 3. Poprečni presek kroz zid Kapije boginje Ištar, Vavilon; Novosumerski zigurat u Uru, prema [126]
Figure 3. Cross section of the Ishtar Gate of Babylon; New-Summerian ziggurat of Ur, after [126]



Slika 4. Rekonstrukcije Palate Sargona II u Korsabadu (Dur-Šarukin) i preseka kroz jugozapadni deo platforme sa oblogom i ispunom, prema [127]
Figure 4. Reconstruction of the Sargon II palace in Khorsabad (Dur-Sharrukin) and the cross section of the western part of the platform with the lining and fill, after [127]

Iskustvo egipatskih graditelja jedno je od najznačajnijih u istoriji građenja. Nekoliko hiljada godina pre naše ere egipatski graditelji su primenjivali neke postupke zaštite od zemljotresa, koji se i danas koriste. Iako ne postoje zapisi o planovima izgradnje ili tekstovi o načinima gradnje, arheološka istraživanja, ipak, daju određene podatke. Najveća pažnja je bila posvećivana pripremi terena ispod temelja, tako da se danas smatra da su Egipćani poznavali neke zakonitosti koje se u savremenoj praksi podvode pod mehaniku tla. Temelji koji su urađeni u kompleksu najstarije, Đoserove piramide, bili su kamene ploče koje su služile kao temelji, ali i kao trotoari. Mnoge druge strukture iz

The experience of Egyptian builders is one of the most significant in the history of construction. Several thousand years BC, the Egyptian builders implemented certain earthquake protection procedures, which are still used today. Although there are no records of construction plans or texts on construction methods, archaeological research still provides some information. The greatest attention was paid to the preparation of the ground below the foundations, so that it is nowadays considered that the Egyptians had knowledge of some laws that are in modern practice the subject of soil mechanics. The foundations that were made in the complex of the oldest, the Djoser pyramid, were stone perioda starih dinastija, pre svega piramide, postavljane su na neku vrstu "temelja” koji su se sastojali od samo tri reda kamenih blokova. Keopsova piramida u Gizi izgrađena je na čvrstoj krečnjačkoj steni i zbog toga joj nisu bili potrebni posebni temelji. Od kasne četvrte dinastije (2613–2494 p. n. e.) i nadalje, temeljni blokovi bili su postavljeni u rovove urezane u zemlju i ispunjeni pustinjskim peskom.

Građevine postavljene na čvrstoj steni često nisu imale duboke temelje. U ranoj Dvanaestoj dinastiji (1991–1802. p. n. e.) prvi put se potvrđuje metoda izravnavanja tla. Mekana zemljišta su uklanjana i zamenjivana novim, peskovitim materijalom, što je i danas jedna od široko primenjivanih metoda. Jedan način bio je postavljanje velikog broja manjih blokova (koji se ponekad uzimaju iz starijih objekata) koji stvaraju neku vrstu podzemne platforme na kojoj je podignuta građevina. Drugi način je bio da se u pripremljene temeljne jame ili trake nasipa suvi pesak, koji je zbog svoje kompaktnosti izvanredno podnosio pritisak. Slično su Egipćani postupali i sa stenovitim podlogama, koje su nivelisali do horizontalnog položaja, a preko tako zaravnjene podloge nasipali su, takođe, sloj peska. Uloga peščanog sloja bila je dvojaka. S jedne strane, opterećenje građevine ravnomerno se prenosilo na tlo, pa otuda nema koncentracije napona u temeljima. S druge strane, sloj peska je imao funkciju izolacionog sistema koji je upijao seizmičke talase i omogućavao građevini da klizi preko njega tokom pokreta tla (slika 5a i slika 5b).

slabs that served as foundations, but also as sidewalks. Many other structures from the period of the old dynasties, primarily the pyramids, were laid on a kind of "foundation" that consisted of only three rows of stone blocks. The Pyramid of Cheops in Giza was built on solid limestone and therefore did not need special foundations. Since the late Fourth Dynasty (2613-2494 BC) onwards, the foundation blocks were placed in trenches carved into the ground and filled with pure desert sand.

Buildings built on solid rock often were without deep foundations. In the early Twelfth Dynasty (1991-1802 BC), the method of levelling the ground was confirmed for the first time. Soft soils were removed and replaced with new, sandy material, which is still one of the widely used methods. One way was to set up a large number of smaller blocks (sometimes taken from older buildings) that created a kind of underground platform on which the building was erected. Another way was to pour dry sand into the prepared foundation pits or strips, which, due to its compactness, withstood the pressure extraordinarily well. The Egyptians acted similarly in the case of rock beds, which were levelled to a horizontal position, and also a layer of sand was poured over such a flat surface. The role of the sand layer was twofold. On one hand, the load of the building was evenly transferred to the ground, so there is no concentration of stress in the foundations. On the other hand, the sand layer had the function of an insulating system that absorbed seismic waves and allowed the building to slide over it during ground movement (Figure 5a and Figure 5b).

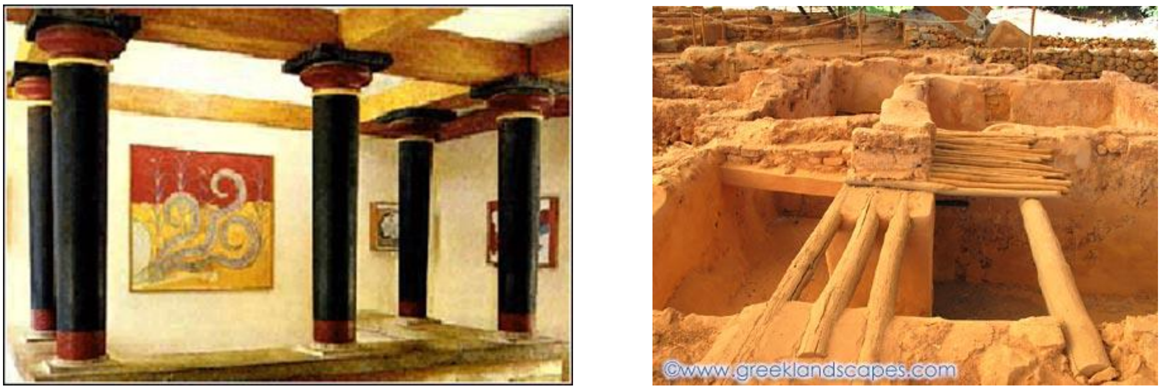
Slika 5. Platforma grobnog hrama u Deir-el-Bahariju; Kompleks grobnica graditelja piramida kod Gize, prema [101] i [129]

Figure 5. Platform of the sepulchral temple in Deir-el-Bahari (a); The complex of tombs of the Giza pyramid builders (b), after [101] and [129]

Mlađa, kritsko-mikenska (egejska) civilizacija (~3.000. do 1100. g. p. n. e) razvijala se na području Egejskog mora, poznatom po velikoj seizmičkoj aktivnosti. Česti zemljotresi su svakako, već u najstarije doba, zahtevali odgovarajuće iskustvo u građenju otpornih struktura. To se najbolje može saznati na osnovu istraživanja palate u Knososu, na Kritu (2100–1600. p. n. e). Konstrukcijski sistem palate uglavnom je rekonstruisan prilikom arheoloških otkopavanja, ali je dugo bilo otvoreno pitanje oblikovanja stubova, koji su bili širi pri vrhu, a uži pri dnu, što u graditeljskom smislu nije uobičajeno. Danas je predložena teorija da je

The younger, Cretan-Mycenaean (Aegean) civilization (~ 3,000 to 1100 BC) developed in the Aegean region, known for its high seismic activity. Frequent earthquakes certainly, from the earliest times, required appropriate experience in building resilient structures. This can best be learned from the research of the palace in Knossos, Crete (2100-1600 BC). The structural system of the palace was mostly reconstructed during the archeological excavations, but the issue of the pillars shape remained open for a long time, as they were wider at the top and narrower at the bottom which is uncommon in the architectural terms. Today, the ovakav oblik stuba proistekao iz potrebe seizmičke otpornosti. Oblik kapitela stuba je pogodan da prihvati jedan deo gredne konstrukcije, dok je u bazi, sužavanjem stuba u odnosu na vrat, formiran zglob. Na taj način, stub može biti samo pritisnut, ali ne i izvijen. Pored ove osobenosti u oblikovanju stubova, osiguranje velikih trospratnih, pa i višespratnih zgrada bilo je izvedeno veoma dubokim fundiranjem velikog broja podužnih i poprečnih zidova, koji su međusobno bili povezani. Broj temeljnih zidova bio je znatno veći od broja zidova na spratovima zgrada (slika 6 a i b).

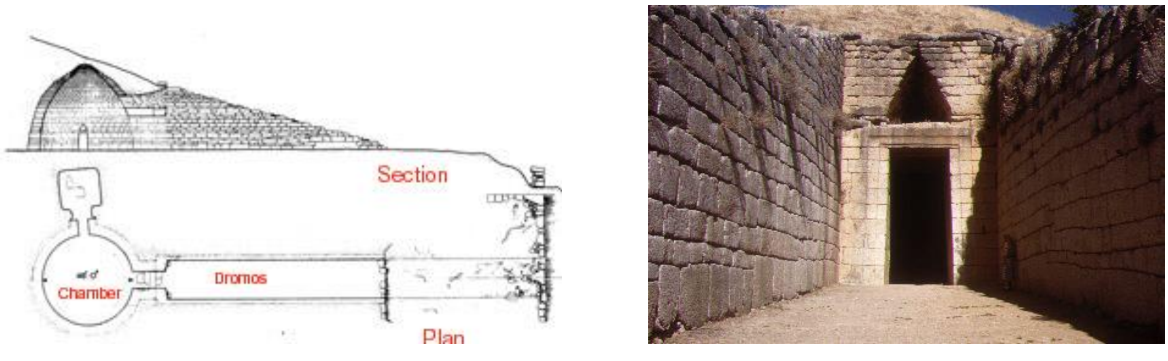
proposed theory is that this shape of the pillars originated from the need for seismic resistance. The shape of the capital of the pillar is suitable to support one part of the beam structure, while at the base, by narrowing the pillar in relation to the neck, a joint is formed. In this way the pillar can only be pressed, but not bent. In addition to this feature in the design of pillars, the securing of large three-storey and even multi-storey buildings was carried out by very deep foundations of a large number of longitudinal and transverse walls, which were interconnected. The number of foundation walls was significantly higher than the number of walls on the floors of buildings (Figure 6 a and b).



Slika 6. Deo palate sa stubovima u Knososu na Kritu; Ostaci palate u Malji na Kritu, prema [113 i [130]
Figure 6. Part of the palace with columns in Knossos on Crete (a); remains of the palace in Malia on Crete (b) after [113] and [130]

U Mikenskoj kulturi na prostoru ispod akropolja nalazile su se grobnice specifično oblikovane sa tzv. lažnim svodom nad kružnom osnovom. Analizom načina formiranja krivine u vertikalnom preseku, koja je bila dobijena postepenim ispuštanjem kamenih blokova, različite veličine oblika i težine, slaganih od baze ka temenu, kao i rasteretnih trougaonih šupljina nad otvorom i zemljanog nasipa koji je stvorio odgovarajući pritisak preko celokupne strukture može se zaključiti da su i tu bili zadovoljeni svi glavni principi aseizmičkog delovanja (slika 7).

In the Mycenaean culture, in the area below the acropolis, there were tombs specifically shaped with the so-called false vault over circular base. The tholos tomb was of a circular, underground, stone structure with an interior rising to a point. The stone construction was obtained with corbelled system where each higher row of stones overlaps or projects farther into space. The analyses of the way of forming the curve in the vertical section, as well as triangular hole over the entrance lintel and the weight of the earth above the construction that created the appropriate pressure over the entire structure indicate that all the main principles of seismic action were satisfied here as well (Figure 7).



Slika 7. Osnova, presek i ulaz "Atrejeve" riznice u Mikeni, prema [131]
Figure 7. Layout, section and entrance to the Treasury of Atreus in Mycenae, after [131]

Za razliku od kritsko-mikenske, arhitektura antičke Grčke i iz perioda helenizma nije tako uspešno odolevala zemljotresima, pošto je uočeno da je većina grčkih hramova bila oštećena u brojnim zemljotresima. Iako analize modela građevina koje su građene isto kao i grčki hramovi, bez bočnih potisaka, s ravnomerno opterećenim elementima od kamena i s potpunom simetrijom svih konstrukcijskih elemenata, pokazuju da do rušenja usled zemljotresa ne bi trebalo da dođe, grčki hramovi su urušeni, jer se na njima uočavaju dva nedostatka. Prvi se iskazuje u veoma visokom podignutom opterećenju delova same građevine, u obliku snažnih arhitravnih greda, frizeva, venaca i timpanona, a drugi se odnosi na neravnomernu krutost strukture.

Ogromna kamena masa koncentrisana na velikoj visini izaziva neizbežnu inerciju seizmičkih sila tokom potresa, koje ruše najveći deo građevine. Smatra se da su grčki graditelji pokušavali da se od zemljotresa brane konsolidacijom terena i pravilnim fundiranjem. Tako je Herin hram u Olimpiji, jedan od najstarijih primera dorskog stilskog reda (VI vek p. n. e.) bio podignut na posebnoj platformi sagrađenoj na gusto pobijenim šipovima, između kojih se nalazio nasip od lomljenog kamena i šljunka. S obzirom na to što su poluostrvo Peloponez na kojem se nalazi Olimpija, kao i cela Grčka, područje za koje je poznato da je često bilo pogađano zemljotresima, ovaj način temeljenja je, najverovatnije, bio smišljen kako bi se građevina oduprla seizmičkim udarima (slika 8 a i b).

Unlike Cretan-Mycenaean, the architecture of ancient Greece from the Hellenistic period failed to successfully withstand earthquakes since it was noticed that most Greek temples were damaged in numerous earthquakes. Although analyses of models of buildings built in the same way as Greek temples, without lateral thrusts, with evenly loaded stone elements and complete symmetry of all structural elements, show that the collapse due to earthquakes should not occur. Greek temples collapsed because they had two deficiencies. The first is the load of the parts of the building itself elevated to a great height, in the form of strong architrave beams, friezes, cornices and tympanums, and the second refers to the non-uniform rigidity of the structure.

A huge rock mass concentrated at a great height causes the inevitable inertia of seismic forces during earthquakes, which destroyed most of the building. It is believed that the Greek builders tried to protect from the earthquake by consolidating the terrain and by proper founding. Thus, the temple of Hera in Olympia, one of the oldest examples of the Doric style (6c. BC), was erected on a special platform built on densely driven piles, between which there was an embankment of crushed stone and gravel. Since the Peloponnese peninsula on which Olympia is located, as well as the whole of Greece, is a well-known area often affected by earthquakes, this method of foundation was designed to withstand seismic shocks (Figure 8 a and b).

Slika 8. Temeljne zone Herinog hrama u Olimpiji i Apolonovog hrama u Delfima, [72] i [62]
Figure 8. Foundation zones of the Temple of Hera in Olympia and Temple of Apollo in Delphi, after [72] and [62]

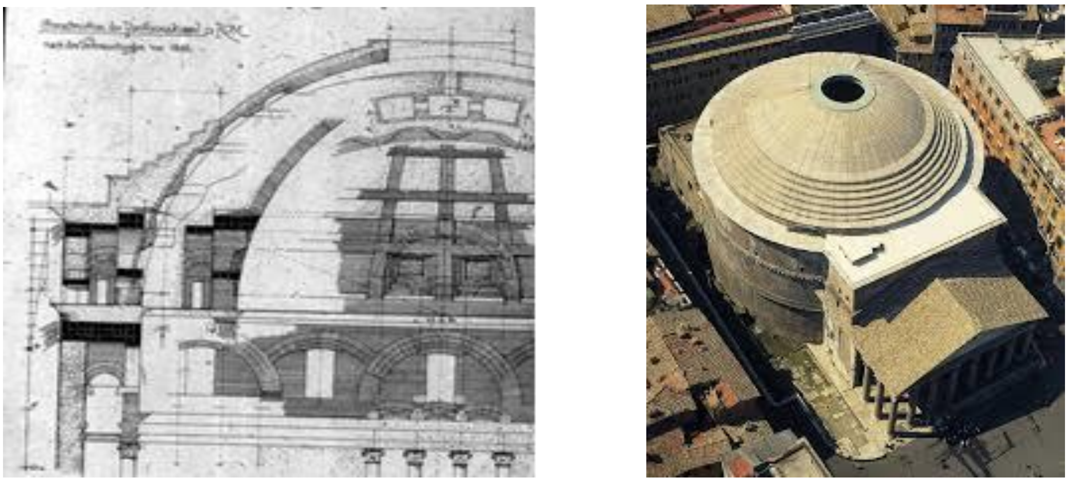
Današnje stanje grčkih hramova najbolje svedoči o navedenim nedostacima, pošto nijedan primer nije sačuvan u celosti, već im nedostaje upravo deo nadstublja, koji je bio najteži i koji se urušavao pri svakom zemljotresu. Najbolje sačuvanom grčkom hramu, Tezeonu (Hefestionu) na atinskoj agori, takođe nedostaje i krov, iako je veliki broj tavanjača ostao sačuvan (slika 9).

The present day condition of Greek temples is the best evidence of the mentioned shortcomings, because no structures have been preserved in their entirety, but they are missing exactly the part of the superstructure, which was the heaviest and which collapsed during every earthquake. The best-preserved Greek temple, Theseus (Hephaestion) on the Athenian Agora, also lacks a roof, although a large number of roof beams have been preserved (Figure 9a) and (Figure 9b).

Slika 9. Ostaci krovne konstrukcije hrama Tezeon (Hefestion) u Atini i urušena krovna konstrukcija hrama u Segesti, prema [prvi autor 62]
Figure 9. Remains of the roof structure of the temple of Theseus (Hephaestion) in Athens (a) and the collapsed roof structure of the temple in Segesta (b), after [authors] and [62]

Seizmički otporne konstrukcije nastale u doba Rimske imperije (do kraja V veka n. e.) i starijeg perioda stvaranja Vizantijskog carstva mogu se zajednički posmatrati, zbog graditeljskog iskustva koje se prenelo iz jednog stilskog perioda u drugi. Rimska tehnika građenja seizmički otpornih građevina oslanja se na veštinu primene rimskog "betona" na zidanje svodnih konstrukcija, posebno kupola. Graditelji su se bavili i otpornošću lučnih konstrukcija i njihovih veza na seizmičke sile. Kao i u mnogim drugim slučajevima, i u ovom je za analizu najpogodnija konstrukcija velikog hrama posvećenog svim rimskim božanstvima, Panteona u Rimu, čije su osnovne karakteristike sa stanovišta seizmičke stabilnosti zadovoljavajuće. U analizi kupole Panteona, koja se sastoji iz dva skeletna sistema, koja su međusobno povezana, iznenađuje činjenica da se rebra ta dva sistema nigde ne poklapaju po vertikali, iako je očigledno da sistemi deluju jedinstveno (Slika 10).

Seismically resistant structures created during the Roman Empire (until the end of the 5th century AD) and in the early period of the Byzantine Empire creation can be observed as one, because of the construction experience that was transferred from one stylistic period to another. The Roman technique of building seismically resistant buildings relies on the skill of using to Roman "concrete" in the construction of vaulted structures, especially domes. The Roman builders also dealt with the resistance of arched structures and their joints to seismic forces. As in many other cases, the most convenient for an analysis is the structure of a large temple dedicated to all Roman deities, the Pantheon in Rome, whose basic characteristics are satisfactory from the aspect of seismic stability. In the analysis of the Pantheon dome, which consists of two skeletal systems, which are interconnected, it is surprising that the ribs of these two systems do not coincide vertically, although it is obvious that the systems act in unison (Figure 10).



Slika 10. Kupola hrama Panteon u Rimu: presek i izgled, prema [132]
Figure 10. Pantheon Temple dome, Rome: cross section diagram and appearance, after [132]

3 ISKUSTVA U BORBI PROTIV ZEMLJOTRESA TOKOM SREDNJEG I NOVOG VEKA

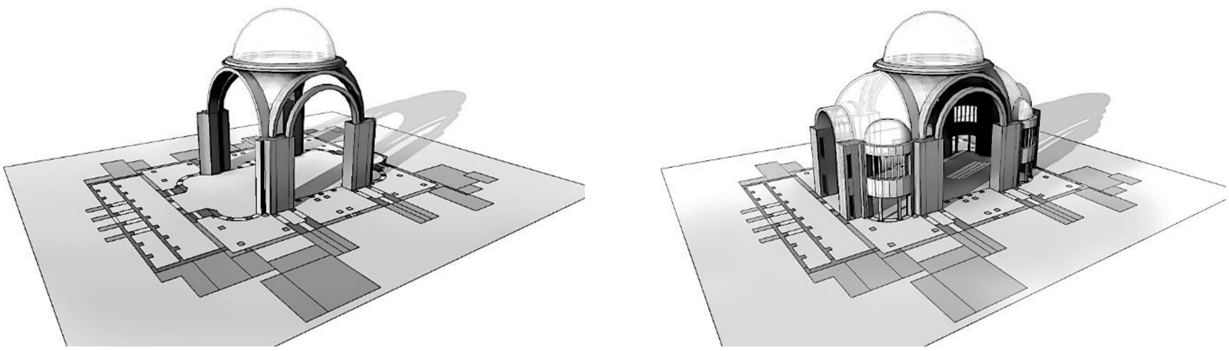
U graditeljskom smislu, nakon propasti Rimske imperije, stvaralaštvo se idejno postepeno razdvojilo u dva osnovna pravca. Istočni deo nekada ogromne države razvio se u Vizantijsko carstvo koje je snažno uticalo na svoje okruženje.

Proučavanje seizmičke stabilnosti vizantijskih građevina prevashodno se zasniva na konstrukcijskom umeću Antemija iz Trala i Isidora iz Mileta, primenjenom na Crkvi Svete Sofije u Carigradu u VI veku. Kako je ova crkva bila u velikoj meri predmet pažljivih i produbljenih istraživanja, pri čemu se stalno analiziraju i konstrukcijska rešenja i posledice nekoliko zemljotresa, koji i danas pogađaju ovo područje, ona ovde nije posebno prikazana. Ipak, treba istaći da njena otpornost na zemljotrese u gornjim zonama, gde se nalaze glavna kupola, podržavajuće polukalote i niže postavljene utežuće četvrtine sfera, nikada nije bila potpuno kvalitetna, ali da se povećavala kroz vreme, kako su graditelji empirijski sticali sve temeljnije iskustvo u građenju seizmički otpornih konstrukcija (slika 11) [4].

3 EXPERIENCES IN THE STRUGGLE AGAINST EARTHQUAKE DURING THE MIDDLE AND NEW AGES

In the architectural sense, after the decline of the Roman Empire, the creative art gradually bifurcated into two basic directions. The eastern part of the once huge state developed into the Byzantine Empire, which strongly influenced its surroundings.

The study of the seismic stability of Byzantine buildings is primarily based on the construction skills of Anthemius of Tralles and Isidore of Miletus, applied to the church of St. Sophia in Constantinople in the 6th century. As this church has been largely the subject of careful and in-depth research, and constant analyses of structural designs and the consequences of several earthquakes, which have hit this area to this day, it is not specifically presented here. However, it should be noted that its resistance to earthquakes in the upper zones, where the main dome, supporting semi-domes and lower bracing quarters of the spheres are located, was never of full quality, but increased over time as builders empirically gained more and more experience in construction of seismically resistant structures (Figure 11) [4].



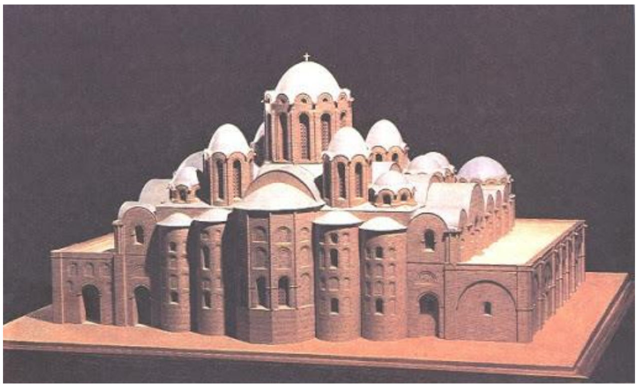
Slika 11. Postepeno formiranje noseće konstrukcije velike kupole Crkve Svete Sofije u Carigradu, prema [67]
Figure 11. Gradual formation of the supporting structure of the large dome of the Church of St. Sophia in Constantinople, after [67]

Crkve kijevske Rusi, razvijane pod velikim uticajem vizantijskog iskustva, na prvom mestu Saborna crkva Svete Sofije u Kijevu, građene su tehnikom tzv. skrivenih ili uvučenih redova opeke, koji su spolja pokriveni malterom, koji deluju kao spojnice iste debljine kao i redovi opeke. Ispitivana su svojstva opeka i krečnog maltera s keramičkim aditivom (mehanička čvrstoća, mineraloške, hemijske i mikrostrukturne analize) i one su pokazale veliku sličnost s ranovizantijskim građevinama Carigrada, potvrđujući svojstva seizmički otpornih tehnika građenja i materijala koji su obezbeđivali kontinualne napone i dilatacije (slika 12).

U poznijim periodima srednjeg veka, religijske građevine u istočnim delovima Evrope nisu više bile tako velikih dimenzija, prilagođavajući nasleđenu primenu konstrukcijskih sistema i tehnika građenja.

The churches of Kievan Rus’, developed under the considerable influence of the Byzantine experience, primarily the cathedral church of St. Sophia in Kiev, were built using the technique of so-called "hidden" or indented rows of bricks, which are covered with mortar on the outside, which appear as joints of the same thickness as the rows of bricks. The properties of bricks and lime mortar with ceramic additive (mechanical strength, mineralogical, chemical and micro structural analyzes) were examined and they showed great similarity with the early Byzantine buildings of Constantinople, confirming the properties of seismically resistant construction techniques and materials that are properties of continuous stress and expansion (Figure 12).

In the later periods of the Middle Ages, religious buildings in the eastern parts of Europe were no longer so large, adapting the inherited application of construction systems and construction techniques.

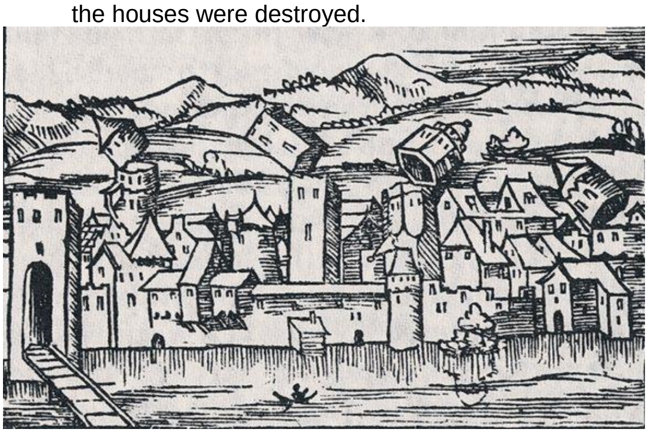
Slika 12. Prezentacija tehnike građenja i rekonstrukcija prvobitnog oblika Crkve Svete Sofije u Kijevu, prema [133]
Figure 12. Presentation of construction techniques and reconstruction of the original shape of the Church of St. Sophia in Kiev, after [133]

Izrazito trusno područje, a istovremeno veoma bogato srednjovekovnim građevinama, jesu Jermenija, Gruzija i zemlje bliskog Istoka i centralne Azije. Na ovom prostranom području iskustva su bila razna i ne uvek uspešna. Mnoge crkve, kao na primer ona u Bagaranu, ispunjavale su sve uslove postavljene s ciljem zaštite od zemljotresa. Druge, izuzetne arhitektonske prefinjenosti, kao crkva u Zvartnocu, rušile su se u zemljotresima, od kojih je naročito razoran bio u X veku. Uzrok rušenja bila je neravnomerna raspodela krutosti na nivou osnove prizemlja, kao i izvijanje do kojeg je došlo u osam svodova velikog raspona od kamena prilikom zemljotresa [5].

Prirodne katastrofe imale su velik uticaj na srednjovekovni svet. Postoji čitav niz svedočanstava o uništavanju gradova ili regiona i o desetinama hiljada mrtvih ili beskućnika. O ovim katastrofama: zemljotresima, poplavama, vulkanskim erupcijama pisali su hroničari tog vremena, koji su ostavili živopisne izveštaje o uništenju koje su prouzrokovali (slika 13). Među deset najtežih prirodnih katastrofa koje su se desile u srednjem veku u Evropi izdvaja se zemljotres na Siciliji iz 1169. godine. O njemu hroničar piše da je bogati grad Katanija bio tako pogođen da su sve kuće bile srušene.

The region of Armenia, Georgia and the countries of the Middle East and Central Asia are rich in the medieval buildings but also an area of high seismic activity. In this vast area, the experiences have been varied and not always successful. Many churches, such as the one of St. Theodor of Bagaran, satisfied all the conditions set for earthquake protection. Others, possessing exceptional architectural refinement, such as the Zvartnots Cathedral, collapsed in earthquakes, of which one in the 10th century was particularly devastating. The cause of the collapse was the uneven distribution of stiffness at the level of the ground floor, as well as the buckling that occurred in eight large span stone arches during the earthquake [5].

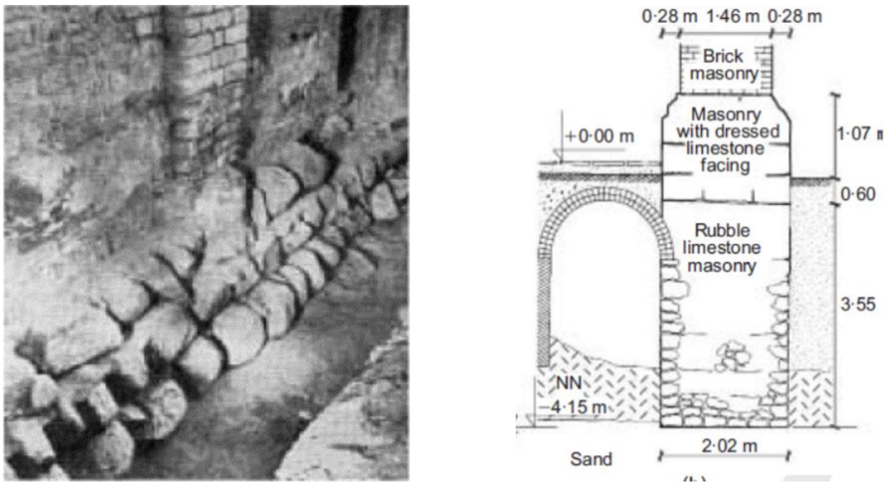
Natural disasters had a great impact on the medieval world. There is a number of testimonies about the destruction of cities or regions and about tens of thousands of people left dead or homeless. Chroniclers of the time wrote about these catastrophes: earthquakes, floods, volcanic eruptions, and left vivid reports of the destruction caused by disasters (Figure 13). Among the ten most severe natural disasters that occurred in the medieval times in Europe, the earthquake in Sicily of 1169 stands out. The chronicler wrote that the rich city of Catania was so affected that all the houses were destroyed.

Slika 13. Srednjovekovna predstava posledica zemljotresa i gravira srednjovekovnog zemljotresa iz XVI veka, prema [134] i [135]
Figure 13. Medieval representation of the effects of an earthquake and engraving of a medieval earthquake from the 16th century, after [134] and [135]

Većina srednjovekovnih zgrada fundirana je na plitkim temeljima. Obično su građene od bondruka, kamena ili opeke i raznih vrsta maltera kao veziva. Na zapadu Evrope, u pred-romaničko doba (do X veka), uobičajeni način postavljanja temelja na noseće tlo bilo je ubacivanje trpanca i raznih otpadaka u iskop, koji je bio jednak ili nešto širi od podzemnog dela građevine. Preko te ispune sipan je vrlo loš (siromašan) malter kao vezivo. Veličina temelja po pravilu je zavisila od raspoloživog prostora, a ne od aktivnog opterećenja i nosivosti. Tipični romanički temelji (od XI do XIII veka) bili su pravljeni tako što se iskop oblagao velikim balvanima, a onda je u jamu bacan trpanac ili manje kamenje, a zatim je preko te mase sipan krečni malter (slika 14). Ponekad izbor terena nije bio dobro odmeren, pa su graditelji intervenisali, kao što je to bio slučaj prilikom izgradnje tornja-zvonika u Pizi na previše mekanom tlu.

Most medieval buildings were founded on shallow foundations. They were usually built inpost-and-pan system, stone or brick and various types of mortar as binders. In the west of Europe, in the pre-Romanesque period (until the 10th century), the usual way of laying the foundations on the soil was to place riprap and various debris into the excavation pit, which was equal to or somewhat wider than the underground part of the building. A very poor (lean) mortar was poured over that filling as a binder. As a rule, the size of the foundation depended on the available space, and not on the active load and bearing capacity. Typical Romanesque foundations (11thto 13thcentury) were made by lining the excavation pit with large logs, and then throwing riprap or smaller stones into the pit, and then pouring lime mortar over that mass (Fig. 14). Sometimes the choice of terrain was not the best, so the builders had to intervene, as it was the case with construction of the bell tower in Pisa on excessively soft ground.

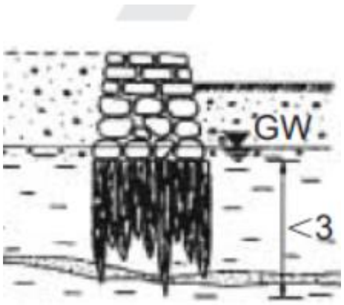


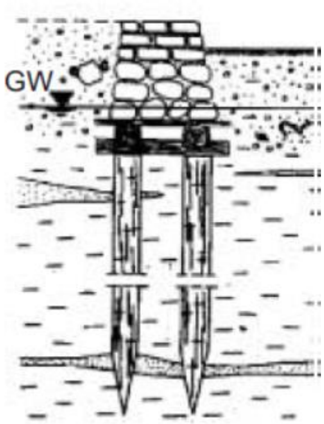
Slika 14. Primeri romaničkog temeljenja, prema [96]
Figure 14. Examples of Romanesque foundations, after [96]

Temelji u periodu Gotike (XII–XVI vek) bili su, generalno, boljeg kvaliteta, s malterom dobrog kvaliteta i bolje isečenih kamenih blokova ili, kasnije, sa običnim opekama. Često su spoljašnje strane temelja bile obložene tesanicima. Veća pažnja je posvećivana izboru lokacija za građenje i to mesto je obično (ali ne uvek) bilo dobro izabrano, i kvalitet tla je prethodno proveravan. Temelji nisu uvek bili širi od zidova iznad njih, zidovi od opeke mogli su biti oslonjeni na slojeve kamenja, što je činilo da pritisak na tlo bude vrlo intenzivan. Postojali su i temelji u obliku kružnih jama punjenih zidarijom, pored kojih su građeni lukovi koji su se povezivali s temeljem na određenom nivou i tako služili kao podupirači. U naseljima pored reka, mora ili jezera gde se nije moglo kopati ispod nivoa vode ili zamenjivati mekano tlo peskom ili šljunkom, koristila se stara, još od Starog veka poznata, tehnika gustog pobijanja kratkih drvenih šipova (slika 15a). Time se opterećenje prenosilo na dublje slojeve sposobne da podnesu nosivost temelja. U poznijim periodima, od XVI stoleća počeli su da se koriste duži i deblji drveni šipovi u različitim kombinacijama s roštiljem preko njih (slika 15b). S obzirom na to što je većina srednjovekovnih

Foundations in the Gothic period (12th to 15th/16th century) were, in general, of better quality, with good quality mortar and better cut stone blocks or, later, with ordinary bricks. The exterior sides of foundations were often lined with hewn stones. Greater attention was paid to the choice of construction sites and that location was usually (but not always) well chosen, and the quality of the soil was previously inspected. Foundations were not always wider than the walls above them, the brick walls could be supported by layers of stones, which made the pressure on the ground very intense. There were also foundations in the form of circular pits filled with masonry, with arches built next to them connected with the foundations at a certain level thus serving as supports. In settlements near rivers, seas or lakes where it was impossible to dig below the water level or replace the soft soil with sand or gravel, the old technique of densely driven short wooden piles, known since the ancient times, was used (Figure 15a). This transferred the load to deeper layers capable of providing the load-bearing capacity of the foundations. In later periods, starting with the 16thcentury, longer and thicker wooden piles began in various combinations to be used with a građevina rađena u bondručnom sistemu, ili kao zidane zgrade od opeke, kamena ili u kombinaciji, sa ovakvim sistemima temeljenja nisu mogle da izdrže snažnije dejstvo zemljotresa. Usled toga je broj delimično ili potpuno porušenih naselja, kao i broj žrtava, kao posledica zemljotresa u srednjem veku bio velik. U pojedinim slučajevima, nakon ovakvih katastrofa, graditelji su sticali nova iskustva i dolazili do novih ideja zaslužnih za stvaranje novih stilskih i konstruktivnih dometa.

grillage over them (Fig. 15b). Since most of the medieval buildings were made in the post-and-pan system, or as masonry buildings made of brick, stone or in their combination, with such foundation systems they could not withstand the more intensive effects of earthquakes. As a result, the number of partially or completely destroyed settlements, as well as the number of victims, due to earthquakes in the Middle Ages was large. In some cases, after such catastrophes, builders gained new experiences and came up with new ideas that were responsible for creating new stylistic and structural achievements.





Slika 15. Primeri temeljenja na plitkim i dubokim šipovima u gotici, prema [96]
Figure 15. Examples of foundations on shallow (a) and deep (b) piles in the Gothic period, after to [96]

U graditeljskom smislu, odnos renesanse i srednjeg veka je veoma složen i zamršen. Humanisti su igrali odlučujuću ulogu u redefinisanju funkcije arhitekte. Njihovo neograničeno divljenje za klasične modele u literaturi stimulisalo je proučavanje rimskih ostataka u svim oblastima stvaralaštva. Oni su očekivali da će taj novootkriveni rečnik formi biti upotrebljen i u savremenoj arhitekturi. Ostaci građevina iz rimskog doba bili su glavni uzori za novi stil, renesansu, koji se počeo razvijati dvadesetih godina XV stoleća u Italiji.

Renesansa je jedan od onih stilskih pravaca kod kojih je uobičajen dvojni arhitektonski jezik. Jedan način izražavanja je konstruktivno-strukturalan, a drugi je plastičan. To znači da tehnička struktura zgrade ne mora odgovarati arhitektonskoj artikulaciji. To je bila revolucionarna ideja u arhitekturi, jer je dekoracija, odnosno ukrašavanje zgrade, bila odvojena od konstrukcije i nije joj morala u potpunosti odgovarati. Zato nije bilo upadljivo novih konstrukcijskih inovacija kada je u pitanju temeljenje i formiranje korpusa građevine, ali su napredovali sistemi građenja svodnih i kupolnih konstrukcija.

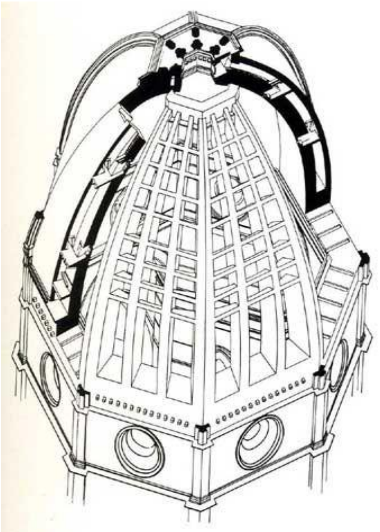
Polazeći od konstrukcije kupole i cele strukture rimskog Panteona i njegove proverene seizmičke otpornosti, treba odmah, odstupajući od hronološke periodizacije, ukazati na zajedničku nit koja koncepcijski povezuje i sve kasnije slične oblike kupola, kao što su renesansna kupola Crkve Santa Marija dei Fiori u Firenci (XV vek) i niz predloga za izgradnju kupole Svetog Petra u Rimu (XVI vek) [3]. Ideja o dva skeletna sistema, sastavljena od vertikalnih rebara i u horizontalnim redovima postavljenih lukova pokazala se do danas

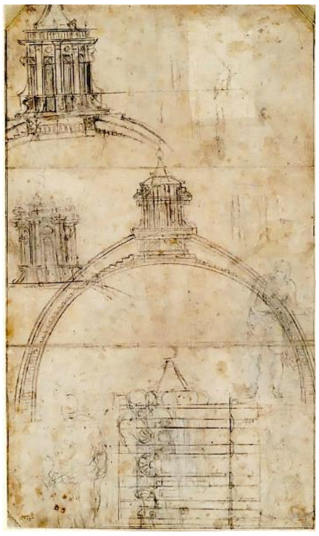
In the architectural sense, the relationship between the Renaissance and the Middle Ages is very complex and intricate. Humanists played a decisive role in redefining the function of the architect. Their boundless admiration for classical models in literature stimulated the study of Roman remains in all areas of creative arts. They expected that this newly discovered vocabulary of form would be used in modern architecture as well. The remains of buildings from the Roman era were the main models for the new style, the Renaissance, which began to develop in Italy in the 15s.

The Renaissance is one of those styles in which a dual architectural language is common. One manner of expression is constructive-structural, and the other is plastic. This means that the technical structure of the building does not have to correspond to the architectural articulation. It was a revolutionary idea in architecture, because the decoration of buildings, was separate from the construction and did not have to correspond to it completely. That is why there were no noticeable new structural innovations when it comes to the foundations and formation of the building core, but rather there were improvements of building systems of vaulted and domed structures.

Starting from the construction of the dome and the whole structure of the Roman Pantheon and its proven seismic resistance, we should immediately, deviating from the chronological periodization, emphasize a common thread that conceptually connects all later similar forms of domes, such as the Renaissance dome of Santa Maria dei Fiori in Florence (15thcentury) (Figure 16a) and a number of proposals for the construction of veoma otpornom, pa postoji niz primera izvedenih u različitim materijalima. S obzirom na to što o svim kupolama i, uopšte, konstrukcijama reprezentativnih zgrada novijeg doba postoje pisani tragovi od ideje do realizacije, a zatim, i o praćenju njihovog ponašanja, može se zaključiti da su sve one pokazale veliku otpornost na zemljotrese koji su, takođe, kroz istoriju od vremena nastanka tih građevina bili registrovani.

the dome of St. Peter in Rome (16thcentury) (Figure 16b) [3].The idea of two skeletal systems, composed of vertical ribs and arches placed in horizontal rows, has proven to be very resistant to this day, so there are a number of examples made in different materials. Considering that there are written documents about all domes and, in general, structures of representative buildings of recent times, from idea to realization, and then, on monitoring their behaviour, it can be concluded that they all exhibited solid resistance to earthquakes which were also registered in history since the time of the construction of these buildings.


a)


b)

Slika 16. Aksonometrijski presek kroz kupolu Crkve Santa Maria dei Fiori u Firenci (a); Mikelanđelov crtež preseka kupole Crkve Svetog Petra u Rimu (b), prema [136]

Figure 16. Axonometric cross section of the Santa Maria dei Fiori church dome in Florence (a); Michelangelo's drawing of the cross-section of the dome of St. Peter's Church in Rome (b), after [136]

U Japanu, izuzetno trusnom području tokom cele istorije, stari graditelji su unapređivali konstrukcije višespratnih hramova od drveta, pagoda, koje su prvobitno loše podnosile zemljotresne udare i rušile se. Kako bi anulirali nemogućnost prijema vibracija od zemljotresa, u vertikalnu osu građevine je ubačen stubac, postavljen u cilindričnu čašicu, koji je unosio pritisak i povećavao otpornost na savijanje konzolne konstrukcije. Pri vibriranju pagode usled zemljotresa, deo energije vibracija pretvarao se u vibracije stupca, koji je udarcima na strane čašice disipirao energiju (slika 17). U savremenim uslovima, isti rezultat postiže se opremom koja automatski reaguje na seizmička dejstva, što je predmet upravljanja konstrukcijama.

Ostali su tragovi da su mere zaštite posle nekog zemljotresa u Japanu, obavljene još 1362. Tada su na staroj učionici (Kodo) budističkog hrama u Kjotu bile postavljene horizontalne drvene grede kao ojačanje. Ista učionica bila je potpuno urušena u zemljotresu iz 1596. godine i ponovo podignuta upotrebom originalnih drvenih delova. Do danas su ostali tragovi tih upotrebljenih delova na vrhu i pri dnu unutrašnjih stubova. Japan se od davnina neprekidno borio s razarajućim posledicama zemljotresa i zato je njihov razvoj iskustva u načinima odbrane od ove prirodne nepogode veoma značajan [85].

In Japan, an area of exceptional seismic activity throughout history, ancient builders improved the construction of multi-storey timber temples, pagodas, which initially poorly withstood earthquakes and collapsed. In order to prevent the transfer of vibrations from the earthquake, a column was inserted into the vertical axis of the building, placed in a cylindrical socket, which introduced pressure and increased the resistance to bending of the cantilever structure. When the pagoda vibrated due to the earthquake, part of the vibration energy was converted into oscillations of the column, which dissipated energy by hitting the socket sides (Figure 17). In contemporary conditions, the same result is achieved with the equipment that automatically responds to seismic actions, which is the subject of structures management.

There are traces that protection measures were carried out after an earthquake in 1362. At that time, horizontal wooden beams were placed as reinforcement in the old teaching hall (Kodo) of the Buddhist temple in Kyoto. The same teaching hall was completely destroyed in the earthquake of 1596 and rebuilt using the original wooden parts. To this day, traces of these used parts remain at the top and bottom of the inner columns. Japan has long struggled with the devastating effects of earthquakes and that is why the development of their experience in defending against this natural disaster is very significant [85].

Slika 17. Shema višespratne pagode i Velika pagoda u Nari, prema [62]
Figure 17. Diagram of the multi-storey pagoda and the Great pagoda in Nara, after [62]

Do XIX stoleća konstrukcijski sistemi su stalno unapređivani, ali su revolucionarni pomaci vezani za nove materijale, tehnologije i tehnike građenja nastali krajem XIX i tokom XX veka i dalje su razvijani do danas.

Ipak, i u periodu baroka graditelji su, naročito u izrazito trusnim područjima, pokušavali da građenje prilagode odbrani kod katastrofalnih šteta, odnosno od potpunog rušenja objekata. Jedan od interesantnih načina odbrane nastao je u kolonijama, u kojima su katoličke misije, najčešće španske, izgradile mnogo crkvenih građevina.

Rezultati numeričkih analiza reprodukovali su uočena oštećenja i potvrdili da vanfazno propadanje fasada nije kritično kod ove vrste crkava u Meksiku. Veoma zanimljiv rezultat je da je poprečni pravac najfleksibilniji, s kulama/zvonicima ili bez njih. Vertikalna vibracija svodova je drugo globalno rešenje, a treće je podužna vibracija broda. To nastaje, uglavnom, zbog velike debljine bočnih zidova i debljine svoda. Bočne potpore pomažu u smanjenju vanjskih oštećenja bočnih zidova. Drugi zanimljiv rezultat je da prisustvo kula/zvonika povećava oštećenja fasada. Kule/zvonici građene su kao integralni deo s fasadom, a ne nezavisno. Kule/zvonici, zato, ograničavaju smanjeno kretanje van ravni bočnih zidova, ali povećavaju unutarnju ravan fasade (slika 18a) [92].

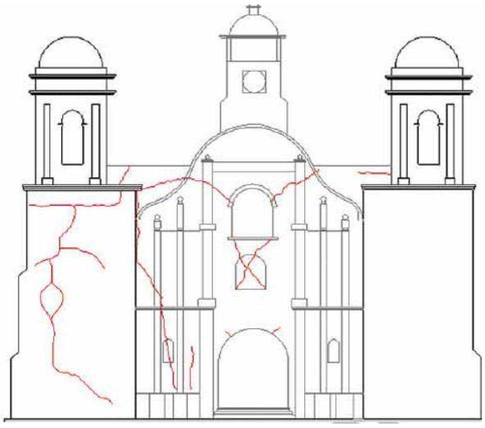
Na Filipinima je monaški red Augustinaca podigao nekoliko crkava u periodu 1790–1800. godine u izrazitoj "zemljotresnoj baroknoj" arhitekturi. Te crkve su bile zdepaste i nisu bile toliko visoke, i sledile su stil koji je usvojen u seizmičkim zonama Meksika i Južne Amerike; Stvorena je nova "mestizo" arhitektura i to se, najčešće, prevodi kao i "zemljotresni barok". Kada su 1863. i 1880. godine zemljotresi, ponovo, opustošili Manilu, skoro sve građevine su se urušile, izuzev, opet, Crkve Svetog Avgustina (slika 18b).

Until the 19th century, construction systems were constantly improved, but the revolutionary leaps related to new materials, technologies and construction techniques that emerged in the late 19th and during the 20th century have continued to develop to this day.

However, even in the Baroque period, builders, especially in extremely seismic areas, tried to adapt the construction to resist catastrophic damage, i.e. the complete collapse of buildings. One of the interesting ways of aseimic adaptations originated in the colonies, in which Catholic missions, mostly Spanish, built a large number of church buildings.

The results of numerical analyzes reproduced the observed damage and confirmed that out-of-phase deterioration of facades is not critical in this type of church in Mexico and South American countries. A very interesting result is that the transverse direction is the most flexible, with or without towers/bell towers. The vertical vibration of the vaults is the second global solution, and the third is the longitudinal vibration of the nave. This is mainly due to the great thickness of the side walls and the thickness of the vault. Side supports help reduce external damage to the side walls. Another interesting result is that the presence of towers/bell towers increases the damage to the facades. Towers/bell towers were built as an integral part with a facade, not independently. Towers/bell towers, therefore, restrict reduced movement outside the plane of the side walls, but increase the inner plane of the façade (Fig. 18a) [92]. The results of numerical analyzes reproduced the observed damages and confirmed that out-of-phase decay of facades is not critical in this type of churches.

In the Philippines, the Augustinian monastic order built several churches in the 1790-1800 period in a distinct "earthquake baroque" architecture. These churches were stocky and not too tall, and followed the style adopted in the seismic zones of Mexico and South America (Figure 18a). A new "mestizo" architecture was created and it is most often translated as "earthquake baroque". When the earthquakes of 1863 and 1880 again devastated Manila, almost all the buildings collapsed, except, again, the church of St. Augustine (Fig. 18b).

Slika 18. Tipična kolonijalna Crkva u J. Americi (a), Crkva Svetog Avgustina u Manili nakon zemljotresa 1880. godine, prema [92] i [62]
Figure 18. Typical western façade of Spanish colonial churches (a): Church of St. Augustine in Manila after the earthquake of 1880 (b), after [92] and [62]

Analize objekata građenih u različitim periodima potvrđuju da su se i stari graditelji načinom građenja suprotstavljali razornim zemljotresima. Pri tome su s posebnom pažnjom birali lokacije, a fundiranje prilagođavali njihovim specifičnostima. Dalje, sem korišćenja metoda fundiranja koje se oslanjaju na princip seizmičke izolacije, primenjivani su dodatni uređaji za ublažavanje vibracionog procesa koji se iz tla prenosi na objekat. Primenjivana su rešenja kojima se menjaju dinamička svojstva objekta da se izbegne rezonantno područje.

4 O DELOVANJU ZEMLJOTRESA NA GRADITELJSKO NASLEĐE

Kulturno nasleđe se može smatrati trodimenzionalnim istorijskim dokumentom. Prošlost se, na osnovu graditeljskog nasleđa, može čitati kroz njegove oblike, primenjene materijale, tehnologiju građenja, upotrebu građevina kroz vreme i brojne druge vrednosti. Zato je potrebno znati što više o graditeljskom nasleđu, tkivu i konstrukciji građevina, kako bi se ta dragocena saznanja očuvala radi što duže kontinualne upotrebe, proučavanja i uživanja u nasleđu sadašnje generacije i budućih generacija.

Fizička briga za graditeljsko nasleđe obuhvata nekoliko faza rada. Moraju se uočiti i definisati faktori koji negativno utiču na opstanak građevine. Faktori su raznovrsni i mogu se podeliti u nekoliko uticajnih grupa:

1. Dejstva iz prirodnog okruženja;
2. Društvene pojave;
3. Uzroci propadanja koji se nalaze unutar samih građevina.

Od dejstava iz prirodnog okruženja, zemljotresno, vulkansko, i požarno dejstvo najčešće imaju katastrofalne posledice, a u svim slučajevima dolazi do narušavanja okruženja, rastresenosti konstrukcija i opšte degradacije nasleđa.

Brojne međunarodne konvencije i preporuke predviđaju niz mogućih i prihvatljivih intervencija koje obuhvataju očuvanje, stabilizaciju, popravke, restauraciju, rekonstrukciju, adaptaciju i niz drugih mera. Ti dokumenti, takođe, preporučuju procenu od

Analyzes of buildings erected in different periods confirm that builders of old, too, countered the destructive earthquakes by their building methods. In doing so, they chose locations with special care, and adapted the foundations to the specific conditions. In addition to the use of foundation methods that rely on the principle of seismic isolation, additional devices were used to mitigate the vibration process that is transmitted from the ground to the building. Designs changing the dynamic properties of the structure so as to avoid a resonant area have been applied.

4 ON THE EARTHQUAKE EFFECTS ON THE BUILT HERITAGE

Cultural heritage can be considered as a three-dimensional historical document. The past, based on the architectural heritage, can be interpreted through its forms, employed materials, construction technology, use of buildings through time and numerous other values. Therefore, it is necessary to know as much as possible about the built heritage, fabric and structure of buildings, in order to preserve this valuable knowledge for as long continuous use as possible, for the study and enjoyment of the heritage of present and future generations.

The physical care for the built heritage includes several phases of work. Factors that negatively affect the survival of the building should be first identified and defined. The factors are diverse and can be classified into several influential groups:

1. Natural environment factors;
2. Social phenomena;
3. Intrinsic building dilapidation causes.

Among the natural environment factors, volcanic, earthquake and fire effects most often have catastrophic consequences, and in all cases, there is a disturbance of the environment, disintegration of structures and general degradation of heritage.

Numerous international conventions and recommendations provide for a range of possible and acceptable interventions that include conservation, stabilization, repair, restoration, reconstruction, adaptation and other measures. These documents also recommend potencijalnog rizika od prirodnih procesa i ublažavanje tog rizika primerenim akcijama. Seizmičkoj zaštiti graditeljskog nasleđa u svetu se posvećuje velika pažnja, jer su iskustva pokazala da razaranja tokom jakih zemljotresa najčešće znače i nepovratan gubitak izvorne vrednosti nasleđa.

Srbija se nalazi u jednoj od aktivnih seizmičkih zona, pa je zato i graditeljsko nasleđe u značajnom riziku od iznenadnih seizmičkih udara ili onih s dugim trajanjem. Jedina sredstva kojima je moguće umanjiti efekte zemljotresa obuhvataju ojačanje tkiva i konstrukcije građevine. Bez obzira na to ko će preduzeti zaštitne korake i određene akcije, pojedinac ili institucija, vlasnik ili staratelj, smanjenje dugotrajnog uticaja od zemljotresa može se obaviti putem nekoliko obaveznih radnji, predviđenih u većini međunarodnih dokumenata. To su:

- dobro pripremljena dokumentacija;
- dobro održavanje i unapred pripremljen plan odbrane od tako neprijatnog događaja kao što je zemljotres.

4.1 Dokumentacija o graditeljskom nasleđu u funkciji posledica od zemljotresa

Potpuno ažurni podaci o spomenicima kulture treba da omoguće obnovu oštećenih ili nedostajućih delova građevina nakon zemljotresa. To su brojni grafički prilozi napravljeni na osnovu niza istraživanja, od vizuelnih opservacija do najsloženijih snimanja najsavremenijim instrumentima, kao i tekstualni prilozi koji obuhvataju razne vrste izvora, od arhivskih dokumenata, preko zapisa usmenih opisa pojedinaca do literarnih tekstova u kojima su na različite načine opisani građevina, njeni detalji ili čak samo emocije koje je kod autora izazivalo postojanje date građevine. Veći nivo detaljnosti dokumentacije pomaže da se obavi tačnija obnova.

Ovaj oblik dokumentacije treba da bude dopunjen drugim elementima u vezi sa istorijom zemljotresa koji su ugrožavali područje na kojem se danas nalazi vredno graditeljsko nasleđe. Sveobuhvatna analitički obrađena dokumentacija nesumnjivo je potrebna za spomenike kulture. Dok je, međutim, za obično dokumentovanje građevinskog fonda dovoljna analiza i interpretacija, koja će objasniti istoriju građevine onoliko koliko se to iz same građevine može sagledati, za spomenike kulture je potreban čitav niz dopunskih izvora i rasprava o značenju i značaju građevine u smislu njene uloge u istorijskom, društvenom, ekonomskom, religijskom, kulturnom i drugim razvojima određene civilizacije.

4.2 Dokumentacija o istorijskim zemljotresima

S obzirom na brzi porast populacije u mnogim zemljama, analiza seizmičkog hazarda postaje sve važnija, čak i u regionima s niskom seizmičnošću. To je od suštinskog značaja, naročito za procenu rizika na područjima s velikim strukturama kulturnih dobara ili prostornim kulturno-istorijskim celinama. Geofizičari i istoričari sarađuju kako bi odgovorili na pitanja, kao što su:

- Koliko su bili jaki zemljotresi tokom istorije u

assessing the potential risk of natural processes and mitigating that risk with appropriate actions. Great attention is paid to the seismic protection of the built heritage in the world, because experience has shown that destruction during strong earthquakes usually means an irreversible loss of the original value of the heritage.

Serbia is located in one of the active seismic zones, so the architectural heritage runs a significant risk of sudden seismic shocks or those with a long duration. The only means by which earthquake effects can be mitigated include reinforcement of the building fabric and structure. Regardless of who takes protective steps and certain actions, an individual or an institution, owner or guardian, the reduction of the long-term impact of the earthquake can be done through several mandatory actions, provided for in most international documents. They are:

- well-prepared documentation;
- proper maintenance and a pre-prepared plan of defence against such disastrous events as earthquakes.

4.1 Documents on the built heritage in terms of the earthquake effects

Completely updated data on cultural monuments should enable the restoration of damaged or missing parts of buildings after earthquakes. Numerous graphic contributions made on the basis of a series of researches, from visual observations to the most complex recordings using the most modern instruments, as well as textual contributions that include various types of sources, from archival documents, through records of oral descriptions of individuals to literary texts describing the building, its details or even just the emotions aroused in an author by the existence of a specific building. A higher level of documentation detail facilitates making a more accurate reconstruction.

This form of documentation should be supplemented with other elements related to the history of earthquakes that endangered the area where the valuable built heritage is located nowadays. Comprehensive analytically processed documentation is undoubtedly needed for cultural monuments. While, however, analysis and interpretation are sufficient for the usual documentation of the building stock, which will clarify the history of the building as much as can be seen from the building itself, cultural monuments require a number of additional sources and considerations on the meaning of the building in terms of its role in the historical, social, economic, religious, cultural and other developments of a particular civilization.

4.2 Documents on historical earthquakes

Considering the rapid population growth in many countries, seismic hazard analysis is becoming increasingly important, even in regions with low seismicity. This is essential, especially for risk assessment in places with large structures of cultural assets or spatial cultural-historical entities. Geo-physicists and historians work together to answer questions such as:

- How strong have earthquakes been throughout pojedinim krajevima i koji su bili regionalni specifični mehanizmi ispoljavanja?

- Koja je bila učestalost pojavljivanja zemljotresa na određenom području tokom vekova?
- Da li je položaj seizmički aktivne zone varirao na području kroz istoriju?
- Kakav seizmički hazard može da sledi na osnovu istorijskih istraživanja za neko određeno mesto?
- Koji se novi podaci mogu prikupiti o društvenim, ekonomskim, političkim, religijskim,
- kulturnim i drugim okolnostima u kojima se razvijalo graditeljstvo i eventualno bilo izloženo zemljotresima kroz istoriju?

Osnova našeg znanja o zemljotresima kroz istoriju nalazi se u savremenoj dokumentaciji i izvorima. Uglavnom se sastoje od tekstova, ali su veoma važne slike, gravire, fotografije i drugi likovni prilozi. U ređim slučajevima, veoma mnogo pomažu vizuelne opservacije o prirodi raznih specifičnosti, kao što su klizišta, oštećenja terena, devastacije i popravke građevina u različitim vremenskim periodima. Savremeni dokumenti mogu biti nedovoljno tačni, jer su podložni deformacijama nastalim tokom vremena, od strane autora koji su u različitim vremenima pisali o događaju. Rad počinje istraživanjem savremenog materijala, utvrđivanjem i upoređivanjem kasnijih tekstova sa izvorima. Jednom kada se tekst dešifruje, sledi interpretacija istorijskih geografskih naziva i prevođenje datuma iz starih kalendara kao i starih mera (razdaljina, dužine trajanja događaja, novčane jedinice računa kojima su plaćane popravke zemljotresom oštećenih građevina i drugo) u savremene merne sisteme.

Najteži deo posla je kritička analiza izvora. Brojni primeri tekstova prolaze kroz vreme različite obrade i promene. Vrednost izvora zavisi od toga s kog stanovišta se analiziraju – seizmološkog ili istorijskog. Sa stanovišta seizmologa, neophodno je da se izvor vrednuje na osnovu kriterijuma kao što su:

- pouzdanost [5];
- tačnost;
- potpunost.

Mapa područja na kojem se nekada u istoriji dogodio zemljotres služi kao izvor i kao primer klasifikacije. Ukoliko je neko iscrtao izoseizmičku kartu koristeći sve izvore, bez obzira na njihov kvalitet, oblici izolinija veoma se razlikuju od onih koje će biti iscrtane korišćenjem samo pouzdanih izvora. Rezultati se moraju dopuniti "skalom ekvivalentnih vrednosti" kako bi mogli da budu uporedivi. Najnovije mape su date u SRPS EN 1998-1/NA (Nacionalni aneks) [95].

Značaj likovnog opisa, kao što su slike, crteži i fotografije, koji služi kao pomoć u interpretaciji efekata zemljotresa kroz istoriju, takođe je veoma značajan. Savremene likovne predstave neke građevine oštećene u zemljotresu mogu je prikazivati iz iste perspektive i zato je moguće neposredno upoređivanje. Smatraju se značajnim podatkom, iako mogu predstavljati upadljive razlike u oblicima. To se delimično može objasniti subjektivnim odnosom likovnog autora prema zemljotresu, ali i različitim potrebama naručioca likovnog dela, ukoliko postoji. Upoređenje likovnih i tekstualnih izvora može se, takođe, razlikovati. Na primer, opis u tekstu može sugerisati da su oštećenja znatno veća nego što je to likovno prikazano, ali i obrnuto, pa je

history in certain areas and what were the regional specific mechanisms of manifestation?

- What has been the frequency of earthquakes in a particular area over the centuries?
- Has the position of the seismically active zone varied in the area throughout history?
- What kind of seismic hazard can be established based on the historical research of a particular place?
- What new data can be collected on social, economic, political, religious,
- Cultural and other circumstances in which building activity developed and was possibly exposed to earthquakes throughout history?

The basis of our knowledge of earthquakes throughout history is found in modern documentation and sources. Documents mainly consist of texts, but paintings, engravings, photographs and other artistic contributions are very important. In rare cases, visual observations of various specifics in nature, such as landslides, terrain damage, devastation and repair of buildings in different periods of time, provide a valuable assistance. Contemporary documents may be insufficiently accurate, as they are subject to distortions created over time by authors who wrote about the event at different times. The work begins by researching contemporary material, identifying and comparing later texts with sources. Once the text is decoded, ensues the interpretation of historical geographical names and translation of dates from old calendars as well as old measures (distance, duration of events, monetary units of bills paid for earthquake-damaged buildings, etc.) into modern measuring

The most difficult part of the job is critical source analysis. Numerous examples of texts undergo various processing and changes. The value of the source depends on the point of view from which it is analyzed - seismological or historical. From the point of view of seismologists, it is necessary to evaluate the source on the basis of criteria such as:

- reliability [5];
- accuracy; and
- completeness.

A map of the area where an earthquake once occurred in history serves as a source and an example of classification. If someone drew an isoseismic map using all sources, regardless of their quality, the shapes of isolines are very different from those that will be drawn using only reliable sources. The results should be supplemented by a "scale of equivalent values" in order to be comparable. The latest maps are given in SRPS EN 1998-1/NA (National annex) [95].

Visual description, such as paintings, drawings and photographs, which aids in the interpretation of earthquake effects throughout history, is also very significant. Contemporary art representations of some buildings damaged in the earthquake can show it from the same perspective, and therefore a direct comparison is possible. They are considered significant piece of data, although they may exhibit striking differences in shapes. This can be partly explained by the subjective attitude of the artist towards the earthquake, but also by the different needs of the commissioner of the work of art, if any. The comparison of artistic and textual sources may also vary. For example, the description in the text may suggest that the damage is significantly greater veoma teško utvrditi istinitost podatka.

Poznavanje zemljotresa tokom istorije može, tako, doprineti zbiru podataka o seizmičkim područjima i hazardu (definisan intenzitetom i povratnim periodom) [35] i [36]. Istraživanje zemljotresa kroz istoriju sastoji se od seizmološke i istorijske komponente. Prva ima cilj koji je jasno definisan, ali koji se teško može ostvariti. To je sticanje pouzdanog znanja o tome šta se stvarno dogodilo tokom zemljotresa i koji su numerički parametri zemljotresa i formiranja mapa hazarda zasnovanih na statističkim podacima. Najnovije mape seizmičkog hazarda naše zemlje date su uz Pravilnik o građevinskim konstrukcijama, tj. Aneksu [95]. Zemljotres ima i društvenu konotaciju. Istraživanje ovog aspekta obuhvaćeno je drugom komponentom istraživanja kroz istoriju. Očajanje i strah zbog iznenadnog i užasavajućeg događaja izaziva različite ljudske aktivnosti. Javna i privatna pomoć žrtvama zemljotresa, molitve, pisma, knjige, novinski članci daju uvid u religijsku, filozofsku, političku, ekonomsku i druge karakteristike perioda u kojem se zemljotres dogodio.

Ove dve metode istraživanja razlikuju se u više aspekata. U stvari, informacioni kapacitet, ono što nazivamo, vrednost pojedinih savremenih izvora o zemljotresima, zavisi od specijalnih saznanja. Tekst s podacima o zemljotresu, kada se pronađe, treba prvo da bude dešifrovan, odnosno preveden. Proučavanje istorijskih izvora zahteva i dobro profesionalno znanje odgovarajuće lingvističke grane. Tadašnji termini treba da budu prilagođeni seizmološkim terminima nastalim u XX veku. Delovi s terminima koji opisuju fenomen zemljotresa, kao što su razaranje ili zvučni efekti, danas, mogu da deluju strano. Istorijski metod utvrđuje i tačno datiranje, ukoliko je u tekstu korišćen neki drugačiji kalendar. Većina tih starih tekstova ne obuhvata analizu pojave kao ni dublju naučnu studiju zbivanja tokom i posle događaja. Sledeći korak je, zato, traženje informacija o podacima na koje se tekst poziva. U pojedinim slučajevima, to u studiji oduzima najviše vremena.

Za mnoge zemljotrese koji su se dogodili u srednjem veku ili ranije, savremeni izvori su izgubljeni ili se ne mogu naći. Ti događaji se mogu samo delimično rekonstruisati na osnovu pisanih svedočanstava. *Stemma*, odnosno genealoško stablo tekstova, pomaže da se shvati kako su mlađi tekstovi zavisili od starijih i kako su se činjenice o nekom zemljotresu transformisale različitim interpretacijama. Upoređivanjem grešaka dobija se predstava o tome kako se izvorni tekst deformisao kroz vekove i često izgubio smisao u delovima koji su najvažniji za sticanje podataka o zemljotresu. Ova analiza, koja se naziva kritika izvora, daje osnovu za procenu vrednosti prvobitnog opisa. U pojedinim slučajevima savremeni istorijski crteži mogu se koristiti kao značajni istorijski izvori.

Nakon zemljotresa u Lisabonu 1755. godine, osmišljena je i uspostavljena nova građevinska praksa. Ona je podrazumevala, po prvi put, da se pre izgradnje naprave i testiraju modeli zgrada kako bi se procenila njihova otpornost na udare zemljotresa. Simulacija vibracija izvedena je učešćem grupa portugalskih vojnih trupa koje su marširale oko modela. Do danas su mnoge zgrade nastale posle katastrofe u Lisabonu opstale kao svedoci prvih svetskih građevina planski izgrađenih u novom veku da budu otporne na zemljotres.

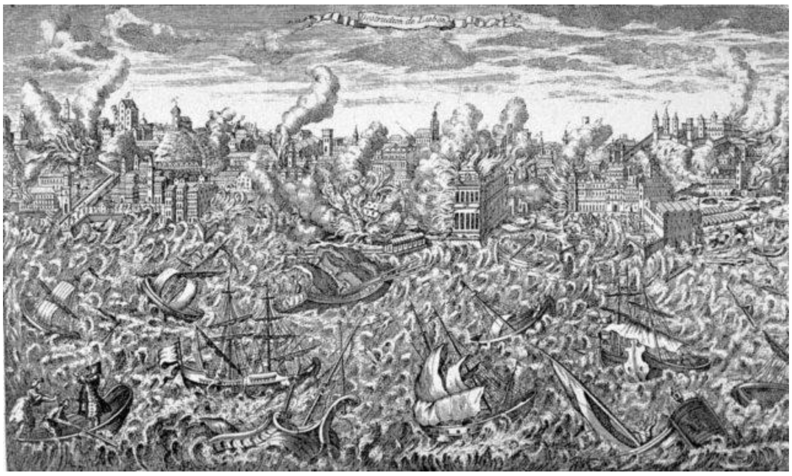
than it is artistically shown, but also vice versa, so it is very difficult to determine the veracity of the data.

Knowledge of earthquakes throughout history can thus contribute to the collection of data on seismic areas and hazards (defined by intensity and return period) [FEMA]. Earthquake research throughout history consists of a seismological and a historical component. The former aims at a goal that is clearly defined, but which is difficult to achieve. It is acquisition of a reliable knowledge about what really happened during the earthquake and what the numerical parameters of the earthquake are and about the formation of hazard maps based on statistical data. The latest maps of seismic hazard of our country are regulated by the Rulebook on building constructions, i.e. Annex [SRP EN 1998-1]. An earthquake also has a social connotation. Research on this aspect has been covered by the latter component of research throughout history. Despair and fear due to a sudden and horrifying event causes various human activities. Public and private assistance to earthquake victims, letters, books, newspaper articles provide insight into the religious, philosophical, political, economic and other characteristics of the period in which the earthquake occurred.

These two research methods differ in several aspects. In fact, the information capacity, what is called the "value" of some contemporary sources on earthquakes, depends on special knowledge. The text with the data on the earthquake, when it is found, should first be decoded, i.e., translated. The study of historical sources also requires good professional knowledge of the appropriate linguistic branch. The terms of that time should be adjusted to the seismological terms that originated in the 20th century. Sections with terminology that describe the earthquake phenomenon, such as destruction or sound effects, today, may seem foreign. The historical method also determines the exact dating, if a different calendar is used in the text. Most of these old texts leave out an analysis of the phenomenon as well as a deeper scientific study of what happened during and after the event. The next step is, therefore, to search for information about the data the text refers to. Sometimes, it takes the most time in the study.

For many earthquakes that occurred in the Middle Ages or earlier, contemporary sources have been lost or cannot be found. These events can only be partially reconstructed on the basis of written testimonies. The stemma, i.e. genealogical tree of texts, helps to understand how the younger texts depended on the older ones and how the facts about an earthquake were transformed by different interpretations. Comparing the errors gives an idea of how the original text has been deformed over the centuries and often lost its meaning in the parts that are most important for obtaining earthquake data. This analysis, called source criticism, provides a basis for assessing the value of the original description. In some cases, contemporary historical drawings can be used as significant historical sources.

After the earthquake in Lisbon in 1755, a new construction practice was designed and established. It meant, for the first time, that models of buildings were made and tested before construction in order to assess their resistance to earthquake shocks. The vibration simulation was performed with the participation of groups of Portuguese military troops marching around the model. To this day, many buildings erected after the Lisbon disaster have survived as witnesses to the world's first buildings of the new age designed to be earthquake resistant.



Slika 19. Bakropis iz 1755. godine koji prikazuje Lisabon u plamenu i cunami koji je preplavio brodove u luci. (Original u: Museu da Cidade, Lisabon), prema [137]
Figure 19. Etching from 1755 showing Lisbon in flames and a tsunami that flooded ships in the harbour. (Original in: Museu da Cidade, Lisbon), after [137]

Razni katalozi zemljotresa koji su u svetu pravljeni pokazuju kako su podaci vremenom postajali sve tačniji i potpuniji. Grafici o broju registrovanih zemljotresa u vremenu mogu se tumačiti kao vrsta "kulturne biografije", koja pokazuje kako se menjao koncept vremena i kako se izoštravala zainteresovanost za pitanja iz oblasti prirodnih nauka. Evropska zejednica zato podržava međunarodni projekt "Pregled zemljotresa kroz istoriju" [84], u okviru kojeg se istražuju zemljotresi koji su se dogodili u periodu od sto godina, tokom XVII i XVIII veka. Evropska Komisija za seizmologiju, u radnoj grupi " Podaci o istorijskim zemljotresima razmatraju pitanja istraživanja s ciljem revizija kataloga zemljotresa, sastavljanja i razvoja preporuke i formiranja monografije uporednih podataka o zemljotresima. U ovoj komisiji radi petnaest geofizičara i istoričara iz petnaest evropskih zemalja.

Očigledno je da se *proučavanju istorije zemljotresa pridaje poseban značaj kada je u pitanju graditeljsko nasleđe*. Razlog je što snažni zemljotresi mogu izazvati katastrofalne štete na spomenicima kulture, a jedno od prvih načela na osnovu kojih se oni proglašavaju jeste autentičnost oblika i materijala od kojih su nastali. Veoma je važno, zato, da se te vrednosti sačuvaju. Zemljotresi ne pripadaju onoj vrsti prirodnih fenomena koji se često i periodično događaju, kao što su poplave, jer se one efikasno sprečavaju preventivnim merama, kao što su odbrambeni nasipi. Zemljotresi se zbivaju iznenadno i ne u velikoj meri prema zakonima statistike. Tek kada se opservira dovoljan broj zemljotresnih događaja tokom odgovarajućeg vremenskog perioda, mogu se izvoditi zaključci o ukupnom zbiru podataka dobijenih statističkim metodama. Upravo zbog toga se vreme, lokacija i magnituda velikih zemljotresa ne može tačno predvideti danas poznatim metodama.

U Srbiji su poznati veliki zemljotresi, ali njihova statistička masa još uvek nije velika. Događa se, zato,

Various catalogues of earthquakes made in the world show how the data became more accurate and complete over time. Graphs on the number of registered earthquakes in time can be interpreted as a kind of "cultural biography", which shows how the concept of time has changed and how interest in issues in the field of natural sciences has sharpened. The European Community therefore supports the international project "Review of Earthquakes through History" [84], which investigates earthquakes that occurred over a period of one hundred years, during the 17^{th} and 18^{th} centuries. The European Commission for Seismology, in the working group "Data on historical earthquakes", considers research issues with the aim of revising the catalogue of earthquakes, compiling and developing recommendations and forming a monograph of comparative data on earthquakes. Fifteen geophysicists and historians from fifteen European countries work in this Commission.

It is obvious that *the study of the history of earthquakes is given special importance when it comes to the built heritage*. The reason is that strong earthquakes can cause catastrophic damage to cultural monuments, and one of the first principles on the basis of which they are proclaimed the cultural monuments is the authenticity of the shapes and materials from which they were created. It is very important, therefore, that these values are preserved. Earthquakes do not belong to the type of natural phenomena that occur frequently and periodically, such as floods, because they are effectively prevented by preventive measures, such as defensive embankments. Earthquakes occur suddenly and largely not according to the laws of statistics. Conclusions be drawn about the total sum of data obtained by statistical methods only when a sufficient number of earthquake events are observed during an adequate period of time. That is why the time, location da projektovanje planiranih građevina zahteva podatke znatno veće preciznosti nego što se mogu dobiti na osnovu empirijskog seizmološkog znanja o određenoj lokaciji. Zato je rizik proizvod verovatnoće pojave hazarda i očekivanih gubitaka. Usled toga, čak i kada je verovatnoća da se dogodi zemljotres mala, povećana gustina gradnje u prostornim kulturno-istorijskim celinama predstavlja opasnost za okruženje. To, takođe, zahteva verniju procenu zemljotresnog hazarda, što se može ispuniti ukoliko se proširi posmatrano vreme seizmiciteta u prethodnim vekovima.

Ove okolnosti objašnjavaju zašto su zemljotresi kroz istoriju mogli povremeno predstavljati i predmet političkih rasprava i važnih odluka za pojedina društva. U savremenoj literaturi najčešće se spominju dva primera. Austrija je 1978. godine plebiscitom odbila rad nuklearne centrale u Zvetendorfu (Zwetendorf). Kao jedan od ključnih argumenata za to je da se 1590. godine dogodio veliki zemljotres, sa epicentrom trideset kilometara udaljenim od tog mesta. Isti razlog su 1989. godine naveli stručnjaci i građani koji su zaustavili izgradnju hidrocentrale u Nađmarošu na Dunavu, jer je 1763. godine u obližnjem gradu Komaromu zabeležen snažan zemljotres, i pored toga što je to ugrozilo ekonomiju Mađarske. To su primeri koliko je značajno što bolje poznavati istoriju zemljotresa na određenom području.

Registrovanje zemljotresa instrumentima počinje krajem XIX veka. Raniji izveštaji su se, uglavnom, zasnivali na pisanoj dokumentaciji o vidljivim, auditivnim i proživljenim efektima zemljotresa. Kroz istoriju su, takođe, beleženi interesantni fenomeni kao što su promene zemljinog reljefa, pojavljivanje i nestajanje izvora, stvaranje pukotina, te oštećenja građevina. To je vrednovanje na osnovu efekata zemljotresa na prirodu i objekte. Na osnovu toga razvijale su se skale seizmičkog identiteta. Od 1964. godine u Evropi seizmolozi koriste skalu intenziteta MSK (Medvedev, Sponheur i Karnik). Godine 1893. F. Omori i Dž. Miln započeli su posmatranje oštećenja nakon Mino-Ovari zemljotresa iz 1891. godine. Na osnovu toga izvedeni su eksperimenti koji su doveli do konstruisanja i usavršavanja potresne platforme između 1893. i 1910. godine; 1908. godine H. F. Rid opisao je teoriju povratne elastične sile u kojoj deformaciona energija geoloških raseda oslobađa vibracionu energiju iznenadnim klizanjem izazvanim smicanjem. K. Sujihiro konstruisao je vibracioni analizator 1926. godine, kojim je merio pomeranja klatna tokom zemljotresa, registrovao ih i utvrdio spektar odgovora za vrlo mala prigušenja. Dž. R. Frimen je 1932. godine najviše doprineo razvoju i instalaciji akcelerograma jakih pokreta tla. Dve godine kasnije, 1934. Dž. Blum je na osnovu svoje doktorske disertacije dalje razvio vezu između teorijskog modela građevina, uzimajući u obzir složenosti kao što su prigušenja i neelastičnost s posmatranjem na terenu i modele testirane na potresnoj platformi. Time je podignut nivo razumevanja odgovora građevina na zemljotres. Predviđanje seizmičkog intenziteta i crtanje tih izoseizmičkih mapa omogućili su i pretpostavljanje seizmičkih parametara, kao što je Rihterova skala magnituda ili akceleracija na lošem zemljištu, zahvaljujući poznatim empirijskim odnosima, objavljena 1935. godine. Dž. Osner je 1941. godine počeo da objavljuje proračune spektara odgovora sa akceleratora. Spektar odgovora izračunat sa akcelerograma

and magnitude of large earthquakes cannot be accurately predicted, by presently known methods.

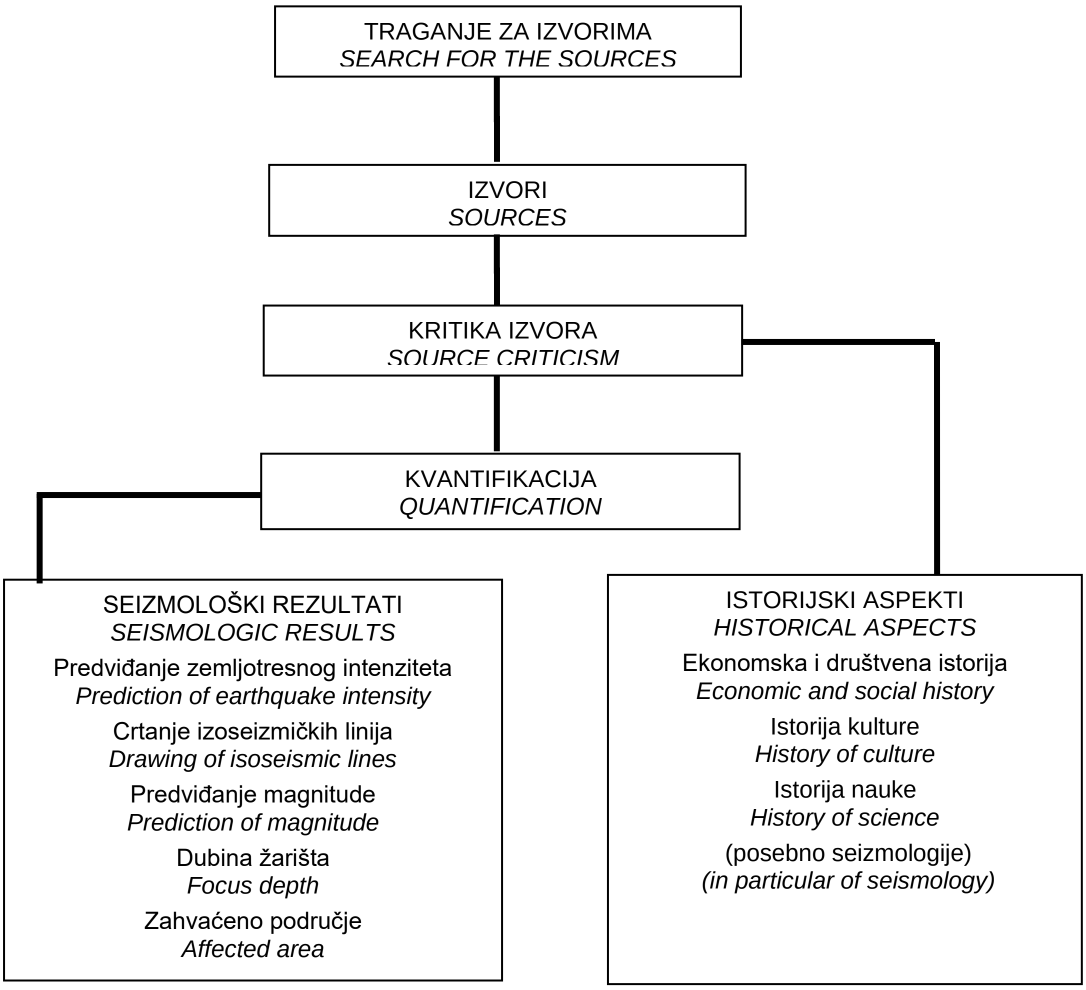
Large earthquakes are known in Serbia, but their statistical mass is still small. It therefore happens that the design of planned buildings requires data of a much higher precision than it can be obtained on the basis of empirical seismological knowledge about a particular location. Therefore, the risk is a product of the probability of hazard occurrence and expected losses. As a result, even when the probability of an earthquake is small, the increased density of construction in spatial cultural and historical entities poses a danger to the environment. This also requires a more accurate assessment of the earthquake hazard, which can be satisfied if the observed time of seismicity in the previous centuries is extended.

These circumstances explain why earthquakes throughout history have occasionally been the subject of political debate and important decisions of individual societies. Two examples are most often mentioned in modern literature. In 1978, Austria rejected the operation of the nuclear power plant in Zwetendorf with a plebiscite. One of the key arguments was the fact that a great earthquake occurred in 1590, with the epicentre thirty kilometres away from that place. The same reason was given in 1989 by experts and citizens who stopped the construction of the hydroelectric power plant in Nagymaros on the Danube, because in 1763 a strong earthquake was recorded in the nearby town of Komarom, despite the fact that it was adverse to the Hungarian economy. These are the examples of how important it is to know the history of earthquakes in a certain area as well as possible.

Registration of earthquakes with instruments began at the end of the 19thcentury. Earlier reports were largely based on written documentation of the visible, auditory, and experienced effects of the earthquake. Throughout history, interesting phenomena have also been recorded, such as changes in the earth's relief, the appearance and disappearance of springs, the creation of cracks, and damage to buildings. It is an evaluation based on the effects of earthquakes on the nature and structures. Based on that, the scale of seismic identity was developed. Since 1964, seismologists in Europe have been using the MSK intensity scale (Medvedev, Sponheur and Karnik). In 1893, F. Omori and J. Milne began observing the damage after the 1891 Mino-Owari earthquake. Based on that, experiments were performed that led to the construction and improvement of the earthquake simulation platform between 1893 and 1910. 1908. H. F. Reed described the theory of elastic rebound theory in which the deformation energy of geological faults releases vibration energy by shear-induced sudden slip. K. Sujihiro constructed a vibration analyzer in 1926 with which he measured the displacements of the pendulum during an earthquake, registered them and determined the range of responses for very small damping. In 1932, J.R. Freeman contributed the most to the development and installation of accelerograms of intense ground movements. Two years later, in 1934, based on his doctoral dissertation, J.Blume further developed the relationship between the theoretical model of buildings, taking into account complexities such as damping and inelasticity, with field observations and models tested on an earthquake platform. This improved informativni je način procene uticaja pokreta zemlje na vibrirajuće strukture. Od kada je E. I. Vilson počeo da stvara SAP (Opšti program strukturalne analize) program, 1970. godine, započeo je ubrzani razvoj modernih kompjuterskih programa koji imaju najveći značaj i primene u zemljotresnom inženjerstvu [51]. Dijagram toka 1 koristi se pri traganju za istorijskim i seizmološkim izvorima.

understanding of the building response to earthquakes. Prediction of seismic intensity and drawing isoseismic maps made it possible to assume seismic parameters, such as the Richter magnitude scale or acceleration on poor soil, thanks to well-known empirical relationships, published in 1935. In 1941, J. Osner began publishing accelerator response spectrum calculations. The response spectrum calculated from the accelerogram is an informative way of estimating the impact of ground motion on vibrating structures. Since E.I. Wilson began creating the SAP (General Structural Analysis Program) program in 1970, commenced the rapid development of modern computer software that have the greatest significance and applications in earthquake engineering [51]. Flowchart 1 is used in the search for historical and seismological sources.

Dijagram toka 1. Metodološki proces istraživanja istorijskih zemljotresa, prema [63]
Flowchart 1 of the methodological process of researching historical earthquakes, after [63]



5 METODOLOGIJA ISTRAŽIVANJA GRADITELJSKOG NASLEĐA POSLE ZEMLJOTRESA

Još značajniji oblik istraživanja odnosi se na utvrđivanje posledica zemljotresa, jer je u ovom slučaju potrebno brzo reagovati, kako bi se oštećenja uočila, pre nego što se stvori vremenski otklon u kojem može doći do dodatnog gubitka delova. To se dešava tokom raščišćavanja otpalih elemenata, odnošenjem materijala s lica mesta i drugim intervencijama.

U Italiji, koja se kroz celu istoriju graditeljstva suočavala s velikim gubicima usled delovanja zemljotresa, postepeno je razvijen metod pregleda seizmičkih oštećenja [11] i [18], koji se može i šire primenjivati, pa i u Srbiji. Utvrđivanje štete zasniva se na uočavanju šesnaest indikatora, od kojih svaki predstavlja mogući mehanizam kolapsa za makroelemente na koje se posmatrana građevina može podeliti. Podela na makro- -elemente u vezi je sa identifikacijom arhitektonskih elemenata koje karakteriše svojstveno seizmičko ponašanje, skoro nezavisno od ostatka građevine. To mogu biti, na primer, spoljašnji zidovi, apside, kupole, kule-zvonici, ukoliko se radi o crkvenom graditeljstvu. Za svaki od tih makroelemenata, u zavisnosti od njihove tipologije i veze sa ostalim delovima crkve, moguće je identifikovati način oštećenja i mehanizam kolapsa. Tokom pregleda je potrebno definisati:

1. podelu na makroelemente;
2. nivo oštećenja (na skali od 0 do 3);
3. povredljivost građevine određenog mehanizma, a u odnosu na specifične detalje konstrukcije.

Ovi podaci omogućavaju da se napravi indeks oštećenja, u rasponu od 1 do 10, kao standardno sredstvo s vrednovanjem oštećenja putem indikatora. Svi, ovako prikupljeni, podaci, mogu biti korisno sredstvo za sticanje pouka za buduće formiranje projekata obnove oštećenih celina [45].

Problem seizmičke povredljivosti [18] u ovom istraživanju vezuje se tako za osnovnu tipologiju crkvenog graditeljstva i omogućuje formiranje baze podataka za buduće nepoželjne slučajeve, kada neki zemljotres ošteti strukturu istog ili sličnog tipa. Metodologija je formirana na osnovu sistematskog istraživanja oštećenja na nizu crkvenih objekata u italijanskim provincijama Umbrija i Marke, s podacima koji su počeli da se prikupljaju još 1944. godine, a zatim su, pri svakom novom zemljotresu, ti podaci proširivani novim saznanjima. Veliki broj od 3000 pregledanih i procenjenih crkava pružio je odličnu osnovu da se statističkom analizom podataka o oštećenjima i uzajamnom vezom s tipologijom građevina omogući predviđanje posledica zemljotresa, od prve procene povredljivosti do brzih procesa opservacije oštećenja [67]. Tom metodologijom je utvrđeno da sledeći osnovni podaci treba da budu zastupljeni prilikom pregleda građevina nakon zemljotresa:

1. Tipološki podaci i dimenzije (ovi podaci se odnose na dekomponovane različite arhitektonske elemente, s posebnim beleženjem konstruktivnih elemenata u pogledu odgovora građevine na zemljotres – kontrafori, zatege i sl.);

2. Oštećenja elemenata umetničke vrednosti (beleže se oštećeni elementi u unutrašnjosti građevine i na njenoj spoljašnosti bez definisanja umanjenja

5 RESEARCH METHODOLOGY OF BUILT HERITAGE AFTER EARTHQUAKES

An even more important form of research refers to determining the consequences of an earthquake, because in this case it is necessary to react quickly, in order to register the damage, before there is a time lapse, in which additional loss of parts can occur. This happens during the clearing of elements that fell off, removal of materials from the site and other interventions.

In Italy, which throughout the history of building has faced great losses due to earthquakes, a method of examining seismic damage has been gradually developed, which can be applied more widely, and so in Serbia. The determination of damage is based on the observation of sixteen indicators, each of which represents a possible collapse mechanism for macro elements into which the observed structure can be divided. The division into macro elements is related to the identification of architectural elements, which are characterized by inherent seismic behaviour, almost independent of the rest of the building. They can be, for example, external walls, apses, domes, bell towers, if concerns church construction. For each of these macro elements, depending on their typology and connection with other parts of the church, it is possible to identify the manner of damage and the mechanism of collapse. During the review it is necessary to define:

1. division into macro elements,
2. damage level (on the 0-3 scale),
3. vulnerability of a building to a specific mechanism, in relation to the specific structural details.

These data facilitate making a damage index, in the range of 1-10, as a standard tool, with damage evaluation using indicators. All the data collected in this way can be a useful tool for acquiring lessons for the future formation of projects of damaged entities restoration.

The problem of seismic vulnerability [18] is thus related to the basic typology of church building and enables the formation of a database for future undesirable cases, when an earthquake damages a structure of the same or similar type. The methodology has been formed on the basis of systematic research of damage to a number of church buildings in the Italian provinces of Umbria and Marche, with data whose collection began in 1944, and then, with each new earthquake, these data were expanded with new knowledge. A large number of 3,000 inspected and assessed churches provided an excellent basis, throughout statistical analysis of damage data and the interrelationship with the typology of buildings, to enable the prediction of earthquake consequences, from the first vulnerability assessment to rapid damage observation processes [67]. This methodology determined that the following basic data should be represented during the inspection of buildings after the earthquake:

1. Typological data and dimensions (these data refer to decomposed different architectural elements, with special recording of structural elements in terms of the building's response to earthquakes - buttresses, braces, etc.);

2. Damage to the elements of artistic value

vrednosti);

3. Indeks oštećenja i indeks povredljivosti (identifikuje se šesnaest mogućih oštećenja i mehanizama kolapsa i karakteri različitih makroelemenata, tako što se za svaki mehanizam utvrđuje prisustvo mehanizma, veličina oštećenja, stvarna povredljivost građevine na taj mehanizam, kao deo indikatora povezanog sa specifičnim konstruktivnim slabostima;

4. Karakteristike zidanja (različita zidarija raznih makroelemenata opisuje se u formularu s pozivanjem na karakteristike obuhvaćenih elemenata i maltera, kompoziciju obrade lica zidova i poprečnih preseka);

5. Sigurnost (procena obrađivača o sigurnosti konstrukcije, sa izborom jedne od četiri mogućnosti: sigurno, sigurno delovanje prve pomoći, delimično sigurno i nesigurno);

6. Napomene-beleške obuhvataju sva dodatna zapažanja o građevini, u vezi sa opštom sigurnosti ili sa onim što nije registrovano pod 1. i 3;

7. Ilustracije podrazumevaju osnove, izglede, preseke i skice detalja, kako bi se što bolje razumeo specifičan mehanizam oštećenja.

Prikupljeni podaci putem jednostavnog uprosečavanja oštećenja makroelemenata i povredljivosti daju dva indeksa:

- Indeks oštećenja je broj od 0 do 1, kojim se iskazuje prosečni nivo oštećenja crkve definisan jednačinom:

(damaged elements in the interior of the building and on its exterior are recorded without defining the value depreciation);

3. Damage index and vulnerability index (sixteen possible damages and collapse mechanisms and characters of different macro elements are identified, so that for each mechanism the presence of the mechanism, damage size, actual vulnerability of the building to that mechanism is determined as part of the indicator related to specific structural weaknesses;

4. Characteristics of masonry (different masonry of various macro elements is described in a form with the reference to the characteristics of the included elements and mortar, the composition of the wall faces and cross-sections treatment);

5. Safety (processor's assessment of the safety of the structure, with the choice of one of four alternatives: safe, safe action of first aid, partially safe and unsafe);

6. Notes include all additional observations on the building related to general safety or to what omitted under 1 and 3;

7. Illustrations include, layouts, views, sections and sketches of details, in order to better understand the specific mechanism of damage.

The data collected by simply averaging macro element damage and vulnerability yield two indices:

- Damage index is the number from 0 to 1, which expresses the average level of church damage, defined by the equation:

$$i_d = \frac{1}{3N}\sum_{k=1}^{16} d_k \qquad (1)$$

gde je dk oštećenje u k mehanizmu (od 0 do 3), N broj mehanizama koji se mogu potencijalno aktivirati u crkvi (N ≤ 16)

- Indeks povredljivosti, koji je vezan za podložnost crkve da bude oštećena u zemljotresu, dobija se iz jednačine:

where dk is the damage in the k mechanism(0-3), N is the number of mechanisms which can be potentially activated in the church (N ≤ 16);

- Vulnerability index, which is related to the susceptibility of the church to the damage in an earthquake, is obtained from the equation:

$$i_d = \frac{1}{3N}\sum_{k=1}^{16} v_k \qquad (2)$$

gde je Vk indikator povredljivosti, prisutan u k mehanizmu (od 0 do 2), N je broj mehanizama koji potencijalno mogu da se aktiviraju u crkvi, m je broj pitanja o povredljivosti na koja nije moguće odgovoriti (na primer, neke zone konstrukcije nije moguće pregledati, za neke elemente nije moguće doneti sud o povredljivosti, i tako dalje).

Na osnovu formirane dokumentacije o istoriji zemljotresa na određenom području i s predloženom metodologijom za procenu oštećenja, moguće je napraviti analizu seizmičkog rizika za sakralnu arhitekturu određenog područja. Ovako pripremljena baza podataka, koja omogućava preventivnu zaštitu, ali i brzo reagovanje nakon događaja, neophodan je strateški prioritet u oblasti zaštite graditeljskog nasleđa.

Za analizu uticaja zemljotresa na građevinske konstrukcije, potrebno je usvojiti odgovarajući dinamički model i definisati pobudu u zavisnosti od načina prikaza seizmičkog dejstva. Seizmička analiza sastoji se iz proračuna dinamičkih karakteristika konstrukcije, određivanja seizmičkih sila na osnovu mehaničkih

where *Vk* is a vulnerability indicator, present in the k mechanism (0 to 2); *N* is the number of mechanisms that can potentially be activated in the church, m is the number of vulnerability questions that cannot be answered (for example, some structural zones cannot be inspected, for some elements it is impossible to make a judgment about vulnerability, etc.).

Based on the documentation formed on the history of earthquakes in a certain area and with the proposed methodology for damage assessment, it is possible to make a seismic risk analysis for the church architecture of a certain area. The database prepared in this way, which enables preventive protection, but also rapid reaction after the event, is a necessary strategic priority in the field of built heritage protection.

For the analysis of the impact of earthquakes on building structures, it is necessary to adopt an appropriate dynamic model and define the excitation depending on the way the seismic action is presented. Seismic analysis consists of the calculation of the dynamic characteristics of the structure, determination of osobina konstrukcije objekta i zadatog pomeranja tla i iz proračuna uticaja u konstrukciji usled dejstva indukovanih seizmičkih sila. Kada se odrede uticaji u konstrukciji usled dejstva seizmičkih sila, sprovodi se dimenzionisanje svih kritičnih preseka za releventnu kombinaciju seizmičkog dejstva i ostalih opterećenja. Nakon toga, uz primenu adekvatnih konstrukcijskih rešenja i razradu detalja specifičnih za aseizmičko projektovanje, obezbeđuje se potrebna nosivost i dovoljan kapacitet deformisanja razmatrane konstrukcije.

Potrebna nosivost prema aktuelnom konceptu seizmičke zaštite određuje se za uticaje u konstrukciji usled seizmičkih sila koje odgovaraju tzv. projektnom nivou (povratni period Tr ≈ 500 god.) [39]. Ove sile određuju se primenom faktora redukcije koji se usvaja u zavisnosti od pretpostavljenog kapaciteta deformisanja konstrukcije. Konstrukcija koja je projektovana na ovakav način po pravilu može bez rušenja da izdrži zemljotresno dejstvo, pod uslovom da stvarne karakteristike događenog zemljotresa odgovaraju usvojenom seizmičkom hazardu. Nedostatak ovog koncepta ogleda se u tome što se na osnovu sprovedenog proračuna nema uvid u veličinu oštećenja noseće konstrukcije. Iskustva iz zemljotresa koji su se dogodili ukazuju da ovakvo projektovanje ne obezbeđuje uniformni rizik jer različite konstrukcije mogu imati različito ponašanje i veoma različit stepen oštećenja u toku istog zemljotresa.

Važan aspekt aseizmičkog projektovanja jeste sprečavanje naglog i nekontrolisanog rušenja konstrukcije. Sadašnja praksa projektovanja predstavlja tradicionalni pristup, zasnovan na silama i određivanju potrebne nosivosti. Poslednjih godina razvija se jedan novi pristup koji se, umesto na silama, zasniva na deformacijama i kontroli oštećenja. Njegova bitna prednost u odnosu na aktuelni koncept projektovanja jeste mogućnost procene seizmičkih performansi objekata, kao kombinacije ponašanja noseće konstrukcije i nenosećih elemenata, kojima se formira kompletan opis ukupnog stepena oštećenja objekta za više nivoa seizmičkog hazarda. Projektom konstrukcije i adekvatnim građenjem potrebno je sprečiti prevelika oštećenja noseće konstrukcije i povrede ljudi za dejstvo proračunskog zemljotresa. Istovremeno se mora obezbediti i adekvatan stepen zaštite za pojavu oštećenja i ograničenja u funkcionisanju objekta za zemljotrese koji se mogu dogoditi više puta u eksploatacionom veku zgrade, ali i dovoljna sigurnost od rušenja za zemljotrese s manjom verovatnoćom pojave od proračunate [34] i [38].

6 NEKI PROBLEMI ZAŠTITE GRADITELJSKOG NASLEĐA OŠTEĆENOG ZEMLJOTRESIMA

U svim oblastima rada, uključujući i radove na spomenicima kulture, postavlja se pitanje iz koje njihove prošlosti počinjemo da razmatramo problem. Da li je to ukupna prošlost ili je to prošlost spomenika kulture koji danas nalazimo i počinjemo se baviti njime. Razlog za ovo pitanje je evolucija koncepata restauracije koja je ostavila traga na zaostavštinu koju danas nalazimo u određenom fizičkom stanju. Ovde se možemo setiti nekih najuticajnijih koncepata. Počevši od E. Viole-l-

seismic forces based on the mechanical properties of the building structure and the given ground movement and from the calculation of the effects on the structure due to the action of induced seismic forces. When the influences in the structure due to the action of seismic forces are determined, the designing of all critical sections for the relevant combination of seismic action and other loads is performed. After that, with the application of adequate structural solutions and elaboration of details specific to seismic design, the required load-bearing capacity and sufficient deformation capacity of the considered structure are provided.

The required bearing capacity according to the current concept of seismic protection is determined for the impacts in the structure due to the seismic forces that correspond to the so-called design level (return period Tr ≈ 500 years). These forces are determined by applying a reduction factor that is adopted depending on the assumed deformation capacity of the structure. A structure designed in this way can, as a rule, withstand an earthquake without collapse, provided that the actual characteristics of the earthquake correspond to the adopted seismic hazard. The disadvantage of this concept is that based on the conducted calculation, there is no insight into the extent of damage to the supporting structure. Experiences from earthquakes indicate that such design lack a uniform risk because different structures may have different behaviour and very different degrees of damage during the same earthquake.

An important aspect of seismic design is the prevention of sudden and uncontrolled collapse of the structure. Current design practice is a traditional approach, based on forces and determining the required load capacity. In recent years, a new approach has been developed which is based on deformations and damage control instead of forces. It is an important advantage over the current design concept is the ability to assess the seismic performance of buildings, as a combination of load-bearing structure and non-load-bearing elements behaviour, which enables forming a complete description of the total degree of damage to the structure for multiple levels of seismic hazard. Using a proper design of the structure and adequate construction, it is necessary to prevent excessive damage to the supporting structure and injuries to people during the action of a designed earthquake. At the same time, an adequate degree of protection against damage and limitations in the operation of buildings must be provided for the earthquakes that can occur several times in the service life of the building, but also a sufficient safety against collapse in the case of earthquakes with less probability of occurrence than the designed one [34] and [38].

6 SOME PROBLEMS OF PROTECTION OF BUILT HERITAGE DAMAGED IN EARTHQUAKES

In all areas of work, including works on cultural monuments, there is a question of what past moment should be the starting point for considering the problem. Is it the entire past or the past of the cultural monument that we find today and begin to deal with? The reason for this question is the evolution of the concepts of restoration that left their mark on the legacy that can be found today in a certain physical state. Some of the most influential concepts can be recalled here. Beginning with

Dika (Viollet-le-Duc, 1814–1879), učenje o strukturama i istraživanje starih tekstova i građevinskih dokumenata bilo je od velikog značaja. Tokom prve polovine XX veka pojavili su se različiti stavovi prema novim materijalima i njihovoj upotrebi. K. Boito (1836–1914) smatrao je da savremene materijale i savremene tehnike treba minimalno koristiti. G. Đovanoni (1873–1947) bio je mišljenja da moderne tehnike, naročito korišćenje armiranog betona, treba koristiti tamo gde tradicionalne metode i materijali nisu dovoljno pouzdani. A. Evans (1851–1941) koji je konzervirao palatu u Knososu, koristio je beton u velikim količinama i na taj način značajno uticao na povećanu upotrebu ovog materijala od strane drugih konzervatora. N. Balanos (1860–1942) prihvatio je armirani beton, smatrajući ga korisnim, čvrstim i izdržljivim alatom za restauraciju najvažnijih grčkih antičkih građevina. Ovi pogledi bili su samo priprema za konačno prihvatanje i preporuku za upotrebu svih raspoloživih savremenih tehnika i materijala, posebno armiranog betona, što je zaključeno Atinskom poveljom 1931. godine. Prvi najvažniji dokument usvojen posle Drugog svetskog rata, Venecijanska povelja iz 1964. godine, preporučuje upotrebu tradicionalnih materijala za strukturalnu stabilizaciju i opštu obnovu. Nove materijale i tehnike treba koristiti samo u slučajevima kada se tradicionalni materijali ne mogu primeniti. U Italijanskoj povelji o restauraciji iz 1989. godine iskazano je nepoverenje u upotrebu novih materijala, uglavnom skrivenih unutar starih građevina, kao što su čelik, fugovanje cementnim malterom ili raznim smolama i beton. Ukazuje se na njihovu ograničenu trajnost, a najviše na nekompatibilnost sa originalnim materijalima, i stoga se naglašeno ističe posvećenost tradicionalnim materijalima koji su lakši za kontrolu i promenu. Danas se ne postavlja pitanje upotrebe novih materijala i tehnologija. Oni su postali neophodni, jer je njihov sastav i način primene takav da mogu ispuniti osnovne principe zaštite izgrađenog nasleđa, uključujući i osiguranje od prirodnih katastrofa, među kojima su zemljotresi, s obzirom na štete koje izazivaju, među najvažnijim [68].

6.1 Učenje iz prošlosti

Mnogi čine grešku misleći da su samo savremene generacije otkrile načine kako da se odupre pretnjama od zemljotresa u konstrukcijskom oblikovanju. Često se veruje da stariji oblici građevinske prakse moraju biti opasniji i štetniji samo zato što su nastali pre nego što su utvrđena savremena pravila građenja, seizmički kodovi i razvijena moderna inženjerska saznanja o zemljotresima [65] i [83]. Svakako, uvođenje čelika omogućava duktilnost tamo gde zidanje ne bi moglo. Ipak, otkriveno je da su otkazali varovi u preko 100 od 400 zgrada sa čeličnom konstrukcijom koje su preživele Nortridž zemljotres u Kaliforniji 1994. godine. To je ukazalo na opasnost koju zemljotres može da izazove i na najsavremenijim građevinama. Mnoge zidane zgrade, stradale u zemljotresima, nisu se uvek potpuno rušile. Kao što se može videti u Makedoniji, Crnoj Gori, Hrvatskoj, Srbiji, Jermeniji, Italiji, Turskoj, Iranu, urušavale su se i moderne armirano-betonske zgrade, dok su starije zidane zgrade u blizini ostale netaknute ili malo oštećene, pa su pružale utočište raseljenim

Viollet-le-Duc (1814-1879), learning about structures and researching old texts and construction documents was of great importance. During the first half of the 20th century, different attitudes towards new materials and their use emerged. C. Boito (1836-1914) considered that modern materials and modern techniques should be used minimally. G. Giovannoni (1873-1947) was of the opinion that modern techniques, especially the use of reinforced concrete, should be used where traditional methods and materials are insufficiently reliable. A. Evans (1851-1941), who conserved the palace at Knossos, used concrete in large quantities and thus significantly influenced the increased use of this material by other conservators. N. Balanos (1860-1942) accepted reinforced concrete, considering it a useful, solid and durable tool for the restoration of the most important ancient Greek buildings. These views were only a preparation for the final acceptance and recommendation for the use of all available modern techniques and materials, especially reinforced concrete, which was concluded by the Athens Charter of 1931. The first important document adopted after the Second World War, the Venice Charter of 1964, recommends the use of traditional materials for structural stabilization and general reconstruction. New materials and techniques should be used only in cases where traditional materials cannot be used. The Italian Charter of Restoration of 1989 expressed distrust in the use of new materials, mostly hidden inside old buildings, such as steel, grouting with cement mortar or various resins and concrete. The charter indicated their limited durability, but most of all the incompatibility with the original materials, and therefore the commitment to traditional materials that are easier to control and change is emphasized. Nowadays, the question of the use of new materials and technologies is not posed. They have become necessary because their composition and method of application are such that they can meet the basic principles of protection of the built heritage, including safeguarding against natural disasters, among which earthquakes, given the damage they cause, are among the most important ones [68].

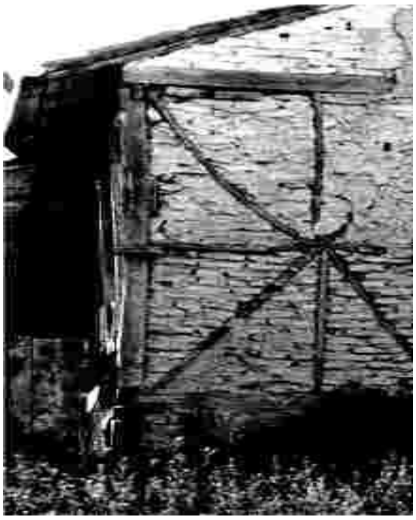
6.1 Lessons of the past

Many make the mistake of thinking that only modern generations have discovered ways to resist earthquake threats in structural design. It is often believed that older forms of construction practice must be more dangerous and harmful only because they originated before modern building rules, seismic codes, and developed modern engineering knowledge of earthquakes were developed [65] and [83]. Certainly, the introduction of steel enables ductility where masonry could not. However, it was discovered that welds in over 100 of the 400 steel-built buildings that survived the 1994 Nortbridge earthquake in California failed. This indicated the danger earthquakes pose even to state-of-the-art buildings. Many masonry buildings, damaged in earthquakes, did not always completely collapse. As can be seen in Macedonia, Montenegro, Croatia, Serbia, Armenia, Italy, Turkey, Iran, modern reinforced concrete buildings collapsed, while older masonry buildings nearby remained intact or slightly damaged, providing shelter to the displaced residents of newer buildings. In various stanovnicima novijih zgrada. Na različitim područjima, kao što su Turska, bivša Jugoslavija, Kašmir i Nikaragva, autohtoni oblici gradnje razvijeni su ili prilagođeni odgovorima na pretnju zemljotresa tamo gde su raspoloživi resursi zahtevali da se zidarija i dalje koristi. Istorijski izveštaji potvrđuju da su ove zgrade bolje podnele zemljotres nego obližnje zgrade naših dana.

Danas se mnogi zalažu da se ovim vernakularnim građevinama obavi zamena postojećih sa armirano-betonskim konstrukcijama, koje se zbog loših lokalnih građevinskih praksi mogu pokazati kao manje otporne od svojih niskotehnoloških, neinženjerskih istorijskih prethodnika (zasnovano na empiriji). Čak i stručnjaci za zaštitu i obnovu ponekad ne uspevaju da razumeju suštinu seizmičke otpornosti u starijim strukturama. Verujući da su građevini neophodno potrebne nosivost i krutost, oni uništavaju originalne konstrukcijske sisteme da bi se intervencijama stekla snaga na štetu ranijih rešenja koja i dalje mogu biti korisna. Primer bi mogao da se nađe u Dubrovniku, gde su restauratori jedne istorijske palate otkrili unutrašnji zid za koji su mislili da je čvrsto zidan, a, u stvari, u unutrašnjosti je imao segmente nalik pletenoj korpi od malih drvnih škriljaca, sa ispunom od opeke ili kamena, lagano uklopljenom među čepove. Na konferenciji je data izjava da je loše izgrađeni zid odmah uklonjen i zamenjen tokom restauracije zgrade. Umesto što je zaključeno da je "loše izgrađen“, moglo se razmisliti o tome da je ovaj zid, možda, namerno bio izgrađen na ovaj način kako bi se odupro zemljotresima. Srušeni zid najverovatnije predstavlja rezultat pouka iz prošlosti, jer je Dubrovnik gotovo u potpunosti bio uništen tokom zemljotresa 1667. godine. Struktura zida je, možda, ukazivala na daleko veće razumevanje seizmičkog inženjerstva nego što se danas može pretpostaviti. Građevine od bondruka ili nepečene opeke često su manje stradale od betonskih tokom zemljotresa u Skoplju 1963. godine (slika 20 a i b).

places, such as Turkey, the former Yugoslavia, Kashmir and Nicaragua, autochthonous forms of construction have been developed or adapted to respond to the earthquake threat where available resources have necessitated the continued use of masonry. Historical reports confirm that these buildings withstood the earthquakes better than the nearby contemporary buildings.

Today, many advocate replacing these vernacular structures with reinforced concrete structures, which due to poor local construction practices may prove less resistant than their "low-tech", non-engineered historical predecessors (based on empiricism). Even conservation and restoration experts sometimes fail to understand the essence of seismic resistance in older structures. Believing that buildings need load-bearing capacity and rigidity, they destroy the original structural systems in order to improve strength through interventions to the detriment of earlier solutions that can still be useful. An example could be found in Dubrovnik, where the restorers of a historic palace discovered an interior wall that they thought was solidly built and, in fact, inside it had segments resembling a wicker basket of small wooden slates, with a brick filling or stone, lightly fitted between the plugs. A statement was made at the conference that "the poorly built wall was immediately removed and replaced during the restoration of the building." Instead of concluding that it was "poorly built", this wall may have been intentionally built in this way to withstand earthquakes. The demolished wall was probably the result of lessons from the past, because Dubrovnik was almost completely destroyed during the earthquake in 1667. The structure of the wall may have indicated a far greater understanding of seismic engineering than can be assumed today. Buildings made on post-and-pan system or unfired bricks, or adobe were often less damaged than concrete ones during the earthquake in Skopje in 1963 (Figure 20 a and b).




Slika 20. Kuća bondručne konstrukcije i Železnička stanica, efekti skopskog zemljotresa iz 1963. godine, prema [67]
Figure 20. House of post-and-pan structure and Railway Station, effects of the Skopje earthquake from 1963, after [67]

6.2 Tehnički propisi i neke tehničke mere

Evropska zajednica neprekidno teži da usaglasi pravila koja važe u različitim zemljama i da ih objedini u jedinstvena pravila. Taj problem, kada je u pitanju graditeljsko nasleđe u različitim zemljama, pokušava se rešiti jedinstvenim univerzalnim merama i preporukama. Kada su u pitanju pravilnici za projektovanje konstrukcija, naglašava se potreba da se za istorijske zgrade izdvoji posebna šifra. Ovaj kodeks treba da se zasniva na ciljnim performansama, a ne na standardnim procedurama. Međunarodni standardi koji se podjednako odnose i na nove i stare zgrade, ne obuhvataju specifičnosti istorijskih tipova zgrada, koje se razlikuju od regiona do regiona. Ono što se smatra dobrom praksom na jednom području, može delovati destruktivno na nekim područjima s drugim kulturološkim vrednostima. Posebne odredbe za istorijske zgrade sa arhaičnim sistemima gradnje i starijim programima prostorne organizacije treba da se uključe u pravilnike ili će mnoge stare zgrade delimično ili potpuno izgubiti svoju vrednost. Republika Srbija je promovisala Zakon o vanrednim situacijama u 2010. godini (Službeni glasnik, 2010). Nacionalna strategija za zaštitu i spašavanje u vanrednim situacijama, usvojena u novembru 2011. godine, nije toliko izraz planiranja za budućnost, već je više neposredna reakcija na elementarne katastrofe, najčešće poplave, s kojima se u poslednje vreme suočava država. Diskusija o odgovarajućim kodeksima, profesionalnoj odgovornosti, pa čak i temama u oblasti naučnog istraživanja, svakako mora da obuhvati i raspravu o definisanju neophodnog nivoa seizmičke zaštite.

Tehnički propisi i pravilnici koriste se za uspostavljanje donje granice performansi koje se primenjuju na građevinu zavisno od njene vrednosti i očuvanosti [103]. Ovo je noviji pristup koji se koristi u projektovanju intervencija na konstrukciji objekta. Prvenstveno se moraju obezbediti performanse: zaštita života, i/ili ograničenje oštećenja zavisno od značaja građevine. Da bi se postigle ciljne performanse, nužna je tehno-ekonomska analiza. Zbog toga se očekuje da se utvrdi i obezbedi finansiranje. Seizmička zaštita, naročito za velike javne projekte, uključuje učešće državnih fondova. Smatra se da određivanje ukupne sume novca, koju za te radove treba planirati dovodi do nesuglasica i da usled toga nema konsenzusa. U mnogim građevinskim propisima odredbe i preporuke odnose se na nove ili postojeće zgrade, znatno manje se odnosi na "stare", tj. istorijske zgrade koje predstavljaju kulturna dobra. Mnogi inženjeri i arhitekti, međutim, nisu uvek spremni da definišu obim prihvatljive štete za istorijske zgrade. U pojedinim slučajevima, naročito kod bondručnih zgrada sa ispunom od opeke, ponekad se uslovljava da se obezbede mere za sprečavanje urušavanja, iako se radi o tipu zgrada koji u prošlosti nije previše stradao u zemljotresima. Teškoće i nesigurnosti s kojima se u ovim slučajevima primene tehnologije suočavaju konzervatori i drugi, uključeni u očuvanje građevinske baštine, ogledaju se u članu 10 Krakovske povelje [107].

Razumevanje delovanja zemljotresa intenzivno se poboljšava u poslednjih sto godina. Predloženo je na desetine parametara za kvantifikaciju zemljotresnog dejstva širom sveta. Njima se definiše složenost

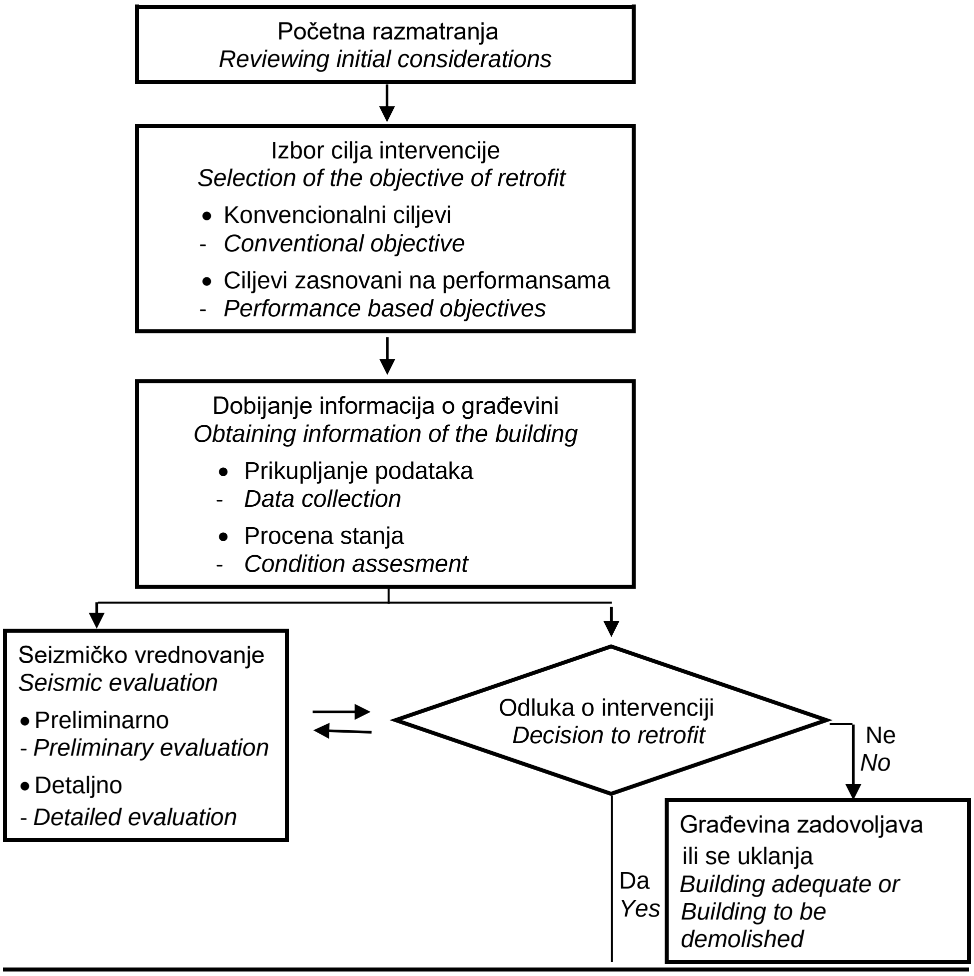
6.2 Technical regulations and some technical measures

The European Union is constantly striving to harmonize the rules that apply in different countries and to unite them into uniform rules. When it comes to the built heritage in different countries, this problem, is being solved with single and universal measures and recommendations. When it comes to regulations for the design of structures, the need to allocate a special code for historic buildings is emphasized. This code should be based on a targeted performance, not standard procedures. International standards, which apply equally to new and old buildings, fails to cover the specifics of historical building types, which differ from region to region. What is considered good practice in one area can be destructive in some areas with other cultural values. Special provisions for historic buildings with archaic building systems and older spatial organization programs should be included in the codes or many old buildings will partially or completely lose their value. The Republic of Serbia promoted the Law on Emergency Situations in 2010 (Official Gazette, 2010). The National Strategy for Protection and Rescue in Emergency Situations, adopted in November 2011, is not so much an expression of planning for the future, but more of a direct reaction to natural disasters, most often floods, which the country has been facing lately. The discussion of appropriate codes, professional responsibility, and even topics in the field of scientific research should certainly include a discussion on defining the necessary level of seismic protection.

Technical regulations and codes are used to establish the lower performance limit applicable to a building depending on its value and preservation condition [103]. This is a newer approach used in the design of interventions on building structures. Primarily protection of life, and / or limitation of damage depending on the importance of the building. In order to achieve the target performance, a techno-economic analysis is necessary. It is therefore expected to identify and secure funding. Seismic protection, especially of large public projects, involves the participation of state funds. It is believed that designation of the total amount of money to be planned for these works leads to disagreements and consequently no consensus. In many building regulations, the provisions and recommendations refer to new or existing buildings, much less to the "old", i.e. historic buildings that represent cultural property. Many engineers and architects, however, are not always ready to define the extent of acceptable damage to historic buildings. In some cases, especially in post-and-pan buildings with brick infill, it is sometimes necessary to provide measures to prevent collapse, although this is a type of building that has not suffered excessively in the past earthquakes. The difficulties and uncertainties faced by conservators and others involved in the preservation of built heritage in these technology application cases are reflected in Article 10 of the Krakow Charter [107]

Understanding the effects of earthquakes has been improving rapidly over the last hundred years. Dozens of parameters for quantification of earthquake action around the world have been proposed. They define the complexity of the problem and contribute to a better problema i doprinosi boljem razumevanju inženjerskog pristupa rešavanju [54]. Ovde je prikazan samo jedan, dijagram toka 2, u nizu procesa kojima se definiše redosled radnji kojima se utvrđuje odluka kako je zemljotres uticao na građevinu i shodno tome kakva će biti njena sudbina, odnosno da li će se popravljati, uklanjati ili delimično uklanjati [115].

understanding of the engineering approach to solving it. Here is just one flow chart in a series of processes that define the sequence of actions that determine the decision on how an earthquake affected the building and, accordingly, what its fate will be, i.e. whether it will be repaired, removed or partially removed [115].



Slika 21. Evolucija zemljotresne katastrofe, prema [115]
Figure 21. Evolution of earthquake disaster [115]

U popisu literature su navedene norme i pravilnici koji se primenjuju u Evropi iz seta (EN 1998) [32-33] koji se odnose na zemljotresno inženjerstvo, a nedavno su usvojeni i kao Standardi koji se moraju primenjivati i kod nas [94]. Pored toga, u popisu su navedeni i dokumenti FEMA [35] koji se primenjuju u SAD i u mnogim zemljama u kojima je s manjim modifikacijama preporučeni kao meritorni dokumenti. Ovi dokumenti su, u najvećem delu, posvećeni određivanju seizmičkih dejstava za primenu u analizi konstrukcija, a zbirka propisa svih zemalja u, seizmički aktivnim područjima, data je u [30], dok je kolekcija istorijskih zemljotresa data u [104]. Seizmičnost Mediterana analizirana je u [23], u Italiji u [46], a takođe i u projektovanju konstrukcija i veza nenosećih elemenata s konstrukcijom [36]. Važno mesto zauzimaju i aspekti klasifikacije oštećenja i upotreb-

The bibliography lists the norms and Regulations that are applied in Europe from the set (EN 1998) [32-33j] which refer to earthquake engineering, and were recently adopted as Standards that must be applied in our country as well [94]. In addition, the list also includes FEMA documents [35] that are applied in the USA and in many countries where it is recommended as a referential document with minor modifications. These documents are, for the most part, devoted to determining seismic effects for application in structural analysis, and a collection of regulations of all countries in seismically active areas is provided in [30], and a collection of historical earthquakes [104]. The seismicity of the Mediterranean was analyzed in [23], in Italy in [46], and also in the design of structures and connections of non-bearing elements with the structure [36]. An important ljivosti objekata, što se, imajući u vidu obim rada, ne obrađuje šire ovde. Takođe, uporedna analiza EN i naših pravilnika razmatrana je u [38] i [39], a i aktuelne metode koje se pri tome primenjuju.

6.3 Neki materijali i tehničke mere

Moderna inženjerska nauka, novi materijali i aktuelni kodovi prešli su dug put s ciljem smanjenja straha od smrti u zemljotresu. Ipak, uprkos tome, potresi su izazivali ozbiljne posledice. Pristupi su se, naročito posle razornih zemljotresa, menjali uz stalnu transformaciju pa i u moderno doba, zahvaljujući napretku računara. Proučavanjem razvoja tehničkih propisa uočava se da su oni unapređivani posle jakih zemljotresa, naročito u Japanu, i SAD (Kalifornija) [38]. Projektovanje seizmički otpornih zgrada je evoluirajući menjano, uglavnom zato što su snažni zemljotresi relativno retki, ali kada se dogode, očekuju se i značajna konstruktivna oštećenja. Linija između prihvatljivog i neprihvatljivog rizika i performansi nedovoljno je jasno određena. Tradicionalno, veće zgrade bile su zidane konstrukcije, a zidovi su oslanjani direktno na zemlju. S trenutnom dominacijom čelika i armiranog betona (AB) kao materijala za građenje, noseća konstrukcija je najčešće ramovska, na koju se pričvršćuje obloga. Početkom XXI veka kontrast između starog i novog sistema postao je posebno uočljiv. Budući da se "postmoderna" orijentacija vraća ka istorijskim formama i detaljima, ovaj pomak stila vratio je želju za projektovanjem zgrada koje imaju noseće masivne zidove kao što su rađene u prošlosti. Često, međutim, na njima nisu uspešno prikazivani tekstura i značenje kao u starijim zgradama.

Zahvaljujući razvoju računarstva i mogućnostima obrade složenih matematičkih problema, inženjeri rade na modeliranju zidanih zgrada. Pri tome ne koriste samo približne metode već sve češće modeliraju nelinearno ponašanje konstrukcije istorijskih zidanih zgrada. To je za zidariju veoma kompleksno pa se primenjuju i druge metode, tj. modeli. Modeli za njihovu analizu su: ekvivalentni model ramova, kruti makroblok model, i metoda konačnih elemenata (MKE- FEM). Ova transformacija u građevinskoj tehnologiji paralelna je sa sličnom promenom inženjerske prakse koja se oslanja i na brze uprošćene analize za projektovanje konstrukcija. Ipak, mnoštvo je objekata graditeljskog nasleđa sa zidanim konstrukcijama. Stabilnost masivnih zidova obično prkosi analizi kompleksnim metodama. Te strukture izdržale su velike zemljotrese u prošlosti, a evidencija štete je poznata [59]. Na primer, brojnim istorijskim zgradama u Srbiji koje su preživele zemljotres u Mionici 1998. i Kraljevu 2010. godine, više prete članovi Zakona o ublažavanju opasnosti [119] nego budući zemljotresi – slika 21 a i b [42].

place is occupied by aspects of the classification of damage and serviceability of buildings, which, given the scope of work, is not covered here. Also, a comparative analysis of EN and our Regulations is discussed in [38] and [39], as well as the current methods used.

6.3 Some materials and technical measures

Contemporary engineering science, new materials and current codes have come a long way with the goal of reducing the fear of death in an earthquake. Nevertheless, the earthquakes have serious consequences. Approaches, especially after the devastating earthquakes, transformed constantly, even in the modern times, thanks to the progress of computers. A study of the development of technical regulations shows that they were improved after strong earthquakes, especially in Japan and the United States (California) [38]. The designing seismically resistant buildings has evolved, mainly because strong earthquakes are relatively rare, but when they occur, significant structural damage is also expected. The line between acceptable and unacceptable risk and performance is unclearly defined. Traditionally, larger buildings were masonry structures, and the walls were supported directly on the ground. With the current dominance of steel and reinforced concrete (RC) as the building material, the load-bearing structure is usually a frame to which the cladding is attached. At the beginning of the 21st century, the contrast between the old and the new system became particularly prominent. As the "post-modern" orientation returns to historical forms and details, this shift in style has restored the desire to design buildings that have massive load-bearing walls as they used to in the past. Often, however, they unsuccessfully display the texture and meaning as in older buildings.

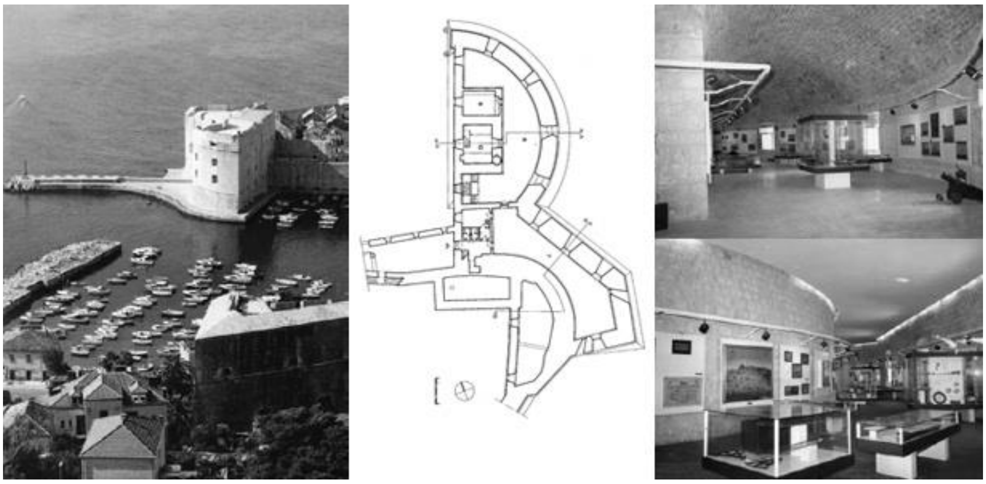
Owing to the development of computing and the ability to process complex mathematical problems, engineers use work on modelling masonry buildings. In doing so, they not only use approximate methods, but increasingly model the nonlinear behaviour of the of historic masonry buildings structure. This is very complex for masonry, so other methods are used, i.e. models. Models for their analysis are: equivalent frame model, rigid macro-block model, and finite element method (FEM) [18]. This transformation in construction technology is parallel to a similar change in the engineering practice that relies on rapid simplified analyses for structural design. However, there are many buildings of built heritage having masonry structures. The stability of massive walls usually defies analysis by complex methods. These structures have withstood major earthquakes in the past, and damage records are known [59]. For example, numerous historical buildings in Serbia that survived the earthquake in Mionica in 1998 and Kraljevo in 2010 are more threatened by the articles of the Law on Mitigation of Danger [118] than by future earthquakes (Figure 21 a and b) [42].

Slika 21. Oštećene zgrade u Mionici i Kraljevu, prema [Foto Ž. Krsmanović]
Figure 21. Damaged buildings in Mionica (a) and Kraljevo (b), [Photo Ž. Krsmanović]

Istorijske zgrade nemaju svoj kulturni značaj samo kao relikvije iz prošlosti. Kulturno značenje mnogih zaštićenih istorijskih građevina odnosi se na njihovu ukupnost. Istorijska konstrukcija je, zato, važna, jer je svedočanstvo nivoa graditeljske veštine i smelosti graditelja neke epohe. Seizmička zaštita i pojačavanje graditeljskog nasleđa prisiljavaju nas, međutim, da se suočimo s jednom od glavnih dilema očuvanja istorijskog tkiva i konstrukcije. Činjenica je da proces očuvanja mora da obuhvati promene i obnovu pojedinih, nekada i većine, delova građevine. Za razliku od održavanja i sanacije stare građevine koja kroz vreme propada, seizmički projekat zaštite dekomponuje istorijsko tkivo zgrade koja može biti i u dobrom stanju i čini je gotovo potpuno novom iz aspekta konstrukcije i materijala. Ponekad se seizmički projekti zaštite promovišu i kao mogućnosti za "vraćanje" prvobitnog izgleda zgrade, uz uklanjanje svih kasnije nastalih izmena (potpuna rekonstrukcija) [69]. Na primer, posle crnogorskog zemljotresa 1979. godine, mnoge građevine u istorijskim gradovima Dubrovniku, Kotoru i Budvi, koji predstavljaju svetsko kulturno nasleđe, rekonstruisane su sa armirano-betonskim (AB) međuspratnim konstrukcijama, koje su zamenile originalnu drvenu građu. Nekim od zgrada su u zidove ubačeni AB stubovi, koji formiraju potpuno nove "AB konstrukcije”. Torkretiranje je korišćeno za tambure, kupole i zidove građevina tako da su oni sada deblji nego što su bili u izvornom stanju. Pored toga, nepovratnim čvrstim povezivanjem starih zidova sa dodatim AB elementima, uništen je integritet tih zidova kao pravih, izvornih zidova. Jedna od glavnih prednosti zidanja u kamenu ili opeci je ta što se zidna masa može popraviti uklanjanjem samo oštećenih delova i preslaganjem. U ovom slučaju je, međutim, originalni zid spojen u jednu čvrstu, sraslu masu s betonom. Godinama kasnije, neće biti moguće popraviti takve zidove bez još većeg oštećenja dragocenog originalnog materijala. U crnogorskom zemljotresu 1979. godine svodna konstrukcija Tvrđave Svetog Ivana u Dubrovniku bila je oštećena, napukla i zidovi su se međusobno razdvojili. Najveće konstruktivne intervencije u obnovi tvrđave bile su izvedene 1982. godine. Postavljeni su horizontalni serklaži, ploče od armiranog betona su postavljene između podrumskih svodova, a bilo je uvedeno i vertikalno proširenje ka gradskim zidinama. To je dobar primer u kojem je originalno tkivo

Historic buildings do not have their cultural significance only as relics from the past. The cultural significance of many protected historical buildings refers to their totality. Historical structure is, therefore, important, because it is a testimony to the level of construction skills and boldness of the builders of an era. Seismic protection and the reinforcement of the built heritage compel us, however, to face one of the main dilemmas of preserving the historical fabric and structures. It is the fact that the preservation process should include changes and renovations of certain, sometimes of most parts of the building. Unlike the maintenance and rehabilitation of an old building that is deteriorating over time, the seismic protection project recomposes the historic fabric of the building, which can be in good condition and makes it almost completely new in terms of structure and materials. Sometimes seismic protection projects are also promoted as opportunities to "restore" the original appearance of the building, with the removal of all subsequent changes (complete reconstruction)[69]. For example, after the Earthquake in Montenegro of 1979, many buildings in the historic cities of Dubrovnik, Kotor and Budva, which represent world cultural heritage, were reconstructed with reinforced concrete (RC) floor structures, which replaced the original timber. In some of the buildings, RC columns are inserted in the walls, forming in this way completely new "RC structures ". Shotcrete was used for the drums, domes and walls of the buildings so that they are now thicker than they were in their original condition. In addition, by irreversibly firmly connecting the old walls with the addition of RC elements, the integrity of those walls as original walls was destroyed. One of the main advantages of building in stone or brick is that the wall mass can be repaired by removing only the damaged parts and rearranging them. In this case, however, the original wall is joined into a single solid, fused mass with concrete. Years later, it will be impossible to repair such walls without even greater damage to the precious original material. In the Montenegro earthquake in 1979, the vaulted structure of the fortress of St. John in Dubrovnik was damaged, cracked and the walls separated from each other. The largest structural interventions in the reconstruction of the fortress were carried out in 1982. Horizontal tie beams were installed, reinforced concrete slabs were placed between the tvrđave čvrsto povezano sa armiranim betonom i više se ne može dezintegrisati i povratiti u prvobitno stanje. Mogućnost povratka u prvobitno stanje je jedno od osnovnih načela svih radova na kulturnom nasleđu – slika 22 (Zavod za obnovu Dubrovnika, 1982–85).

ground vaults, and a vertical extension to the city walls was introduced. This is a good example showing how the original fabric of the fortress is firmly connected to the reinforced concrete and can no longer be disintegrated and restored to its original state. The possibility of reversibility is one of the basic principles of all cultural heritage works (Figure 22) (Institute for the Reconstruction of Dubrovnik, 1982-85).



Slika 22. Tvrđava Svetog Ivana u Dubrovniku, posle obnove, prema [66]
Figure 22. The Fortress of Saint John, Dubrovnik, after renewal, after [66]

Postoje i primeri kod kojih je doneta odluka da se uklone neki elementi na građevini bez dubljeg razumevanja njihove uloge u njoj. Kroz obimne zidove crkve manastira Petkovica na Fruškoj gori bile su pre više od 100 godina provučene zatege kao odbrana od zemljotresa. Sa spoljne strane zidova bile su vidljive pločice od livenog gvožđa kojima je zatega bila oslonjena na obimne zidove. Tokom konzervacije, ove zatege su uklonjene. Ta zatega je, međutim, bila svedočanstvo da je crkva utezana da bi se sprečilo razmicanje zidova i njihovo postepeno urušavanje [39].

R. Žarnić sažeo je savremeno iskustvo očuvanja u svom izveštaju o tehnologijama za zaštitu spomenika baštine u Sloveniji [120]. Koncept sanacije zida uključuje skup mera koje uspostavljaju krut odgovor kao reakciju zgrade na zemljotresnu pobudu. Predlaže sledeće tehničke mere koje su neophodne za uspostavljanje stabilnosti i zemljotresne otpornosti zidane baštine:

- konsolidacija temelja;
- spajanje zidova i podne konstrukcije;
- pojačavanje zidova fugovanjem i / ili injektiranjem pukotina;
- pojačavanje zidnih svodova;
- sistematsko obnavljanje postojećih podnih konstrukcija ili njihova zamena novim;
- obnova drvene krovne konstrukcije, popravka i pojačavanje nekonstruktivnih elemenata.

U praksi postoje razne vrste metoda zaštite, od onih u kojima se zahteva strogo pridržavanje tradicionalnih zanata i tehnika do onih u kojima se uvode u potpunosti novi materijali i konstruktivni sistemi [8], [12] i [25]. Poslednjih decenija i u celom regionu bivše Jugoslavije razvijane su, ili modifikovane i poboljšane različite tehnologije korišćenjem rezultata laboratorijskih

There are also examples where the decision was made to remove some elements on the building without a deeper understanding of their role in it. More than 100 years ago, a brace was installed through the extensive walls of the church of the Petkovica monastery on Fruška Gora as a defence against earthquakes. On the outside of the walls, cast iron tiles were visible, with which marked the contact of points of the brace and the large walls. During conservation, these braces were removed. That brace, however, was a testimony that the church was braced in order to prevent the walls from spreading apart and gradually collapsing [39].

R. Žarnić summarized the contemporary experience of preservation in his report on heritage monument protection technologies in Slovenia [120]. The concept of remediation of the wall includes a set of measures that establish a rigid response as a reaction of the building to the earthquake excitation. He proposed the following technical measures necessary to establish the stability and earthquake resistance of the heritage masonry buildings:

- consolidation of foundations,
- joining walls and floor structures,
- strengthening of walls by pointing joints and/or grouting cracks,
- strengthening of wall vaults,
- systematic renovation of existing floor structures or their replacement with new ones,
- renovation of timber roof structure, repair and reinforcement of non-structural elements.

In practice, there are various types of protection methods, from those that require strict adherence to traditional crafts and techniques to those that introduce completely new materials and structural systems [8], [12 eksperimentalnih istraživanja podržanih analitičkim istraživanjima [50]. Posebno velika pažnja se posvećuje izvođenju što bezbolnijih i kvalitetnijih povezivanja starih i novih materijala, jer te veze utiču na očuvanje stilske celine cele građevine i dugotrajnost spregnute (staro-novo) konstrukcije. Kao jedan od materijala, još uvek aktuelan za povezivanje, jesu mešani materijali na bazi epoksida. Prethodno je neophodno proceniti kompatibilnost fizičkih / mehaničkih svojstava (gustina, linearna toplotna ekspanzija) materijala za povezivanje i materijala koji se povezuju, zapreminu materijala kojim se spaja, veličinu spoja koji se puni i temperaturu oko spoja da bi se sprečilo naprezanje između smole i okolne konstrukcije [104]. Značajna novina na polju očuvanja graditeljskog nasleđa bila je pojava i upotreba polimera ojačanih vlaknima (FRP). Njihov razvoj je tekao veoma brzo, od upredenih vlakana do tkanina praktično neograničenih dimenzija. U obnovi kulturnih dobara od posledica zemljotresa upotreba FRP vlakana je danas skoro nezamenljiva [26]. Ipak, rasprava o tome koja vlakna su najprikladnija za vezivanje sa starim građevinskim materijalima, vlakna od ugljenika, aramidna ili stakla i dalje je veoma živa [21].

Jedan od obećavajućih pravaca u obnovi graditeljskog nasleđa posle zemljotresa je upotreba starih, tradicionalnih materijala značajno unapređenih novim tehnologijama. Njihova primena u obnovi graditeljskog nasleđa omogućava poštovanje jednog od osnovnih principa konzervacije, reverzibilnost. Slično unapređenim starim materijalima, potpuno novi nano materijali omogućavaju delikatne intervencije kojima se maksimalno čuva originalno tkivo građevina koje je ostalo neoštećeno ili malo oštećeno u zemljotresima. O novim materijalima i tehnikama obnove graditeljskog nasleđa, s obzirom na složenost i obim pregleda, biće raspravljano u drugom tekstu

U svetu, a naročito u zemljama koje često pogađaju zemljotresi, mnoštvo je preporuka kako pristupiti ublažavanju dejstva zemljotresa. Veoma teško je pratiti i prikazati sve, u nekim zemljama se te preporuke unapređuju i dopunjuju. Ipak, među preporukama ima dosta sličnosti, jer je problem uvek isti. Novi Zeland je zemlja koju zemljotresi često pogađaju i vrlo je aktivna u objavljivanju preporuka, naročito u predstavljanju koraka u postupcima procene i tehnikama analize [3]. Autori s Novog Zelanda predložili su uprošćenu analizu bočnih mehanizama, SlaMA (Simple Lateral mehanizam Analysis). To su ključni koraci koji su vrlo korisni za ublažavanje mogućih efekata zemljotresa [109]:

- Korak 1: Procena konfiguracije i puteva sila radi identifikacije ključnih konstruktivnih elemenata, potencijalnih slabosti i ozbiljnih konstruktivnih slabosti;
- Korak 2: Sračunavanje relevantne verovatne nosivosti i kapaciteta deformisanja pojedinih elemenata.
- Korak 3: Određivanje verovatnog neelastičnog ponašanja elemenata upoređenjem verovatnog kapaciteta i vrednovanje hijerarhije nosivosti.
- Korak 4: Procena podsistema neelastičnog mehanizma proširenjem lokalnog u globalno ponašanje.
- Korak 5: Formiranje izgleda potencijalnog upravljačkog mehanizma za celokupnu građevinu kombinovanjem različitih pojedinačnih mehanizama i proračun verovatne smičuće sile u osnovi i merenje ukupnog kapaciteta pomeranja vrha primarne konstrukcije za bočne sile. Ukupni kapacitet pomeranja

and [25]. In recent decades, various technologies have been developed or modified and improved in the entire region of the former Yugoslavia, using the results of laboratory experimental research supported by analytical research [50]. Particular attention has been paid to the least intrusive and best quality connections between old and new materials, because these connections affect the preservation of the stylistic unity of the entire building and the longevity of the combined (old-new) structure. Epoxy-based mixed materials are still relevant for bonding as one of such materials. It is previously necessary to assess the compatibility of physical/mechanical properties (density, linear thermal expansion) of the bonding material and the bonded materials, the volume of the bonding material, the size of the bonding joint and the temperature around the joint to prevent stress between the resin and the surrounding structure [104]. A significant novelty in the field of preservation of architectural heritage was the emergence and use of fibre-reinforced polymers (FRP). Their development was very fast, from twisted fibres to fabrics of practically unlimited dimensions. In the restoration of cultural property from the effects of earthquakes, the use of FRP is almost irreplaceable today. Nevertheless, the debate over which fibres are most suitable for bonding with old building materials, carbon fibre, aramid, or glass is still very lively [21].

One of the promising directions in the restoration of the architectural heritage after the earthquake is the use of old, traditional materials considerably improved by new technologies. Their application in the restoration of the built heritage ensures the observation of one of the basic principles of conservation, reversibility. Similar to the improved old materials, the completely new nano-materials enable delicate interventions that maximally preserve the original fabric of buildings that remained intact or slightly damaged in earthquakes. New materials and techniques for the restoration of built heritage, given the complexity and scope of the review, will be discussed in another text.

In the world, and especially in countries that are often affected by earthquakes, there are many recommendations on how to approach the mitigation of earthquakes. It is very difficult to follow and show everything, in some countries these recommendations are being improved and supplemented. Yet, there are a lot of similarities between the recommendations, because the problem is always the same. New Zealand is a country that is often affected by earthquakes and is very active in publishing recommendations, especially in presenting steps in assessment procedures and analysis techniques [3]. Authors from New Zealand proposed a simplified analysis of lateral mechanisms, SlaMA (Simple Lateral Mechanism Analysis). These are the key steps that are very useful for mitigating the possible effects of an earthquake [109]:

- Step 1: Assess the structural configuration and load paths to identify key structural elements., potential structural weaknesses (SSWs) and severe structural weaknesses (SSWs).
- Step 2: Calculate the relevant probable strength and deformation capacities for the individual members.
- Step 3: Determine probable inelastic behaviour of elements by comparing probable member capacities and evaluating the hierarchy of strength.

se ograničava, za sistem s najnižim kapacitetom pomeranja.

- Korakom 6 određuje se ekvivalentni SDOF (Single Degree of Freedom) sistem, i definišu seizmički zahtevi.

Za zidane konstrukcije, kako je već naglašeno, sve analize su znatno kompleksnije nego za konstrukcije od AB ili čelika. Za procenu ponašanja istorijskih zidanih konstrukcija, pod seizmičkim dejstvima, u [4] opisana je metodologija koja uključuje i restauraciju sa sledećih osam koraka: 1) istorijska i eksperimentalna dokumentacija; 2) karakteristike materijala; 3) model konstrukcije; 4) dejstva; 5) analize; 6) kriterijumi loma i procena nosivosti; 7) odluka za intervencije usmerene na sanacije i/ili pojačavanja i ponovna analiza; 8) izveštaj sa objašnjenjem. Ova metodologija je zasnovana i usaglašena s Preporukama ICOMOS-a. Od značaja je pomenuti da se u koraku 1 sumiraju podaci dobijeni pregledom objekata posle zemljotresa, ali i rezultati eksperimentalnih istraživanja, korišćenjem ambijent-vibracija, do najsloženijih ispitivanja na vibro-platformama na čemu se zasnivaju mnogi numerički modeli [60].

- Step 4: Assess the sub-system inelastic mechanisms by extending local to global behaviour.
- Step 5: Form a view of the potential governing mechanism for the global building by combining the various individual mechanisms and calculate the probable base shear and global displacement capacity measured at the top of the *primary* lateral structure. The global displacement capacity will typically be limited to that for the system with the lowest displacement capacity.
- Step 6: determines the equivalent SDOF (Single Degree of Freedom) system, seismic demand and % NBS.

For masonry structures, as already pointed out, all analyses are significantly more complex than for RC or steel structures. To assess the behaviour of historic masonry structures, under seismic action, a methodology is described in [4] that includes restoration with the following eight steps: 1) historical and experimental documentation; 2) material characteristics; 3) structural model; 4) actions; 5) analyses; 6) failure criteria and bearing capacity assessment; 7) decision for interventions aimed at repairs/strengthening and reanalysis; 8) report with an elucidation. This methodology is based on and harmonized with the ICOMOS Recommendations. It is important to mention that in step 1, the data obtained by examining structures after the earthquake are summarized, but also the results of experimental research using ambience vibrations, up to the most complex tests on vibro-platforms on which many numerical models are based [60].

7 ZAVRŠNE NAPOMENE I ZAKLJUČCI

Veoma značajno je proučavanje empirijskog iskustava graditelja iz prošlosti koji su se, kao i danas, suočavali s potrebom zaštite građevina od zemljotresa. Evolucijom tog iskustva došlo se do savremene prakse koja se zasniva na nataloženom teorijskom iskustvu i sada dostupnim moćnim računarima. To potvrđuje potrebu da se graditeljsko nasleđe, njegovo tkivo, tj. konstrukcija pažljivo prouči pre projektovanja i izvođenja intervencija na njemu.

Od značaja je upotreba adekvatnih materijala i tehnologija izvođenja radova, tj. intervencija na konstrukciji i ostalim komponentama građevina. Mogu se primeniti i inovativni materijali kojima se ne narušava autentičnost građevine [77]. Potrebno je da njihov sastav i način primene bude takav da mogu ispuniti osnovne principe zaštite izgrađenog nasleđa. To obuhvata i zahtev ostvarivanja visokog stepena otpornosti od prirodnih nepogoda i katastrofa, među kojima su zemljotresi među najvažnijim.

Svaka intervencija treba da bude odmerena tako da bude samo minimalno neophodna za opstanak, prihvatljiva samo uz minimalan gubitak postojećeg tkiva. Planirani novi radovi treba da budu jasno razdvojeni od originalnog tkiva i za to postoje raznovrsne tehnike i materijali koji se pažljivo biraju. Svi novi, primenjeni materijali i tehnike treba, u najvećoj meri, da poštuju tradicionalnu praksu. Upotreba savremenih materijala, kao zamena za originalne materijale, pogodna je samo ukoliko ispunjava nekoliko preduslova:

7 CLOSING REMARKS AND CONCLUSIONS

It is very important to study the empirical experience of builders from the past who, same as today, needed to protect buildings from earthquakes. The evolution of that experience led to the modern practice based on accumulated theoretical experience and on the powerful computers now available. This confirms the need to carefully study the built heritage, its fabric, i.e. its structure prior to designing and performing interventions on it.

The use of adequate materials and technologies for the execution of works is important, i.e. intervention on the structure and other components of buildings. Innovative materials that do not compromise the authenticity of the building can also be used [77]. It is necessary that their composition and manner of application be such that they can meet the basic principles of protection of the built heritage. This includes the requirement to achieve a high degree of resilience to natural disasters and catastrophes, the earthquakes being among the most important of them.

Each intervention should be designed so that it provides only the minimum necessary for survival, acceptable only with a minimal loss of the existing building fabric. The planned new works should be clearly separate from the original fabric and for that there are various techniques and materials that are carefully selected. All new, used materials and techniques should observe the traditional practice to the greatest extent. The use of modern materials as a replacement for the original ones is suitable only if it meets several prerequisites:

• pruža značajnu prednost koja se može prepoznati;
• njihova upotreba ima čvrstu naučnu osnovu;
• njihova upotreba je podržana iskustvom.

Ukoliko se koriste novi materijali, nužno je birati takve koji su kompatibilni sa izrazom, izgledom, teksturom i oblikom originalnih. Novi materijali treba, takođe, da ispunjavaju zahteve i fizičkih i geografskih karakteristika podneblja, kao i lokalnih načina života stanovništva.

Kada je u pitanju zaštita graditeljskog nasleđa od zemljotresa, idealno bi bilo da se ona preventivno realizuje, naročito u zemljama sa izraženom seizmičkom aktivnošću. To je, međutim, najčešće teško izvodljivo, pre svega iz finansijskih razloga i složenih imovinskih problema. U okviru UNESCO-a, u oblasti kulture neprekidno se razmatraju mogućnosti donošenja međunarodnog normativnog instrumenta u ovoj oblasti, koji bi sadržao tehničke i pravne mere zaštite graditeljskog nasleđa u trusnim područjima. Međunarodni komitet za spomenike spomeničke celine ICOMOS, takođe, daje smernice za preventivnu zaštitu i obnovu kulturnih dobara ugroženih zemljotresom, a koje slede osnovne principe i preporuke zaštite graditeljskog nasleđa. To je trajan proces u kojem se postepeno menjaju pojedini zaključci, uz praćenje savremenog razvoja novih saznanja u oblastima seizmologije, seizmičkog inženjerstva, materijala, tehnologija i tehnika.

• it provides a significant recognizable advantage;
• their use has a solid scientific basis;
• their use is supported by experience.

If new materials are used, it is necessary to choose those that are compatible with the expression, appearance, texture and shape of the original. The new materials should also meet the requirements of both the physical and geographical characteristics of the climate as well as of the local lifestyles of the population.

Considering the protection of the built heritage from earthquakes, it would be ideal if it were preventive, especially in countries with a pronounced seismic activity. The need to prevent damage and destruction of the built heritage is emphasized in many recommendations such as [24]. However, this is usually difficult to accomplish, primarily due to financial reasons and complex property problems. Within the framework of UNESCO, in the field of culture, the possibilities of adopting an international normative instrument in this field, which would contain technical and legal measures for the protection of the built heritage in seismic areas, are constantly being considered. The International Council Monuments and Sites (ICOMOS) also provides guidelines for the preventive protection and restoration of cultural property endangered by earthquakes, which follow the basic principles and recommendations for the protection of the built heritage. It is an ongoing process in which individual conclusions are gradually changing, following the modern development of new knowledge in the fields of seismology, seismic engineering, materials, technologies and techniques.

ZAHVALNOST

Istraživanje prikazano u ovom radu finansijski je podržalo Ministarstvo za obrazovanje, nauku i tehnološki trazvoj Republike Srbije u okviru Projekta „Sveobuhvatni pristup unapređenju interdisciplinarnih istraživanja u obrazovanju i nauci u oblasti građevinarstva“ Univerzitet u Novom Sadu, Fakultet tehničkih nauka, Departman za građevinarstvo i geodeziju. Zahvalan na toj pomoći (R. Folić).

ACKNOWLEGEMENT

The research described in this paper was financially supported by the Ministry of Education and Sciences of Republic of Serbia within the Project: “A comprehensive approach to improvement of interdisciplinary researches in construction education and science” (University of Novi Sad, Faculty of Technical Sciences, Department of Civil Engineering and Geodesy). This support is gratefully acknowledged (R. Folić).

8 LITERATURA REFERENCES

[1] Adami, A. et al. The survey of cultural heritage after an earthquake: The case of Emilia-Lombardia in 2012, The Intern. Archives of the Photogr. Remote Sensing and spatial Inform. Sciences, Vol. XLI-B5, 2016.

[2] Assessment and Strengthening of Historical Stone Masonry Structures Subjected to Seismic Actions, Proceedings of the ISCARSAH Symposium, (M.Humo, S.Kulukcija, Eds.), Interprojekt d.o.o. Mostar 2009.

[3] Assessment, Draft for Sector Briefings; Part C2: Assessment Procedures and Analysis Techniques, Ministry of Business, Innovation and Employment; the Earthquake Commission; the New Zealand Society for Earthquake Engineering and Geotechnical Society, June 2016.

[4] Asteris, P.G., et al. Seismic vulnerability assessment of historical masonry structural systems, Engineering Structures, 62–63, 2014, pp. 118–134.

[5] Augusty, G., Ciampoli, M. Heritage buildings and seismic reliability, Prog. Struct. Engng Mater. 2, 2000, pp. 225–237.

[6] Ballarin, M., et al. Survey methods for seismic vulnerability assessment of historical masonry buildings, The Intern, Archives of he Photogram. Remote Sensing and Spatial Inf. Sciences, Vol. XLII-5/W1, Florence, Italy, 2017, pp. 55–59.

[7] Banfill, Ph., Bridgwood, B, Maxwell, I.: Understanding conservation.Org - Support for Developing a Practitioner Portfolio in Built Environment Conservation, Journal of Cultural Heritage Management and Sustainable Development, Vol. 2 Iss: 1, 2012.

[8] Barou, L; Oikonomopoulos, F; Bristogianni, T; Veer, F.A; R. Nijsse. Structural glass: A new remedial tool for the consolidation of historic structures. Heron 63, No 1/2, 2018, pp. 159–198.
[9] Baškirov, A.S. Antiseismism of ancient architecture, 4 vol., Moskva-Kalinjin-Jaroslav, 1945–49. (in Russian)
[10] Bernanardini, A., Lagomarsino, S. The seismic vulnerability architectural heritage, ICE virtual Library.com/doi/pdf/10.1680/stub. 161.4.171, 2008.
[11] Binda, L., Saisi, A., Tiraboschi, C. Investigation Procedures for the Diagnosis of Historic Masonries, Construction and Building Materials 14, No. 4, 2000; pp. 199–233.
[12] Branco, M. Guerreiro, L.M. Seismic rehabilitation of historical masonry buildings, Engineering Structures 33, Elsevier, 2011, pp.1626–1634.
[13] Brabdio, F. et al. Seismic behavior assessment of a Brazilian heritage construction, Frattura ed Integrita Structurale, 45, 2018, pp. 14–32.
[14] Calvi, G.M.: Engineers Understanding of Earthquake Demand and Structure Response, Earthquake Engineering in Europe; Geotechnical and Earthquake Engineering 17 (M.Garevski, A.Ansal, eds.), Springer Sciences+Buiss. Media, B.V. 2010, pp.223–247.
[15] Cardani, G, Belluco, P. Reducing the Loss of Built Heritage in Seismic Areas, Buildings 8, 19; 2018, doi:10.3390/buildings8020019, 1–12.
[16] Cardiani, G. Belluco, P. The Architectural Heritage in Seismic Area: Geometrical Survey for Damage Analysis and Strengthening Design, in Putting Tradition into Practice: Heritage, Place and Design, Proceedings of 5th INTBAU International Annual Event, (G. Amoroso, ed.), Springer IP AG 2018,
[17] Ceroni, F. et al.: Assessment of Vulnerability of a Historical Masonry Buildings, Buildings, 2012/2, pp. 332–358.
[18] Castori, G. et al.: Seismic vulnerability assessment of a monumental masonry building, Engineering Structures, April, 201. https://www.researchgate.net/publication/312916429
[19] Conservation Institute, and Analysis Techniques, Ministry of Business, Innovation and Employment; The based Approach to Earthquake Protection of Cultural Heritage, Advanced Materials, 2003.
[20] Conservation Perspectives-Seismic Retrofitting, The GSI Newsletter, Vol.30. No 1, The Getty Conservation Institute, Spring 2015.
[21] Croci, G.: “New technologies to protect historic building from seismic risk”, 14th European Conference on Earthquake Engineering, (keynote address), Ohrid, Macedonia, 2010.
[22] Cultural Heritage and Natural Disaster, Risk Preparedness and the Limits of Prevention, (R. Meier, M. Petzet, Will, T, Eds.), Heritage at Risk, Special Edition, ICOMOS, 2007. 254 p.
[23] Cultural Heritage and Seismic Risk: Some European Experiences, European and Mediterranean Hazard Agreement (EUR-OPA), Published in “Risk Wise” on the occasion of the 08 Davos International Disaster and Risk Conference, 2008.
[24] Cultural heritage: Building resilience to natural disasters. Session of Joint Statements of G7 Academies Meeting, Official hand-over of the three G7 Academics Joint Statements to the Italian Government, 23–25 March and 3 May, Rome, 2017.
[25] De Canio, G.: Marble Device for the Basic Isolation of the Two Bronzes of Riace: a proposal for the David of Michelangelo, 15th World Conference on Earthquake Engineering, Lisboa, 2012, pp. 1–10.
[26] De Lorenzis, L. and Nanni, A.: International Workshop on Presentation of Historical Structures with FRP Composites, Final Report, National Science Foundation (NSF), Arlington, July 2004.
[27] Del Guidice, V., De Paola P., Forte, F. Evaluation Methodologies of Earthquake Damages to Cultural Heritage, Int. J. of Applied Eng. Research, Vol. 13, 2018, pp.1647–1653.
[28] Devaux, M. Lestuzzi, P. Seismic vulnerability of monumental buildings in Switzerland, Structural Studies, Repairs and Mantenance of Heritage Architecture IX, WIT Transactions on The Built Environment, Vol. 83, WIT Press, 2005.
[29] Drdàcký, M. Protecting Cultural Heritage against Earthquake, NIKER Workshop Protection of Cultural Heritage, Tel Aviv/Akko, December 16–17, 2012.
[30] Earthquake Resistant Regulations, A World List – IAEE, 2004.
[31] Earthquake-prone heritage buildings-information for building owners, Sustainable Management of Historic Heritage Guidance Series, Heritage New Zealand, December 2014.
[32] EN 1998-1 – Eurocode 8-1: Design of Structures for Earthquake Resistance – Part 1: General Rules, Seismic Actions and Rules for Buildings, European Committee for Standardization (CEN), Brussels, 2004.
[33] EN 1998-3 – Eurocode 8-3 Design of Structures for Earthquake Resistance – Part 3: Assessment and Retrofitting of Buildings, CEN, Brussels, 2005.
[34] Fajfar, P., Earthquake Engineering, Are we able to protect structures? Predavanje, SANU, Belgrade, 19 May 2014.
[35] FEMA 356, Prestandard and Commentary for the Seismic Rehabilitation of Buildings, Federal Emergency Management Agency (FEMA), Washington D.C. 2000.
[36] FEMA-273 / 274: NEHRP Guidelines for the Seismic Rehabilitation of Buildings. Federal Emergency Management Agency, Washington, D.C., October 1997.
[37] Fielden, Sir B. Between Two Earthquakes, Cultural Property in Seismic Zones, Fielden, Sir B. Between Two Earthquakes, Cultural Property in Seismic Zones, ICCROM and the Getty Conservation Institute, 1987.
[38] Folić R. : Stanje i pravci razvoja aseizmičkog projektovanja novih i postojećih zgrada. V. Banja, JDGK – Simpozijum, 29. septembar – 1. oktobar '04, Uvodni referat, 2004, Knjiga 1, str. 129–148.
[39] Folić R., Lađinović, Đ.: Uporedna analiza Evrokoda 8 za projektovanje seizmički otpornih konstrukcija sa nekim nacionalnim odredbama. Građevinski kalendar '03, SDGITJ, 2003, str. 429–485.

[40] Fregonese, L., et al.: Surveying and monitoring for vulnerability assessment of an ancient building, Sensors MDPI-Basel Switzerland, Jul 31, 2013.

[41] Fusco, E., et al. Seismic assessment of historical natural stone masonry buildings through non-linear analysis, 14th WCEE, October 12–17, Beijing, China, 2008.

[42] Gavrilović, P.: Seizmička zaštita konstrukcija objekata kulturnog nasleđa, Iskustva i pouke stečene nakon zemljotresa u Kraljevu od 3.11.2010, Izgradnja I, grad Kraljevo, juni 2011, pp. 1–11.

[43] GCI Publications, Newsletter 30.1, Spring 2015, pp. 1–10.

[44] Gilani, A.S.J. and Miyamoto, K.H.: Base Isolation Retrofitting Challenges in a Historical Masonry Buildings (2012/2), pp. 332–358.

[45] Giovambattista R. Di, Tertulliani A, and Zaccaria, M, "Doubtful Events Reported in Current Italian Earthquake Catalogues: The Medieval Earth-quakes of Subiaco (Central Italy)", *Natural Hazards* 16/1, Springer Netherlands, 2004, pp. 39–55

[46] Guisasola, A.: Base Isolation in Architecture, 14th World Conference on Earthquake Engineering, Beijing, 2008, pp. 1–8.

[47] Harley McKee, Masonry (Washington, DC: National Trust/Columbia University Series, 1980, 61.

[48] Harouthiounian, V, Hasrathian, M. Monuments of Armenia. Beirut, 1975.

[49] Heritage and Catastrophe: Prevention, Emergency, Restoration and Transformation in 2009 L'Aquila Earthquake, Report on the results of a case study research project, Technische Universitât Berln (Urban Management Programs), 2014.

[50] Heromat FP7 THEME [ENV-NMP. 2011.3.2.1-1 NMP]

[51] Historic developments in evolution of earthquake engineering (essays R. Reitherman), Consortium of Universities for research in earthquake engineering (CUREE), 1998. http:/www.curee.org

[52] Heymen, J. How to design a cathedral: some fragments of the history of structural engineering, Proc. Intit. Civ. Engrs, Vol. 92, Feb. 1992, pp. 21-29.

[53] http://www.bradshawfoundation.com/pyramids_of_egypt/construction.php THE BUILDING SITE

[54] *Improving Earthquake Mitigation trough Innovations and Applications in Seismic Science*, Engineering, Communication, and Response, Proceedings of a US-Iran Seismic Workshop, Irvin, California June 29–July 1, 2009.

[55] Johnnides, C. Disaster Preparedness for Cultural Heritage, EAP DRM Knowledge Notes, Disaster Risk Management in East Asia and the Pacific, Working Paper Series No. 14, The World Bank and GFDRR (Global Facility for Disaster Reduction and Recovery, 2010, pp. 1–5.

[56] Jorquera, N. et al. Revealing Earthquake-resistant Geometrical Features in Heritages Masonry Architecture in Santiago, Chile, Intern. J. of Architectural heritage, Vol. 11, no.4, 2017, pp. 519–538.

[57] Jorquera, N., Jonathan, R., Torres, G. Analysis of seismic design criteria of Santo Domingo Church, a Colonial Heritage of Santiago, Chile, M. Code: 736, 2016. pp. 388–400.

[58] Karkee, M.B., Cuarda, C., Sunuwar, L. The challenges of protecting heritage architecture in developing countries from earthquake disasters, WIT Transformations on the Built Environment, Vol. 83, 2005. pp. 407–418.

[59] Kirikov, B.A. Earthquake Resistance and History, Mir, Publishers, Moscow, 1991. (in Russian)

[60] Krstevska, L, Shendova, V, Rakicevic, Z.T, Tashkov, Lju. Shaking Table Testing Shacing of Models of Histoorical Monuments-IZIIS Experience, in Computer Vision System for Monitoring in Dynamic Structural Testing (Ed. M.N. Fardis and Z.T, Rakićević, Springer, 2010.

[61] Kunwar, R.R., Chand, U. Natural disaster and heritage Tourism: A study on the Impact of Earthquake in Bhaktapur, Nepal, Journal of Tourism and Hospitality, Vol. 6, 2016.

[62] Kurtović-Folić, N.: Zemljotres – veliki problem kroz istoriju graditeljstva, Zbornik radova sa savetovanja "Zemljotresno inženjerstvo i inženjerska seizmologija", (R. Folic, Ed.) Sokobanja, 13 – 16. jun '08, Beograd, Savez građevinskih inženjera Srbije, 2008, pp. 373–380.

[63] Kurtović-Folić, N.: Conservation of built heritage by using new technologies, Tehnika 5/2009, Savez inženjera i tehničara Srbije, Beograd, 2009, pp. 1-8.

[64] Kurtović-Folić, N,: O delovanju zemljotresa na graditeljsko nasleđe, Zbornik radova sa drugog naučno-stručnog savetovanja "Zemljotresno inženjerstvo i inženjerska seizmologija, (R. Folić, ed.), Divčibare 27–30. april 2010, pp. 395–404.

[65] Kurtovic-Folic, N,**:** New materials and techniques for conservation of built heritage subjected to earthquake damages**,** Third International Conference "Seismic Engineering and Engineering Seismology", Association of Civil Engineers of Serbia, Conference Proceedings (R. Folic ed.), Divčibare, 22–24. Maj 2012, pp.193–202.

[66] Kurtovic-Folic, N,: Standards for Restoration of Built Heritage Endangered by Natural Hazards", Keynote lecture, 14th International Conference "Structural Faults & Repair", (M. Forde ed.), July 3-5th, 2012, Edinburg, Book of Abstracts and CD Rom, 2012, pp.1–10.

[67] Kurtovic Folic, N.: Built heritage subjected to earthquake disasters and their mitigation", Invited lecture at plenary session, Proceedings of the XVIII Anniversary International Scientific Conference "Construction and Architecture" VSU'2018, Sofia, Plenary reports presentations, Vol.1 (D.Partov, A. Handrulova, Eds.), October 18–20, 2018, pp. 7–22.

[68] Kurtovic Folic, N.; Architects Understanding of Earthquake Demands and Architectural Monuments Seismic Response", 6th International Conference "Earthquake Engineering and Engineering Seismology", Conference Proceedings (R. Folic, ed.), June 13–15, Kraljevo, Association of Civil Engineers of Serbia, 2018, pp. 333–342.

[69] Kurtović-Folić, N., Folić, R.: Some new experiences in built heritage restoration, International Scientific Coference BASA’2019 – Bulgarian Academy of Sciences and Art, 21–23 November/19, Proc. Ed. N. Tuleškov and D. Partov; Sofia, 2019, pp 31–46.
[70] Lagomarsino, S., Modaressi, H., Pitilakis, K., Bosiljkov, V., Calderini, C., D'Azala, D., Benaouar, Dj., Cattari, S., PERPETUATE Project: the Proposal of a Performance-based Approach to Earthquake Protection of Cultural Heritage, Advanced Materials Research Vols. 133–134), Trans Tech Publications, Switzerland, 2010, pp. 1119–1124.
[71] Langenbach, R. "The Integrity of structure: Should what is hidden inside the wall be considered a part of a historic building’s cultural value“, 13th ICOMOS General Assembly and Scientific Symposium, Madrid, 2002, pp.161–167.
[72] Lobell, J.A. A New View of the Birth Place of the Olympics, Archaeological Institute of America: Archaeology Sept/Oct 2016.
[73] Lourenço, P. Reducing Seismic Vulnerability, Retrofitting Historic Buildings, Conservation Perspectives, The Getty Conservation Institute, GCI Publication News, letter 30. 1, Spring 2015, pp.1–10.
[74] Mahin, S.A. Lessons from damage to steel buildings during the Northbridge earthquake, Engineering Structures, Vol. 20, Iss. 4, April–June 1998, pp. 261–270.
[75] Mainstone, R.J.,"The Structure of the Church of St. Sophia, Istanbul," Transactions of the Newcomen Society 38; 1965–66, pp. 23–49.
[76] Makris, N. The reconstruction of the north-east corner of the temple of Zeus at Nemea, Greece. Proceedings of 3rd Greece-Japan Workshop: Seismic Design, Observation, and Retrofit of Foundations, Santorini, 2009, pp.665–677.
[77] Manfredi, G., Ascione, L., Innovative Materials for the Vulnerability Mitigation of Existing Structures, in Manfredi.G., Dolce, M. (eds.) The state of Earthquake Engineering Research in Italy: the ReLUIS-DPC-2008 Project, Napoli, Doppiavoce, 2009. pp. 321–378.
[78] Mehdizadeh Saradj, F., Pilakoutas, K., Hajirasouliha, I. *Prioritization of Interventions for Strenghtening Architectural Heritage*, National Institut for Research and Development in urban Planning and Sustainable Territorial Development URBAN-INCERC, Cluj/Napoca, in *Urbanism,* Architectura, Constructii, 8/3, Bucurestii, 2017.
[79] Menon, A.: Seismic Hazard Assessment of the Historical Site in Jam and Stability Analysis of the Minaret, dissertation for the Master Degree in Earthquake Engineering, European School of Advanced Studies in Reduction of Seismic Risk, Università degli studi di Pavia, Februar 2004.
[80] Minchev, K. Minchev, I. Binding-Counterfort Fortification of Buildings. International Conference on Civil Engineering Design and Construction, 14–16 September 06', Varna, 2006, pp. 263–266.
[81] Monumental Building in Romania, 15th World Conference on Earthquake Engineering, Lisboa, 2012, pp.1–11.
[82] Murao, N. Architects and earthquake-resistant design, Earthquake-Resistant Building Design for Architects, Revised edition, The Japan Institute of Architects and Japan Aseismic Safety Organisation, 2015, pp. IX–XIII.
[83] New integrated knowledge-based approach hes to the protection of cultural heritage from earthquake-induced risk, Deliverable 3.1, Inventory of earthquake-induced failure mechanisms related to construction types, structural elements, and materials, Workpackage 3: Damages based selection of technologies, Project 244123 NIKER, Coordinator Università di Padova, April, 2010.
[84] NIKER Deliver. 3.1 Inventory of earthquake induced failure mechanisms related to construction types, structural elements, and materials, 2010. p. 160.
[85] Nishikawa, E. Development of earthquake countermeasures on heritage buildings in Japan, Archeomatica, No. 1, Marzo, 2017. pp. 34–38.
[86] Oliveira, C. S. Seismic Vulnerability of Historical Constructions: A Contribution, Bulletin of Earthquake Engineering, Volume 1 No. 1, (A. Ansal, Ed.), Kluwer Academic Publishers, Netherland, 2003. pp. 37–82.
[87] Oo, P.S., Cho, A. M. Seismic analysis of cultural heritage structure in Mandalay City, IJRCMCE, Vol. 4, Issue 1, 2017.
[88] Pampanin, S. Controversial Aspects in Seismic Assessment and Retrofit of Structures in Modern times: Understanding and Implementing Lessons from Ancient Heritage, Bulletin of New Zealand Society for Earthquake Engineering, Vol.38/2, June '06, 2006. pp. 120–133.
[89] Parduccci, A. Seismic protection of Italy's historical heritage using the seismic isolation approach, !2th WCEE, Pap. 1200, Auckland, NZ, 2000. p. 8.
[90] Paulay T., Priestley M.J.N.: Seismic Design of Reinforced Concrete and Masonry Buildings. John Wiley & Sons, Inc., 1992.
[91] Paupério, E. et al. A Methodology for the vulnerability assessment of heritage buildings and contents under catastrophic hazard, Special Issue Seismic safety Assessment, February 2017. pp. 1–10.
[92] Peña, F, Chávez, M.M. Seismic Behavior of Mexican Colonial Churches, International Journal of Architectural heritage, Vol. 10/2016, Iss. 2–3: Special Issue on SACH Conference 2014, pp. 332–345.
[93] Pla, F. Cultural heritage and seismic risk: Some European experiences Published in “Risk Wise” on the occasion of the 2008 Davos International Disaster and Risk Conference European and Mediterranean Major Hazards Agreement EUR-OPA, Council of Europe, 7. Sept. 2008.
[94] Pravilnik o tehničkim normativima za izgradnju objekata visokogradnje u seizmičkim područjima, Službeni list SFRJ, Beograd, br. 31/81, 49/82, 21/88, 52/90.
[95] Pravilnik za građevinske konstrukcije, Sl. glasnik RS, br. 89 od 18. decembra 2019. i prateći dokumenti SRP EN 1998-1, Nacionalni Annex.

[96] Przewło´cki, J. Et al. Review of historical buildings foundations,Geotechnique, 55, 2005, pp. 363–372
[97] Preciado, A., et al. Protection of Cultural Heritage Buildings against Earthquake Forum a Sensitized Structural Engineering Perspective, 2017. http://hdl.handle.net/11117/5034 (accessed February, 2020).
[98] Putting Tradition into Practice: Heritage, Place and Design, Proceedings of the 5th INTBAU International Annual Event, (Amoruso, G., ed.), Springer, 2018.
[99] Repair and Strengthening of Historical Monuments and Buildings in Urban Nuclei, Volume Building Construction under Seismic Conditions in the Balkan Region, UNDP/UNIDO Project RER/79/015, United Nations Industrial Development Organization, Vienna, 1984.
[100] Romãoa,,X., Paupériob, E., Pereiraa, N. A framework for the simplified risk analysis of cultural heritage assets, Cultural HELP, Spec. Issue 2014, Elsevier Masson SAS, 2016. pp. 696–708.
[101] Rossi, C. Architecture and Mathematics in Ancient Egypt, Cambridge University Press, 2007. XIX+282 p.
[102] Saradj, F.M, Pilakoutas, K, Hajirasouliha. Prioritization of Interventions for Strengthening Architectural Heritage, Urbanisation, Architecturã, Constrcţii, Vol.8, Nr.3, URBAN INCERC, 2017.
[103] Sezen, H, Dogangun, A. Seizmic Performance of Historical and Monumental Structures, Ch. 7, INTECH, Open science, 2012.
[104] Sidraba, I.: “New materials of stone monuments in Latvia”, Institute of Silicate Materials, Riga Technical University, 2001, 1–13.
[105] Sincrain, G.E and Guerreiro, M.C.: Use of Base Isolation in Historical and Traditional Structures, 11th World Conference on Earthquake Engineering, Paper Nº 1324, Elsvier Science Ltd. 1996, pp. 1–9.
[106] Quist, W.J. Replacement of natural stone in conservation of historic buildings, Heron, Volume 54 (2009) No. 4, pp.251–278.
[107] The Charter of Cracow 2000, International Conference on Conservation "Krakow 2000“, Cracow 2000, pp. 1–5.
[108] The Ian T. Kozak Collection, Images of Historical Earthquakes-List, (1996), NISEE Berkeley.edu, (10.03.2010.)
[109] The Seismic Assessment of Existing Buildings, Technical Guidelines for Engineering Assessments, Draft for Sector Briefings June '16, Part C2: Assessment Procedures and Analysis Techniques, New Zealand Society for Earthquake Engineering, 2016.
[110] Tomaževic, M.: Earthquake Resistant Design of Masonry Buildings, Series on Innovation in Structures and Constructions, London, Imperial College Press, Vol.1.
[111] Vamvatsikos, D. Patazopulou, S. J. Development of a simplified mechanical model to estimate the seismic vulnerability of critical heritage masonry buildings, 9th HSTAM Intern. Congress on Mechanics, Limassol, Cyprus, 12–14 July, 2010.
[112] Veerappan, A: Are heritage structures in Tamilhandu seismically vulnerable? The Indian Concrete Journal, March 2012.
[113] Warren, P. The Aegean Civilizations. The Making of the Past, Peter Bedrick Books, 1988, 192 p.
[114] Wenk, T., Beyer, K. Seismic Conservation Strategies for Cultural Heritage Buildings in Switzerland, Second European Conference on Earthquake Engineering and Seismology, Istanbul, Aug. 25–29, 2014, pp. 1–11.
[115] Xie, L, Qu, Z. On Civil Engineering Disasters and Their Mitigation, 1st Huixian Earthquake Engineering Lecture 2016, Beijing, print in Earthquake Engineering and Engineering Vibration, Vol.17, issue 1, 2018, pp.1–10.
[116] Xu, X., Heath,T., Xia,Q., Zhang,Y. Disaster prevention and mitigation strategies for architecture heritage concentrated areas in China, ArchNet-Inter. Jour. of Architect. Rrsearch (IJAR), Vol. 9.Issue 1-March 2015, pp. 108–121.
[117] Yön, B., Sayin, E., Onat, O. Earthquakes and Structural Damages, Earthquake – Tectonics, Hazard and Risk Mitigation, Chapter 13, INTECH, 2017.
[118] Zakon o vanrednim situacijama, Službeni glasnik Republike Srbije (br. 111/2009, 92/2011 i 93/2012).
[119] Zakon o smanjenju rizika od katastrofa i upravljanju vanrednim situacijama, Službeni glasnik Republike Srbije, (br. 87/2018).
[120] Žarnić, R.: Technologies for Safeguarding of Heritage Buildings in Slovenia, pp.1-13. http://docplayer.net/11578156 (approached October 2018).
[121] Zimmermann, T, Strauss, A. In plane Response of old Masonry under Seismic Loads, Proceedings of 3rd Greece-Japan Workshop: Seismic Design, Observations, and Retrofit of Foundations, Santorini 2009, pp. 658–664.
[122] https://cromwell-intl.com/travel/france/saumur-megaliths/ (pristup april 2020).
[123] https://www.alamy.com/stock-photo/arthurs-grave.html (pristup april 2020).
[124] http://www.ancient-wisdom.com/portoriotorto.htm (pristup april 2020).
[125] https://whc.unesco.org/en/list/977/ (pristup april 2020).
[126] https://www.gettyimages.co.nz/ (pristup april 2020).
[127] https://www.ancient-origins.net/ancient-places-asia/dur-sharrukin-0011587 (pristup april 2020).
[128] https://search.library.wisc.edu/digital/AWY67YSAHZDME58L (pristup april 2020).
[129] https://www.guardians.net/hawass/buildtomb.htm (pristup april 2020).
[130] https://www.tripline.net/trip/Greece:_Dylan_Nivens (pristup april 2020).

[131] http://people.ucls.uchicago.edu/~bwildem/art_hist_laba/myceneaen/beehive.htm (pristup april 2020).
[132] https://thewestologist.wordpress.com/2013/12/04 (pristup april 2020).
[133] http://www.encyclopediaofukraine.com/display.asp (pristup april 2020).
[134] https://www.medievalists.net/2015/12/10-natural-disasters-that-struck-the-medieval-world/ (pristup april 2020).
[135] https://www.geologieportal.ch/it/temi/pericoli-geologici/terremoti.html (pristup april 2020).
[136] https://manpodcast.com/portfolio/no-439-michelangelo/ (pristup april 2020).
[137] https://www.researchgate.net/figure/1755-copper-engraving-depicting-the-1755-Lisbon-earthquake-and-tsunami-City-Museum_fig4_272739500 (pristup april 2020).

REZIME

PROŠLOST I NEKI AKTUELNI PROBLEMI ZAŠTITE GRADITELJSKOG NASLEĐA OD ZEMLJOTRESA

Nađa KURTOVIĆ-FOLIĆ
Radomir FOLIĆ

Graditeljsko nasleđe neprestano je izloženo prirodnim nepogodama među kojima su i brojni zemljotresi. Zbog toga je važno preduzeti mere za redukciju povredljivosti i povećanje zaštite objekata u zavisnosti od izloženosti seizmičkom hazardu i značaju zgrade. Proučavanjem istorije građenja, nalaze se primeri građenja zgrada s ciljem da se zaštite od zemljotresa. Zbog toga su i ovde prezentirani takvi primeri, počev od objekta iz daleke prošlosti sve do sada. Komentarisani su dokumentacija, u vezi s delovanjem zemljotresa kroz istoriju, i postupci pri planiranju mera za zaštitu objekata da bi se nasleđe sačuvalo od propadanja. Prikazani su primeri nepravilne primene materijala i tehnologija građenja kojima se oštećuje originalno tkivo, a time i vrednost koje određeno kulturno dobro ima.

Ključne reči: seizmička dejstva, graditeljsko nasleđe, dokumentacija, ublažavanje povredljivosti, značaj objekata, planiranje intervencija.

ABSTRACT

PAST AND SOME TOPICAL PROBLEMS OF BUILT HERITAGE PROTECTION FROM EARTHQUAKES

Nadja KURTOVIC-FOLIC
Radomir FOLIC

Built heritage is incessantly exposed to natural disasters including numerous earthquakes. Therefore, it is important to take measures to reduce vulnerability and increase the protection of buildings depending on the exposure to seismic hazard and the importance of the building. Studying the history of construction reveals examples of building constructions aimed at protecting against earthquakes. For this reason, such examples are presented here, starting with the buildings from the distant past until now. The documentation related to the action of earthquakes throughout history and the procedures in planning the building protection measures in order to preserve the heritage from dilapidation were commented. The paper, also, presents some examples of incorrect use of materials and construction technologies that damage the original structural fabric, and thus, the value of a certain cultural property.

Key words: Seismic action, built heritage, documentation, vulnerability mitigation, structure importance, intervention planning

UPUTSTVO AUTORIMA*

Prihvatanje radova i vrste priloga

U časopisu Materijli i konstrukcije štampaće se neobjavljeni radovi ili članci i konferencijska saopštenja sa određenim dopunama, iz oblasti građevinarstva i srodnih disciplina (geodezija i arhitektura). Vrste priloga autora i saradnika koji će se štampati su: originalni naučni radovi, prethodna saopštenja, pregledni radovi, stručni radovi, prikazi objekata i iskustava (studija slučaja), kao i diskusije povodom objavljenih radova.

Originalni naučni rad je primarni izvor naučnih informacija i novih ideja i saznanja kao rezultat izvornih istraživanja uz primenu adekvatnih naučnih metoda. Dobijeni rezultati se izlažu sažeto, ali tako da poznavalac problema može proceniti rezultate eksperimentalnih ili teorijsko numeričkih analiza, tako da se istraživanje može ponoviti i pri tome dobiti iste ili rezultate u okvirima dopuštenih odstupanja, kako se to u radu navodi.

Prethodno saopštenje sadrži prva kratka obaveštenja o rezultatima istraživanja ali bez podrobnih objašnjenja, tj. kraće je od originalnog naučnog rada.

Pregledni rad je naučni rad koji prikazuje stanje nauke u određenoj oblasti kao plod analize, kritike i komentara i zaključaka publikovanih radova o kojima se daju svi neophodni podaci pregledno i kritički uključujući i sopstvene radove. Navode se sve bibliografske jedinice korišćene u obradi tematike, kao i radovi koji mogu doprineti rezultatima daljih istraživanja. Ukoliko su bibliografski podaci metodski sistematizovani, ali ne i analizirani i raspravljeni, takvi pregledni radovi se klasifikuju kao stručni radovi.

Stručni rad predstavlja koristan prilog u kome se iznose poznate spoznaje koje doprinose širenju znanja i prilagođavanja rezultata izvornih istraživanja potrebama teorije i prakse.

Ostali prilozi su prikazi objekata, tj. njihove konstrukcije i iskustava-primeri u građenju i primeni različitih materijala (studije slučaja).

Da bi se ubrzao postupak prihvatanja radova za publikovanje, potrebno je da autori uvažavaju Uputstva za pripremu radova koja su navedena u daljem tekstu.

Uputstva za pripremu rukopisa

Rukopis otkucati jednostrano na listovima A-4 sa marginama od 31 mm (gore i dole) a 20 mm (levo i desno), u Wordu fontom Arial sa 12 pt. Potrebno je uz jednu kopiju svih delova rada i priloga, dostaviti i elektronsku verziju na navedene E-mail adrese, ili na CD-u. Autor je obavezan da čuva jednu kopiju rukopisa kod sebe.

Od broja 1/2010, prema odluci Upravnog odbora Društva i Redakcionog odbora, radovi sa pozitivnim recenzijama i prihvaćeni za štampu, publikovaće se na srpskom i engleskom jeziku, a za inostrane autore na engleskom (izuzev autora sa govornog područja srpskog I hrvatskog jezika).

Svaka stranica treba da bude numerisana, a optimalni obim članka na jednom jeziku, je oko 16 stranica (30000 slovnih mesta) uključujući slike, fotografije, tabele i popis literature. Za radove većeg obima potrebna je saglasnost Redakcionog odbora.

* **Uputstvo autorima je modifikovano i treba ga, u pripremi radova, slediti.**

GUIDELINES TO AUTHORS

Acceptance and types of contributions

The Building Materials and Structures journal will publish unpublished papers, articles and conference reports with modifications in the field of Civil Engineering and similar areas (Geodesy and Architecture).The following types of contributions will be published: original scientific papers, preliminary reports, review papers, professional papers, objects describe / presentations and experiences (case studies), as well as discussions on published papers.

Original scientific paper is the primary source of scientific information and new ideas and insights as a result of original research using appropriate scientific methods. The achieved results are presented briefly, but in a way to enable proficient readers to assess the results of experimental or theoretical numerical analyses, so that the research can be repeated and yield with the same or results within the limits of tolerable deviations, as stated in the paper.

Preliminary report contains the first short notifications on the results of research but without detailed explanation, i.e. it is shorter than the original scientific paper.

Review paper is a scientific work that presents the state of science in a particular area as a result of analysis, review and comments, and conclusions of published papers, on which the necessary data are presented clearly and critically, including the own papers. Any reference units used in the analysis of the topic are indicated, as well as papers that may contribute to the results of further research. If the reference data are methodically systematized, but not analyzed and discussed, such review papers are classified as technical papers.

Technical paper is a useful contribution which outlines the known insights that contribute to the dissemination of knowledge and adaptation of the results of original research to the needs of theory and practice.

Other contributions are presentations of objects, i.e. their structures and experiences (examples) in the construction and application of various materials (case studies).

In order to speed up the acceptance of papers for publication, authors need to take into account the Instructions for the preparation of papers which can be found in the text below.

Instructions for writing manuscripts

The manuscript should be typed one-sided on A-4 sheets with margins of 31 mm (top and bottom) and 20 mm (left and right) in Word, font Arial 12 pt. The entire paper should be submitted also in electronic format to e-mail address provided here, or on CD. The author is obliged to keep one copy of the manuscript.

As of issue 1/2010, in line with the decision of the **Management Board of the Society and the Board of Editors, papers with positive reviews, accepted for publication, will be published in Serbian and English, and in English for foreign authors (except for authors coming from the Serbian and Croatian speaking area).**

Each page should be numbered, and the optimal length of the paper in one language is about 16 pages (30.000 characters) including pictures, images, tables and references. Larger scale works require the approval of the Board of Editors.

Naslov rada treba sa što manje reči (poželjno osam, a najviše do jedanaeset) da opiše sadržaj članka. U naslovu ne koristiti skraćenice ni formule. U radu se iza naslova daju ime i prezime autora, a titule i zvanja, kao i ime institucije u podnožnoj napomeni. Autor za kontakt daje telefon, adresu elektronske pošte I poštansku adresu.

Uz sažetak (rezime) od oko 150-250 na srpskom i engleskom jeziku daju se ključne reči (do sedam). To je jezgrovit prikaz celog članka i čitaocima omogućuje uvid u njegove bitne elemente.

Rukopis se deli na poglavlja i potpoglovlja uz numeraciju, po hijerarhiji, arapskim brojevima. Svaki rad ima uvod, sadržinu rada sa rezultatima, analizom i zaključcima. Na kraju rada se daje popis literature.

Kod svih dimenzionalnih veličina obavezna je primena međunarodnih SI mernih jedinica.

Formule i jednačine treba pisati pažljivo vodeći računa o indeksima i eksponentima. Autori uz izraze u tekstu definšu simbole redom kako se pojavljuju, ali se može dati i posebna lista simbola u prilogu.

Prilozi (tabele, grafikoni, sheme i fotografije) rade se u crno-beloj tehnici, u formatu koji obezbeđuje da pri smanjenju na razmere za štampu, po širini jedan do dva stupca (8 cm ili 16,5 cm), a po visini najviše 24,5 cm, ostanu jasni i čitljivi, tj. da veličine slova i brojeva budu najmanje 1,5 mm. Originalni crteži treba da budu kvalitetni i u potpunosti pripremljeni za presnimavanje. Mogu biti i dobre, oštre i kontrastne fotokopije. Koristiti fotogrfije, u crno-beloj tehnici, na kvalitetnoj hartiji sa oštrim konturama, koje omogućuju jasnu reprodukciju.

U popisu literature na kraju rada daju se samo oni radovi koji se pominju u tekstu. Citirane radove treba prikazati po abecednom redu prezimena prvog autora. Literaturu u tekstu označiti arapskim brojevima u uglastim zagradama, kako se navodi i u Popisu citirane literature, napr [1]. Svaki citat u tekstu mora se naći u Popisu citirane literature i obrnuto svaki podatak iz Popisa se mora citirati u tekstu.

U Popisu literature se navode prezime i inicijali imena autora, zatim potpuni naslov citiranog članka, iza toga sledi ime časopisa, godina izdavanja i početna i završna stranica (od - do). Za knjige iza naslova upisuje se ime urednika (ako ih ima), broj izdanja, prva i poslednja stranica poglavlja ili dela knjige, ime izdavača i mesto objavljivanja, ako je navedeno više gradova navodi se samo prvi po redu. Kada autor citirane podatke ne uzima iz izvornog rada, već ih je pronašao u drugom delu, uz citat se dodaje «citirano prema...».

Autori su odgovorni za izneseni sadržaj i moraju sami obezbediti eventualno potrebne saglasnosti za objavljivanje nekih podataka i priloga koji se koriste u radu.

Ukoliko rad bude prihvaćen za štampu, autori su dužni da, po uputstvu Redakcije, unesu sve ispravke i dopune u tekstu i prilozima.

Rukopisi i prilozi objavljenih radova se ne vraćaju. Sva eventualna objašnjenja i uputstva mogu se dobiti od Redakcionog odbora.

Radovi se mogu slati i na e-mail: folic@uns.ac.rs ili miram@uns.ac.rs

Veb sajt Društva I časopisa: www.dimk.rs

The title should describe the content of the paper using a few words (preferably eight, and up to eleven). Abbreviations and formulas should be omitted in the title. The name and surname of the author should be provided after the title of the paper, while authors' title and position, as well as affiliation in the footnote. The author should provide his/her phone number, e-mail address and mailing address.

The abstract (summary) of about 150-250 words in Serbian and English should be followed by key words (up to seven). This is a concise presentation of the entire article and provides the readers with insight into the essential elements of the paper.

The manuscript is divided into chapters and subchapters, which are hierarchically numbered with Arabic numerals. The paper consists of introduction and content with results, analysis and conclusions. The paper ends with the list of references. All dimensional units must be presented in international SI measurement units. The formulas and equations should be written carefully taking into account the indexes and exponents. Symbols in formulas should be defined in the order they appear, or alternatively, symbols may be explained in a specific list in the appendix. Illustrations (tables, charts, diagrams and photos) should be in black and white, in a format that enables them to remain clear and legible when downscaled for printing: one to two columns (8 cm or 16.5 cm) in height, and maximum of 24.5 cm high, i.e. the size of the letters and numbers should be at least 1.5 mm. Original drawings should be of high quality and fully prepared for copying. They also can be high-quality, sharp and contrasting photocopies. Photos should be in black and white, on quality paper with sharp contours, which enable clear reproduction.

The list of references provided at the end of the paper should contain only papers mentioned in the text. The cited papers should be presented in alphabetical order of the authors' first name. References in the text should be numbered with Arabic numerals in square brackets, as provided in the list of references, e.g. [1]. Each citation in the text must be contained in the list of references and vice versa, each entry from the list of references must be cited in the text.

Entries in the list of references contain the author's last name and initials of his first name, followed by the full title of the cited article, the name of the journal, year of publication and the initial and final pages cited (from - to). If the doi code exists it is necessary to enter it in the references. For books, the title should be followed by the name of the editor (if any), the number of issue, the first and last pages of the book's chapter or part, the name of the publisher and the place of publication, if there are several cities, only the first in the order should be provided. When the cited information is not taken from the original work, but found in some other source, the citation should be added, "cited after ..."

Authors are responsible for the content presented and must themselves provide any necessary consent for specific information and illustrations used in the work to be published.

If the manuscript is accepted for publication, the authors shall implement all the corrections and improvements to the text and illustrations as instructed by the Editor.

Writings and illustrations contained in published papers will not be returned. All explanations and instructions can be obtained from the Board of Editors.

Contributions can be submitted to the following e-mails: folic@uns.ac.rs or miram@uns.ac.rs

Website of the Society and the journal: www.dimk.rs

Izdavanje časopisa "Građevinski materijali i konstrukcije" finansijski su pomogli:

REPUBLIKA SRBIJA
MINISTARSTVO PROSVETE, NAUKE I TEHNOLOŠKOG RAZVOJA

UNIVERZITET U BEOGRADU
GRAĐEVINSKI FAKULTET

DEPARTMAN ZA GRAĐEVINARSTVO I GEODEZIJU
FAKULTET TEHNIČKIH NAUKA NOVI SAD

INSTITUT IMS AD, BEOGRAD

MATEST
YOUR PARTNER IN TESTING

iT TECH

INELAS ERECO d.o.o

MATEST "iT TECH" KONTROLNA JEDINICA

JEDNA TEHNOLOGIJA MNOGO REŠENJA

IT Touch Techlogy je Matestov najnoviji koncept koji ima za cilj da ponudi inovativna i user-friendly tehnologiju za kontrolu i upravljanje najmodernijom opremom u domenu testiranja građevinskih materijala

Ova tehnologija je srž Matestove kontrolne jedinice, software baziran na Windows platformi i touch screen sistem koji je modularan, fleksibilan i obavlja mnoge opcije

iT TECH pokriva

- INOVATIVNOST
- INTERNET KONEKCIJA
- INTERFEJS SA IKONICAMA
- INDUSTRIJALNA TEHNOLOGIJA

SISTEM JEDNOG RAZMIŠLJANJA JEDNOM SHVATIŠ - SVE TESTIRAŠ

NAPREDNA TEHNOLOGIJA ISPITIVANJA ASFALTA

- GYROTRONIC - Gyratory Compactor
- ARC - Electromechanical Asphalt Roller Compactor
- ASC - Asphalt Shear Box Compactor
- SMARTRACKER^{tm} - Multiwheels Hamburg Wheel Tracker, DRY + WET test environment
- SOFTMATIC - Automatic Digital Ring & Ball Apparatus
- Ductilometers with data acquisition system

MULTIFUNKCIONALNI RAMOVI ZA TESTIRANJE

- CBR/Marshall digital machines
- Universal multispeed load frames
- UNITRONIC 50kN or 200kN Universal multipurpose compression/flexural and tensile frames

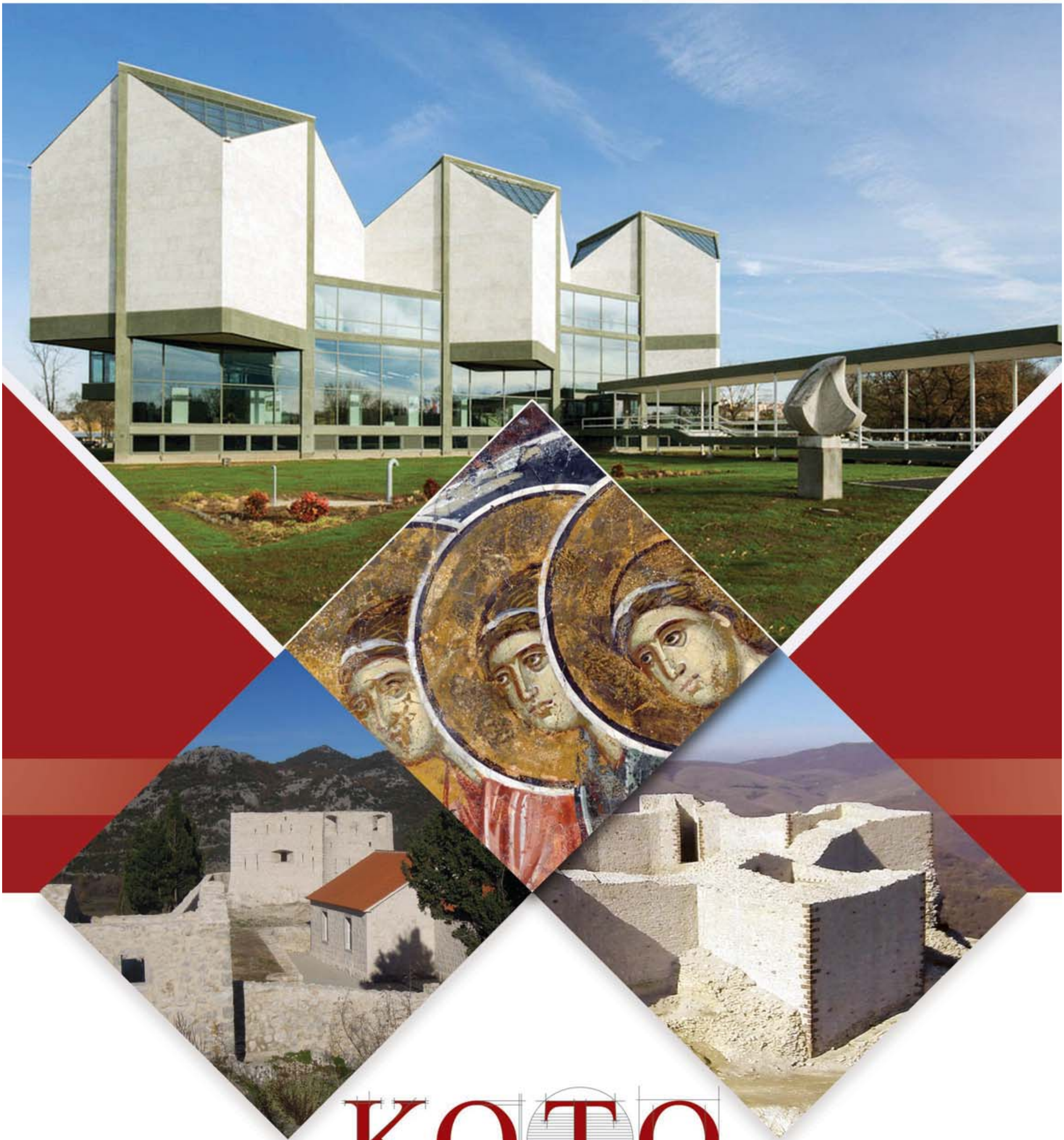
OPREMA ZA GEOMEHANIČKO ISPITIVANJE

- EDOTRONIC - Automatic Consolidation Apparatus
- SHEARLAB - AUTOSHEARLAB - SHEARTRONIC Direct / Residual shear testing systems
- Triaxial Load Frame 50kN

MIXMATIC - Automatic Programmable Mortar Mixer

INELAS ERECO D.O.O

Tošin bunar 274a, 11070 , Novi Beograd tel. +381 11 2284 574 email. info@inelasereco.rs



Institut za ispitivanje materijala IMS, sa tradicijom od 1929. godine, predstavlja najstariju naučno-istraživačku instituciju u Srbiji. Osnovna ideja prilikom osnivanja bila je potreba za jedinstvenom institucijom koja bi se osim istraživanja bavila i kontrolom građevinske industrije.

Delatnost Instituta IMS obuhvata laboratorijska ispitivanja građevinskih materijala, sertifikaciju proizvoda, nadzor nad izvođenjem radova i ispitivanje različitih tipova konstrukcija, izradu projektne dokumentacije, kao i naučno - istraživački rad u svim oblastima građevinarstva.

Poslovni centri Instituta IMS :

- Centar za puteve i geotehniku
- Centar za materijale
- Centar za metale i energetiku
- Centar za konstrukcije i prednaprezanje

INSTITUT IMS a. d.
Bulevar vojvode Mišića 43
11 000 Beograd
Tel: 011-2651-949
Faks: 011-3692-772
office@institutims.rs
www.institutims.rs

Institut IMS sertifikovao je sistem kvaliteta prema zahtevima standarda SRPS ISO 9001:2001. Svoju kompetentnost je potvrdio najvećim obimom akreditacije kod Akreditacionog tela Srbije (ATS) i Sertifikacionog tela.

Kadrovsku strukturu Instituta IMS čine doktori nauka, diplomirani inženjeri sa licencama Inženjerske komore Srbije i stručni tehnički kadar. Inženjeri Instituta IMS aktivno učestvuju na naučno-stručnim skupovima u zemlji i inostranstvu.

Institut IMS kontinuirano unapređuje kvalitet poslovanja na svim nivoima, kako u okviru terenskih i laboratorijskih ispitivanja, tako i na izradi projektno-tehničke dokumentacije s ciljem uspešne realizacije postavljenih zadataka.

Izvođenje istražnih radova sa pontona za novi most Beška,2007.god.

Geotehnička istraživanja i ispitivanja – in situ

Od terenskih istražnih radova izdvajamo izvođenje istražnih bušotina (IB), standardnih penetracionih opita (SPT), statičkih penetracionih opita (CPT i CPTU), opita dilatometarskom sondom (DMT i SDMT), ispitivanja vodopropustljivosti tla različitim terenskim metodama (VDP), ugradnja pijezometara i dr.

Terenske metode ispitivanja šipova zauzimaju značajno mesto u našoj delatnosti, a na tržištu se izdvajamo kao lideri u toj oblasti u protekloj deceniji.

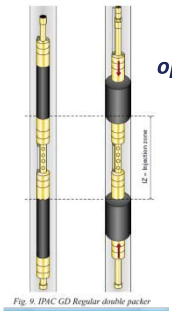
DLT-dinamičko ispitivanje šipova

Ispitivanje šipova

SLT metoda (Static load test) ispitivanje nosivosti šipova statičkim opterećenjem;
DLT metoda (Dynamic load test) ispitivanje nosivosti šipova dinamičkim opterećenjem;
PDA metoda (Pile driving analysis) omogućava praćenje i optimizaciju procesa pobijanja prefabrikovanih betonskih i čeličnih šipova u tlo;
PIT (SIT) metoda (Pile(Sonic) integrity testing) koristi se za ispitivanje integriteta izvedenih šipova (dužine, prekida, suženja ili proširenja).

CPT/CPTU opiti

Aktivno klizište



oprema za ispitivanje vodopropusnosti stena pod pritiskom do 10 bar-a metodom LIŽONA

Laboratorija za puteve i geotehniku

Laboratorija za puteve i geotehniku akreditovana je kod Akreditacionog tela Srbije – ATS prema SRPS ISO/IEC 17025:2006. U njoj se vrše ispitivanja tla (identifikaciono–klasifikaciona ispitivanja, fizičko–mehanička modelska ispitivanja), kamenog agregata i brašna, bitumena i bitumenskih emulzija, asfaltnih mešavina. U okviru laboratorijskih ispitivanja na terenu vrši se kontrola kvaliteta ugrađenog materijala i izvedenih radova (prethodna, tekuća, kontrolna ispitivanja i izvođenja opita in situ).

Projektovanje puteva i sanacija klizišta

U okviru projektovanja značajno mesto u radu zauzimaju geotehnička istraživanja terena i projekti sanacije klizišta - nestabilnih kosina useka i nasipa puteva i prirodno nestabilnih padina . Značajna su i projekovanja svih vrsta fundiranja specijalnih geotehničkih konstrukcija. Ističe se i iskustvo u oblasti putarstva, na projektovanju novih, rehabilitacija i rekonstrukcija postojećih puteva svih rangova sa pratećim objektima i dimenzionisanjem kolovoznih konstrukcija.

Nadzor

Naši inženjeri imaju veliko iskustvo u kontroli i proveri kvaliteta izvođenja svih vrsta radova, kontroli građevinske dokumentacije i praćenju radova u skladu sa njom, kao i rešavanju novonastalih situacija tokom izvođenja radova.

BUILDING TRUST

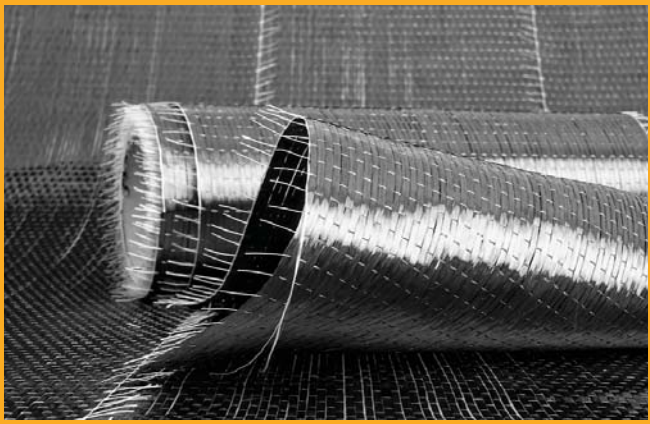
NAPREDNA SIKA REŠENJA U OBLASTI STRUKTURALNIH OJAČANJA

Kompanija Sika pruža trajnu dodatnu vrednost vlasnicima građevinskih objekata, njihovim konsultantima i izvođačima, kao i tehničku podršku tokom svih faza projekta, od ispitivanja uslova i razvoja inicijalnog koncepta ojačanja pa sve do uspešnog završetka i primopredaje projekta

SIKA – VAŠ PARTNER NA GRADILIŠTU

- Globalni lider na tržištu građevine i građevinske hemije
- Najbolja tehnička ekspertiza i praksa za sanaciju betona i strukturalna ojačanja
- Odlična reputacija kod vodećih izvođača i ugovarača posla

SIKA VREDNOSTI I INOVACIJE U GRAĐEVINI



- Integrisani proizvodi i sistemi visokih performansi koji mogu da povećaju i poboljšaju kapacitet, efikasnost, trajnost i estetiku zgrada i drugih objekata – u korist naših klijenata i boljeg održivog razvoja
- Sika mreža obučenih i iskusnih građevinskih stručnjaka

JEDINSTVENA SIKA REŠENJA U ZAHTEVNIM USLOVIMA

- Rešenja za gotovo sve uslove apliciranja
- Kontrolisano vreme rada, vreme sazrevanja i očvršćavanja za različite vremenske uslove
- Posebna rešenja završnih ojačanja za korišćenje kod betona slabije jačine i drugih podloga

POTVRĐENI SIKA SISTEMI I TEHNIKE APLICIRANJA

- Preko 40 godina iskustva u strukturalnim ojačanjima, sistemima i tehnikama
- Proizvodi i sistemi sa brojnim testovima i procenama kako internim tako i eksternim
- Najviši međunarodni standardi proizvodnje i kontrole kvaliteta

PUT INŽENJERING

Put inženjering d.o.o punih 25 godina radi kao specijalizovano preduzeće za izgradnju infrastrukture u niskogradnji i visokogradnji, kao i proizvodnjom kamenog agregata i betona. Preduzeće se bavi i transportom, uslugama građevinske mehanizacije i specijalne opreme.

Za spravljanje betona koristimo drobljeni krečnjački agregat sa našeg kamenoloma, deklarisanih frakcija, kontrolisane vlažnosti. Kompletan proces proizvodnje i kontrole kvaliteta vršimo prema važećim standardima.

Kao generalni izvođač radova, vršimo koordinaciju svih učesnika na projektu, planiranje, praćenje i nabavku materijala, kontrolu kvaliteta izvedenih radova, poštujući zadate vremenske rokove i finansijski okvir investitora.

Obradu armature vršimo brzo, stručno i kvalitetno, sa kompjuterskom preciznošću i dimenzijama po projektu.

Osnovi princip našeg poslovanja zasniva se na individualnom pristupu svakom klijentu i pronalaženje najoptimalnijeg rešenja za njegove transportne i logističke potrebe.

Koristeći inovativne tehnike i kvalitetan građevinski materijal iz sopstvenih resursa, spremni smo da odgovorimo na mnoge zahteve naših klijenata iz oblasti niskogradnje.

Naša kompanija u oblasti visokogradnje primenjuje sistem prefabrikovnih betonskih elemenata koji u odnosu na klasičnu gradnju ima brojne prednosti.

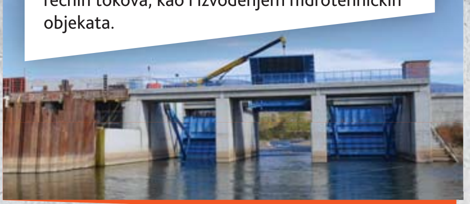
Usluge građevinskom mehanizacijom vršimo tehnički ispravnim mašinama, sa potrebnim sertifikatima kako za rukovaoce građevinskim mašinama tako i za same mašine.

Osnovna prednost prefabrikovane konstrukcije jeste brzina kojom konstrukcija može biti projektovana, proizvedena, transportovana i namontirana.

Prednapregnute šuplje ploče su konstruktivni elementi visokog kvaliteta, proizvedeni u fabrički kontrolisanim uslovima.

Raspolažemo opremom i mašinama za sve zemljane radove, kipere i dampere za rad u teškim terenskim uslovima, automiksere i pumpe za beton, autodizalice, podizne platforme.

Izvodimo hidrograđevinske radove u izgradnji kanalizacionih mreža za odvođenje atmosferskih, otpadnih i upotrebljenih voda, izvođenjem hidrograđevinskih radova u okviru regulacije rečnih tokova, kao i izvođenjem hidrotehničkih objekata.



Izrađujemo betonske "New Jersey profile" koji se u svetu koriste za preusmeravanje saobraćaja i zaštitu pešaka u toku izgradnje puta, kao i Betonblock sistem betonskih blokova.

Sakupljanje i privremeno skladištenje otpada vršimo našim specijalizovanim vozilima i deponujemo na našu lokaciju sa odgovarajućom dozvolom. Kapacitet mašine je 250 t/h građevinskog neopasnog otpada.

Površinski kop udaljen je 35 km od Niša. Savremene drobilice, postrojenje za separaciju i sejalica efikasno usitnjavaju i razdvajaju kamene agregate po veličinama. Tehnički kapacitet trenutne primarne drobilice je 300 t/h.

Uslugu transporta vršimo automikserima, kapaciteta bubnja od 7 m³ do 10 m³ betonske mase. Za ugradnju betona posedujemo auto-pumpu za beton, radnog učinka 150 m³/h, sa dužinom strele od 36 m.

NIŠ
Knjaževačka bb, 18000 Niš - Srbija
+381 18 215 355
office@putinzenjering.com

BEOGRAD
Jugoslovenska 2a, 11250 Beograd – Železnik
+381 11 25 81 111
beograd@putinzenjering.com

www.putinzenjering.com


Ваш партнер
за сигурну будућност
www.grading.rs
Имате локацију за изградњу
у Београду или Крагујевцу?
Контактирајте
нас!
тим стручњака
25 година искуства
више стотина објеката