



2012.  
GODINA  
LV



# GRAĐEVINSKI MATERIJALI I KONSTRUKCIJE

# 4

## 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

Odlukom Skupštine ***Društva za ispitivanje materijala i konstrukcija***, održane 19. aprila 2011. godine u Beogradu, promenjeno je ime časopisa **Materijali i konstrukcije** i od sada će se časopis publikovati pod imenom **Građevinski materijali i konstrukcije**.

According to the decision of the Assembly of the ***Society for Testing Materials and Structures***, at the meeting held on 19 April 2011 in Belgrade the name of the Journal **Materijali i konstrukcije** (Materials and Structures) is changed into **Building Materials and Structures**.

Professor Radomir Folic  
Editor-in-Chief

# 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

---

## INTERNATIONAL EDITORIAL BOARD

Professor **Radomir Folić**, Editor in-Chief  
Faculty of Technical Sciences, University of Novi Sad, Serbia  
Fakultet tehničkih nauka, Univerzitet u Novom Sadu, Srbija  
e-mail: [folic@uns.ac.rs](mailto:folic@uns.ac.rs)

Assoc. professor **Mirjana Malešev**, Deputy editor  
Faculty of Technical Sciences, University of Novi Sad,  
Serbia  
Fakultet tehničkih nauka, Univerzitet u Novom Sadu, Srbija  
e-mail: [miram@uns.ac.rs](mailto:miram@uns.ac.rs)

Dr **Ksenija Janković**  
Institute for Testing Materials, Belgrade, Serbia  
Institut za ispitivanje materijala, Beograd, Srbija

Dr **Jose Adam, ICITECH**  
Department of Construction Engineering, Valencia,  
Spain.

Professor **Radu Banchila**  
Dep. of Civil Eng. „Politehnica“ University of  
Timisoara, Romania

Professor **Dubravka Bjegović**  
Civil Engineering Institute of Croatia, Zagreb, Croatia

Assoc. professor **Meri Cvetkovska**  
Faculty of Civil Eng. University "St Kiril and Metodij",  
Skopje, Macedonia

Professor **Michael Forde**  
University of Edinburgh, Dep. of Environmental Eng.  
UK

Dr **Vladimir Gocevski**  
Hydro-Quebec, Motreal, Canada

Professor **Miklos Ivanyi**  
University of Pecs, Faculty of Engineering, Hungary.

Professor **Asterios Liolios**  
Democritus University of Thrace, Faculty of Civil Eng.,  
Greece

**Predrag Popović**  
Wiss, Janney, Elstner Associates, Northbrook, Illinois,  
USA.

Professor **Tom Schanz**  
Ruhr University of Bochum, Germany

Professor **Valeriu Stoin**  
Dep. of Civil Eng. „Poloitehnica“ University of  
Timisoara, Romania

Acad. Professor **Miha Tomazević**, SNB and CEI,  
Slovenian Academy of Sciences and Arts,

Professor **Mihailo Trifunac**, Civil Eng.  
Department University of Southern California, Los  
Angeles, USA

Lektori za srpski jezik: Dr **Miloš Zubac**, profesor

Proofreader: **Aleksandra Borojev**, profesor  
Prof. **Jelisaveta Šafranj**, Ph D

Technical editor: **Stoja Todorovic**, e-mail: [saska@imk.grf.bg.ac.rs](mailto:saska@imk.grf.bg.ac.rs)

## PUBLISHER

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

REVIEWERS: All papers were reviewed  
COVER: Stabilizaciona AB greda, brana "Modrac", BiH  
RC stabilization beam, "Modrac" Dam, B and H

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

## SADRŽAJ

<b>Ast. LIOLIOS</b> <b>G. HATZIGEORGIU</b> <b>Ang. LIOLIOS</b> EFEKAT VIŠESTRUKIH ZEMLJOTRESA NA SEIZMIČKI ODGOVOR KONSTRUKCIJE <b>Rad sa naučno-stručnog skupa</b> .....	3
<b>Bartul SKENDEROVIĆ</b> <b>Arpad ČEH</b> ISPITIVANJE MOGUĆNOSTI POBOLJŠANJA HIDRAULIČNE AKTIVNOSTI DOMAĆEG LETEĆEG PEPELA <b>Prethodno saopštenje</b> .....	15
<b>Mirza MEMIĆ</b> <b>Radomir FOLIĆ</b> <b>Adnan IBRAHIMOVIĆ</b> METODE NUMERIČKOG MODELIRANJA I SANACIJE NESTABILNE PADINE U IZMENJENOJ SERPENTINSKOJ STENSKOJ MASI <b>Originalni naučni rad</b> .....	23
<b>Uputstvo autorima</b> .....	46

## CONTENTS

<b>Ast. LIOLIOS</b> <b>G. HATZIGEORGIU</b> <b>Ang. LIOLIOS</b> EFFECTS OF MULTIPLE EARTHQUAKES TO THE SEISMIC RESPONSE OF STRUCTURES <b>From Scientific-professional meeting</b> .....	3
<b>Bartul SKENDEROVIĆ</b> <b>Arpad ČEH</b> POSSIBLE IMPROVEMENTS OF HYDRAULIC ACTIVITIES OF FLY ASH PRODUCED IN SERBIA <b>Preliminary report</b> .....	15
<b>Mirza MEMIĆ</b> <b>Radomir FOLIC</b> <b>Adnan IBRAHIMOVIC</b> NUMERICAL MODELING AND SLOPE REPARATION METHODS IN AN ALTERED AND UNSTABLE SERPENTINE ROCK MASS <b>Original scientific paper</b> .....	23
<b>Preview report</b> .....	46

СРП - 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. 1 (2011)-  
- Beograd (Kneza Miloša 9) : Društvo za  
ispitivanje i istraživanje materijala i  
konstrukcija Srbije, 2011- (Novi Beograd :  
Hektor print). - 30 cm

Tromesečno. - Je nastavak: Materijali i  
konstrukcije = ISSN 0543-0798  
ISSN 2217-8139 = Građevinski materijali i  
konstrukcije  
COBISS.SR-ID 188695820



# EFEKAT VIŠESTRUKIH ZEMLJOTRESA NA SEIZMIČKI ODGOVOR KONSTRUKCIJE

## EFFECTS OF MULTIPLE EARTHQUAKES TO THE SEISMIC RESPONSE OF STRUCTURES

Ast. LIOLIOS  
G. HATZIGEORGIU  
Ang. LIOLIOS

RAD SA NAUČNO-STRUČNOG SKUPA<sup>1)</sup>  
FROM SCIENTIFIC-PROFESSIONAL MEETING<sup>1)</sup>  
UDK: 624.041.61:699.841 = 861

### 1 UVOD

Sadašnji seizmički propisi, npr. EC8 [1], imaju važna ograničenja: ovim propisima usvaja se isključivo izolovan i redak „proračunski zemljotres“, dok se uticaj fenomena višestrukih zemljotresa potpuno ignoriše. Uprkos činjenici da je ovaj problem kvalitativno potvrđen, u literaturi se može naći izrazito malo studija koje se bave fenomenom višestrukih zemljotresa. Hatzigeorgiou i Beskos [2] i Hatzigeorgiou [3-5] proučavali su uticaj višestrukih zemljotresa u brojnim SDOF sistemima i pronašli su da niz seizmičkih potresa vodi povećanju pomeranja, u poređenju s „projektovanim“ zemljotresom. Nedavno, Hatzigeorgiou i Beskos [2] pokazali su opštu zabrinutost u vezi s datim problemom, uzimajući u obzir MDOF sisteme za armiranobetonske konstrukcije u seizmički podložnim zonama u svetu.

Ovaj rad prikazuje obimno parametarsko istraživanje neelastičnih odgovora četiri AB ravna rama pod uticajem pet stvarnih seizmičkih potresa. Ti višestruki zemljotresi zabeleženi su u istoj stanici, u istom smeru i u kratkom roku (tokom tri dana). Ispitivana su dva standardna i dva vertikalno nestandardna rama (stepenasto uvučeni spratovi). Vremenski odgovori betonskih ramova procenjeni su pomoću sredstava za analizu opterećenja softvera RUAUMOKO [7]. Kreirana je baza podataka sa

Professor, Democritus University of Thrace, Department of Civil Engineering, GR-67100 Xanthi, Greece, e-mail: [liolios@civil.duth.gr](mailto:liolios@civil.duth.gr)  
Assist. Professor, Democritus University of Thrace, Department of Environmental Engineering, GR-67100 Xanthi, Greece, e-mail: [gchatzig@env.duth.gr](mailto:gchatzig@env.duth.gr)  
PhD Candidate, Democritus University of Thrace, Department of Civil Engineering, GR-67100 Xanthi, Greece, e-mail: [aliolios@civil.duth.gr](mailto:aliolios@civil.duth.gr)

<sup>1)</sup> "Savremena građevinska praksa 2012." 17. i 18. maj 2012. Andrevlje, str. 67-75

### 1 INTRODUCTION

Current seismic design codes, e.g. EC8 [1], usually present an important limitation: they exclusively adopt the isolated and rare “design earthquake”, while the influence of repeated earthquake phenomena is ignored. Despite the fact that the problem has been qualitatively acknowledged, very few studies have been reported in the literature regarding the multiple earthquake phenomena. Hatzigeorgiou and Beskos [2] and Hatzigeorgiou [3-5] examined the influence of multiple earthquakes in numerous SDOF systems and found that seismic sequences lead to increased displacement demands in comparison with the “design earthquake”. Recently, Hatzigeorgiou and Beskos [2] presented a global consideration of the above problem considering MDOF systems for reinforced concrete (RC) structures in seismic-prone regions.

This paper presents an extensive parametric study on the inelastic response of four RC planar frames under five real seismic sequences. The multiple earthquakes have been recorded by the same station, in the same direction and in a short period of time, up to three days. Two regular and two vertically irregular (with setbacks) frames are examined. The time-history responses of these concrete frames are evaluated by means of the

Professor, Democritus University of Thrace, Department of Civil Engineering, GR-67100 Xanthi, Greece, e-mail: [liolios@civil.duth.gr](mailto:liolios@civil.duth.gr)  
Assist. Professor, Democritus University of Thrace, Department of Environmental Engineering, GR-67100 Xanthi, Greece, e-mail: [gchatzig@env.duth.gr](mailto:gchatzig@env.duth.gr)  
PhD Candidate, Democritus University of Thrace, Department of Civil Engineering, GR-67100 Xanthi, Greece, e-mail: [aliolios@civil.duth.gr](mailto:aliolios@civil.duth.gr)

<sup>1)</sup> "Contemporary Civil Engineering Practice 2012." 17. i 18. maj 2012. , Andrevlje, pp. 67-75

sveobuhvatnim analizama kako bi se izvukli važni zaključci.

## 2 OPIS RAMOVSKIH KONSTRUKCIJA I NJIHOVO MODELIRANJE

U datoj komparativnoj studiji, posmatrane su četiri ramovske konstrukcije (Ramovi: A1, A2, A2 I A4) koje predstavljaju AB zgrade, niske visine (trospratne) i srednje visine (osmospratne). Ove četiri tipične AB zgrade sastoje se od greda i stubova bez smičućih zidova i locirane su u delovima Evrope koji su visoke seizmičnosti, a uzeta su u obzir i gravitaciona i seizmička opterećenja, gde su pretpostavljeni  $PGA=0,2g$  i tlo klase B. Ove konstrukcije projektovane su za sledeću kombinaciju opterećenja:

- a)  $1.35G+1.50Q$ ,
- b)  $1.00G+yQ\pm 1.00E$ ,

gde  $G$ ,  $Q$  i  $E$  redom odgovaraju stalnom, povremeno pokretnom i seizmičkom opterećenju, a  $y$  je koeficijent kombinacije i u ovoj studiji, za pokretno opterećenje, pretpostavljen je  $y=1.00$ . Slučaj smičućeg otkaza ovde nije ispitivan zbog odgovarajućeg poprečnog ojačanja. Stalna (izuzimajući sopstvenu težinu) i pokretna opterećenja redom su jednaka  $20 \text{ kN/m}$  i  $10 \text{ kN/m}$ , i nanešena su direktno na grede. Sve međuspratne tavanice su pretpostavljene kao krute u svojoj ravni i imaju efekat dijafragme betonskih ploča. Pretpostavljena je čvrstoća betona na pritisak  $20 \text{ MPa}$  (marka betona MB20), a za podužnu i poprečnu armaturu pretpostavljena je čvrstoća na razvlačenje (granica razvlačenja čelika). Na slici 1 prikazan je karakterističan unutrašnji ram konstrukcije koji predstavlja 2-D model ovih zgrada. Faktori ponašanja,  $q$ , kompatibilni su sa odredbama §5.2.2.2 EC8 – DCM kriterijuma. Zbog pojave pukotina, prilikom projektovanja uzete su redukovane vrednosti momenta inercije štapova ramovske konstrukcije,  $I_{ef}$ , za grede  $I_{ef}=0.5I_g$  i stubove  $I_{ef}=0.9I_g$ , gde je  $I_g$  momenat inercije odgovarajućeg poprečnog preseka [8].

Kako bi se ispitao odgovor konstrukcije, korišteni su neelastični strukturni MDOF sistemi s viskoznom prigušenim odnosom sila-deformacija. Jednačina kretanja rešena je pomoću naprednog programa za seizmičku analizu ramovskih konstrukcija RUAUMOKO [7]. Zbog uklještene osnove, fenomen interakcije između tla i konstrukcije nije uzet u obzir. Efekti drugog reda ( $P-D$  efekti) uzeti su u obzir. Grede i stubovi modelirani su kao nelinearni elementi rama s plastičnim zglobovima na oba kraja greda i stubova. Pretpostavljeno je da su aksijalne sile u gredama jednake nuli, zbog pretpostavke o međuspratnim tavanicama kao krutim u sopstvenoj ravni, a koje imaju efekat dijafragme betonskih ploča. Za modeliranje poprečnih preseka svakog stuba i grede, u ovom radu korišten je program RESPONSE-2000 [9]. Treba primetiti da je za celu grupu analiza i sve članove usvojen histerezisni model Takeda [10]. Na parametre ovog modela utiče krajna otpornost greda i stubova. Objašnjenje ovih parametara i oblik histerezisne petlje analitički su prikazani u uputstvu za korišćenje programa RUAUMOKO [7].

structural analysis software RUAUMOKO [7]. Comprehensive analysis of the created response databank is employed in order to derive important conclusions.

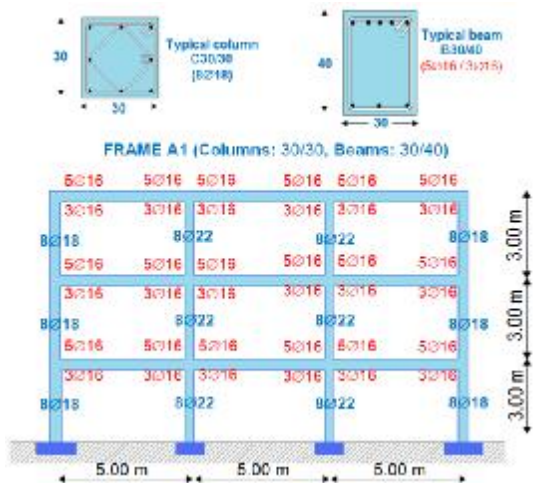
## 2 DESCRIPTION OF CONSIDERED STRUCTURES AND THEIR MODELLING

In the present comparative study, four structures (Frames: A1, A2, A3 and A4) are considered to represent low-rise (3-storey) and medium-rise (8-storey) RC buildings for study. They consist of 4 typical beam-column RC buildings without shear walls, located in a high-seismicity region of Europe considering both gravity and seismic loads where a  $PGA$  of  $0.2g$  and soil class B are assumed. These structures have been designed for the following load combinations:

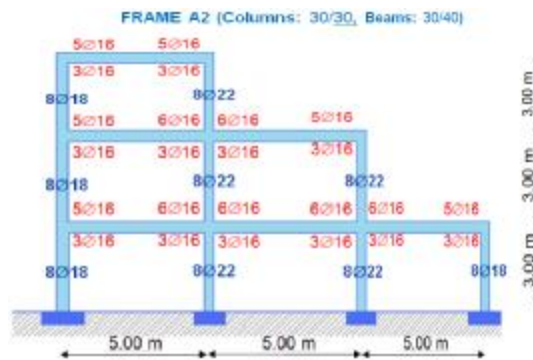
- a)  $1.35G+1.50Q$ ,
- b)  $1.00G+yQ\pm 1.00E$ ,

where  $G$ ,  $Q$  and  $E$  correspond to dead, live and earthquake loads, respectively, and  $y$  is the combination coefficient for live load, assumed to be  $y=1.00$  in this study. The case of shear failure is not examined here assuming adequate transverse reinforcement. The dead loads (excluding self-weight) and live loads are equal to  $20 \text{ kN/m}$  and  $10 \text{ kN/m}$ , respectively, and are directly applied on the beams. All floors are assumed to be rigid in plan to account for the diaphragm action of concrete slabs. Material properties are assumed to be  $20 \text{ MPa}$  for the concrete compressive strength (concrete grade C20) and  $500 \text{ MPa}$  for the yield strength of both longitudinal and transverse reinforcements (steel grade S500s). The characteristic interior frames of these structures, as shown in Fig. 1, represent 2-D models of these buildings. The behaviour factors,  $q$ , are compatible with the provisions of §5.2.2.2 of EC8 – DCM criteria. Reduced values of member moments of inertia,  $I_{ef}$ , were considered in the design to account for the cracking; for beams  $I_{ef}=0.5I_g$  and for the columns  $I_{ef}=0.9I_g$ , where  $I_g$  is the moment of inertia of the corresponding gross section [8].

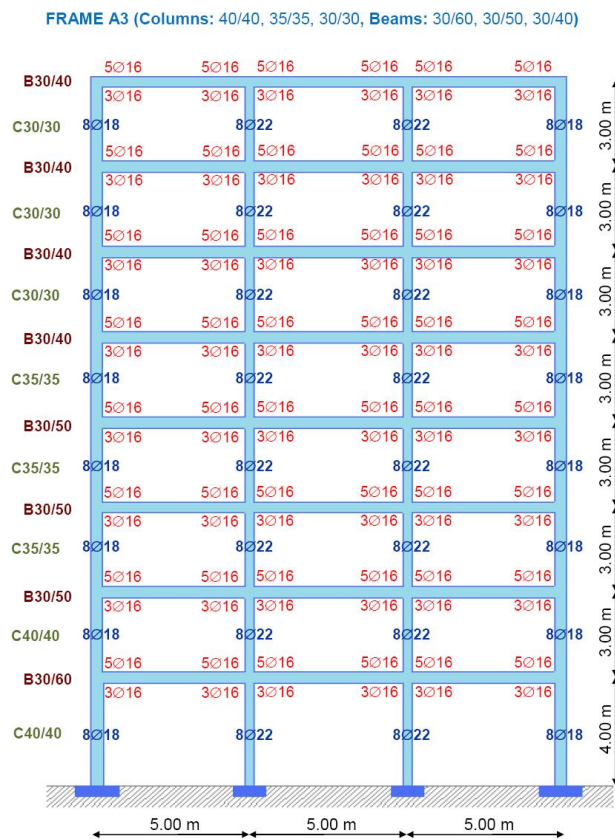
An inelastic structural MDOF system with viscously damped force-deformation relationship is used to investigate the structural response. The solution of the equation of motion has been performed using the RUAUMOKO program [7], which is an advanced program for seismic analysis of framed structures. The soil-structure interaction phenomenon is not taken into account, considering fixed base conditions. Second-order effects ( $P-D$  effects) are investigated. Beam and column elements are modelled as nonlinear frame elements with lumped plasticity by defining plastic hinges at both ends of the beams and columns. On the beams, axial forces were assumed to be zero since all floors are assumed to be rigid in plan to account for the diaphragm action of concrete slabs. In this work and for each column and beam, the program RESPONSE-2000 [9] is used for the section modelling. It should be noted that for the entire group of analyses and members, the modified Takeda [10] hysteretic model is adopted. The parameters of this model are affected by the end resistances of beams and columns. An explanation of these parameters and the shape of the hysteresis model are analytically presented in the RUAUMOKO user manual [7].



Slika 1. Ram A1  
Figure 1. Frame A1

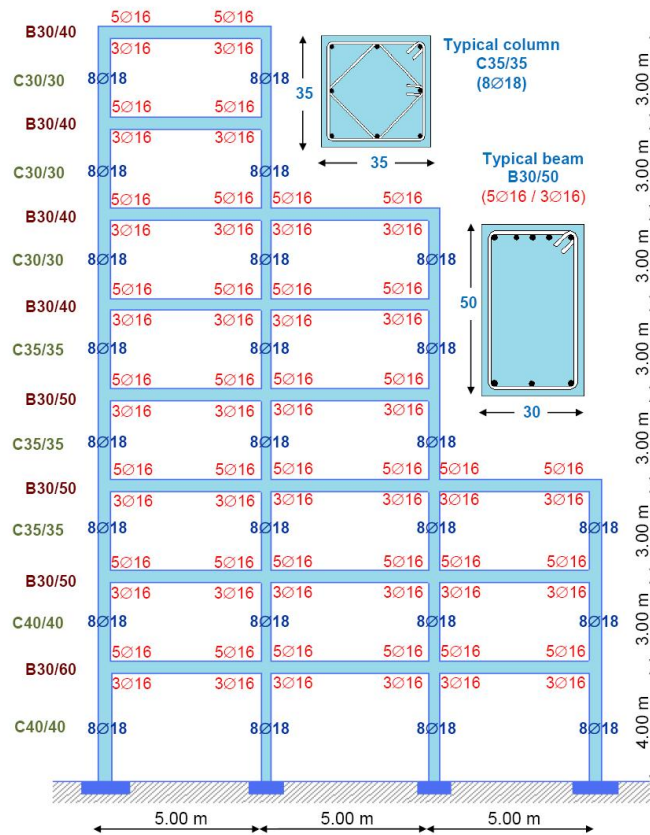


Slika 2. Ram A2  
Figure 2. Frame A2



Slika 3. Ram A3  
Figure 3. Frame A3

FRAME A4 (Columns: 40/40, 35/35, 30/30, Beams: 30/60, 30/50, 30/40)



Slika 4. Ram A4  
Figure 4. Frame A4

### 3 SEIZMIČKI ULAZNI PODACI

Baza podataka u vezi s pomeranjem tla sastoji se od niza pet realnih seizmičkih potresa koji su snimljeni za kratko vreme (do tri dana) u istoj stanici, u istom smeru, i na skoro istom odstojanju. Ovi nizovi seizmičkih potresa nazvani su zemljotresima: *Mamot Jezero* (maj 1980 – pet događaja), *Kalfant Dolina* (jul 1986 – dva događaja), *Koalinga* (jul 1983 – dva događaja), *Imperial Dolina* (oktobar 1979 – dva događaja) i *Vitier Klanci* (oktobar 1987 – dva događaja). Kompletan lista ovih zemljotresa preuzeta je iz baze podataka o pomeranju tla od Pacifičkog zemljotresnog inženjerskog istraživačkog centra (PEER) [11]. Videti tabelu 1.

Sve registracije uzastopnih pomeraja tla postaju jedan snimak pomeranja tla (serijski niz), gde je između dva uzastopna seizmička događaja apliciran vremenski razmak od 100 sekundi. Ovaj razmak je sasvim dovoljan da prekine pomeranje bilo koje konstrukcije zahvaljujući prigušenju. Na slikama 5a i 5b može se videti istorija korištenih nizova seizmičkih potresa. Zbog kompatibilnosti s procesom projektovanja, nizovi seizmičkih potresa su normalizovani i imaju  $PGA=0.2g$ .

### 3 SEISMIC INPUT DATA

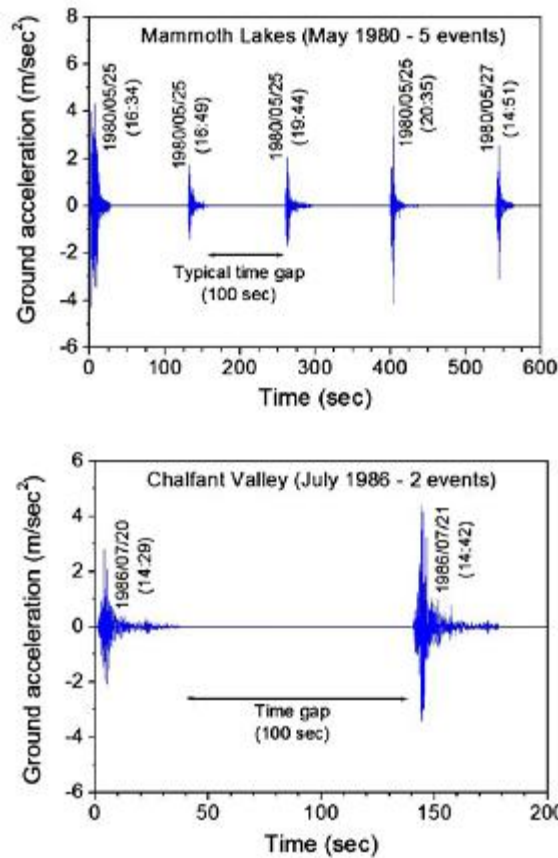
The strong ground motion database consists of five real seismic sequences, which have been recorded during a short period of time (up to three days), by the same station, in the same direction, and almost at the same fault distance. These seismic sequences are namely: Mammoth Lakes (May 1980 - 5 events), Chalfant Valley (July 1986 - 2 events), Coalinga (July 1983 - 2 events), Imperial Valley (October 1979 - 2 events) and Whittier Narrows (October 1987 - 2 events) earthquakes. The complete list of these earthquakes, which were downloaded from the strong motion database of the Pacific Earthquake Engineering Research (PEER) Center [11], appears in Table 1.

Every sequential ground motion records becomes a single ground motion record (serial array) where between two consecutive seismic events a time gap is applied, which is equal to 100 sec. This gap is enough to cease the moving of any structure due to damping. Figures 5a and 5b show the time histories of used seismic sequences. For compatibility reasons with the design process, the seismic sequences are normalized to have  $PGA=0.2g$ .

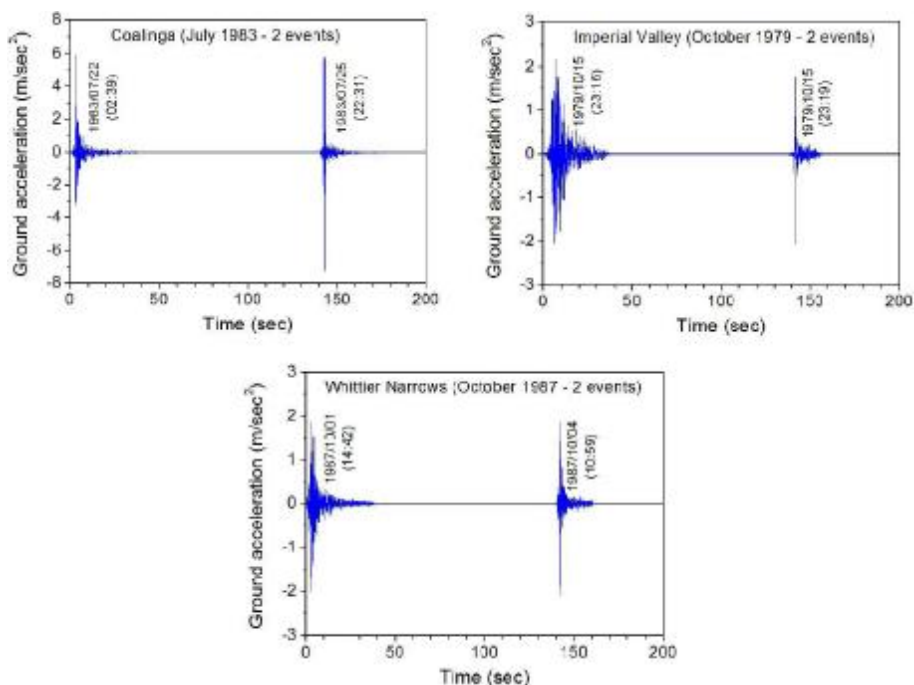


Tabela 1. Seizmički ulazni podaci  
Table 2. Seismic input data

No.	Seismic sequence	Station	Comp.	Date (Time)	Recorded PGA(g)
1	Mammoth Lakes	54099 Convict Creek	N-S	1980/05/25 (16:34)	0.442
				1980/05/25 (16:49)	0.178
				1980/05/25 (19:44)	0.208
				1980/05/25 (20:35)	0.432
				1980/05/27 (14:51)	0.316
2	Chalfant Valley	54428 Zack Bros Ranch	E-W	1986/07/20 (14:29)	0.285
				1986/07/21 (14:42)	0.447
3	Coalinga	46104 CIP	N-S	1983/07/22 (02:39)	0.605
				1983/07/25 (22:31)	0.733
4	Imperial Valley	5055 Holtville P.O.	HPV315	1979/10/15 (23:16)	0.221
				1979/10/15 (23:19)	0.211
5	Whittier Narrows	24101 San Marino	N-S	1987/10/01 (14:42)	0.204
				1987/10/04 (10:59)	0.212



Slika 5a. Zemljotresi Mamot Jezero i Kalfant Dolina  
Figure 5a. Mammoth Lakes and Chalfant Valley earthquakes



Slika 5b. Zemljotresi Koaling, Imperial Dolina i Vitier Klanci  
 Figure 5b. Coalina, Imperial Valley and Whittier Narrows earthquakes

#### 4 IZABRANI REPREZENTATIVNI REZULTATI

U ovom delu rada proučavano je neelastično ponašanje ispitivanih AB ramovskih konstrukcija. Ovo istraživanje fokusira se na sledeće osnovne projektne parametre: lokalni ili globalni indeks oštećenja prema Park i Ang pristupu [12], maksimalno horizontalno pomeranje međuspratnih tavanica, odnosi međuspratnog pomeranja, razvoj plastičnih zglobova, odgovor konstrukcije prema tehnici inkrementalne dinamičke analize (*IDA*) [13] i trajna pomeranja. Park-Ang model [12] najpoznatiji je i najprimenjeniji indeks oštećenja (*DI*), koji se definiše kao kombinacija maksimalne deformacije i histerezisne energije:

$$DI = \frac{d_m}{d_u} + \frac{b}{d_u P_y} \int dE_h \quad (1)$$

gde je  $\delta_m$  maksimalna deformacija elementa,  $\delta_u$  krajnja deformacija, a  $\beta$  konstanta modela (obično se kreće  $\beta=0.05\sim 0.20$ ), koja kontroliše pogoršanje čvrstoće;  $\int dE_h$  je histerezisna energija koju apsorbuje element za vreme zemljotresa, a  $P_y$  je čvrstoća razvlačenja elementa. U ovom radu, parametar  $\beta$  je 0.20. Ovaj oštećeni model se takođe može primeniti i na spratove i ukupni obim (globalni indeks oštećenja) sabiranjem indeksa oštećenja, koristeći odgovarajuće uvećane težine.

Slika 6 prikazuje lokalna i globalna oštećenja rama A2 pod uticajem zemljotresa *Mamot Jezero* (1980) i *Vitier Klanci* (1987). Očigledno je da, u svim slučajevima, nizovi seizmičkih potresa vode povećanju oštećenja – i na lokalnom i globalnom nivou.

Odnos međuspratnog pomeranja (*IDR*) za ram A3 i A4 može se videti na slici 7, za jedan pomeraj, ali i za

#### 4 REPRESENTATIVE SELECTED RESULTS

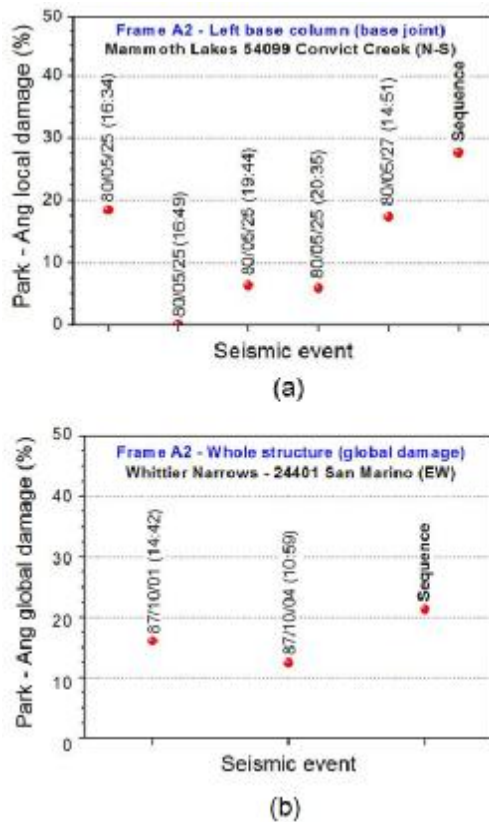
The inelastic behaviour of the examined RC framed structures is investigated in this section. This study focuses on the following basic design parameters: local or global damage index according to Park and Ang approach [12], maximum horizontal floor displacements, interstorey drift ratios, development of plastic hinges, structural response according to incremental dynamic analysis (*IDA*) [13] technique and permanent displacements. The Park-Ang model [12] is the best known and most widely used damage index (*DI*), which is defined as a combination of maximum deformation and hysteretic energy:

where  $\delta_m$  is the maximum deformation of the element,  $\delta_u$  is the ultimate deformation,  $\beta$  is a model constant parameter (usually,  $\beta=0.05\sim 0.20$ ) to control strength deterioration,  $\int dE_h$  is the hysteretic energy absorbed by the element during the earthquake, and  $P_y$  is the yield strength of the element. In this work, parameter  $\beta$  is set equal to 0.20. This damage model can also be extended to the storey and overall scales (global damage index), by summation of damage indices using appropriate multiplication weights.

Figure 6 depicts the local and global damage, for the Frame A2 under the Mammoth Lakes(1980) and Whittier Narrows(1987) earthquakes. It is evident that, in any case, seismic sequences lead to increased damage, both in local and global level.

The interstorey drift ratio (*IDR*) for Frames A3 and A4 appear in Figure 7, both for single and sequential ground

niz pomeraja tla (zemljotresi *Koalinga* i *Imperial Dolina*). Očigledno je da niz seizmičkih potresa vodi do uvećanja *IDR*, u poređenju sa odgovarajućim jednim seizmičkim događajem.



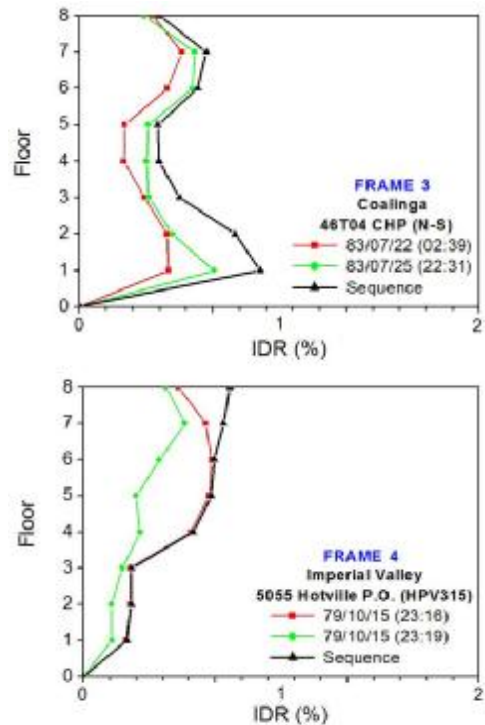
Slika 6. Lokalna i globalna oštećenja rama A2  
Figure 6. Local and global damage for Frame A2

Konačni razvoj/konačna raspodela plastičnih zglobova na rami A1 može se videti na slici 8. Očigledno je to da je zbog više zemljotresa raspodela plastičnih zglobova drugačija nego u slučaju odgovarajućeg jednog/izolovanog seizmičkog događaja.

Sve ispitivane konstrukcije analizirane su pomoću *IDA* tehnike [13]. Na slici 9 prikazani su rezultati za ramove A1 i A2 pod uticajem jednog i višestrukog pomeranja tla. Očigledno je da niz seizmičkih potresa vodi ka primetno različitim odgovorima u poređenju sa odgovarajućim jednim seizmičkim događajem, što uzrokuje potrebu za uvećanjem pomeranja. Kao što je očekivano, povećanje potrebe za pomeranjem vodi ka većim vrednostima pomeranja i oštećenja. Osnovni cilj *IDA* jeste da odredi količinu rezerve kapaciteta konstrukcije, kako ne bi došlo do kolapsa konstrukcije.

Otkako se u analizama uzima u obzir stanje kolapsa u vezi s degradacijom jačine nosivosti i čvrstoće, *IDA* tehnika pokazala se kao veoma korisna. Pretpostavlja se da se stanje loma postiže ekstremno velikim horizontalnim pomeranjima. Na slici 9 se vidi, za ispitivane konstrukcije i njihove *PGA*, da do kolapsa dolazi samo u slučajevima niza seizmičkih potresa, a ne u slučaju „izolovanog” jednog pomeraja tla.

motions (Coalinga and Imperial Valley earthquakes). It is evident that seismic sequences lead to larger *IDR* in comparison with the corresponding single events.

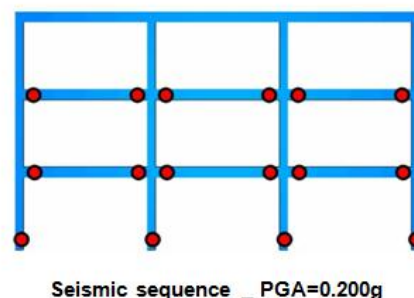
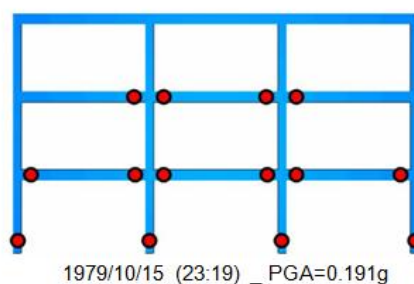
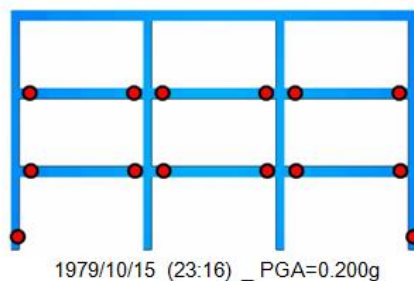


Slika 7. *IDR* za ramove A3 i A4  
Figure 7. *IDR* for Frames A3 and A4

The final development/distribution of plastic hinges of Frame A1 appears in Figure 8. It is evident that due to the multiplicity of earthquakes, the distribution of plastic hinges seems to be different than the corresponding one for single/isolated seismic events.

All the examined structures have been analyzed using the *IDA* technique [13]. Figure 9 shows selected results for the Frames A1 and A2 under single and multiple strong ground motions. It is evident that the seismic sequences lead to noticeably different response in comparison with the corresponding single seismic events and require increased displacement demands, in any case under consideration. As it is expected, the increased displacement demands lead to higher values of drift and damage. The primary goal of *IDA* is to quantify the reserve capacity of a structure against collapse. Since the analyses take into account the collapse state considering stiffness and strength degradation, the *IDA* seems to be very useful for this study. Assuming that the collapse state is represented by extremely large horizontal displacements, Figure 9 shows, for the examined structures and *PGA*'s that the collapse appears only for the cases of seismic sequences and not for the 'isolated' single ground motions.

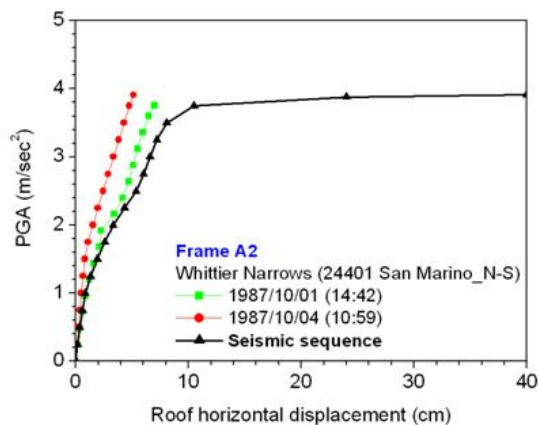
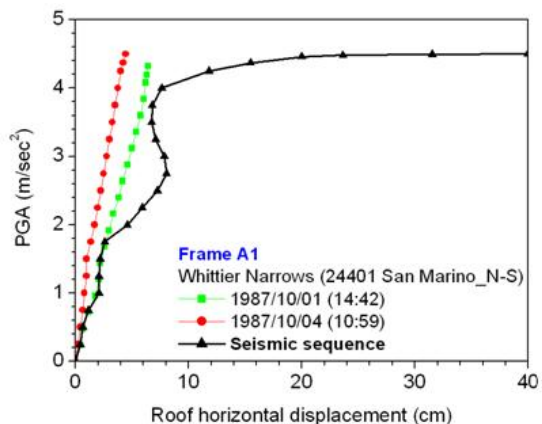
**Frame A1**  
Imperial Valley 5055 Holtville P.O. (HPV315)



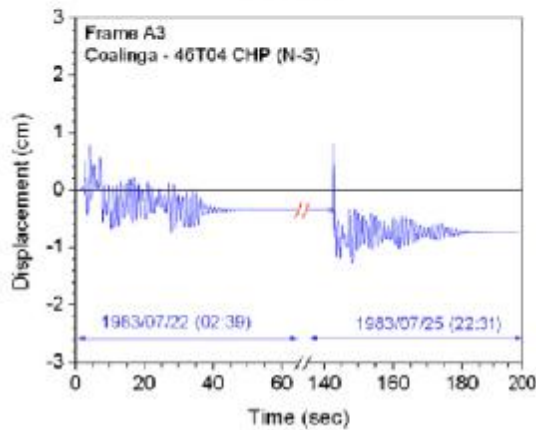
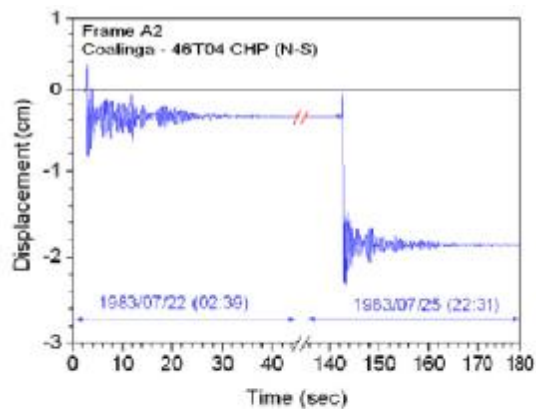
*Slika 8. Raspodela plastičnih zglobova za pojedinačno i sekventno pomeranje tla – Ram A1*  
*Figure 8. Plastic hinges distribution for single and sequential ground motions – Frame A1*

Dobro je poznato da se trajna pomeranja moraju tačno proceniti, kako bi se zadovoljio željeni nivo ponašanja konstrukcije pod uticajem predefinisane seizmičke opasnosti. U ovom radu, pronađeno je da višestrukost zemljotresa snažno utiče na trajna pomeranja. Prema tome, fenomen višestrukog zemljotresa mora biti uzet u obzir, kako bi se postigao bezbedan nivo procene trajnog pomeranja. Na slici 10 prikazani su izabrani rezultati posmatranih konstrukcija, koje su podvrgnute nizu seizmičkih potresa, gde je prikazana i istorija horizontalnog pomeranja vrha ramova. Akumulacija trajnih pomeranja očigledna je u svakom posmatranom slučaju.

It is well-known that in order to satisfy the targeted performance levels under pre-defined seismic hazard levels, the permanent displacement should be accurately estimated. In this work, it is found that the multiplicity of earthquakes strongly influences the permanent displacements and therefore multiple earthquakes phenomena should be taken into account to achieve dependable estimation of permanent displacements. Figure 10 shows selected results for the considered structures subjected to seismic sequences, where the time history of horizontal displacement for the top of the frames is presented. The accumulation of permanent displacement is obvious, in any case under consideration.

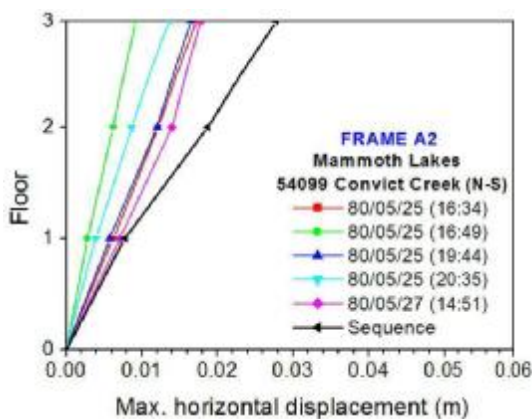
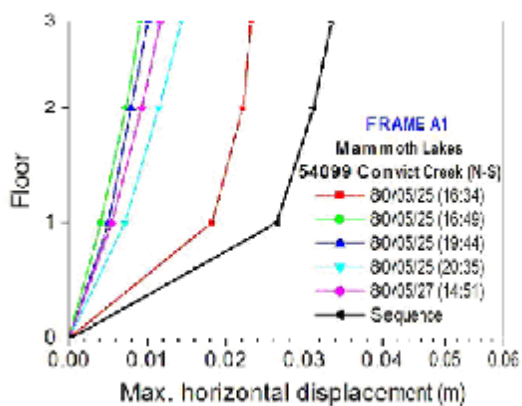


Slika 9. Aplikiranje IDA za sekventno pomeranje tla  
Figure 9. Application of IDA for sequential ground motions



Slika 10. Akumulacija trajnog pomeranja za ramove A2 i A3.

Figure 10. The accumulation of permanent displacement for Frames A2 and A3.

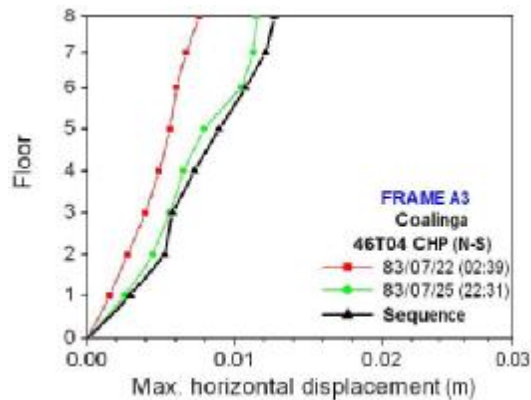


Slika 11a. Maksimalno horizontalno pomeranje – Ram A1

Figure 11a. Max. horizontal displacement – Frame A1

Slika 11b. Maksimalno horizontalno pomeranje – Ram A2

Figure 11b. Max. horizontal displacement – Frame A2



Slika 11c. Maksimalno horizontalno pomeranje – Ram A3  
Figure 11c. Max. horizontal displacement – Frame A3

Konačno, kada su u pitanju maksimalna pomeranja i potreba duktilnosti, slike 11a, 11b, 11c prikazuju profile maksimalnih horizontalnih pomeranja, za jedan i niz uzastopnih pomeranja tla. Preciznije su ispitivani ramovi A1, A2 i A3, pod dejstvom zemljotresa *Mamot Jezera* i *Koalinga*. Pronađeno je da se pod uticajem višestrukih zemljotresa povećava potreba za pomeranjem, u svakom slučaju koji se razmatra. Dobro je poznato da neelastični fleksibilni sistemi pokazuju trajna pomeranja za pojedinačne jake zemljotrese. Za svaki drugi naredni pomeraj tla, trajna pomeranja se nagomilavaju i prema tome – maksimalna pomeranja se povećavaju. Osim toga, maksimalna pomeranja su u direktnoj vezi s potrebama duktilnosti.

## 5 ZAKLJUČCI

Pod uticajem više snažnih pokreta tla, istražili smo neelastična ponašanja ravnih AB ramova. Ispitali smo dve vrste ramova: prvi je regularan, a drugi vertikalno neregularan ram (stepenasto uvučeni spratovi). Ovi ramovi projektovani su za vertikalno odnosno za vertikalno i seizmičko opterećenje. Detaljno parametarsko istraživanje problema dovelo je do sledećih glavnih zaključaka:

- Višestruki zemljotresi dovode do povećanja pomeranja, u poređenju s jednim seizmičkim događajem. Osim toga, seizmička oštećenja su veća usled višestrukih zemljotresa nego u slučaju jedinog pomeraja tla. Ove karakteristike veoma su važne i trebalo bi ih uzeti u obzir prilikom seizmičkog projektovanja konstrukcija, ili pri konvencionalnom projektovanju zasnovanom na sili ili putem novije metode projektovanja, bazirane na pomeranju, a koja traži veoma visoku tačnost prilikom određivanja pomeranja.

- Istražili smo trajna pomeranja konstrukcija koje su bile izložene uzastopnom nizu pomeraja tla. Pronašli smo da sekventno pomeranje tla akumulira trajna pomeranja. Prema tome, za njihovo tačno određivanje trebalo bi uzeti u obzir fenomen višestrukih zemljotresa.

- Niz uzastopnih pomeraja tla snažno utiče na razvoj/raspodelu plastičnih zglobova, što se razlikuje u slučaju jednog/izolovanog seizmičkog događaja.

- Istražili smo tehniku inkrementalne dinamičke

Finally, concerning maximum displacements and ductility demands, the Figures 11a,b,c present maximum horizontal displacement profiles, both for single and sequential ground motions. More specifically, the Frames A1, A2 and A3, under the Mammoth Lakes and Coalinga seismic sequences are examined. It is found that due to the multiplicity of earthquakes, increased displacement demands are required, in any case under consideration. It is well-known that inelastic flexible systems present permanent displacements for single strong earthquakes. For any other oncoming ground motion, permanent displacements are obviously cumulated and therefore the maximum displacements appear to be increased. Furthermore, the maximum displacements are directly related to the ductility demands.

## 5 CONCLUDING REMARKS

The inelastic behaviour of planar RC frames under sequential strong ground motions has been investigated. Two families, the first of regular and the second one of vertically irregular (with setbacks) frames, are examined. These frames have been designed either for vertical or both for vertical and seismic loads. A detailed parametric study of the problem leads to the following main conclusions:

- Multiple earthquakes require increased displacement demands in comparison with single seismic events. Furthermore, the seismic damage for multiple earthquakes is higher than that for single ground motions. These characteristics are very important and should be taken into account for the seismic design of structures either by the conventional force-based or especially by the more recent displacement-based design method, which requires a high accuracy estimation of displacements.

- The permanent displacements of the structures, which are subjected to sequential ground motions, have been investigated. It is found that the sequential ground motions accumulate the permanent displacements. Therefore, an accurate estimation of them requires taking into account the multiple earthquakes phenomena.

- Sequential ground motions strongly affect the development/distribution of plastic hinges, which can be

analize (*IDA*) pod uticajem niza uzastopnih pomeranja tla. Pronašli smo da su odgovori konstrukcije pod nizom seizmičkih potresa znatno drugačiji nego u slučaju odgovarajućeg jednog seizmičkog događaja. Osim toga, za ispitivane konstrukcije i njihove PGA, kolaps se javlja samo u slučaju niza seizmičkih potresa, dok se u slučaju „izolovanog” jednog pomeranja tla ne javlja.

Konačno, ovde prikazana procedura može se primeniti i u slučajevima seizmičke interakcije susednih AB konstrukcija pod uticajem višestrukih zemljotresa. Prvi rezultati ovog istraživanja pojavili su se nedavno [14].

different than that for the case of single/isolated seismic events.

- The incremental dynamic analysis (*IDA*) technique under sequential ground motions has been also investigated. It is found that the seismic sequences lead to quite different responses than the corresponding ones for single seismic events. Furthermore, for the examined structures and *PGA*'s, the collapse appears only for the cases of seismic sequences and not for the 'isolated' single ground motions.

Finally, the herein presented procedure can be extended to the case of seismically interacting adjacent RC structures under multiple earthquakes. First results of this research have appeared recently [14].

## 6 LITERATURA REFERENCES

- [1] EN 1998-1 Eurocode 8. Design of structures for earthquake resistance; Part 1: General rules, seismic actions and rules for buildings. European Committee for Standardization, Brussels, 2005.
- [2] Hatzigeorgiou G., Ductility demand spectra for multiple near- and far-fault earthquakes. *Soil Dynamics and Earthquake Engineering*, vol. 30, 170-183, 2010.
- [3] Hatzigeorgiou G., Behaviour factors for nonlinear structures subjected to multiple near-fault earthquakes. *Computers and Structures*, vol. 88, 309-321, 2010.
- [4] Hatzigeorgiou G. and D. Beskos, Inelastic displacement ratios for SDOF structures subjected to repeated earthquakes. *Engineering Structures*, vol. 31, 2744-2755, 2009.
- [5] Hatzigeorgiou G., Ductility demands control under multiple earthquakes using appropriate force reduction factors, *Journal of Earthquake and Tsunami*, vol. 4(3), 231-250, 2010.
- [6] Hatzigeorgiou G. and A. A. Liolios. Nonlinear behaviour of RC frames under repeated strong ground motions. *Soil Dynamics and Earthquake Engineering*, vol. 30, 1010-1025, 2010.
- [7] Carr A.J., RUAUMOKO - Inelastic Dynamic Analysis Program. Department of Civil Engineering, University of Canterbury, Christchurch, New Zealand, 2008.
- [8] Paulay T. and M.J.N. Priestley, *Seismic Design of Reinforced Concrete and Masonry Buildings*, Wiley, New York, 1992.
- [9] Bentz E.C. and M.P. Collins, Response-2000 Section analysis program, v1.0.5, <http://www.ecf.utoronto.ca/~bentz/home>. Last access: 2011/02/15.
- [10] Takeda T., M Sozen and N Nielsen, Reinforced concrete response to simulated earthquakes, *Journal of Structural Division ASCE* 1970, 96(12), 2557-2573.
- [11] Pacific Earthquake Engineering Research Center. PEER Strong Motion Database. <http://peer.berkeley.edu/smcat>. Last access: 2011/02/15.
- [12] Park Y.J. and A.H.S. Ang. Mechanistic seismic damage model for reinforced concrete, *Journal of Structural Division ASCE*, vol. 111(4), 722-739, 1985.
- [13] Vamvatsikos D. and C.A. Cornell. Incremental dynamic analysis. *Earthquake Engineering Structural Dynamics*, vol. 31, 491-514, 2002.
- [14] Efraimiadou S., Hatzigeorgiou, G. and Liolios A., Inelastic pounding of adjacent reinforced concrete structures under multiple earthquakes, paper No 19 in: Boudouvis, A. and Stavroulakis, G. (eds), *Proceedings of 7th GRACM Intern. Conf. Computational Mechanics*, Athens, 30.6.-2.7.2011, 2011.

## REZIME

### EFEKAT VIŠESTRUKIH ZEMLJOTRESA NA SEIZMIČKI ODGOVOR KONSTRUKCIJE

Ast. LIOLIOS  
G. HATZIGEORGIOU  
Ang. LIOLIOS

Prethodna istraživanja pokazala su da su dobro projektovane, moderne, armiranobetonske (AB) zgrade, kao što su AB ramovske konstrukcije, sposobne da obezbede sigurnost stanara za vreme jakog zemljotresa. U seizmički aktivnim delovima sveta, armiranobetonski otporni ramovi su najčešći oblik trgovačkih, industrijskih i stambenih objekata. Međutim, postoje značajne mane u sadašnjim seizmičkim propisima. Slaba strana seizmičkih propisa jeste usvajanje isključivo izolovanog i retkog „projektnog-proračunskog zemljotresa“, dok se uticaj fenomena višestrukih zemljotresa potpuno ignoriše. Uprkos činjenici da je ovaj problem kvalitativno potvrđen, u literaturi se može naći veoma malo studija koje se bave fenomenom višestrukih zemljotresa. Ovaj rad proučava ponašanje AB ramova koji su izloženi višestrukim zemljotresima. Ustanovljeno je da uzastopni niz pomeraja tla ima značajan efekat na odgovor, a samim tim i na projektovanje armiranobetonskih konstrukcija.

**Ključne reči:** Armiranobetonske konstrukcije; seizmičko projektovanje; višestruki zemljotresi.

## SUMMARY

### EFFECTS OF MULTIPLE EARTHQUAKES TO THE SEISMIC RESPONSE OF STRUCTURES

Ast. LIOLIOS  
G. HATZIGEORGIOU  
Ang. LIOLIOS

Previous research has shown that well-designed modern reinforced concrete (RC) structures, e.g. RC frame buildings, are able to ensure the safety of building occupants during a strong earthquake. Reinforced concrete (RC) moment resisting frames are a prevalent form of commercial, industrial and multi-family residential construction in seismic-prone regions worldwide. However, there is a significant drawback for the current seismic codes. This concerns exclusive adoption of the isolated and rare “design earthquake”, while the influence of repeated earthquake phenomena is ignored. Despite the fact that the problem has been qualitatively acknowledged, very few studies have been reported in the literature regarding the multiple earthquake phenomena. This paper examines the behaviour of RC frames which are subjected to multiple earthquakes. It is found that the sequences of ground motions have a significant effect on the response and, hence, on the design of reinforced concrete structures.

**Key words:** Reinforced concrete structures; seismic design; multiple earthquakes



# ISPITIVANJE MOGUĆNOSTI POBOLJŠANJA HIDRAULIČNE AKTIVNOSTI DOMAĆEG LETEĆEG PEPELA

## POSSIBLE IMPROVEMENTS OF HYDRAULIC ACTIVITIES OF FLY ASH PRODUCED IN SERBIA

*Bartul SKENDEROVIĆ  
Arpad ČEH*

PRETHODNO SAOPŠTENJE  
PRELIMINARY REPORT  
UDK: 662.613.13 = 861

### 1 UVODNE NAPOMENE

Poznato je da leteći pepeo naših termoelektrana ima slabu hidrauličnu aktivnost, zbog čega se nedovoljno koristi u proizvodnji cementa. Nije potrebno dokazivati da je posredi velika ekonomska šteta, a i ekološki problem [7],[8].

Mnogi naučni radovi bavili su se mogućnostima primene letećeg pepela iz domaćih termoelektrana u građevinarstvu. Istraživanja primene pepela u putogradnji pokazala su da pri stabilizaciji letećeg pepela dodatak kreča već u malim količinama povoljno utiče na mehaničke karakteristike nasipa. Rezultati su ukazali na to da je reč o relativno sporoj reakciji, ali dodatak kreča ima značajan doprinos čvrstoći u dužem periodu – od godinu dana i više [1],[3],[6].

Gips je vezivo koje takođe povoljno utiče na hidrauličnu aktivnost letećeg pepela i koristi se pri proizvodnji presovanih elemenata za zidanje od letećeg pepela u mnogim zemljama [9],[10].

Radili smo istraživanja s ciljem da se s jeftinim i lako dostupnim dodacima poboljša hidraulična aktivnost letećeg pepela domaćih termoelektrana, te da se od tako dobijenog cementa dobije beton dobrog kvaliteta i trajnosti [4],[2],[5].

Ogledne smo radili s komercijalnim cementom u kome je 30% bilo zamenjeno osušenim mlevenim letećim pepelom domaće termoelektarane. Ogledne prizme od cementnog maltera držane su tri godine u različitim sredinama u kojima se obično nalaze betonske konstrukcije, a zatim su ispitivane njihove osobine.

---

Prof. dr Bartul Skenderović, dipl. inž. tehn., redovni profesor u penziji, Građevinski fakultet Subotica, Kozaračka 2a, Subotica, Srbija, [email:ceh@gf.uns.ac.rs](mailto:ceh@gf.uns.ac.rs)  
Arpad Čeh, dipl. inž. građ., asistent, Građevinski fakultet Subotica, Kozaračka 2a, Subotica, Srbija, [email:ceh@gf.uns.ac.rs](mailto:ceh@gf.uns.ac.rs)

### 1 INTRODUCTION

Fly ashes from Serbian power plants have low hydraulic activity, hence the insufficient use in production of cement. It is unnecessary to prove that it is a cause of major economic damage but also an environmental problem [7], [8].

The possibilities of applying fly ash from local power stations in construction industry had been dealt with in many scientific works. Studies on applying the fly ash in road construction had shown that lime in small quantities has a positive effect in stabilizing the fly ash and an increase of mechanical properties of fly ash-landfills. The results indicated a relatively slow reaction, but the addition of lime also had a significant contribution to the strength over a longer period (one year or more) [1], [3], [6].

Gypsum is used as a binder that also positively affects the hydraulic activity of fly ash used in the production of fly ash bricks and other masonry units in many countries [9], [10].

The research performed has a goal to improve the hydraulic activity of fly ashes in local power plants with inexpensive and easily available additives and to obtain cement containing fly ash which would result into concrete with good quality and durability [4], [2], [5].

Specimens were prepared in test mortars the usual way by using commercial cement with or without a 30 % replacement of dried, grinded fly ash from local power plant. Test prisms made that way were cured in water for 28 days and kept for 3 years in different conditions (indoor and outdoor), in which concrete constructions normally exist then after, the properties were tested.

---

Bartul Skenderović, PhD, Full professor, University of Novi Sad, Faculty of Civil Engineering Subotica, Kozaračka 2a, Serbia, [email:ceh@gf.uns.ac.rs](mailto:ceh@gf.uns.ac.rs)  
Arpad Čeh, Assistant, University of Novi Sad, Faculty of Civil Engineering Subotica, Kozaračka 2a, Serbia, [email:ceh@gf.uns.ac.rs](mailto:ceh@gf.uns.ac.rs)

## 2 ISPITIVANJA ZBOG IZBORA VRSTA I KOLIČINA OGLEDNIH DODATAKA

Za ogledne je korišćen kupljeni cement (CEM I – 42,5R), koji verovatno sadrži i neke hidraulične dodatke, čija vrsta i količina nam nije bila poznata. Hemijskom analizom utvrđen je sastav korišćenog cementa:

Tabela 1. Hemijski sastav korišćenog cementa  
Table 1. Compounds of the used cement

CaO	MgO	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	SO <sub>3</sub>
54.12%	5.44%	21.00%	4.25%	2.99%	3.40%

Ogledni leteći pepeo osušen je i samleven do finoće od 0,09 mm. Analizom mu je utvrđen sledeći hemijski sastav:

Tabela 2. Hemijski sastav oglednog letećeg pepela  
Table 2. Compounds of the used fly ash

CaO	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	SO <sub>3</sub>	gubitak žarenjem na 600 <sup>o</sup> C ignition loss on 600 <sup>o</sup> C
2.23%	55.16%	25.75%	4.55%	1.28%	11.13 %

Ovako nizak sadržaj CaO u letećem pepelu mogao bi biti jedan od uzroka slabe hidraulične aktivnosti. Poznato je da za hidrataciju glavnih sastojaka letećeg pepela (SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>), potrebno prisustvo dovoljnih količina kalcijum-hidroksida (Ca(OH)<sub>2</sub>) kao neposrednog reagensa, a i kao jedinjenja koje će stvoriti baznu sredinu potrebnu za hidrataciju prisutnog pepela [2],[7]. Stoga je odlučeno da jedan od oglednih dodataka bude hidratizirani kreč (Ca(OH)<sub>2</sub>) u prahu, u količinama od 5% i 10%, kao i smeša od 10% (Ca(OH)<sub>2</sub>) i 3% gipsa. Gips, kao dodatak, izabran je pošto je u većini ogleda 30% cementa zamenjeno mlevenim letećim pepelom, čime je (za blizu 1%) smanjena količina gipsa u oglednim cementima. Sem toga, gips u svom sastavu (CaSO<sub>4</sub>) sadrži poželjne atome kalcijuma koji mogu preći u jone (Ca<sup>++</sup>), poželjne za procese hidratacije dodatog pepela [10]. Na taj način, izabrane su tri vrste oglednih dodataka (aditiva) za prve ogledne: 5% i 10% hidratizirani kreč (Ca(OH)<sub>2</sub>) u prahu i smeša od 10% Ca(OH)<sub>2</sub> i 3% gipsa.

U prvim, orijentacionim ogledima, ispitivali smo mešavine sa odabranom tri dodatka cementu u kome je 30% bilo zamenjeno mlevenim letećim pepelom, kao i cementu bez dodataka domaćeg oglednog letećeg pepela.

Ovo smo uradili kako bismo utvrdili uticaj odabrana tri ogledna dodatka na brzinu hidratacije i na osobinu oglednih prizmi ako cement sadrži manje hidrauličnih dodataka.

Ogledne prizme (4x4x16 cm) izrađene su od navedena dva cementa (sa zamenom i bez zamene 30% s letećim pepelom), kvarcnog peska i vode na uobičajen način, uz navedene tri vrste dodataka. Kontrolni uzorci (bez dodataka) izrađeni su s vodocementnim faktorom (V/C) mešavine 0,50. Prilikom izrade oglednih maltera s dodacima, bilo je potrebno dodati nešto više vode za dobijanje maltera iste obradivosti – konzistencije. To povećanje

## 2 PRELIMINARY TESTS FOR THE SELECTION OF THE TYPES AND QUANTITY OF ADDITIVES

Tests were made using Portland cement (CEM I – 42,5R) whose composition was determined by chemical analysis and is shown in the following table:

Fly ash sample was dried and grinded to a fineness of 0.09 mm. Analysis determined the following chemical composition of the fly ash:

The low content of CaO in the fly ash could be one of the causes of its low hydraulic activity. As acknowledged, the hydration of the major components of fly ash (SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>) and the presence of sufficient amount of calcium hydroxide (Ca(OH)<sub>2</sub>) as a direct reagent is needed, as well as the compound that creates the alkaline environment necessary for the hydration process of present fly ash [2],[7]. Therefore, it was decided that one of the additives should be hydrated lime (Ca(OH)<sub>2</sub>) powder in quantities of 5 and 10%, and the mixture of 10% (Ca(OH)<sub>2</sub>) and 3% gypsum. These additives were selected as in most of the experiments and 30% of cement was substituted with grinded fly ash and through that reduced the amount of gypsum (for about 1%) in the experimental cements. Besides, gypsum in its composition has desirable calcium atoms, which may be calcium ions (Ca<sup>++</sup>) needed for the hydration processes of fly ash [10]. This way three types of experimental additives were chosen for the first experiments: 5% and 10% hydrated lime (Ca(OH)<sub>2</sub>) powder and a mixture of 10% Ca(OH)<sub>2</sub> and 3% gypsum.

Three additive mixtures were added to cement with and without 30% grinded fly ash replacement in these preliminary tests.

The reason this decision had been made was to see the effect of the three additives on the speed of hydration and the properties of the samples when cement contains less hydraulic additives.

Sample prisms (4x4x16 cm) were made of two cement, quartz sand and water in the usual way then adding the three types of additives. In the control samples (without additives), the water/cement ratio v/c=0.50 was used. However, the production of experimental mortars with additives was possible only with an additional water to obtain the same workability of mortars. The increase in water/cement ratio is indicated in Table 3. If the ingredients (hydrated lime and gypsum) are also regarded as binders, the overall water/binder

vodocementnog faktora naznačeno je u tabeli 3. Ukoliko se dodaci (hidratirani kreč i gips) posmatraju takođe kao veziva, ukupni vodovezivni faktor u mešavinama ostaje 0,5.

Ogledne prizme negovane su u vodi 21 dan, a zatim su držane u atmosferi laboratorije radi delimičnog sušenja pre merenja čvrstoće. Ovakav tretman izabrali smo kako bismo stekli izvestan uvid i u uticaj oglednih dodataka na osobine delimično osušenog maltera (betona).

Brzina hidratacije oglednih maltera praćena je merenjem brzine prostiranja ultrazvuka u oglednim prizmama nakon sedam dana, 21 dan i 28 dana. Dobijeni rezultati tih merenja prikazani su na slici 1. Čvrstoće na pritisak merene su samo nakon 28 dana, a rezultati su prikazani u tabeli 3.

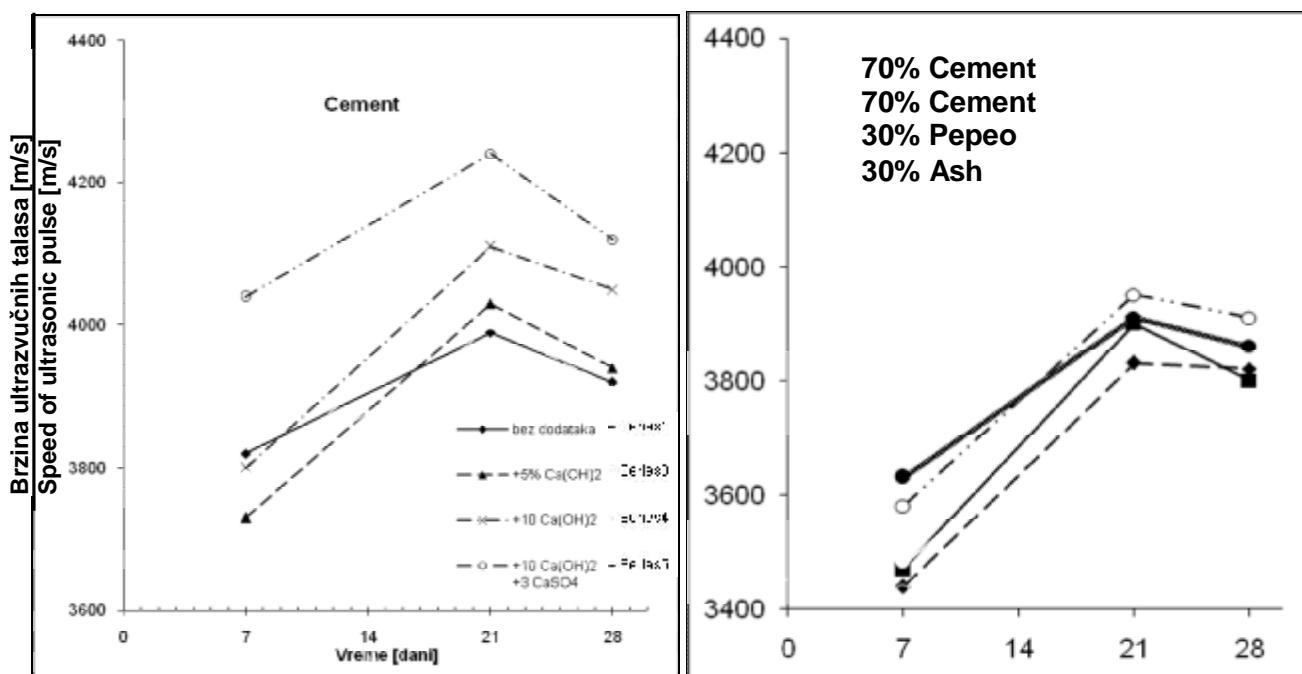
ratio in mixtures remains with the same value,  $v/(c+b)=0.50$ .

Sample specimens were cured in water for 21 days and were kept in laboratory atmosphere to partially dry before testing. This treatment was chosen to gain some insight into the effect of experimental additives on the properties of a partially dried mortar (concrete).

The speed of hydration for mortar samples were evaluated by measuring the speed of ultrasonic pulse propagation through experimental prisms after 7, 21 and 28 days. The results of these measurements are shown in Figure 1. Compressive strengths were measured only after 28 days and the results are shown in Table 3.

Tabela 3. Čvrstoće na pritisak nakon 28 dana  
Table 3. Compressive strengths of test prisms after 28 days

Dodaci [%] Additives[%]	v/c	Čvrstoća pri pritisku [MPa] Compress. Strength [MPa]	
		Cement Cement	70% Cement 70% Cement 30% Pepeo 30%Ash
Bez dodataka No Addit.	0.50	40.4	30.5
+5 Ca(OH) <sub>2</sub>	0.53	42.2	31.5
+10 Ca(OH) <sub>2</sub>	0.55	45.8	33.6
+10 Ca(OH) <sub>2</sub> +3 CaSO <sub>4</sub>	0.56	46.4	34.2



Slika 1. Brzine ultrazvučnih talasa  
Figure 1. Ultrasonic pulse speeds of test prisms

Kao što se moglo očekivati, dodavanjem kreča znatno je ubrzana hidratacija oba ispitivana cementa, zbog povećanja pH-vrednosti sredine i prisustva znatnih količina poželjnog reagensa  $\text{Ca}(\text{OH})_2$ . Naravno, to je slabije izraženo ako je dodato svega 5%  $\text{Ca}(\text{OH})_2$ .

Iz slike 1. jasno je da dodavanje 10% kreča sa i bez 3% gipsa ubrzava hidrataciju kod oba ogledna cementa u prvih 28 dana zbog povećanog pH.

U tabeli 3. jasno se vidi da su uzorci sa oglednim dodacima, u oba ogledna cementa, nakon 28 dana imali povećane čvrstoće u poređenju s kontrolnim uzorcima.

Sušenje između 21. i 28. dana, naravno, imalo je za posledicu osetni pad brzine ultrazvuka, jer je voda u porama bila zamenjena vazduhom, ali odnosi između pojedinih uzoraka ostali su približno isti.

U tabeli 3. uočljivo je da je logično to što su uzorci s bržom hidratacijom imali i nešto veće čvrstoće na pritisak nakon 28 dana.

Na osnovu prvih, orijentacionih oglada, odlučeno je da će se za glavne ogledne (do tri godine) koristiti dodaci koji su dali najbolje rezultate, a to su: 10%  $\text{Ca}(\text{OH})_2$  i 10%  $\text{Ca}(\text{OH})_2$  + 3% gipsa.

Međutim, za praksu je važnije kako će neki dodatak uticati na konačnu osobinu očvrstlog betona. Stoga smo, u glavnom ogledu, ogledne prizme držali tri godine u sredinama u kojima se nalazi većina betonskih konstrukcija: u sobnim uslovima, u vanjskoj atmosferi, gde su bili izloženi dejstvu sunca, povremenim padavinama i vrlo promenljivim temperaturama tokom godine.

### 3 ISPITIVANJE UTICAJA ODABRANIH DODATAKA NA OSOBINE OGLEDNIH UZORAKA, DRŽANIH TRI GODINE U RAZLIČITIM USLOVIMA

Ogledne prizme za ove ogledne pripremane su na već opisan način, a nakon negovanja tokom 28 dana u vodi, te merenja njihove čvrstoće, držane su tri godine u sledećim uslovima: u sobnoj atmosferi (temperature 20-25°C) i u vanjskoj atmosferi, izložene delovanju sunca, atmosferskim padavinama i promenljivim temperaturama.

Ogledne prizme u ovom ogledu izrađene na već opisan način, s vezivom koje se sastojalo od 70% cementa (isti cement CEM I 42,5R) i 30% mlevenog letećeg pepela, a kao dodaci koristili su se 10%  $\text{Ca}(\text{OH})_2$  ili 10%  $\text{Ca}(\text{OH})_2$  + 3% gipsa, dok su kontrolni uzorci bili izrađeni od mešavine bez dodataka.

Nakon tri godine, na svim oglednim prizmama ispitivana je čvrstoća pri pritisku, a rezultati su prikazani na slici 2.

Na osnovu rezultata merenja čvrstoće na pritisak (slika 2), vrlo je očito da su nakon tri godine u obe ogledne sredine uzorci sa oba ogledna dodatka imali uočljivo veće čvrstoće od kontrolnih uzoraka bez dodataka. Te razlike su izračunate i u postocima iznose između 25% i 30%, što svakako ukazuje na značajan doprinos čvrstoći tih dodataka.

Pošto se u uzorcima oglednih prizmi s dodatkom 10%  $\text{Ca}(\text{OH})_2$  + 3% gipsa nalazilo za oko 2% više gipsa nego što je našim propisima dozvoljeno, te zbog opasnosti od eventualne sulfatne korozije betona, sve tri vrste oglednih prizmi dodatno su držane godinu dana u rastvoru sulfata (4,5%  $\text{MgSO}_4$  + 2,5%  $\text{Na}_2\text{SO}_4$ ), da bi se proverilo da li će se usled pojave korozije smanjiti čvrstoća. Međutim, merenjem čvrstoće na pritisak nakon

As expected in the addition of lime, hydration in both tested cement were significantly accelerated due to the increased pH value of the environment and the presence of important amounts of desirable reagent  $\text{Ca}(\text{OH})_2$ . Naturally the increase is less with only 5%  $\text{Ca}(\text{OH})_2$  added.

According to Figure 1. it is evident that the addition of 10% lime, with or without 3% gypsum accelerates the hydration of cement in both experimental mixtures (with and without fly ash replacement) in the first 28 days, due to increased pH-value.

Table 3. clearly shows that samples with experimental additives, in both experimental mixtures after 28 days had increased strength in comparison with control samples.

Drying between the 21st and 28th day led to a decline of considerable velocity of ultrasonic pulse, as the water in the pores were replaced by air, but even so, relations have remained approximately the same between different specimens.

From Table 3, it is obvious and coherent that the samples with faster hydration had a slightly higher compressive strength after 28 days.

On the basis of these preliminary experiments it was determined which additives gave the best results, and it is as follows: 10 %  $\text{Ca}(\text{OH})_2$  and 10 %  $\text{Ca}(\text{OH})_2$  + 3 % of gypsum.

For practical use, on the other hand, it is more important how some additives affect the final characteristics of the hardened concrete. Consequently, in the main experiment, the specimens were held three years in environments where most concrete structures exist: indoors and outdoors ambient conditions, where they were exposed to sunlight, occasional rainfall and highly variable temperatures during the year.

### 3 EXPERIMENTAL ANALYSIS RESULTS OF SAMPLES KEPT 3 YEARS IN VARIOUS ENVIRONMENTS

Sample prisms for these experiments were prepared in the described manner, curing for 28 days in water then measuring their compressive strength and after that were held 3 years in the following conditions: indoor environment (temperature 20-25°C) and outdoor ambient exposed to sunlight, atmospheric rainfall and varying temperatures.

Specimens in this experiment were made from 70% of the same type of cement (CEM I – 42,5R) and 30% of dried, grinded fly ash as it was used in the first experiment and additives such as 10%  $\text{Ca}(\text{OH})_2$  or 10%  $\text{Ca}(\text{OH})_2$  + 3% gypsum were used, while control samples were prepared from mixture without additives.

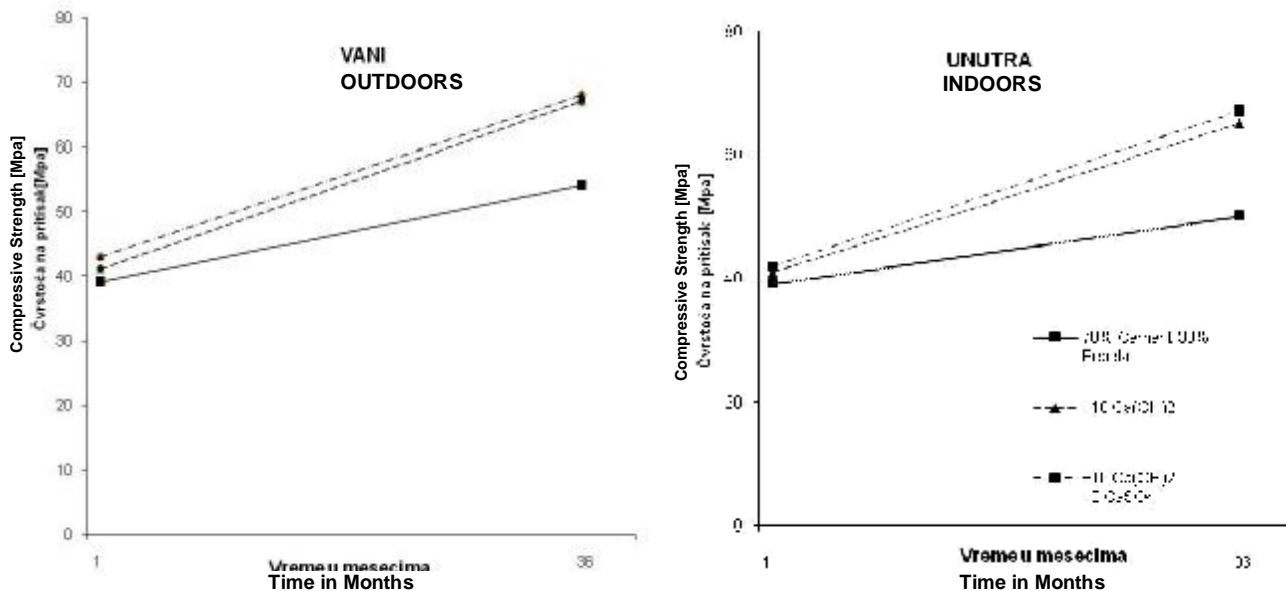
After 3 years on all types of testing prisms, compressive strength were measured and the results are shown in Figure 2.

The results of compressive strength (Fig. 2) are evident under both environmental conditions. Experimental samples with both experimental additives, after 3 years, had noticeably higher strength than the control samples without additives. These differences in percentages are between 25 and 30%. Of course, it is very satisfying to have such good results.

All three types of experimental specimens were additionally held 1 year in sulphate solution (4.5%

godinu dana, utvrdili smo da nije bilo pada, nego čak blagog povećanja čvrstoće u uzorcima s dodatkom 10% kreča i 3% gipsa. Stoga smo konstatovali da nema opasnosti od sulfatne korozije ako se cementu s visokim sadržajem letećeg pepela doda nešto više gipsa od propisanog.

MgSO<sub>4</sub> + 2.5% Na<sub>2</sub>SO<sub>4</sub>) to check how corrosion decreases the strength, for the reason that the experimental samples with the addition of 10% Ca(OH)<sub>2</sub> + 3% gypsum contained about 2% more gypsum than allowed under current standards due to risk of possible sulphate corrosion of concrete. But one year later, instead of the decrease in compressive strength, a slight increase was measured in samples prepared with addition of 10% Ca(OH)<sub>2</sub> + 3% gypsum. Therefore, it was concluded that there is no risk in sulphate-corrosion if the cement with high content of fly ash contains a bit more gypsum than prescribed.



Slika 2. Čvrstoće pri pritisku  
Figure 2. Compressive strengths of test prisms

Pored merenja čvrstoće na pritisak, merena je i debljina karbonatizovanog sloja, pomoću rastvora fenolftaleina, a rezultati su prikazani u tabeli 4.

In addition to measuring the compressive strength, the thickness of the carbonated layer was determined using phenolphthalein solution and the results are shown in Table 4.

Tabela 4. Debljine karbonatizovanog sloja nakon tri godine  
Table 4. Depth of carbonated layer of test prisms after 3 years

Vrste veziva [%] Additives [%]	Debljina karbonatizovanog sloja Carbonat. Layers [mm]	
	Vani Outdoors	U sobi Indoors
Bez dodatka No Addit.	8.4	14.6
+10 Ca(OH) <sub>2</sub>	6.0	11.7
+10 Ca(OH) <sub>2</sub> +3 CaSO <sub>4</sub>	8.9	14.8

Kao što se moglo i očekivati, povećane količine Ca(OH)<sub>2</sub> u oglednim uzorcima usporile su karbonatizaciju u uzorcima s dodatkom 10 % Ca(OH)<sub>2</sub>. Međutim, iz prikazanih rezultata se jasno vidi da su

As expected, increased amounts of Ca(OH)<sub>2</sub> in the experimental samples had naturally slowed down the carbonation in samples with 10% additives of Ca(OH)<sub>2</sub>. However, the presented results clearly showed that the

uzorci s dodatkom 10% kreča i 3% gipsa imali u obe sredine nešto povećanu karbonatizaciju, iako su imali čak povećanu čvrstoću nakon tri godine. To znači da su, u celini uzevši, najbolji rezultati postignuti sa ogleđnim uzorcima sa 10% kreča, bez dodatka 3% gipsa. Brža karbonatizacija kod uzoraka držanih u sobnim uslovima logična je posledica toga što su njihove pore sve vreme bile skoro suve, što je omogućavalo brže prodiranje CO<sub>2</sub> iz vazduha i bržu karbonatizaciju.

#### 4 ZAKLJUČAK

Osnovni cilj ovih istraživanja bio je da se ispita mogućnost da se u izvesnim dodacima cementu s visokim sadržajem domaćeg letećeg pepela ubrza i intenzivira hidratacija, da bi se povećala upotreba letećeg pepela naših termoelektrana u proizvodnji cementa dobrog kvaliteta.

Prethodnim ogleđima utvrđeno je da se najbolji rezultati postižu dodavanjem 10% hidratisanog kreča Ca(OH)<sub>2</sub> u prahu s dodatkom ili bez dodatka 3% gipsa.

Ogledne prizme od maltera izrađene su od komercijalnog cementa, u kome je 30% bilo zamenjeno mlevenim letećim pepelom, držane su tri godine u sobnoj i vanjskoj atmosferi, a zatim je merenjem čvrstoće ogleđnih prizmi utvrđeno da su u obe ogleđne sredine uzorci s navedenim dodacima imali osetno veće čvrstoće od kontrolnih uzoraka. Sem toga, utvrđeno je da je karbonatizacija bila vidno sporija u uzorcima s dodatkom 10% hidratisanog kreča (Ca(OH)<sub>2</sub>) u prahu, ali bez dodatka 3% gipsa. Tako da su najbolji rezultati dobijeni ako je cementu s dodatkom 30% letećeg pepela, dodato 10% hidratisanog kreča (Ca(OH)<sub>2</sub>) u prahu. Smatramo da su ovi rezultati ohrabrujući, ali nedovoljni za primenu u praksi. Stoga se predlažu dalja istraživanja u koja bi trebalo da budu uključeni i stručnjaci koji se bave proizvodnjom cementa i betona, kao i laboratorije opremljene za svestranija i sveobuhvatnija ispitivanja.

#### 5 LITERATURA REFERENCES

- [1] Cmiljanić S., Vujanić V., Jotić S., Rosić B., Tošović S., Mitrović P.: Prethodni rezultati IRP: „Primena elektrofiltarskog pepela u putogradnji”, Simpozijum o istraživanjima i primeni savremenih dostignuća u našem građevinarstvu u oblasti materijala i konstrukcija – Zbornik radova, 2008, 3-12
- [2] Fraay A.L.A., J.M. Bijen, Y.M: de Haan: The reaction of fly ash in concrete, *Cement and concrete res.*, 19,2,235-246
- [3] Marinković S., Kostić-Pulek A.: Examination of the system fly ash–lime–calcined gypsum–water, *Journal of Physics and Chemistry of Solids*, 2007, 68, 1121–1125
- [4] Marsh B.K., R.L. Day: Puzzolanic and cementitious reactions of fly ash in blended cement pastes, *Cement and concrete res.*, 18,2,301-310
- [5] Ravina D., P.K. Mehta: Compressive strength low cement/high fly ash concrete, *Cement and concrete res.*, 18, 571-583

samples with the addition of 10% hydrated lime powder and 3% gypsum, in both areas, had a slightly increased carbonation, even though, they had increased strength after 3 years. Considered in general, the best performance was achieved by experimental samples with 10% lime, without the addition of 3% gypsum. Faster carbonation in those kept inside is a logical consequence of the fact that their pores were all the time almost dry, which allowed faster penetration of CO<sub>2</sub> from the air and rapid carbonation.

#### 4 CONCLUSION

The main objective of this study is to explore the possibility of acceleration and intensify the hydration of cements with high content of flying ash with some additives in order to maximize the use of fly ash from local power plants in the production of good quality cement.

By preliminary experiments the best results were achieved by adding 10% Ca(OH)<sub>2</sub> hydrated lime powder with or without the additional of 3% gypsum.

The experimental specimens made with commercial cement in which 30% were replaced by minced fly ash, were kept 3 years in an inside and outside atmosphere. Afterwards, the strength of experimental prisms was measured and found in both environments that specimens with the aforementioned additives have considerably higher strength than control samples. Moreover, it was determined that the carbonation would be considerably slower in mixtures with 10% (Ca(OH)<sub>2</sub>) and without 3% gypsum. The best results were received in mixtures of cement with 30% fly ash with addition of 10% hydrated lime (Ca(OH)<sub>2</sub>) powder. It is believed that these results are encouraging, but insufficient for practical application. Therefore, it is a good proposal to continue the research and include experts engaged in the production of cement and concrete, as well as laboratories equipped for versatile and comprehensive tests.

- [6] Rosić B. Rosić A.: „Vreme i mehaničke čvrstoće letećeg pepela sa malim dodacima kreča ili cementa”, Simpozijum o istraživanjima i primeni savremenih dostignuća u našem građevinarstvu u oblasti materijala i konstrukcija – Zbornik radova, 2008, 43-47
- [7] Skenderovic B.: „Građevinski materijali sa osnovama građevinske hemije”, Građevinski fakultet, Subotica, 1983
- [8] Skenderovic B. Kekanović M.: „Građevinski materijali – hemija, struktura, tehnologija i korozija”, Građevinski fakultet, Subotica, 2011, 31-59
- [9] Wesche K.: Fly Ash in Concrete Properties and Performance, RILEM Report 7, Chapman & Hall, London, 1991, 173-180
- [10] Xu Aimin, Shondeep L. Sarkar: Microstructural study of gypsum activated fly ash hydration in cement paste, *Cement and Concrete Research*, Volume 21, Issue 6, November 1991, Pages 1137-1147

## REZIME

### ISPITIVANJE MOGUĆNOSTI POBOLJŠANJA HIDRAULIČNE AKTIVNOSTI DOMAĆEG LETEĆEG PEPELA

*Bartul SKENDEROVIĆ  
Arpad ČEH*

Leteći pepeo iz domaćih termoelektrana nedovoljno se koristi u proizvodnji cementa, što predstavlja veliku ekonomsku štetu, ali i ozbiljan ekološki problem. Cilj ovih istraživanja bio je da se ispita mogućnost povećanja hidraulične aktivnosti tog pepela, upotrebom nekih jeftinih domaćih dodataka.

U prethodnim istraživanjima utvrđeno je da su za to najpovoljniji dodaci od 10% hidratisanog kreča  $\text{Ca(OH)}_2$  u prahu, s dodatkom ili bez dodatka 3% gipsa.

U glavnom ogledu, ogledne prizme od maltera izrađene su od komercijalnog cementa (CEM I – 42,5R), u kome je 30% bilo zamenjeno mlevenim letećim pepelom domaće termoelektrane, s dodacima ili bez odabranih dodataka. Nakon nege od 28 dana u vodi, prizme su držane tri godine u sobnoj (ustaljenoj) i vanjskoj atmosferi, izložene suncu, padavinama i čestim promenama temperature. Nakon tri godine, merene su pritisne čvrstoće i debljine karbonatizacije sloja prizmi.

Na osnovu prikazanih rezultata, očito je da uzorci s dodatkom odabranih aditiva imaju vidno veće čvrstoće na pritisak i tanji karbonatizovani sloj nego kontrolni uzorci bez ovih dodataka.

**Ključne reči:** hidraulična aktivnost, kreč, leteći pepeo, osobine cementnog kamena

## SUMMARY

### POSSIBLE IMPROVEMENTS OF HYDRAULIC ACTIVITIES OF FLY ASH PRODUCED IN SERBIA

*Bartul SKENDEROVIĆ  
Arpad ČEH*

Fly ashes from local power plants are insufficiently used in production of cement, which means major economic damage and serious environmental problem. The research aimed to investigate the possibility of increasing hydraulic activity of fly ash using some inexpensive local additives.

In previous studies it was confirmed that the best results were achieved by using 10% of hydrated lime  $\text{Ca(OH)}_2$  powder with or without an addition of 3% gypsum.

In the main experiment, mortar prism samples were made with commercial cement (CEM I – 42,5) in which 30% was replaced with fly ash from local power plants with or without selected additives. After 28 days of curing in the water, prisms were kept inside and outside, exposed to sunlight, rain and frequent temperature changes. Compressive strength and carbonation layer of samples were measured 3 years later.

According to the obtained results it is obvious that the samples with the addition of selected additives had noticeably higher compressive strength and a thinner layer of carbonation, than control samples without these additives.

**Keywords:** hydraulic activity, hydrated lime, fly ash, properties of hardened cement paste





# METODE NUMERIČKOG MODELIRANJA I SANACIJE NESTABILNE PADINE U IZMENJENOJ SERPENTINSKOJ STENSKOJ MASI

## NUMERICAL MODELING AND SLOPE REPARATION METHODS IN AN ALTERED AND UNSTABLE SERPENTINE ROCK MASS

Mirza MEMIĆ  
Radomir FOLIĆ  
Adnan IBRAHIMOVIĆ

ORIGINALNI NAUČNI RAD  
ORIGINAL SCIENTIFIC PAPER  
UDK: 624.071.23 = 861

### 1 UVODNE NAPOMENE

U inženjerskoj praksi se vrlo često javlja problem rešavanja sanacije stenskih padina kod kojih je izražena pojava površinske dezintegracije. U tim slučajevima, neophodno je preduzimanje mera za smanjenje ili otklanjanje uticaja onih dejstava koji vode daljnjoj dezintegraciji stene i sprečavanju pokreta potencijalno nestabilnih delova. Pri tome se, vodeći računa o ekonomskim aspektima sanacije, nastoji da se uz što manje zahvate ojača i poveže ispucala stena, kako bi se povećala monolitnost na kritičnim delovima i uspostavila narušena stabilnost.

Padine su obično obrasle rastinjem koje svojim korenjem zalazi u postojeće pukotine, što omogućava dublje prodiranje vode i njeno progresivno neželjeno dejstvo, naročito u zimskom periodu nakon smrzavanja i otapanja. Dejstvo atmosferilija izaziva hemijsku dekompoziciju i fizičku dezintegraciju stenske mase. Na taj način, najčešće se stvaraju uslovi za intenzivnijom i bržom promenom površinskih slojeva stene na padini.

Iznalaženju adekvatnog rešenja sanacije predhodi inženjersko-geološko kartiranje stenske padine, lociranje najznačajnijih familija diskontinuiteta koji su vidljivi na površini padine te definisanje stabilnih, uslovno stabilnih i nestabilnih zona stenske mase. Na osnovu toga formiraju se zone jednakih svojstava sa gledišta stabilnosti čije se saniranje može izvesti istim tehničkim merama.

---

Mirza Memić, "Cubus" d.o.o.Lukavac, BiH  
[e-mail:mirza.memic@bih.net.ba](mailto:mirza.memic@bih.net.ba)  
Prof. dr Radomir Folić, Univerzitet u Novom Sadu,  
Fakultet tehničkih nauka, Srbija, [e-mail:folic@uns.ac.rs](mailto:folic@uns.ac.rs)  
Adnan Ibrahimović, Univerzitet u Tuzli, RGGF, BiH  
[e-mail:adnan.ibrahimovic@untz.ba](mailto:adnan.ibrahimovic@untz.ba)

### 1 INTRODUCTION

The problem of repairing rock slopes with highly pronounced surface disintegration is very common in engineering practice. In these cases, it is necessary to undertake measures for reducing or eliminating the impacts of actions that lead to further rock disintegration and preventing potentially unstable moving areas. In doing so, the goal is to strengthen and interconnect the cracked rocks with as few interventions as possible and taking into account the economic aspects of reparation, in order to increase monolithicity in critical parts and establish the disturbed stability.

Slopes are usually covered with vegetation that is rooted into existing cracks, allowing water to penetrate deeper and progressively exercise its unwanted impact, especially in winter conditions after freezing and thawing. Atmospheric precipitations are leading to the chemical decomposition and physical disintegration of the rock mass. In this way, conditions are often created for a more intense and rapid alteration in surface rock layers of the slope.

Finding adequate repairing solutions requires preceding engineering-geological rock slope mapping, determining the location of major set of discontinuities that are visible on the slope surface and defining the stable, conditionally stable and unstable zones of the rock mass. This is the basis on which zones of equal

---

Mirza Memić, "Cubus"d.o.o.Lukavac, B and H  
[e-mail:mirza.memic@bih.net.ba](mailto:mirza.memic@bih.net.ba)  
Prof. dr Radomir Folić, University of Novi Sad, Faculty of  
Technical Scinces, Serbia [e-mail:folic@uns.ac.rs](mailto:folic@uns.ac.rs)  
Adnan Ibrahimović, University of Tuzla, Faculty of MGCV, B  
and H, [e-mail:adnan.ibrahimovic@untz.ba](mailto:adnan.ibrahimovic@untz.ba)

U radu predložen je model projektovanja i izvođenja radova na sanaciji stenskih, serpentinških, padina kod kojih je izražena pojava izmenjenosti površinskih slojeva, relativno tankih, uz određena ograničenja primene. Za jednu reprezentativnu padinu, sprovedena je predložena metodologija koja obuhvata inženjersko-geološku klasifikaciju sa procenom parametara čvrstoće i modula deformacije stenske mase na osnovu Hoek-Brownov kriterija loma. Detaljno je opisan numerički model za analizu stabilnosti, u kome su opisani ulazni parametri za analizu stabilnosti i uslovi loma, te utvrđeni bitni pokazatelji ponašanja stenske mase i padine za postojeće stanje i svaku fazu predviđenih radova. Rezultati su analizirani sa aspekta koeficijenta sigurnosti, uz formulisane odgovarajućih zaključaka i preporuka za primenu i ograničenja predloženog modela. Predloženi model može poslužiti kao primer za rešavanje sličnih slučajeva u praksi.

## 2 KLASIFIKACIJA I ODREĐIVANJE PARAMETARA ČVRSTOĆE I DEFORMABILNOSTI STENSKE MASE

Pri rešavanju problema stabilnosti padina, temeljnija objekata i izvođenja podzemnih građevina u stenskoj masi, osnovni problem pri analizama i projektovanju predstavlja procena čvrstoće i deformabilnosti stene. Naime, čvrstoća i modul deformacije stenske mase jesu osnovni i potrebni parametri za numeričku analizu stabilnosti i prognozu deformacija geotehničkih konstrukcija. Stena je najčešće diskontinualna, heterogena i anizotropna sredina. Zbog toga, laboratorijska ispitivanja na uzorcima jezgra i terenska ispitivanja ne reprezentiraju ponašanje stenske mase većeg volumena. Kao takve, ne omogućuju dobijanje reprezentativnih deformacijskih parametara za proračun. Reprezentativna ispitivanja čvrstoće i deformabilnosti stenske mase probnim opterećenjima retko su praktično ili ekonomski moguća [2].

Određivanje strukturnih sistema diskontinuiteta uobičajeno se sprovodi inženjersko-geološkim kartiranjem, kao površinsko kartiranje i kartiranje otvorenih profila. Podaci dobijeni determinacijom jezgra istražnih bušotina omogućuju bolje razumevanje i pozicioniranje slabijih zona stenske mase dublje u stenskoj masi, a koje površinskim kartiranjem nije moguće sprovesti (slika 1).

properties are being formed from the viewpoint of stability the reparation of which can be performed by applying the same technical measures.

In this paper, the authors have proposed a model for designing and performing the reparation works on serpentine rocky slopes where the phenomenon of alteration of the relatively thin surface layers is highly expressed, with certain restrictions in its application. The proposed methodology is implemented for a single representative slope, including the engineering-geological classification, along with the estimation of parameters of strength and modulus of deformation of the rock mass based on the Hoek-Brown failure criterion. A numerical model for stability analysis has been described in details, describing the input parameters for stability analysis as well as the failure conditions, and identifying the relevant indicators of the rock mass and slope behaviour in the current state and for the each phase of the planned works. The results were analyzed in terms of the safety coefficients, along with formulating the adequate conclusions and recommendations for the application of the proposed model and its limitations. The proposed model can serve as a model of resolving similar cases in practice.

## 2 CLASSIFICATION AND IDENTIFICATION OF PARAMETERS OF THE ROCK MASS STRENGTH AND DEFORMABILITY

In solving the problems of slope stability, structure founding and constructing underground structures in the rock mass the basic analysis and design-related problem is assessing the rock strength and deformability. Namely, the strength and the modulus of deformation of the rock mass are the basic and required parameters for performing numerical stability analysis and predicting the deformations of geotechnical structures. The rock is usually a discontinuous, heterogeneous and anisotropic environment. Therefore, laboratory tests on core samples and field tests do not represent the behaviour of a rock mass of greater volume. As such, they do not allow obtaining representative deformation parameters for calculation. Representative strength and deformability investigations of the rock mass by using test loads are seldom practical or economically feasible [2].

Structural systems of discontinuity systems are usually identified based on engineering-geological mapping, in the form of surface mapping and open sections



Slika 1. Geotehnički istražni radovi  
Figure 1. Geotechnical explorations

Inženjersko-geološkom rekognosacijom padine i okolnog terena i istražnim radovima, klasifikuje se stenska masa čime se omogućava određivanje parametara čvrstoće i deformabilnosti stenske mase. Na osnovu toga, definiše se geotehnički model potreban za analizu stabilnosti stenske padine. Stabilnost se analizira u zavisnosti od mogućeg mehanizma loma, jednom od odgovarajućih metoda, pri čemu je stabilnost padine determinisana kvantitativno preko faktora sigurnosti. Najčešće se za analizu stabilnosti padina koristi metoda granične ravnoteže, koja je dostupna u većini komercijalnih programskih paketa.

Ukupna smičuća čvrstoća stenske mase jeste funkcija čvrstoće diskontinuiteta i čvrstoće ispune u stenskoj masi, koji razdvajaju diskontinuitete. U analizama čvrstoća stenske mase i čvrstoće ispune diskontinuiteta, presudnu ulogu ima veličina normalnih naprezanja na ravan loma, odnosno na ravan diskontinuiteta.

Modul deformabilnosti stenske mase neophodan je parametar za sve numeričke analize u stenskoj masi. Deformabilnost stenske mase zavisi od stepena ispućalosti stenske mase i stišljivosti materijala ispune u pukotinama. Jače raspucala stenska masa ima znatno veću deformabilnost od intaktne stene. Osim toga, ispitivanje deformabilnosti stenske mase u većim razmerama je skupo i previše složeno za praktičnu upotrebu. Zbog navedenih razloga, danas se uglavnom koriste empirijske metode u kojima se deformabilnost stenske mase određuje na osnovu njene klasifikacije [1].

Prilikom projektovanja kosine, temelja i objekata u i na stijeni uvek se traži pouzdana procena čvrstoće stenskog materijala i njegovih deformacionih karakteristika. Prema [15] Hoek i Brown (1980) predložili su metod za procenu čvrstoće ispućale stenske mase. Njihov metod baziran je na međusobnom uklinjanju (blokiranju) stenskih blokova i stanju površina između ovih blokova. S obzirom na različite probleme koji su pratili ovaj metod, došlo je do izvesnih modifikacija odnosno prilagođavanja kriterijuma trenutnim uslovima, koji nisu bili razmatrani u trenutku nastanka tog kriterijuma (Hoek i Brown, 1988). Takođe, primena za stene slabog kvaliteta prouzrokovala je dalje modifikacije (Hoek, Wood i Shah, 1992), ali i razvoj nove klasifikacije koja je nazvana Geološki indeks čvrstoće (Geological Strength Index – GSI), [15].

U današnjoj praksi, u te svrhe najčešće se koristi Hoek–Brown-ova klasifikacija i kriterijum loma stenske mase, [7] i [8], gde su povezani parametri čvrstoće s glavnim naponima pri lomu, a deformabilnost, kako su predložili Hoek, E.; Carranza-Torres, Corkum, B. [14]:

mapping. Data obtained by identifying the core of exploration wells allow the weaker areas of the rock mass to be better understood and positioned deeper in the rock mass; these data cannot be obtained by surface mapping (Figure 1).

The rock mass is classified based on the engineering-geological reconnaissance of the slope and the surrounding terrain and the exploration activities, enabling the determination of its parameters of strength and deformability, as well as the identification of the geotechnical model required for the analysis of the rock slope stability. Stability is analyzed depending on the possible failure mechanism by using one of the appropriate methods, while the slope stability is determined quantitatively through the safety factor. The most common method for analyzing the slope stability is the limit equilibrium method, which is available in most commercial software packages.

The overall shear strength of the rock mass is defined by the strength of discontinuity and the strength of the fillings in the rock mass that separate the discontinuities. In analyzing the strength of the rock mass and the strength of the discontinuity filling the role of magnitude of stresses normal to the failure plane, i.e. the discontinuity plane is vital.

The modulus of the rock mass deformation is a parameter required for all numerical analyses of rock mass. The rock mass deformability depends on the degree to which the rock mass is cracked and the compressibility of the filling material in cracks. The deformability of a strongly cracked rock mass is considerably higher than that of the intact rock. In addition, performing larger scale inspections of rock mass deformability is expensive and too complicated for practical use. Therefore, nowadays mainly empirical methods are used in which the rock mass deformability is determined based on its classification [1].

What is always required when designing slopes, foundations and structures in and on rock is providing a reliable estimation regarding the strength of the rock material and its deformation properties. According to [15], Hoek and Brown (1980) have proposed a method for estimating the strength of cracked rock mass. Their method is based on the mutual interlocking (blocking) of rock blocks and condition of the surfaces between these blocks. Given the various problems for which the method has been used, the criterion has been somewhat altered or adjusted to the current conditions, which were not considered at the time when the criterion was conceived (Hoek and Brown, 1988). The use of the criterion for poor quality rocks has also led to further alterations (Hoek, Wood and Shah, 1992), as well as the development of a new classification method – Geological Strength Index (GSI) [15].

The most often used criterion in today's practice is the Hoek-Brown rock mass classification and failure criterion, [7] and [8], in which the strength parameters are associated with the principal stresses at failure, while deformability is as suggested by Hoek, E. Carranza-Torres, Corkum, B. [14]:

$$s_1' = s_3 + s_c \left( m_b \frac{s_3'}{s_c} + s \right)^a \quad (1)$$

gde su:

$m_b, s$  i  $a$  – parametri čvrstoće koji zavise od karakteristika stenske mase,

$\sigma_c$  - jednoosna čvrstoća na pritisak intaktne stene,

$\sigma_1$  - veći glavni napon pri lomu,

$\sigma_3$  - manji glavni napon pri lomu.

Parametri čvrstoće i procena modula deformacije  $E_m$  se određuju iz izraza:

$$m_b = m_i \cdot e^{\frac{GSI-100}{28-14D}}; \quad s = e^{\frac{GSI-100}{9-3D}}; \quad a = \frac{1}{2} + \frac{1}{6} \left( e^{\frac{-GSI}{15}} - e^{\frac{-20}{3}} \right); \quad E_m = \left( 1 - \frac{D}{2} \right) \sqrt{\frac{s_c}{100}} \cdot 10^{\frac{GSI-10}{40}} \quad (2)$$

Kriterijum je primenjiv i u intaktnoj steni i u znatno raspucalim stenskim masama, a za obe sredine se može usvojiti da se ponašaju homogeno i izotropno (slika 2).

$sigci$  - čvrstoća na pritisak intaktne stenske mase,

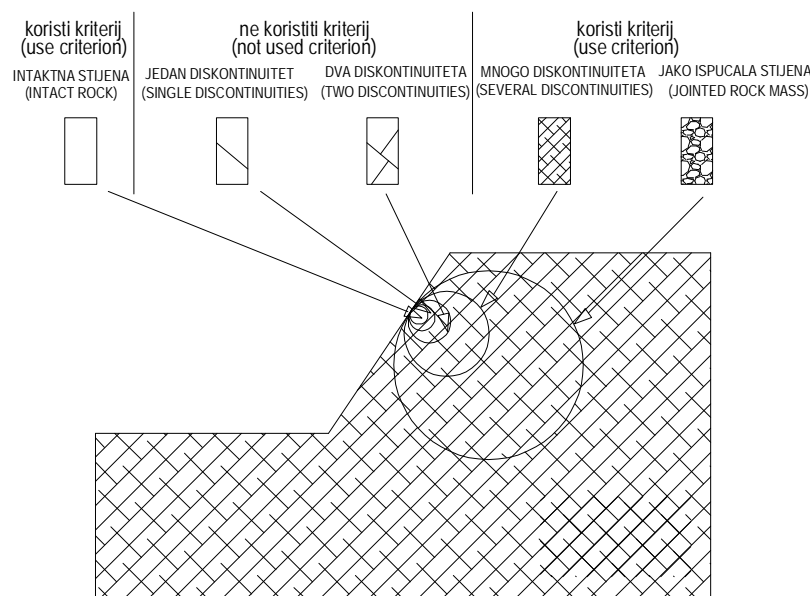
$GSI$  - geološki indeks čvrstoće stenske mase,

$m_i$  - vrednost koja se određuje iz troosnih opita na uzorcima stene pri različitim naprezanjima ili se procenjuje prema vrsti stene,

$D$  - faktor poremećenosti stenske mase, varira od nula za

neporemećenu do jedan za vrlo poremećenu stensku masu. (Tabela 2.1),

$E_i$  - modul deformacije intaktne stenske mase, (slika 3), [10].



Slika 2. Uslovi stenske mase pri kojima se može koristiti Hoek–Brownov kriterijum čvrstoće stenske mase [10]

Figure 2. Applicability of the Hoek-Brown failure criterion for slope stability problems

Prilikom numeričkog modeliranja u mehanici stena, osnovni problem predstavlja određivanje ulaznih parametara stenske mase. Na osnovu opšteg Hoek-Brown kriterijuma loma, razvijen je softverski program „RocLab“ koji na vrlo jednostavan način omogućuje dobijanje pouzdane procene svojstava stenske mase, kako za postojane tako i za vrlo slabe stenske mase. Pri tome se

where:

$m_b, s$  and  $a$  - strength parameters which depend on the rock mass properties,

$\sigma_c$  - uniaxial compressive strength of the intact rock,

$\sigma_1$  - maximal stress at failure,

$\sigma_3$  - minimal principal stress at failure.

Strength parameters and the estimated deformation  $E_m$  are determined from the following expression:

The criterion is applicable both for the intact rock and the considerably cracked rock masses significantly; both environments can be adopted as behaving homogeneously and isotropically (Figure 2).

$sigci$  - compressive strength of the intact rock mass,

$GSI$  - Geological Strength Index of the rock mass,

$m_i$  - this value is determined based on triaxial tests performed on rock samples at various stresses or it can be estimated based on the type of rock,

$D$  - disturbance factor of the rock mass, varying between zero (for undisturbed rock) and one (for highly disturbed rock mass). (Table 2.1),

$E_i$  - modulus of deformation of intact rock mass (Figure 3), [10].





Slika 3. Hoek-Brown Klasifikacija („RocLab“)

Figure 3. Hoek-Brown Classification („RocLab“)

The basic problem in numerical modelling in rock mechanics is to determine the input parameters of rock mass. Based on the general Hoek-Brown failure criterion, a software program called "RocLab" has been developed. In a very straightforward manner, this software allows obtaining reliable estimates regarding the rock mass properties, both for strong and very weak rock

Tabela 2.1. Smernice za određivanje faktora poremećenosti D  
Table 2.1. Guidelines for estimating disturbance factor D

	<p>Miniranje manjih razmera na padinama rezultira umerenim oštećenjem stenske mase, osobito ako se kontrolisano miniranje primenjuje na steni koja je prikazana na lijevoj strani slike. Međutim, relaksacija naprezanja rezultira poremećenjem. Small scale blasting in civil engineering slopes results in modest rock mass damage, particularly if controlled blasting is used as shown on the left hand side of the photograph. However, stress relief results in some disturbance.</p>	<p>D = 0,7 Dobro miniranje Good blasting</p> <p>D = 1,0 Loše miniranje Poor blasting</p>
	<p>Vrlo veliki otvoreni dnevni kopovi trpe znatno poremećenje zbog teškog proizvodnog miniranja i zbog relaksacije napona koje je posledica iskopa. U nekim mekšim stenama iskop se može vršiti mašinski, te je stepen oštećenja padine manji. Very large open pit mine slopes suffer significant disturbance due to heavy production blasting and also due to stress relief from overburden removal. In some softer rocks excavation can be carried out by ripping and dozing and the degree of damage to the slopes is less.</p>	<p>D=1.0 Proizvodno miniranje Production blasting</p> <p>D=0.7 Mašinski iskop Mechanical excavation</p>

izračunavaju ekvivalentni Mohr-Coulomb parametri kohezija ( $c$ ) i ugao unutrašnjeg trenja ( $\varphi$ ) koji su neophodni kao ulazni parametri za numeričku analizu u programima, u kojim će se obavljati proračun stabilnost i analiza napona. Određivanje parametara čvrstoće i deformabilnosti stenske mase ( $mb$ ,  $s$ ,  $i$ ), u programu „RocLab“ zasniva se na utvrđivanju sledećih ulaznih podataka pokazanih na slici 3, koji se procenjuju na osnovu tabela 2.2 do 2.5:

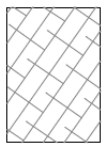
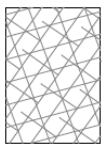


masses. In doing so, the equivalent Mohr-Coulomb parameters of cohesion ( $c$ ) and angle of internal friction ( $\varphi$ ) are also being calculated; these are required as input parameters for the numerical analysis in programs performing the calculation of stability and stress analysis. Parameters of the rock mass strength and deformability ( $mb$ ,  $s$ ,  $i$ ) in the "RocLab" are determined based on the identification of the following input data displayed in Figure 3, which are estimated according to Tables 2.2 through 2.5:

Tabela 2.2. Terenska procena jednoosne čvrstoće na pritisak (Brown, 1981) [6]  
Table 2.2. Field estimates of uniaxial compressive strength (Brown, 1981) [6]

Stepen Grade	Opis stenske mase Term	Jednoosna čvrstoća na pritisak Uniaxial Comp. Strength (MPa)	Tačkasti opit (PLT) Point Load Index(MPa)	Terenska procena čvrstoće Field estimate of strength	Primeri Examples
R6	Ekstremno čvrsta Extremely Strong	>250	>10	Uzorak se s geološkim čekićem jedino okrzne Rock material only chipped under repeated hammer blows, rings when struck	Sveži bazalt, čert, diabaz, gnajs, granit, kvarcit Fresh basalt, chert, diabase, gneiss, granite, quartzite
R5	Vrlo čvrsta Very strong	100-250	4-10	Uzorak zahteva veliki broj udaraca geološkim čekićem da bi se slomio Requires many blows of a geological hammer to break intact rock specimens	Amfibiolit, peščenjak, riolit, bazalt, mramor, gabbro, gnajs, granodiorit, vapnenac, tuf Amphibolite, sandstone, tuff basalt, gabbro, gneiss, marble, granodiorite, limestone,
R4	Čvrsta Strong	50-100	2-4	Uzorak zahteva više od jednog udarca geološkim čekićem da bi se slomio Hand held specimens broken by a single blow of geological hammer	Vapnenac, mramor, filit, peščenjak, škriljevac, šejl Limestone, marble, phyllite, sandstone, schist, shale
R3	Srednje čvrsta Medium strong	25-50	1-2	Uzorak nije moguće zarezati ili rascepiti nožem, ali se može slomiti jednim udarcem geološkog čekića Firm blow with geological pick indents rock to 5 mm, knife just scrapes surface	Glinjak, ugljen, beton, škriljevac, šejl, siltit Claystone, coal, concrete, schist, shale, siltstone
R2	Meka Weak	5-25	**	Uzorak se može zarezati nožem uz teškoće, a pojedini odlomci mogu se odcepiti lakim udarcima geološkog čekića Knife cuts material but too hard to shape into triaxial specimens	Kreda, kamena sol, potaša Chalk, rocksalt, potash
R1	Vrlo meka Very weak	1-5	**	Uzorak se raspada pod lakim udarcem geološkog čekića i može se rezati nožem Material crumbles under firm blows of geological pick, can be shaped with knife.	Jako raspadnute stene ili izmenjene stene Highly weathered or altered rock
R0	Ekstremno meka Extrem. weak	0.25-1	**	Razdvaja se pod pritiskom nokta Indented by thumbnail	Meka pukotinska ispuna Clay gouge

Tabela 2.3. Procena vrednosti  $mb/mi$ ,  $s$  i  $a$ , modula deformacije  $Em$ ,  $n$ , i GSI (Hoek, 1995) [11]

Table 2.3. Estimation of  $mb / mi$ ,  $s$  and  $a$ , deformation moduls  $Em$ ,  $n$ , i GSI (Hoek, 1995) [11]

OPŠTI HOEK-BROWNOV KRITERIJUM ČVRSTOĆE GENERALISED HOEK-BROWN CRITERION			STANJE POVRŠINE DISKONTINUITETA / SURFACE CONDITION				
			VRLO DOBRO, vrlo hrapavo, površine diskontinuiteta neoštećene VERY GOOD Very rough, unweathered surfaces	DOBRO, hrapavo, lagano oštećene površine, metalna boja površine GOOD, rough, slightly weathered, iron stained surfaces	POVOLJNO, glatko, srednje oštećena ili promenjena površina FAIR, smooth, moderately weathered or altered surfaces	LOŠE, ispućala, jako oštećena površina sa zbijenom naslagom ili ispunom koja sadrži uglaste fragmente stene POOR, slickensided, highly weathered surfaces with compact coatings or fillings containing angular rock fragments	VRLO LOŠE, ispućala, jako oštećena površina sa slojem ili ispunom od mekane gline VERY POOR, slickensided, highly weathered surfaces with soft clay coatings or fillings
$s_1 = s_3 + s_c \left( m_b \frac{s_3}{s_c} + s \right)^a$ <p><math>s_1</math> - veći glavni efektivni napon, - major principal effective stress at failure, <math>s_3</math> - manji glavni efektivni napon, - minor principal effective stress at failure <math>s_c</math> - jednoosna čvrstoća na pritisak intaktne stene, - uniaxial compressive strength of intact pieces of rock, <math>m, s, a</math> - konstante koje zavise o sistemu, strukturi i stanju površine stenske mase - are constants which depend on the composition, structure and surface conditions of the rock mass.</p>							
STRUKTURA STENSKE MASE / STRUCTURE							
	BLOKOVI - Vrlo dobro uklještena i neporemećena stijenska masa s kubičnim blokovima formiranim s 3 ortogonalna diskontinuiteta BLOCKY - very well interlocked undisturbed rock mass consisting of cubical blocks formed by three orthogonal discontinuity sets	$mb/mi$ $sa$ $Em$ $v$ GSI	0.60 0.190 0.5 75 000 0.2 85	0.49 0.021 0.5 40 000 0.2 75	0.26 0.015 0.5 20 000 0.25 62	0.16 0.003 0.5 9 000 0.25 48	0.08 0.0004 0.5 3 000 0.25 34
	UGLAVNOM BLOKOVI - Uklješteno, delimično poremećena stenska masa s višeplošnim uglatim blokovima formiranim s 4 ili više diskontinuiteta VERY BLOCKY – interlocked, partially disturbed rock mass with multi-faceted angular blocks formed by four or more discontinuity sets	$mb/mi$ $sa$ $Em$ $v$ GSI	0.40 0.062 0.5 40 000 0.2 75	0.29 0.021 0.5 24 000 0.25 65	0.16 0.003 0.5 9 000 0.25 48	0.11 0.001 0.5 5 000 0.25 38	0.07 0 0.53 2 500 0.3 25
	BLOKOVI / SLOJEVITO - Naborano s rasjedima te ispresijecano s mnogo diskontinuiteta koji formiraju uglaste blokove BLOCKY/SEAMY – folded and faulted with many intersecting discontinuities forming angular blocks	$mb/mi$ $sa$ $Em$ $v$ GSI	0.24 0.012 0.5 18 000 0.25 60	0.17 0.004 0.5 10 000 0.25 50	0.12 0.001 0.5 6 000 0.25 40	0.08 0 0.5 3 000 0.3 30	0.06 0 0.55 2 000 0.3 20
	ZDROBLJENO - Loše uklinjena, jako zdrobljena stenska masa s mješavinom uglatih i zaobljenih blokova CRUSHED - poorly interlocked, heavily broken rock mass with a mixture of angular and rounded blocks	$mb/mi$ $sa$ $Em$ $v$ GSI	0.17 0.004 0.5 10 000 0.25 50	0.12 0.001 0.5 6 000 0.25 40	0.08 0 0.5 3 000 0.3 30	0.06 0 0.55 2 000 0.3 20	0.04 0 0.60 1 000 0.3 10

Hoek–Brown-ov kriterijum čvrstoće stenske mase jeste empirijski kriterijum zasnovan na podacima triaksijalnog ispitivanja stenske mase. Ukoliko ne postoji mogućnost ispitivanja jednoosne pritisne čvrstoće stene (ili vrednosti PLT), Brown je predložio terensku procenu jednoosne čvrstoće na pritisak prikazanoj u Tabeli 2.2. Za vrednost parametara  $mb$ ,  $s$  i  $a$  Hoek, Kaiser i Bawden, [11] – predlažu izraze u zavisnosti od vrednosti geološkog indeksa čvrstoće (*Geological Strength Index–GSI*), (Tabela 2.3). Geološki indeks čvrstoće predstavlja pojednostavljeni klasifikacijski sistem određivanja čvrstoće stenske mase, zasnovan na proceni vrednosti GSI na osnovi strukture stenske mase, karakteristikama intaktne stene, uslovima površine diskontinuiteta, kao i

The Hoek-Brown rock mass strength criterion is an empirical criterion that is based on the data resulting from triaxial testing of the rock mass. If there is no possibility of investigating the uniaxial compressive strength of rocks (or the PLT value), Brown has proposed that the uniaxial compressive strength should be field-evaluated, as shown in Table 2.2.

For determining the value of parameters  $mb$ ,  $s$  and  $a$ , Hoek, Kaiser and Bawden, [11] suggest expressions depending on the value of the Geological Strength Index (GSI) (Table 2.3). the Geological Strength Index is a simplified classification system for determining the rock mass strength, which is based on the estimated GSI value according to the rock mass structure, intact rock

uslova koji proizlaze iz geometrije intaktnih delova stene i njihovog ponašanja pod delovanjem promene uslova stanja naprezanja u stenskoj masi.

Hoek-Brown-ova konstanta  $m_i$  može se odrediti jedino iz triaksijalnog opita stenske mase ili proceniti na osnovu kvalitativnog opisa stenskog materijala, [9]. Ukoliko nije moguće sprovesti triaksijalni opit na uzorku stenske mase, procenu parametra  $m_i$  potrebno je izvršiti na osnovi tabele 2.4, [16]. Kako konstanta  $m_i$  najmanje utiče na određivanje Hoek-Brown-ovog kriterijuma loma, procene date u tabeli dovoljno su tačne za praktičnu upotrebu. Modul deformacije intaktne stenske mase  $E_i$  može se orjentaciono proceniti pomoću modula  $MR$ , ( $E_i=MR \times sigci$ ) prema Tabeli 2.5, [12].

Kako je vrlo često, na stenskim padinama izražena pojava površinskog raspadanja, što predstavlja opasnost od obrušavanja manjih pa i većih blokova, predloženo je geotehničko-tehnološko rešenje koje je detaljno opisano iz metodološkog aspekta (studija slučaja-Case study) kako bi moglo poslužiti kao primer za rešavanje sličnih slučajeva u praksi, uz određena ograničenja i eventualne modifikacije. Naime, postupak je ograničen na slučajeve kada je zona površinskog raspadanja stene male debljine. Zasniva se na odstranjivanju površinskog, izmenjenog, sloja drobine, a zatim se obavlja ankerovanje potencijalnih nestabilnih delova, takođe zahvaćenih izmenama usled inženjersko-geoloških procesa stenske mase, čime se ona pretvara u stabilnu.

properties, discontinuity surface conditions, as well as the conditions resulting from the geometry of the intact parts of the rock and their behaviour under the influence of changes of stress conditions in the rock mass.

The Hoek-Brown constant  $m_i$  can be obtained only based on performing triaxial tests on the rock mass or it can be estimated from the qualitative description of the rock material, [19]. If a triaxial test is not possible to be performed on a rock mass sample, the  $m_i$  parameter should be estimated based on Table 2.4, [16]. Given that the determination of the Hoek-Brown failure criterion is the least influenced by the  $m_i$  constant, estimates provided in the table are sufficiently accurate for practical use. The value of deformation modulus of the intact rock mass  $E_i$  can be approximately evaluated using the  $MR$  module, ( $E_i=MR \times sigci$ ) according to Table 2.5, [12].

As rock slopes very often contain signs of pronounced surface decomposition leading to the risk of collapsing of smaller or larger blocks, a geotechnical-technological solution has been proposed and described in details from the methodological aspect (case study) for using as an example for resolving similar cases in practice, albeit with certain limitations and possible alterations. Namely, the procedure is limited to cases where the thickness of zone of surface decomposition is small. It is based on the removal of the altered surface layer of debris, followed by anchoring the potentially

Tabela 2.4. Vrednosti  $m_i$  za intaktnu stenu u zavisnosti od geološkog porekla za opšti oblik Hoek-Brownovog kriterijuma loma (Marinos and Hoek, 2001), [16].

Table 2.4. Values of the constant  $m_i$  for intact rock, by rock group. Note that values in parenthesis are estimates, [16].

Tip stene Rock type	Klasa Class	Grupa Group	Tekstura / Texture				
			Krupna Course	Srednja Medium	Fina Fine	Vrlo fina Very fine	
SEDIMENTNE SEDIMENTARY	Klastične Clastic		Konglomerat / Conglomerate (22)		Peščar Sandstone 19	Silit Siltstone 9	Argilit Claystone 4
			Grauvaka / Greywacke 18				
	Neklastične Non-Clastic	Organske Organic	Kreda / Chalk 7 Ugljen / Coal (8-21)				
		Karbonatne Carbonate	Breča / Breccia (20)	Sparitni / Sparitic vapnenac / limestone (10)	Mikritni / Micritic vapnenac / limestone 8		
		Kemijske Chemical	Gips / Gypstone 16		Anhidrit / Anhydrite 13		
METAMORFNE METAMORPHIC	Neškriljave / Non Foliated		Mermer / Marble 9	Hornfels / Hornfels (19)	Kvarcit / Quartzite 24		
	Slabo škriljave / Slightly foliated		Migmatit / Migmatite (30)	Amfibolit / Amphibolite 25-31	Milonit / Mylonites (6)		
	Škriljave / Foliated		Gnajs / Gneiss 33	Škriljavac / Schists 4-8	Filit / Phyllite (10)	Slejt / Slate 9	
MAGMATSKA IGNEOUS	Svetle (Kisele) Light		Granit / Granite 33	Riolit / Rhyolite (16)		Opsidijan / Obsidian (19)	
	Tamne (Lužnate) Dark		Granodiorit / Granodiorite (30)	Dacit / Dacite (17)			
			Diorit / Diorite (28)	Andezit / Andesite 19			
			Gabro / Gabbro 27 Norit / Norite 22	Dolerit / Dolerite (19)	Bazalt / Basalt (17)		
Efuzivni piroklastični tip Extrusive pyroclastic type		Aglomerat / Agglomerate (20)	Breča / Breccia (18)	Tuf / Tuff (15)			

Tabela 2.5. Vrednost modula MR [6]  
Table 2.5. Guidelines for the selection of modulus ratio (MR)

Tip stene Rock type	Klasa Class	Grupa Group	Tekstura / Texture					
			Krupna Course	Srednja Medium	Fina Fine	Vrlo fina Very fine		
SEDIMENTNE SEDIMENTARY	Klastične Clastic		Konglomerat Conglomerate 300-400 Breča / Breccia 230-350	Pješčar Sandstone 200-350	Silit Siltstone 350-400 Grauvaka/Greywacke 350	Argilit-Claystone 200-300		
	Neklastične Non-Clastic	Organske Organic	Kreda / Chalk 1000+					
		Karbonatne Carbonate	Kristalne/ Crystalline Dolomiti/Dolomites 400-600	Sparitni / Sparitic vapnenac / limestone 600-800	Mikritni / Micritic vapnenac / limestone 800-1000	vapnenac / limestone 300-500		
		Kemijske Chemical	Gips / Gypstone (350)      Anhidrit / Anhydrite (350)					
METAMORFNE METAMORPHIC	Neškrljave / Non Foliated		Mermer / Marble 700-1000	Hornfels / Hornfels 400-700	Kvarcit / Quartzite 300-450			
	Slabo škrljave / Slightly foliated		Migmatit / Migmatite 350-400	Amfibolit / Amphibolite 400-500	Gnajs / Gneiss 300-750			
	Škrljave / Foliated		Škrljavac / Schists 250-1100	Filit / Phylites 300-800	Slejt / Slate 400-600			
MAGMATSKÉ IGNEOUS	Svetle (Kisele) Light		Granit / Granite 300-550		Diorit / Diorite 300-350			
			Granodiorit / Granodiorite 400-450		Dolerit / Dolerite 300-350			
	Tamne ( Lužnate) Dark		Gabro / Gabbro 400-500		Norit / Norite 350-400			
			Porfir-Porphyrries (400)		Diabaz/Diabase 300-350		Peridotit/Peridotite 250-300	
			Riolit / Rhyolite 300 -500 Andezit-Andesit 300-500		Dacit/Dacite 350-450 Bazalt/Bazalt 250/450			
Efuzivni piroklastični tip Extrusive pyroclastic type		Aglomerat / Agglomerate 400-600		Breča / Breccia (500)		Tuf / Tuff 200-400		

Voda je skoro u svim slučajevima, direktno ili indirektno, povezana s nastankom pokreta na padinama, tako da je njena uloga veoma značajna. Nakon jakih padavina ili nakon otapanja snega dolazi do pojačane infiltracije vode, tlo ili stena postaju sve zasićeniji vodom i stvaraju se uslovi za redukcije smičuće čvrstoće, zbog povećanog pomoga pritiska u tlu ili steni. Osim toga, dodatno je povećana gravitacijska smičuća sila nastala zbog povećane težine tla ili stene zasićene vodom. Kada tlo ili stena postanu u potpunosti zasićeni vodom, faktor sigurnosti je minimalan i znatno se povećava verovatnoća nastanka pokreta - nestabilnosti na padinama. Na neravnotežu sila i stabilnost padine utiče niz faktora: vrsta geološkog materijala (stena, tla) na padini, nagib padine i topografija, količina padavina i nivo podzemne vode, klimatski uslovi i vegetacija, vreme i sl.

unstable areas also affected by alterations resulting from the engineering-geological processes of the rock mass, converting it thereby into a stable area.

In almost all cases, either directly or indirectly water is associated with the emergence of slope displacement, so it has great importance. Increased water infiltration occurs after heavy precipitations or snow melting, the soil or rock becomes increasingly saturated with water, creating favourable conditions for the reduction of shear strength due to increased pore pressure in the soil or rock. In addition, the gravitational shear force is also increased due to the increased weight of the soil or rock as a result of water-saturation. When the soil or rock becomes completely saturated with water the safety factor drops to minimum level increasing significantly the probability of slope displacement (instability). The imbalance of forces and slope stability are influenced by a series of factors: the type of geological materials (rocks, soils) on the slope, slope inclination and topography, the amount of precipitation and groundwater level, climate and vegetation, weather, etc.



### 3 ILUSTRACIJA PREDLOŽENE METODOLOGIJE SANACIJE STENSKE PADINE

Nakon utvrđivanja inženjersko-geoloških parametara stenske padine i sagledavanjem problema u celini, predložena je procedura (algoritam) tehnologije izvođenja radova na sanaciji padina:

- čišćenje niskog i visokog rastinja na površini predviđenoj za sanaciju (sl. 4),
- uklanjanje jako ispucale stene sa detaljnim čišćenjem kontaktne površine (slika 5), (pripremljena podloga za izvođenje predviđenih sanacionih radova (slika 6),
- mašinsko nanošenje prvog kontaktnog sloja mlaznog betona, (slika 7),
- ugradnja heksagonalne pletene pocinkovane čelične mreže. (slika 8),
- ugradnja trajnih štapnih sidara, (slika 9),
- nanošenje završnog sloja mlaznog betona.



Slika 4. Čišćenje niskog i visokog rastinja  
Figure 4. Cleaning of low and high vegetation

### 3 ILLUSTRATION OF THE PROPOSED METHODOLOGY FOR ROCK SLOPE REPAIR

After determining the engineering-geological parameters of rock slopes and considering the overall problem, a procedure (algorithm) has been proposed for the technology of slope reparation:

- cleaning of low and high vegetation in the area designated for reparation, (Figure 4),
- removing the strongly cracked rocks and a very detailed cleaning of contact surface (Figure 5), (the prepared construction base for the intended repair works (Figure 6),
- application of the first contact layer of concrete (Figure 7),
- installation of hexagonal woven galvanized steel mesh (Figure 8),
- installation of permanent bar anchors (Figure 9),
- application of the final layer of concrete.



Slika 5. Čišćenje oslabljenih blokova stene  
Figure 5. Cleaning the weakened wall blocks



Slika 6. Pripremljena podloga  
Figure 6. Prepared construction base



Slika 7. Nanošenje kontaktnog sloja mlaznog betona  
Figure 7. Application of contact layer sprayed concrete



Slika 8. Ugradnja heksagonalne pletene pocinčane čelične mreže  
Figure 8. Installation of hexagonal woven galvanized steel net



Slika 9. Ugradnja štapnih sidara  
Figure 9. Installing anchors piston

Ukoliko su na padini registrovana područja s jako ispućalom stenskom masom ili rasedi, što za posledicu može imati potencijalnu opasnost od klizanja i obrušavanja većih stenskih blokova, kao mera sanacije predlaže se izrada vertikalnih stabilizacionih AB greda odgovarajućih dimenzija. Kroz AB grede se ugrađuju stabilizacioni elementi, tj. štapna sidra, (slika10).

Zaštita od osipanja materijala sa padine, iznad površine predviđene za sanaciju, postiže se izradom AB zida u nagibu minimum 1%. Iza zida je neophodno izraditi drenažni sistem za prikupljanje i odvodnju površinskih voda sa gornjih delova padine. Procediranje vode iza konstrukcije od mlaznog betona omogućuje se ugradnjom odgovarajućeg broja PVC cevi, što je prikazano na slici 11.

If the slope contains areas with highly cracked rock mass or discontinuous, which may result in imminent danger of slipping and collapsing of large blocks of rock, vertical RC stabilization beams of appropriate dimensions are proposed as a repair measure. Through these RC beams, stabilizing elements, i.e. bar anchors, are installed (Figure 10).

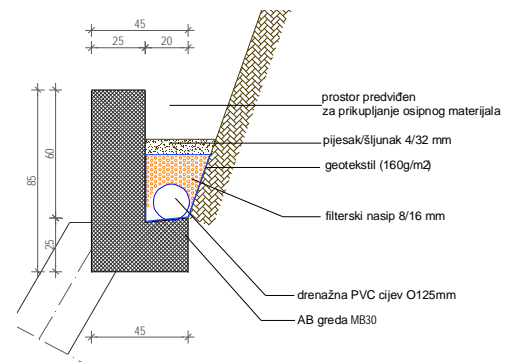
Protection against the dispersing slope material above the surface intended for reparation is achieved by constructing an RC wall of minimum 1% inclination. Behind the wall it is necessary to develop a drainage system for collecting and draining surface waters from the upper parts of slope. Water is enabled to trickle behind the concrete structure by installing an appropriate number of PVC pipes, as shown in Figure 11.



Slika 10. Stabilizaciona AB greda  
Figure 10. RC stabilization beam

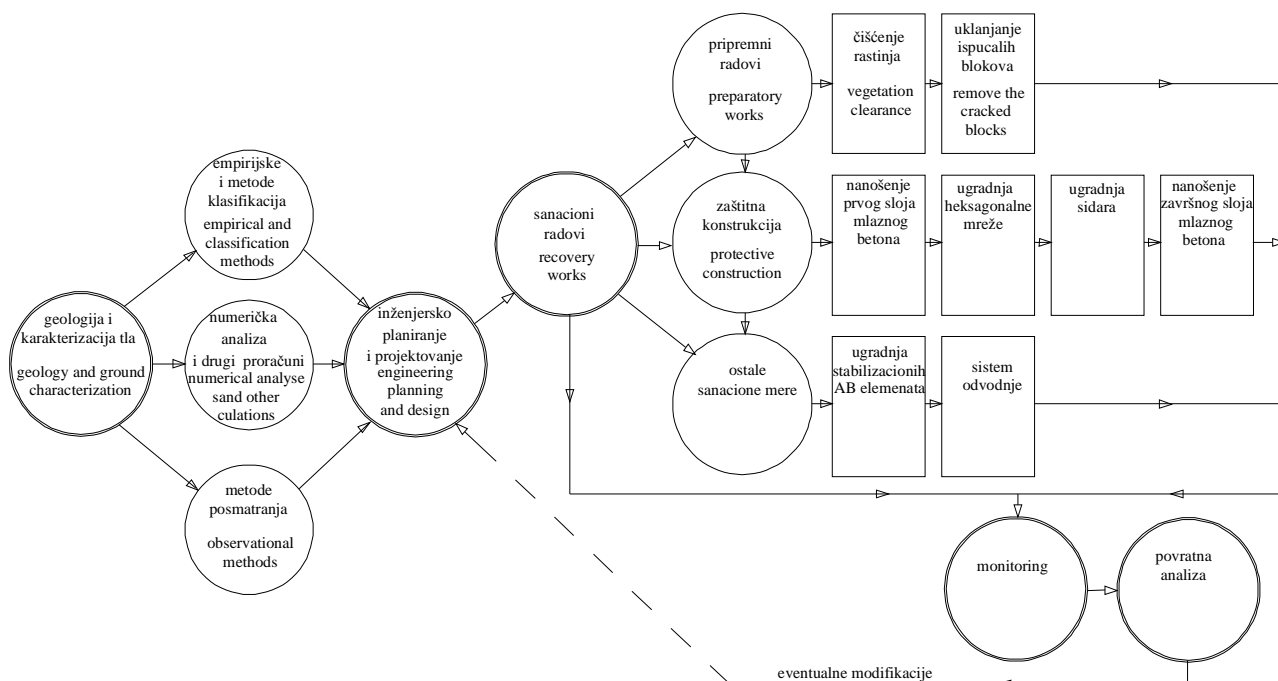


Slika 11. Zaštitna AB greda a) izvedeno stanje b) poprečni presek  
Figure 11. Protective RC beam a) final state b) cross section



U savremenoj praksi koriste se različiti pristupi i metodologije pri projektovanju i izvođenju određenih zahvata u izmenjenoj stenskoj masi (postojeće empirijske metode, analitičke metode, numeričko modeliranje, ili opservacijske metode), zavisno od okolnosti. U nekim slučajevima, samo iskustvo može biti dovoljno za rešavanje određenog problema, dok je u drugim neophodno primeniti sve alate dostupne u savremenom rešavanju geotehničkih problema vezanih za stensku masu. Na slici 12 je dat blok dijagram koji uključuje osnovne korake u rešavanju problema pri projektovanju kosina ili sanaciji padina formiranih u stenskom materijalu.

In contemporary practice, various approaches and methodologies have been used when designing and performing certain operations in an altered rock mass (existing empirical methods, analytical methods, numerical modelling, or observational methods), depending on the circumstances. In some cases, problems can be resolved based on the exiting experience, while in other cases it is necessary to apply all tools available in today's rock mass-related geotechnical problem solving. In Figure 12 a flowchart is provided which includes the essential problem solving steps in designing and repairing slopes formed in the rock material.



Slika 12. Blok dijagram - generalizirano tehnološko rešenje sanacije stenskih padina  
Figure 12. Flowchart – a generalized technological solution of repairing rock slopes

#### 4 PRIMENA PREDLOŽENE TEHNOLOGIJE SANACIJE OSLONAČKE PADINE BRANE „MODRAC“

Predloženi tehnološki postupak primenjen je pri sanaciji oslonačkog boka brane „Modrac“ (BiH). Usled stalnog odrona većih i manjih kamenih blokova i zbog mnogih potencijalno nestabilnih blokova ugrožena je lokalna, a daljim gubitkom stenske mase s padine i globalna stabilnost padine. Proces dezintegracije je bio u stalnom razvoju i imao je progresivan karakter, te je stoga bilo potrebno hitno pristupiti rešavanju ovog problema imajući u vidu složenost i kategoriju predmetnog objekta o kome je reč. Na slici 13 ilustrovano je njegovo postojeće stanje.



Slika 13. Postojeće stanje  
Figure 13. Present condition (state)

#### 4 APPLICATION OF THE PROPOSED TECHNOLOGY FOR REPAIRING THE SUPPORT SLOPE OF THE "MODRAC" DAM

The proposed technological procedure has been applied in repairing the support side of the "Modrac" dam (Bosnia and Herzegovina). Due to the frequent sliding of larger and smaller blocks of stone and many potentially unstable blocks, both the local and global slope stability are endangered as a result of further losses of rock mass. The problem of progressive process of disintegration has required an urgent solution, having in mind its complexity and category. Its present condition is illustrated in Figure 13.



Slika 14. Postojeće stanje – ispucala stenska masa  
Figure 14. Present condition – cracked slope

Visina uslovno stabilnog dela padine doseže do 20 m sa prosečnom širinom 18,30 m. Padinu izgrađuje stena serpentin, nagiba do 60°, u kojoj je veoma izražena pojava površinske dezintegracije stenske mase, bez značajnog priliva oborinskih voda. Prisustvo velikog broja familija diskontinuiteta ukazuje na značajne tektonske pokrete odnosno tektonske pojave (slika 14).

U slučajevima, poput ovog, kada je stepen izmenjenosti stenskog materijala veoma visok, a fizičko-mehaničke karakteristike ocenjene lošim, uz njihovo dalje pogoršanje nepovoljnim dejstvom vode provode se tehnike poboljšanja stenskog materijala. Njima se eliminišu nepovoljni uticaji inženjerskogeoloških uslova kroz povećanje kompatibilnosti stenske mase čime se postiže zahtevana stabilnost padine. Poboljšanja svojstava tla i stena obuhvata zbijanje, injektiranje, dreniranje, armiranje (geosintetici, sidra), sušenje, promene temperature i sl. Stabilnost je direktno u funkciji kvaliteta tla i stenske mase. Primenom adekvatnih tehnika poboljšanja postižu se bolje fizičko-mehaničke karakteristike medija, a s tim i kvalitet i ukupnu stabilnost tla i stena. Tehnike poboljšanja stalno se razvijaju, a među najnovije ubrajaju se: armirano i igleno tlo, te upotreba geosintetičkih materijala [4].

Analizirajući sve navedene činjenice, osobito veliku visinu padine, izraženu lokalnu nestabilnost i ugrožavanje sigurnosti oslonačkog dela samog objekta, pristupilo se izradi projekta sanacije padine vodeći računa o optimalnom rešenju s aspekta osiguranja sigurnosti, lakšeg izvođenja radova i ekonomičnosti. Imajući u vidu specifičan način raspadanja serpentina, odabrana je kao racionalno sistematsko sidrenje u dubljim delovima stabilne stenske mase.

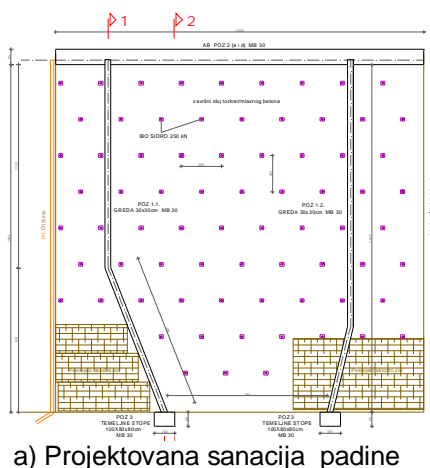
Usvojeni geometrijski elementi primenjeni za stabilizaciju padine prikazani su na slici 15, prema [17].

The height of the conditionally stable slope part is up to 20 m, with an average width of 18.30 m. The slope is built of a 60° serpentine rock, with a highly pronounced disintegration of the rock mass surface without any significant inflow of precipitations. The presence of a large number of set of discontinuity points to the significant tectonic displacements and tectonic phenomena (Figure 14).

In such cases of highly altered rock material, with poorly rated physical and mechanical properties, and with their further deterioration by the adverse impacts of water, techniques of improving the rock material are implemented. These techniques are vehicles for eliminating the adverse impacts of engineering-geological conditions by increasing the rock mass compatibility, achieving thereby the required slope stability. Improving the soil and rock properties includes compacting, grouting, draining, reinforcing (geo-synthetics, anchors), drying, temperature-changing and the like. Stability is directly dependent on the quality of soil and the rock mass. Appropriate improving techniques result in enhanced physical and mechanical properties of the media, increasing the overall soil and rock quality and stability. Improvement techniques are constantly evolving, with the latest including: reinforced and needle soil, and the use of geo-synthetic materials, [4].

The repair project has been created by analyzing all the above facts, especially the slope height and the degree of local instability and level of insecurity of the supporting part of the building, taking into account the optimal solution in terms of ensuring safety, facilitating the works and the cost-effectiveness. Having in mind the specific way of serpentine disintegration, the systematic anchoring in deeper parts of the stable rock mass has been chosen as a rational solution.

The adopted geometrical elements applied for stabilizing the slope are shown in Figure 15, according to [17].



Slika 15. Stabilizacija padine (izgled)  
Figure 15. Slope stabilization (outlook)

Na osnovu provedenih istraživanja [2], vidimo da je predložena tehnologija primenjiva pri izvođenju zaseka ukoliko je reč o relativno tankim naslagama pokrivača i tankim rastrošenim delom flišne podloge, gde se pri iskopu brzo ulazi u flišnu stensku podlogu (prethodno pomno okarakteriziranu) s relativno slabim režimima podzemnih voda u zaleđu padina.

Based on the investigations [2], we see that the proposed technology is applicable for cuts if the cladding layers are relatively thin with a thin loosen flysch substrate, where the excavation quickly enters into the flysch rock surface (previously carefully characterized) with a relatively low groundwater regime in the slope background.

## 5 ANALIZA STABILNOSTI PADINE

### 5.1 Opšte napomene

Numeričkim metodama u analizama stabilnosti padina modelira se stanje u padini i numerički postupci kojima se to stanje određuje. U numeričkim analizama potrebno je zadovoljiti granične uslove predloženog modela, diferencijalne jednačine ravnoteže, konstitutivne relacije materijala, te odgovarajuće jednačine pomeranja. Kao rezultat analiza u numeričkim modelima, dobijaju se vrednosti koje omogućuju sagledavanje naponskih stanja i pomeranja u elementima modela izloženog spoljašnjim opterećenjima i graničnim uslovima. Pri tome, mogu se koristiti različiti konstitutivni modeli ponašanja materijala, primereni različitim vrstama materijala u usvojenom modelu. To omogućuje znatno bolje opisivanje složenijih uslova geometrije padine nego u slučaju korišćenja metode granične ravnoteže [1].

U razmatranom primeru, obavljena je dvodimenzionalna analiza u programu „Plaxis”, uz primenu Mohr–Coulombovih modela tla, u koju su uključeni elementi podgrade i izvođenje sanacije po fazama. Analize stabilnosti padina, korišćenjem numeričkih metoda, sprovode se u dva koraka – u prvom koraku, numeričkim metodama utvrđuje se stanje napona padine, dok se u drugom metodama granične ravnoteže utvrđuje kritična ravan loma u padini (zaseku), te pripadajući faktor sigurnosti u odnosu na smičuću čvrstoću materijala na ravni loma. Osnovni parametri potrebni za bilo koji tip analize stenske padine jesu čvrstoća i deformabilnost stenske mase, svojstva diskontinuiteta, sidara i smese koja se upotrebljava za injektiranje.

### 5.2 Ulazni parametri za analizu

Geološki i geomehanički parametri stenske mase korišćeni u analizi stabilnosti preuzeti su iz postojećih izvora [3],[5],[18],[19],[20], te na osnovu dodatnih geotehničkih istražnih radova koji su se sastojali od *in situ* ispitivanja, istražnog bušenja, laboratorijskih ispitivanja uzoraka stena, inženjersko-geološkog kartiranja otvorenih profila u stenskoj masi, te geodetskih snimanja postojećeg stanja i stanja nakon obavljenog čišćenja površinskog drobinskog sloja.

Kao geološki supstrat, na ovom lokalitetu pojavljuju se čvrste autometamorfne stene serpentina. Petrografski su prilično homogene, ali su jako ispucale usled tektonskih pokreta, te su površinski slojevi delimično izmenjeni i predstavljaju izdrobljenu stensku masu. Na delu padine preko serpentina leži osulinski materijal u vidu drobine i sitnijih blokova, kao i glinovitog materijala. Debljina ovog pokrivača je različita i kreće se do 0,80 m. Ispod se nalazi sloj ispucale i poremećene stenske mase serpentina debljine do 1,20 m, u kome se izdvajaju manji uglasti blokovi jasno odvojeni (ispunjeni ili neispunjeni) diskontinuitetima (slika 16). Pojava podzemne vode je registrovana na koti nivoa reke Spreča (184,0 m.n.v.), [19]. U toku rekognosciranja terena i inženjersko-geoloških istraživanja *in situ*, nije ustanovljeno prisustvo vode u zaleđu padine koje bi negativno uticalo na hidrostatski pritisak vodenog stuba doprinosilo povećanju nestabilnosti padine. U tom smislu ni diskontinualni setovi te pukotine, nastale u toku procesa izmenjenosti stenske mase, ne predstavljaju hidrološke

## 5 SLOPE STABILITY ANALYSIS

### 5.1 General Notes

The condition in the slope and numerical procedures of its determination are modelled by numerical methods of analyzing slope stability. In numerical analyses it is necessary to satisfy the boundary conditions of the proposed model, the differential equations of equilibrium, the constitutive relation of material and corresponding equation of motion. Values obtained as a result of numerical model analysis allow consideration of stress states and displacements in elements of the model which are exposed to external loads and boundary conditions. In doing so, various constitutive models of material behaviour can be used which are appropriate to different types of materials in the adopted model. It provides significantly better description of the more complex slope geometry than in the limit equilibrium method [1].

In the considered case, a two-dimensional analysis is performed using the "Plaxis" software and the Mohr–Coulomb soil model, which include the support units and reparation in phases. The numerically based slope stability analyses are carried out in two steps. In the first step, the numerical methods are used to identify the slope stress state; in the second step, based on the limit equilibrium method, the critical failure plane is identified in the slope (cut and fall), as well as the corresponding safety factor with respect to the material's shear strength in the plane of failure. The basic parameters required for any type of rock slope analysis are the rock mass strength and deformability, properties of discontinuities, anchors and compounds that are used for injection.

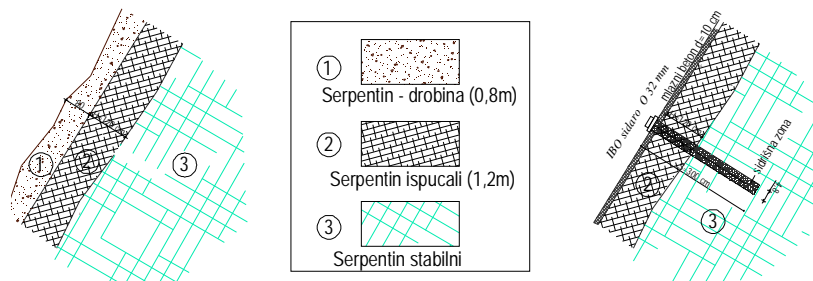
### 5.2 The input parameters for analysis

The geological and geotechnical parameters of the rock mass used in the stability analysis are taken from the existing sources [3], [5], [18-20] as well as based on additional geotechnical investigations *in situ*, exploration drilling, laboratory testing of rock samples, engineering-geological mapping of open rock mass profiles and geodetic surveys of the existing conditions (state) and the state after cleaning surface layer of debris.

As a geological substrate in this locality, solid autometamorphic serpentine rocks appear. Petrographically, they are rather homogeneous, but highly cracked due to tectonic displacements, while the surface layers are partially altered, representing a fractured rock mass. Part of the slope above the serpentine is covered by material in the form of debris and smaller blocks, as well as by clay material. The thickness of this cover varies, ranging up to 0.80 m. Below is a layer of cracked and disturbed serpentine rock mass of thickness of up to 1.20 m, with smaller angular blocks clearly separated (filled or unfilled) by discontinuities (Figure 16). The occurrence of groundwater is registered at the elevation level of the river Spreča (184.0 meters above sea level), [19]. Also, during the field survey and engineering-geological research *in situ*, there was no water in the slope backing that would contribute the increasing slope instability by adversely affecting the hydrostatic pressure of the water column. Therefore, the sets discontinuities and cracks formed during the process of rock mass alteration, also fail to represent hydrological pathways and locations of occurrence of filtration forces, which

puteve i mesta pojave filtracionih sila, koje bi dodatno negativno uticali na stabilnost padine. Zbog toga uticaj vode u proračunskom modelu nije uzet u obzir.

would be an additional negative impact on slope stability. Thus, the impact of water is not taken into account in the calculation model.



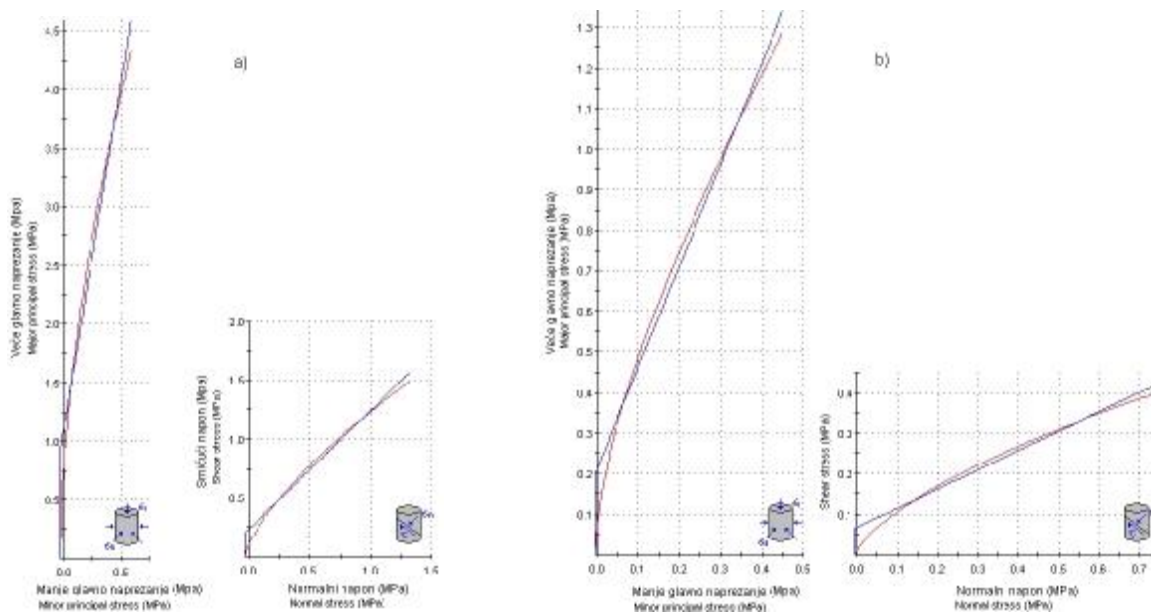
Slika 16. Inženjersko – geološki i geomehantički profil  
Figure 16. Engineering-geological and geotechnical profile

Na osnovu prikupljenih ulaznih podataka geodetskih snimanja i geotehničkih istražnih radova, te procene u programu „RocLab”, [6], definisana su svojstva intaktne i poremećene stenske mase, na osnovu kojih je definisan geotehnički model potreban za analizu stabilnosti (slika 18). Za sve zone stenske mase pretpostavljeno je da se ponašaju homogeno i izotropno. Prema [13], ako stena sadrži deset ili više skupova diskontinuiteta, njeno ponašanje može se aproksimirati kao ponašanje homogenog i izotropnog medija, uz samo 5% pogreške zbog pretpostavljenog stanja. Isto tako, ako stenski masiv sadrži vrlo malo diskontinuiteta, može se idealizirati da se ponaša kao homogeni medij.

Rezultati procene svojstava stenske mase sa izračunavanjem ekvivalentnih Mohr–Coulomb-ovih parametara  $c$  i  $\phi$  dati su u tabeli 5.1, dok je odnos glavnih napona, kao i odnos smičućih i normalnih napreznja prikazan na sl. 17.

Based on the input data collected from geodesic recordings and geotechnical investigations as well as estimation conducted in the "RocLab" software, [6], properties of the intact and the disturbed rock mass are defined on the basis of which the geotechnical model is defined which is required for stability analysis (Figure 18). All zones of the rock mass were assumed to behave homogeneously and isotropically. According to [13], if the rock contains 10 or more sets of discontinuities, its behaviour can be approximated as the behaviour of a homogeneous and isotropic media, with only a 5% error due to the assumed condition. Also, if the rock massif contains very low discontinuities, it can be idealized to behave as a homogeneous medium.




Results of the evaluation of the rock mass properties based on the calculation of equivalent Mohr-Coulomb parameters  $c$  and  $\phi$  are given in Table 5.1, while the ratio of the major stresses and the ratio of shear and normal stresses are shown in Figure 17.

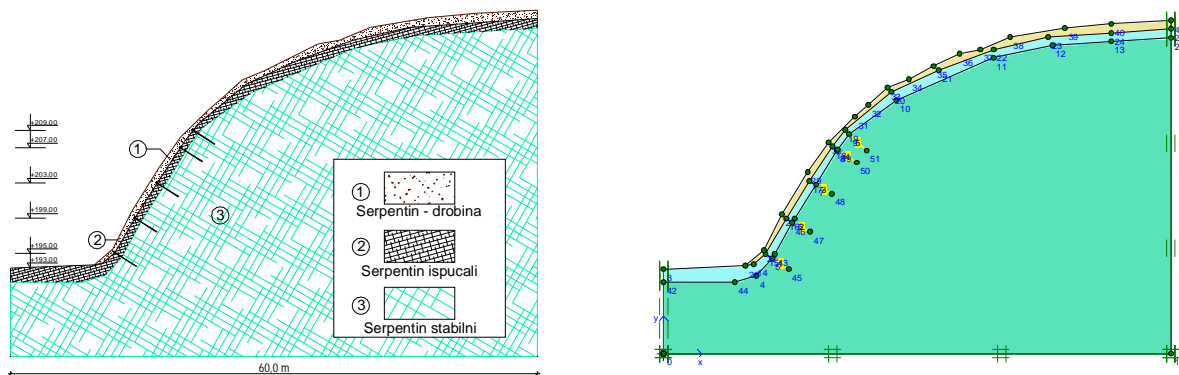


Slika 17. Hoek–Brown-ov kriterijum čvrstoće stenske mase, prikazan kao odnos glavnih napona, te kao odnos smičućih i normalnih napona: a) čvrsti serpentin; b) ispucali serpentin.

Figure 17. The Hoek-Brown criterion for the rock mass strength shown as the major stress ratio, and as the shear-normal stress ratio

Tabela 5.1. Ulazni parametri za klasifikaciju i rezultati procene sprovedene u programu „RocLab”  
 Table 5.1. Input parameters for classification and results of the "RocLab" evaluation

	Jedinica Unit	Serpentin čvrsti Serpentine is tight	Serpentin ispucali Serpentine fired	Serpentin drošina Serpentine debris
<b>Hoek Brown Klasifikacija</b> <b>Hoek Brown Classification</b>				
		Vrlo dobro ukleštena i neporemećena stenska masa	Delimično poremećena stenska masa s višepovršinskim uglastim blokovima i više diskontinuiteta	Loše uklinjena, jako zdrobljena stenska masa s mešavinom uglatih i zaobljenih blokova
sigci - čvrstoća na pritisak intaktne stenske mase sigci – intact uniaxial comp. strength	MPa	61	32	10
GSI		42	27	16
Mi		10	8	7
D – faktor poremećenja D – disturbance factor		0,7	0,9	1,0
Ei	MPa	33550	12000	2500
<b>Hoek Brown Kriterijum</b> <b>Hoek Brown Criterion</b>				
Mb		0.413033	0.069891	0.0173513
S		0.000223568	9.28322e-006	8.31529e-007
A		0.509923	0.527338	0.557147
<b>Failure Envelope Range</b>				
Application Slopes				
sig3max	MPa	0.587812	0.451053	0.35035
Specifična težina/ Unit weight	MN/m <sup>3</sup>	0.0273	0.0241	0.0226
Visina padine / Slope height	m	25	25	25
<b>Mohr-Coulombovi ekvivalentni parametri</b> <b>Mohr-Coulomb Fit (equivalent)</b>				
c - kohezija / c - cohesion	MPa	0.233107	0.0666606	0.0153415
$\hat{j}$ – ugao unutrašnjeg trenja Phi – friction angle	Stepen °	45.15	25.41	9.32468
<b>Parameteri stenske mase</b> <b>Rock Mass Parameters</b>				
sigt – čvrstoća stenske mase sigt – tensile strength	MPa	-0.0330182	-0.00425038	-0.000479232
sigc – jednoosna čvrstoća na pritisak sigc – jednoosna uniaxial compressive strength	MPa	0.839092	0.0710277	0.00409712
sigcm - globalna čvrstoća na pritisak sigcm - global strength	MPa	4.99556	0.929301	0.107443
Em – modul deformacije Em – deformation modulus	MPa	2191.55	334.923	55.827



Slika 18. Numerički modeli  
Figure 18. Numerical models

Tabela 5.2. Ulazni parametri za numeričku analizu stabilnosti, „Plaxis” – Mohr–Coulomb-ov model tla  
Table 5.2. Input parameters for the numerical stability analysis, "Plaxis" software, Mohr Coulomb soil model

Sloj Layer	$g_{unstat}$ [kN/m <sup>3</sup> ]	$E_{ref}$ [kN/m <sup>2</sup> ]	$n$	$c_{ref}$ [kN/m <sup>2</sup> ]	$j$ °	$G_{ref}$ [kN/m <sup>2</sup> ]	$E_{oed}$ [kN/m <sup>2</sup> ]	$V_s$ [m/s]	$V_p$ [m/s]	$K0$	$R_{inter}$
1	22,6	55827	0,20	15	9,32	23260	62030	100,4	164	0,838	1
2	24,1	334923	0,25	67	25,42	134000	401900	233,4	404,3	0,571	1
3	27,3	2191550	0,25	233	45,15	876600	2630000	561	971,6	0,291	1

### 5.3 Karakteristike elemenata podgrade

Za sprovođenje numeričke analize stabilnosti usvojeni su parametri podgradnih elemenata (sidra prema tabeli 5.3 i sidrišne zone prema tabeli 5.4).

### 5.3 Properties of the of supporting elements

For implementing the numerical stability analysis, the parameters of supporting elements were adopted (anchors according to Table 5.3 and anchoring zones according to Table 5.4).

Tabela 5.3. Parametri štapnih IBO sidara (230 kN) Ø 32 mm dužine 3,0 m  
Table 5.3. Parameters of the Ø 32 mm, 3.0 m IBO bar anchors (230 kN)

ID	Naziv Name	$A$ (m <sup>2</sup> )	$E$ (kN/m <sup>2</sup> )	$EA$ (kN/m)	$L$ - razmak(m)	$L$ sidra(m)	$n$	$Mp$ (kNm/m)	$Np$ (kN/m)
1	Sidro Anchor	0,000804248	$2 \times 10^8$	1.608495439E+05	1.0	3.0	0,25	1.00E+15	1.00E+15

Tabela 5.4. Parametri zone sidrenja prečnika Ø48 mm  
Table 5.4. Parameters of the Ø 48 mm anchorage zone

ID	Naziv /Name	$A$ (m <sup>2</sup> )	$E$ (kN/m <sup>2</sup> )	$EA$ (kN/m)	$Np$ (kN/m)
1	Zona sidrenja Anchorage zone	0,001809557	$3 \times 10^7$	5,428E+04	1.00E+10

Naglašavamo da je neophodno obratiti posebnu pažnju pri izboru vrste sidara koji će se upotrebiti pri izvođenju geotehničkih zahvata i stabilizaciji površinski izmjenjenih padina sa nepovoljnim fizičko-mehaničkim karakteristikama, kod kojih je izraženo prisustvo agresivnih voda, i gde se mogu očekivati razna delovanja čoveka na promeni konfiguracije terena (miniranje, iskop i sl.). Prema (EN 1537:1999) u zavisnosti od izbora strukturnih elemenata upotrebljenih za sidro i s obzirom na primenjenu antikorozivnu zaštitu sidra se dele na: privremena i trajna. Privremena sidra

Note that it is necessary to focus a special attention when selecting the types of anchors while performing geotechnical operations and stabilizing surface-altered slopes of poor physical and mechanical properties, where the presence of aggressive water is pronounced, and where a variety of terrain configuration-related human activities can be expected (mining, excavation, etc.). According to (EN1537: 1999), depending on the selection of structural elements used for the anchor and considering the applied corrosion protection, anchors are divided into: temporary and permanent anchors.



imaju ograničenu trajnost, do 24 meseca, postaju nepotrebna nakon nekih faza gradnje, kod njih je manje bitna antikorozivna zaštita, te imaju ograničeni monitoring, (mehanički usidrena sidra i sl.). Primenjuju se kao privremena zaštita građevinskih jama podzemnih objekata kod kojih je projektom predviđeno da opterećenje od okolnog tla, nakon izgradnje podzemnih etaža, preuzme konstrukcija budućeg objekta. Njima se često osigurava neophodna radna površina, kod izrade temelja većih objekata, mostova, brana i sl., gde će se nakon izgradnje izvršiti zatrpavanje i nivelacija okolnog prostora. Ukoliko je neophodno zadovoljiti uslov da je vek trajanja sidra jednak veku trajanja konstrukcije isključivo se primenjuju trajna sidra. To su uređaji koji moraju dugotrajno funkcionirati, zahtevaju obveznu antikorozivnu zaštitu i praćenje (naknadne kontrole sile, eventualna dotezanja zbog gubitka usled tečenja-puzanja), te osigurati trajnu stabilnost građevina usled raznih dejstava u eksploataciji. Takođe, da ukoliko se radi o faznom saniranju većih dužina nestabilnih padina, koje se izvode prema određenom vremenskom rasporedu, tada se u graničnim zonama mogu ugrađivati privremena sidra. Ona se u narednim fazama sanacije, kako napreduju geotehički radovi na trajnoj zaštiti i sanaciji padine, zamenjuju stalnim sidrima uz sve preduzete zaštitne mere na samim sidrima.

Iz navedenog sledi da se za sigurnost sidra obezbeđuje postupcima izvođenja koji garantuju trajnu zaštitu protiv uticaja korozije i sprečavaju pojavu najmanjeg oštećenja koji može prouzrokovati stvaranje korozije. Stoga, zaštititi od uticaja korozije treba posvetiti posebnu pažnju pri transportu, ugrađivanju i u toku eksploatacije objekta. Zbog značaja objekta i potrebe da se trajno stabilizuje padina i spreče bilo kakvi drugi procesi koji dovode do destabilizacije primenjuju se trajna sidra.

Ukupna površina padine na kojoj su izvedene predložene mere sanacije je 330,0 m<sup>2</sup>. Za sanaciju je upotrijebljeno 75 komada IBO samobušivih sidara (DYWIDAG-SYSTEMS R32N). Investiciona vrednost svih radova izvedenih na sanaciji padine iznosi cca 85,0 €/m<sup>2</sup> sanirane površine.

#### 5.4 Rezultati analize i njihova diskusija

Numerički model i analiza stabilnosti stenske padine za postojeće stanje i svaku fazu predviđenih radova i ugradnju sidara izvršena je u programu „Plaxis”. Dobijeni rezultati proračuna i faktora sigurnosti dati su u tabeli 5.5.

U geotehničkom modelu, za postojeće stanje stenske padine dobijen je faktor sigurnosti  $F_s=1,35$ , čija je vrednost znatno niža od zahtevanog faktora ( $F_s \geq 1,50$ ). Prva faza radova obuhvata „rasterećenje padine”, skidanje drobinskog materijala s padine, nakon čega je postignut  $F_s=1,59$  koji je iznad zahtevanog, ali – imajući u vidu da je reč o ispucalom serpentinu, podložnom brzom dezintegraciji usled atmosferskih i drugih uticaja – predloženo je zatvaranje površinskih pukotina nanošenjem sloja mlaznog betona sa sistemskim sidrenjem u zonu stabilnog serpentina. Nakon faze ugradnje prvog reda sidara, faktor sigurnosti je znatno veći ( $F_s=3,34$ ) i neznatno se povećava nakon svake naredne faze, te po završetku svih poduzetih mera sanacionih radova iznosi  $F_s=3,35$ .

Temporary anchors are of limited durability up to 24 months and unnecessary after some stages of construction; the corrosion protection is less important and their monitoring is limited (mechanically anchored bolts and the like). They are used as temporary protection of construction pits in underground facilities, where the load from the surrounding soil is anticipated by the project for the future object's structure after the completion of the underground floors. They often used to secure the necessary work surfaces, when laying the foundation for larger buildings, bridges, dams and the like, where the surrounding area should be backfilled and levelled after the completion of works. If it is necessary to satisfy the requirement that the lifetime of anchors should be the same as that of the structure, permanent anchors are exclusively applied. These devices need to work on a long run, require corrosion protection and monitoring (subsequent force controls, possible tightening due the creep-related loss), providing the structure with long-term stability due to various impacts during the service life. Temporary anchors can be installed also in cases when longer portions of unstable slopes are repaired in stages which are performed based on a specific time schedule. In these cases temporary anchors are installed in boundary zones. In the subsequent stages of repair, as the geotechnical works on the permanent protection and reparation of the slope progress these anchors are replaced with permanent anchors by taking the required protective measures at the anchors themselves.

Consequently, for ensuring the safety of anchors procedures are required for ensuring a permanent protection against the effects of corrosion and prevent even the minimum damage that can induce corrosion. Thus, corrosion protection should be given a special attention during transportation, installation and operation of facility. Permanent anchors will be applied because of the importance of the facility and the consequent need for permanent slope stabilization in order to prevent any process that leads to destabilization.

The overall area of the slope on which the proposed repair measures were undertaken amounts 330.0 m<sup>2</sup>. The repair was accomplished by using 75 pieces of self-drilling IBO anchors (DYWIDAG-SYSTEMS R32N). The investment value of the slope repair works was approximately €85.0 /m<sup>2</sup> of surface repaired.


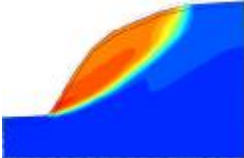
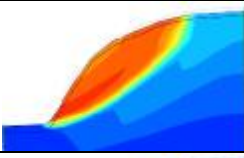
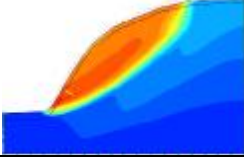
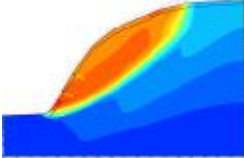
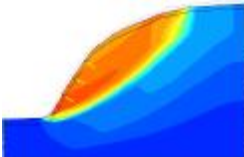
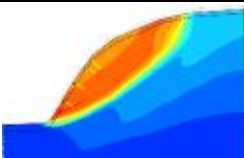
#### 5.4 Analysis and discussion of results

Numerical modelling and stability analysis of the rock slope for current condition and each phase of the planned works and installation of anchors were accomplished in the "Plaxis" software. The obtained calculation and safety factors results are presented in Table 5.5.

In the geotechnical model, for the current condition of the rock slope the safety factor is obtained as  $F_s = 1.35$ , which is much lower than the required value ( $F_s \geq 1.50$ ). The first phase of work includes "unloading" by removing the debris material from the slope; this phase resulted with  $F_s = 1.59$ , which is above the required level. However, given that it is cracked serpentine, which is the subject to rapid disintegration due to weathering and other effects, it was proposed to close the surface cracks by applying a layer of concrete along with a systematic anchoring into the stable serpentine zone. After installing

the first row of anchors, the safety factor is much higher ( $F_s = 3.34$ ), slightly increasing after each subsequent phase, while upon the completion of all repair works it is equal to  $F_s = 3.35$ .

Tabela 5.5. Ulazni parametri i rezultati analize stabilnosti padine po fazama  
Tabele 5.5. Input parameters and results of the stability analysis by phase

Faza sanacije Phase repair	Način sanacije Repair measures	Sidra Anchors (m.n.v)	Geotehnički parametri Geotechnical parameters	Analiza stabilnosti Stability analysis	Faktor sigurnosti Safety factor	Pomeranja Displacements (mm)
Postojeće stanje			Drobina serpentina sa tamnom glinom		$F_s=1,35$	41,19
Faza I skidanje raspadnutog materijala sa padine			$g = 226 \frac{kN}{m^3};$ $j = 9,3^\circ;$		$F_s=1,59$	35,75
Faza II prvi red sidara	DYWIDAG-systems R32N -dužina sidra L=3,0 m, -dužina sidrišne deonice LO=1,80 m, -promer sidrišta D= 0,048 m,	195	$c = 15 \frac{kN}{m^2};$  Ispucali serpentin:		$F_s=3,34$	17,11
Faza III drugi red sidara		199	$g = 241 \frac{kN}{m^3};$ $j = 25^\circ;$		$F_s=3,34$	16,47
Faza IV treći red sidara		203	$c = 66 \frac{kN}{m^2};$		$F_s=3,34$	14,98
Faza V četvrti red sidara		207	Čvrsti serpentin $g_2 = 27,3 \frac{kN}{m^3};$ $j = 45^\circ;$		$F_s=3,35$	13,70
Faza VI peti red sidara		209	$c = 233 \frac{kN}{m^2};$		$F_s=3,35$	12,70

Nakon ugradnje prvog reda sidara, dobijene su visoke vrednosti faktora sigurnosti, čime su zadovoljeni uslovi stabilnosti padine. Sprovedenjem ostalih faza sanacije ne utiče se bitno na povećanje sigurnosti, ali postiže se znatno smanjenje pomeranja površinskih slojeva stenske mase (62%).

Predviđenim radovima na sanaciji padine, znatno su smanjena pomeranja površinskih slojeva stenske mase. Analizom deformacija numeričkog modela geotehničke konstrukcije, maksimalne vrednosti pomeranja očekuju se u podnožju padine (tabela 5.5; slika 19).

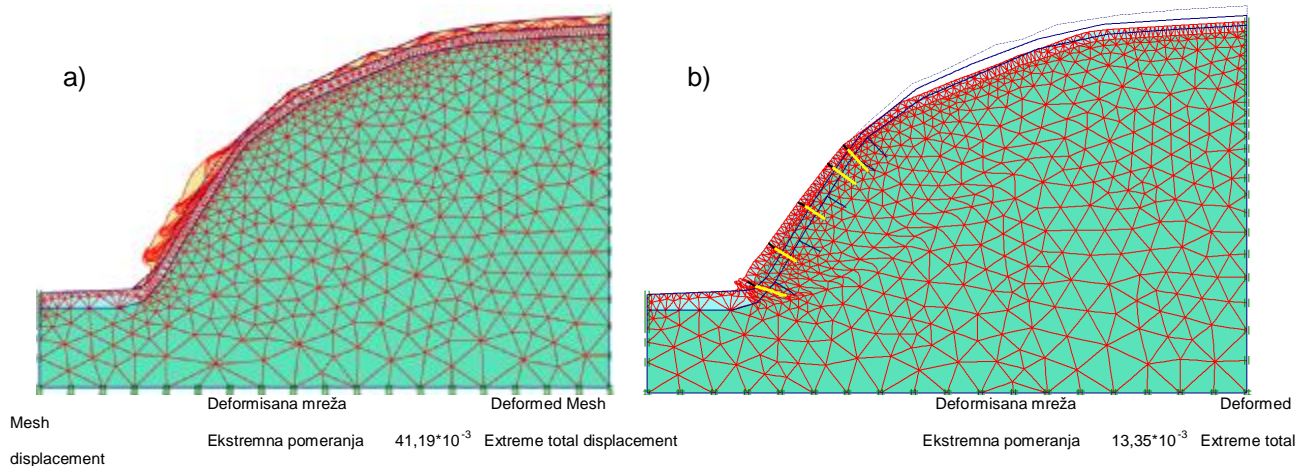
After installing the first row of anchors high safety factor values were obtained, meeting the conditions of slope stability. The implementation of other phases of reparation does not affect the increase of security to a significant degree. However, a considerable reduction has been achieved in displacements of the surface layers of rock mass (62%).

The planned repair works on the slope significantly reduced the displacement of the surface layers of rock mass. As indicated by the analysis of deformation of the geotechnical structure conducted on the numerical

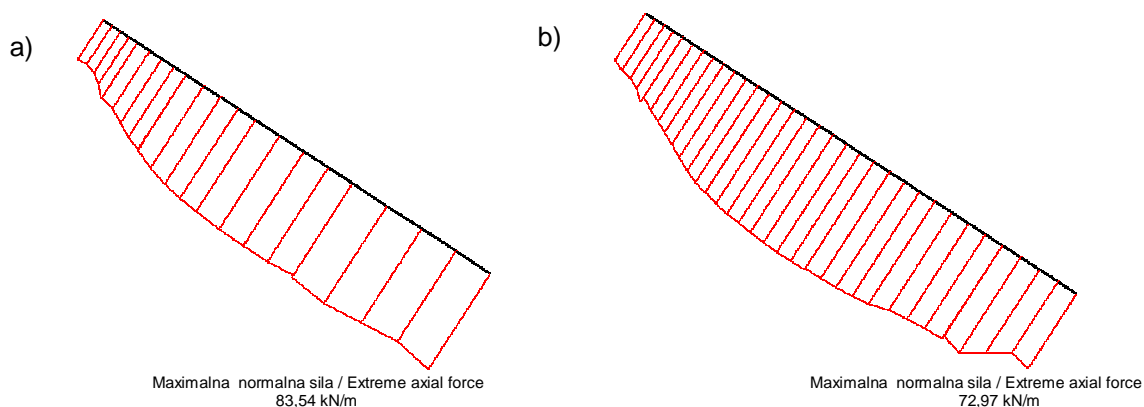
Nakon ugradnje prvog reda sidara max. sila u sidru iznosila je  $F=83,54$  kN. Po instaliranju drugog reda sila u istom sidru iznosila je  $F=77,35$  kN, a posle završetka sanacije max. sila je  $F=72,97$  kN. Evidentno je da se, završetkom svake naredne faze ugradnje, smanjuje intenzitet sile i naprezanja u sidrima koja su ugrađena u ranijim fazama (12,6%) (slika 20).

model, the maximum displacement values are expected to occur at the slope foot (Table 5.5). (Figure 19).

After the installation of the first row of anchors, the maximum force in the anchor was  $F = 83.54$  kN. After the installation of the second row of anchors, the maximum force in the same anchor was  $F = 77.35$  kN, while after the completion of repair works, the maximum force is  $F = 72.97$  kN. It is evident that after the completion of each subsequent phase of installation, the intensity of forces and stresses in the anchors installed in the previous phases has been reduced (12.6%) (Figure 20).



Slika 19. Deformacije padine a) Postojeće stanje b) Stanje nakon izvedenih radova na sanaciji  
Figure 19. Slope deformation: a) existing condition, and b) condition after the repair works



Slika 20. Naponi u sidru a) Ugrađen prvi red sidara b) Stanje nakon izvedene sanacije  
Figure 20. Anchor stresses: a) with the first row of anchors installed, and b) condition after the completion of repair works

Geološki indeks čvrstoće (GSI) predstavlja faktor čija vrednost bitno utiče na procenu parametara čvrstoće i deformabilnosti stenske mase, a time i na predviđanje ponašanje padine u celini. Indeks GSI određuje se na osnovu iskustva i subjektivne procene geotehničara ukupnog stanja strukture stenske mase, površine stene diskontinuiteta i geometrijskog oblika. Prema [11], vrednost geološkog indeksa čvrstoće za neporemećenu stensku masu iznosi  $GSI > 25$ , a za poremećenu stensku masu  $GSI < 25$ . Delimično poremećena stenska masa (čvrsti serpentin) ocenjena je u rasponu GSI od 51

The Geological Strength Index (GSI) is a factor the value of which significantly affects the estimation of parameters of strength and deformability of the rock mass, and thus the prediction of the overall slope behaviour. The GSI index is determined based on the geotechnician's experience and subjective evaluation regarding the overall condition of the rock mass structure, surface of rock discontinuities and the geometric shape. According to [11], the value of the Geological Strength Index for undisturbed rock mass is  $GSI > 25$ , while for the disturbed rock mass, this value is

do 42. Za proračun je uzeta najniža vrednost GSI = 42. Ispucali serpentin ima jako oštećenu površinu i ocenjen je u rasponu GSI od 42 do 27. Za proračun je uzeta najniža vrednost GSI = 27 (tabela 5.1).

Nesigurnost pri proceni svojstava stenske mase značajno utiče na projektovanje i izvođenje geotehničkih radova u stenskoj masi. Na osnovu dosadašnjih primera, istraživanja u ovom području pokazuju da su rasponi izračunatih faktora sigurnosti veoma veliki, čak i kada se koriste „najbolje” procene. Imajući u vidu važnost predmetnog objekta, te naglašenu subjektivnost procene vrednosti GSI, izvršena je dopunska analiza s ciljem utvrđivanja uticaja na stabilnost padine, u slučaju kada se takva procena vrednosti GSI za date slojeve stene umanji za 20%. U proračunu su uzete vrednosti za stabilni serpentin GSI = 38, a za ispucali GSI = 21. Nakon proračuna parametara čvrstoće i deformabilnosti stenske mase, te provedene numeričke analize dobijen je faktor sigurnosti  $F_s=2,69$ . U konkretnom slučaju, iako je faktor sigurnosti manji za 24 % ( $F_s=3,35$ ), stabilnost padine nije ugrožena.

Ukupno pomeranje nakon zadnje faze ugradnje sidara znatno je veće i iznosi 24,19 mm (90,5%), što je posledica manjih vrijednosti parametara čvrstoće i deformabilnosti stenske mase, a odražava se i na proračun odgovarajućih Mohr-Coulomb-ovih parametara.

Ovi rezultati ukazuju na to da dalji razvoj inženjersko-geoloških procesa, ukoliko bi taj razvoj bio moguć, a što bi uzrokovalo dalje promene stenske mase i time smanjenja njenih parametara čvrstoće, neće dovesti do drastičnih promena u pogledu zahtevanog faktora sigurnosti, odnosno njegova vrednost neće pasti ispod zahtevane. To je posebno značajno iz aspekta iznenadnog akcidentnog događaja loma stenske padine, jer takav karakter i red veličine izmene stenske mase zahteva duži period (izmene su niskog intenziteta i jasno uočljive tokom vremena). Redovan i sistematičan monitoring omogućuje pravovremenu identifikaciju tih promena, te preduzimanje geotehničkih mera zaštite na padini, kako bi se procesi zaustavili, a faktor sigurnosti zadržao na dostignutom nivou. Posebno je ohrabrujuća činjenica da predložena metoda sanacije obuhvata i geotehničke mere zaštite koje obezbeđuju visok nivo otpornosti u pogledu daljeg nepovoljnog razvoja inženjersko-geoloških procesa.

Međutim, iako faktor sigurnosti ostaje u granicama zahtevanog, ne može se zanemariti činjenica da, u ovoj situaciji, imamo značajno povećanje pomeranja, posebno u području stope padine. To ukazuje na mesto koje bi sasvim sigurno bilo mesto inicijacije procesa loma padine, te se zato posebna pažnja treba posvetiti ovom delu padine, prilikom planiranja, projektovanja i izvođenja sanacionih mera. Ovaj deo padine predstavlja neuralgično mesto, čijim se ispravnim geotehničkim sanacionim radovima ili radovima na zaštiti tog dela padine, eliminišu negativni uticaji savremenih inženjersko-geoloških procesa koji dezintegrišu stensku masu i padinu dovode u stanje nestabilnosti.

Očigledno je da procenjena vrednost GSI bitno utiče na našu percepciju ponašanja padine. Neophodno je posvetiti veliku pažnju pri klasifikaciji stenske mase, kako bi dobijeni rezultati u analizama i proračunima što realnije opisali stvarno stanje napona i deformacija padine.

GSI <25. The partially disturbed rock mass (solid serpentine) was evaluated in the GSI range of 51-42. The calculation was based on the lowest GSI = 42. The surface of cracked serpentine is severely damaged, receiving GSI ranging between 42-27. The calculation was based on the lowest GSI = 27, Table 5.1.

Uncertainty in estimating the rock mass properties significantly affects the design and the execution of geotechnical works in the rock mass. As indicated by previous research examples in this area, the ranges of calculated safety factors are very high, even when using the "best" estimates. Given the importance of the underlying subject, as well as the subjective nature of GSI evaluations, an additional analysis was performed in order to determine the impact on the slope stability in cases where such GSI evaluation for the given rock layers is reduced by 20%. In calculation, the GSI values were taken as 38 and 21, for stable and cracked serpentine, respectively. The calculation of parameters of strength and deformability of the rock mass, and the numerical analysis resulted by the safety factor of  $F_s = 2.69$ . The slope stability in this particular case is not compromised, even though the safety factor is lower by 24% ( $F_s = 3.35$ ).

The overall displacement after the last phase of installation of anchors is much larger – 24.19 mm (90.5%), resulting from the lower values of parameters of strength and deformability of the rock mass and it is reflected also to the calculation of the corresponding Mohr-Coulomb parameters.

These results suggest that the further development of engineering-geological processes (provided that this development is possible) that would lead to further changes in the rock mass and thus to the reduction in its strength parameters, will not lead to drastic changes in terms of the required safety factor, i.e. its value will not fall below the required. This is particularly important in terms of sudden accidental failure event of the rock slope, because such a nature and magnitude of changes in the rock mass requires a longer period of time (low-intensity and clearly visible changes over time). Regular and systematic monitoring allows these changes to be timely identified and to take geotechnical measures of protection on the slope, in order to stop the process and keep the safety factor at the same level. It is particularly encouraging that the proposed method of reparation includes also some geotechnical measures of protection that ensure a high level of protection against the further development of unfavourable engineering-geological processes.

However, even though the safety factor remains within the required boundaries, one cannot ignore the fact that in this situation we have significantly increased displacements, especially in the slope foot area, highlighting the place that would certainly be the location of initiation of slope failure processes. Thus, when planning, designing and implementing repair measures, the attention should be specifically focused on this part of the slope. This part of the slope is a neuralgic spot – through proper geotechnical or protective repair works performed on this part of slope the negative impacts of modern engineering and geological processes that facilitate the disintegration of the rock mass, leading to slope instability, would be eliminated.

Obviously, the estimated value of GSI significantly

## 6 ZAKLJUČCI I PREPORUKE

Izražene pojave površinskog raspadanja na stenskim padinama predstavljaju opasnost od obrušavanja manjih i većih blokova, što uslovljava prikladnu sanaciju. Na osnovu dostupne literature, uočljivo je da je ovaj problem vrlo malo istraživan i metodološki nedovoljno razvijen za primene u praksi s ciljem stabilizacije padine.

Rešenja ovog problema su uglavnom, do sada, bila na nivou jednostavnih intuitivnih inženjerskih rešenja bez ili uz jako malo (nužno potrebnih) analiza koje bi dale optimalno geotehničko rešenje. Zbog toga, postoje različite metode sanacije, uglavnom pojednostavljene, koje – prema dosadašnjim iskustvima – ne obezbeđuju dovoljnu trajnost izvedenih radova, jer nedovoljno sprečavaju nepovoljne inženjersko-geološke procese. Imajući to u vidu, predložene su metode za projektovanje i izvođenje radova na sanciji, koji uključuje adekvatan izbor materijala i tehnoloških postupaka. Model objedinjuje geotehničke, konstrukterske i izvođačke aspekte. On može poslužiti kao primer za rešavanje sličnih problema u serpentinama manje ili veće izmenjenosti (zona površinskog raspadanja stene male debljine), uz eventualne modifikacije saglasno lokalnim uslovima.

Pokazano je da je za predlog adekvatnog rešenja sanacije padine neophodna detaljna geološko-geotehnička kategorizacija stenske mase i zoniranje delova prema stepenu stabilnosti. Na osnovu rasporeda i položaja familija pukotina, pretpostavljeno je da globalna stabilnost padine nije ugrožena. Prema inženjersko-geološkim karakteristikama stenske mase koja sačinjava padinu, u slučajevima površinskog raspadanja, pouzdano se može koristiti Hoek–Brown-ov kriterijum loma, koji je primenjiv ili u intaktnoj steni ili u znatno raspucalim stenskim masama. Primena adekvatnih kompjuterskih programa, kao što je „RocLab“, omogućuje da se na vrlo jednostavan način procene svojstva stenske mase sa mogućnošću variranja ulaznih parametara i dobijanja varijantnih rešenja. Između ostalog, kao rezultat sprovedene analize, dobijeni su izračunati ekvivalentni Mohr–Coulomb-ovi parametri  $c$  i  $\varphi$  te modul deformacije  $E_m$  koji su neophodni za numeričku analizu.

Veoma je važna procena stanja postojeće padine te prognoza njene stabilnosti u zavisnosti od uticaja potencijalnih neželjenih faktora koji se mogu javiti tokom vremena. Na osnovu tih procena, uzimajući u obzir važnost objekata u njenom okruženju, biraju se adekvatne mere sanacije padine.

Predložene mere sanacije znatno će umanjiti dejstva koja vode daljnjoj dezintegraciji stene, sprečiti pokretanja potencijalno nestabilnih delova te povećati globalnu stabilnost padine uz smanjenje deformacija padine u celini. U prilog tome idu i dodatna ojačanja AB gredama na mestima gde je uočena lokalna nestabilnost pojedinačnih blokova. Dominantnu ulogu u izboru parametara sidrenja ima ispucalost stenskih masa, koja utiče na njenu deformabilnost.

Treba napomenuti da u drugačijim slučajevima, kada su pojave podzemne vode obilne ili kada je moguća značajna filtracija površinskih (oborinskih) voda u zaleđe padine, treba neizostavno uticaje vode uneti u proračunski model i analizirati zajedno sa ostalim ulaznim parametrima.

affects our perception of slope behaviour. It is necessary to focus great attention to the classification of the rock mass in order to get further results of analyzes and calculations that describe the actual stress-strain condition of the slope as realistically as possible.

## 6 CONCLUSIONS AND RECOMMENDATIONS

The pronounced occurrence of surface decomposition on rock slopes imposes a risk of collapse of smaller and larger blocks which requires adequate reparation. Based on the available literature this problem is obviously insufficiently investigated, and its methodology scarcely developed for practical application with the goal of stabilizing the slopes.

So far, this problem has mainly been resolved at the level of simple intuitive engineering solutions without any or very little (but required) analyses that would lead to optimal geotechnical solutions. Therefore, various repair methods (mostly simplified) are used which, according to past experience, fail to provide construction works with sufficient durability given their insufficient ability of preventing adverse engineering-geological processes. Having this on mind, a model has been proposed for designing and executing repair works that include appropriate choice of materials and technologies. The model combines geotechnical, designing and building aspects. It can serve as a model for solving similar problems in serpentines of minor or major level of changes (zone of surface disintegration of rocks of small thickness), with possible alterations in accordance with local conditions.

It is shown that the proposal for the adequate slope reparation requires a detailed geological and geotechnical rock mass categorization and section zoning according to the degree of stability. Based on the layout and position of the set of cracks, it is assumed that the global slope stability is not compromised. Based on the engineering-geological properties of the rock mass of which the slope consists, in the case of surface decomposition, the Hoek-Brown failure criterion can be reliably used – it can be applied either in the intact rock or in the significantly fractured rock masses. Using the appropriate computer programs, such as the "RocLab", allowing the possibility of varying the input parameters and obtaining alternative solutions, the properties of the rock mass can be evaluated in a rather straightforward manner. Among the other things, the analysis resulted with the calculation of the equivalent Mohr-Coulomb parameters  $c$  and  $\varphi$ , as well as the modulus of deformation  $E_m$ , required by numerical analysis.

It is highly important to estimate the condition of the existing slope and forecast its stability depending on the potential adverse impact of unwanted factors which may occur over time. The adequate slope repair measures are selected based on these estimates, and taking into account the importance of facilities in its environment.

The proposed repair measures will significantly reduce the effects that lead to further rock disintegration, preventing the initiation of potentially unstable parts and increasing the global stability by reducing the overall slope deformation. This is facilitated also by the additional reinforcement by RC beams in places where a local instability of individual blocks is observed. The level of cracking of rock mass is crucial in selecting anchoring

U konkretnom slučaju su, zbog prethodno rečenog, ugrađena trajna sidra, ali je moguća ugradnja i privremenih sidara u zavisnosti od uslova na padini i planiranih procedura izvođenja sanacionih mera na padinini, što je specifičnost svakog slučaja za sebe i u tom smislu je modifikacija tipa sidra moguća.

Monitoring i povratna analiza veoma su bitni algoritamski koraci, čak neophodni. Oni:

- obezbeđuju procenu izvršene sanacione mere ali i procenu tačnosti odabira i proračuna neophodnih ulaznih parametara u postupku analize;

- omogućuju nam korekciju tih parametara te utvrđivanje najverovatnijih kvantitativnih vrednosti na osnovu kojih se ocenjuje stabilnost padine, a na osnovu toga, planiraju se, projektuju i izvode geotehnički zahvati koji će modifikovati postojeće sanacione radove i povećati njihov stepen efikasnosti odnosno učiniti ih optimalnim geotehničkim rešenjem.

Prikazana analiza i geotehničko rešenje prihvatljivi su i u tehničkom i u ekonomskom pogledu.

parameters, which affects its level of deformability.

It should be noted that in different cases, where the occurrence of groundwater is significant or when there is a possibility of significant surface water (precipitation) filtration in the slope backing, the impacts of water should be unconditionally included into the calculation model and analyzed along with other input parameters.

In this specific case, because of the above facts, permanent anchors were installed, but it is possible to install also temporary anchors, depending on the slope conditions and planned repair procedures on the slope, which is again case-specific and allows the anchor type to be altered.

Monitoring and feedback analysis are very important, even necessary algorithmic steps.

- They enable the repair measures to be evaluated, as well as the evaluation of accuracy of selection and calculation of required input parameters in the analysis process.

- They allow the correction of these parameters and determine the most probable quantitative values based on which the slope stability is evaluated and based on which the geotechnical procedures of modifying the existing repair works and increasing their level of efficiency, making them optimal geotechnical solutions, are planned, designed and performed.

The above analysis and geotechnical solution are acceptable both in technical and economic terms.

## Zahvalnost

Ovaj rad je deo istraživanja u okviru projekta TR 36017 koji podržava Ministarstvo za obrazovanje i nauku. Autor R. Folić se na tome zahvaljuje.

## Acknowledgements

The work reported in this paper is a part of the investigation within the research project TR 36017 supported by the Ministry for Science and Education, Republic of Serbia. This support is gratefully acknowledged (R. Folić).

## 7 LITERATURA REFERENCES

- [1] Arbas, Ž.: *Projektiranje u stijenskim masama*, Tečaj stručnog usavršavanja, Rijeka 2008.
- [2] Brunčić, A., Jurić-Kačunić, D., Kovačević, M.S.: *Projektiranje i izvedba zasjeka u flišnoj stijenskoj masi*, Građevinar 62 1, str.13-23, 2010.godine.
- [3] Građevinski fakultet Beograd: *Geomehanički elaborat*, Beograd, 1956.
- [4] Milovanović, D.: *Glavni projekat brane Modrac*, Građevinski fakultet Beograd, 1961.
- [5] Stević, M., Mulać, M.: *Elaborat o geološkim i geomehaničkim ispitivanjima temeljnog tla za potrebe sanacije terena i izrade potpornog zida na brani Modrac*, „Earth“ d.o.o. Tuzla, Novembar 2005.
- [6] Stević, M., Mulać, M.: *Stručno mišljenje o geološkim karakteristikama terena i opštim geološkim uslovima izvođenja planirane sanacije brane Modrac*, „Earth“ d.o.o. Tuzla, Novembar 2007.
- [7] Džindo, A.: *Stručno mišljenje o uzrocima oštećenja padine na desnom nizvodnom boku akumulacije Modrac sa prijedlogom mjera sanacije*, „Werkos ing“ d.o.o. Tuzla, 2011.
- [8] Folić, R., Memić, M.: *Pregled tehnika poboljšanja tla I stabilizacije kosina pri gradnji brana*, Zbornik radova – Geotehnički aspekti građevinarstva, str. 221-230, SGIS, novembar.2011. godine.
- [9] Memić, M., Folić, R.: *Sanacija padine desnog boka nizvodno od objekta brane „Modrac“*, Zbornik radova Geotehnički aspekti građevinarstva, str. 267-274, SGIS, novembar.2011. godine.
- [10] Hoek, E.; Carranza-Torres, Corkum, B.: *Hoek-Brown Failure Criterion-2002 Edition*, Proceedings of 5<sup>th</sup> North American Rock Mech. Symp., Toronto, Canada, Dept. Civ. Eng., University of Toronto (2002) pp. 267-273.
- [11] Hoek, E and Diederichs, M.S. (2006), *Empirical estimation of rock mass modulus*. International Journal of Rock Mechanics and Mining Sciences, 43, 203–215, 2006.g.
- [12] Hoek, E., Brown, E.T *Practical Rock Engineering-An Ongoing Set of Notes*, available on the Rocscience website

- [13] Hoek, E., Brown, E.T., (1980a), *Underground Excavations in Rock*, Institution of Mining and Metallurgy, London.
- [14] Hoek, E., Brown, E.T., (1980b), *Empirical Strength Criterion for Rock Masses*, Jour. Geotech. Engng. Div., ASCE 106, (GT9), pp. 1013-1035.
- [15] Hoek, E., Brown, E.T., (1997), *Practical Estimates of Rock Strength*, Int. J. Rock Mech. & Mining Sci. & Geomechanics Abstracts, Vol. 34 (8), pp. 1165-1187.
- [16] Hoek, E., (1991), *When is a Design in Rock Engineering Acceptable?*, In: Proc. 7<sup>th</sup>. Int. Congress on Rock Mech. (Aachen, 1991), Vol. 3, Rotterdam: A. A. Balkema.
- [17] Hoek, E., Kaiser, P.K., Bawden, W.F., (1995), *Support of Underground Excavations in Hard Rock*, Rotterdam: A.A. Balkema, 215 p.
- [18] Marinou, P., Hoek, E., (2001), Estimating the Geotechnical Properties of Heterogeneous Rock Masses such as *Flysch*, Bull. Eng. Geol. Env., 60, pp 85-92.
- [19] Hoek, E., Bray, J.W., (1977) *Rock Slope Engineering, revised second edition*, The Institute of Mining and Metallurgy, London, 402 p.
- [20] Ibrahimović, A., "Teorije loma stijenskog materijala u rješavanju stabilnosti građevinskih objekata u stijenskoj masi", Magistarski rad, RGGF, Univerzitet u Tuzli, 2003.

## REZIME

### METODE NUMERIČKOG MODELIRANJA I SANACIJE NESTABILNE PADINE U IZMENJENOJ SERPENTINSKOJ STENSKOJ MASI

Mirza MEMIĆ  
Radomir FOLIĆ  
Adnan IBRAHIMOVIĆ

Sanacije padine u dezintegriranoj i površinski izmenjenoj stenskoj masi predstavlja problem koji se javlja vrlo često u inženjerskoj praksi. Kvalitetno rešenje iziskuje inženjersko-geološko kartiranje postojećeg stanja detaljno istraživanje stanja stabilnosti padine, te izrade projekta sanacije. U ovom radu predložen je model projektovanja i izvođenja radova na sanaciji izmenjene i nestabilne stenske mase. Projektno rešenje se zasniva na: terenskim i laboratorijskim ispitivanjima stanja stenske mase i diskontinuiteta, utvrđivanju kriterijuma loma sa procjenom čvrstoće i deformabilnosti stenske mase i stanja diskontinuiteta neophodnih za geostatičku analizu te predlogom mera sanacije. U radu je predložen princip i tehnologija saniranja stenskih padina, koji može poslužiti kao primer za rešavanje sličnih slučajeva u praksi. Cilj i osnovna strategija ovakve sanacije je sprečavanja pokretanja potencijalno nestabilnih delova padine te smanjenje i neutralizacija nepoželjnih inženjersko-geoloških procesa koji utiču na daljnju dezintegraciju stene. Detaljno je opisana metodologija klasifikovanja i određivanja parametara čvrstoće i deformabilnosti stenske mase. Model je ilustriran na konkretnom objektu (case study), uz opis svih faza koje prethode projektovanju i izvođenja radova. To je učinjeno na primeru sanacije oslonačke padine brane „Modrac“ - BiH, koju sačinjava stena serpentin različitog stepena izmenjenosti. Prikazana praktičana primena predloženog modela može biti od koristi i kod rešavanju sličnih problema.

**Cljučne reči:** stabilnost padine, sanacija, štapna sidra, mlazni beton, stabilizaciona rebra, galvanizirana armaturna mreža

## SUMMARY

### NUMERICAL MODELING AND SLOPE REPARATION METHODS IN AN ALTERED AND UNSTABLE SERPENTINE ROCK MASS

Mirza MEMIĆ  
Radomir FOLIĆ  
Adnan IBRAHIMOVIĆ

Slope reparation in disintegrated and surface-altered rock mass is a frequently occurring problem in engineering practice. A high-quality solution requires engineering-geological mapping of the current state, a detailed slope stability inspection, as well preparing a reparation project. In this paper, the authors have proposed a design and construction model for repairing the altered and unstable rock mass. The project design is based on field and laboratory investigations regarding the state of the rock mass and its discontinuities, establishing the failure criteria along with the estimations regarding the strength and deformability of the rock mass and the condition of discontinuities required for geostatic analysis, as well as based on a repair proposal. The paper proposes a rock slope repairing principle and technology, which can serve as a model for resolving similar cases in practice. The aim and the basic strategy of this reparation are to prevent the potentially unstable parts of slope from moving and to reduce and neutralize the undesirable engineering-geological processes affecting the further disintegration of rocks. A detailed description of methodology is provided for classifying and determining the parameters of strength and deformability of the rock mass. The model is illustrated with a specific example (case study), describing all phases that precede the phases of design and construction. The authors used the example of repairing the support slope of the "Modrac" dam (Bosnia and Herzegovina), consisting of serpentine rocks of different degrees of alteration. The practical application of the proposed model may be useful also in solving similar problems.

**Key words:** slope stability, repair, bar anchors, jet concrete, stabilizing ribs, galvanized steel mesh.

## UPUTSTVO AUTORIMA\*

### Prihvatanje radova i vrste priloga

U časopisu Materijali i konstrukcije štampaće se neobjavljeni radovi ili članci i konferencijska saopštenja sa određenim dopunama ili bez dopuna, prema odluci Redakcionog odbora, a samo izuzetno uz dozvolu prethodnog izdavača prihvaćaju se i objavljeni rad. Vrste priloga autora i saradnika koji će se štampati su: originalni naučni radovi, prethodna saopštenja, pregledni radovi, stručni radovi, konferencijska saopštenja (radovi sa naučno-stručnih skupova), kao i ostali prilozi kao što su: prikazi objekata i iskustava - primeri, diskusije povodom objavljenih radova i pisma uredništvu, prikazi knjiga i zbornika radova, kao i obaveštenja o naučno-stručnim skupovima.

*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 kratko, jasno i objektivno, ali tako da poznavalac problema može proceniti rezultate eksperimentalnih ili teorijsko numeričkih analiza i tok razmišljanja, 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. U ovu kategoriju spadaju i diskusije o objavljenim radovima ako one sadrže naučne doprinose.

*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 raspravljani, takvi pregledni radovi se klasifikuju kao stručni pregledni 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. On sadrži i rezultate razvojnih istraživanja.

*Konferencijsko saopštenje* ili rad sopšten na naučno-stručnom skupu koji mogu biti objavljeni u izvornom obliku ili ih autor, u dogovoru sa redakcijom, bitno preradi i proširi. To mogu biti naučni radovi, naročito ako su sopštenja po pozivu Organizatora skupa ili sadrže originalne rezultate prvi put objavljene, pa ih je korisno uz određene dopune učiniti dostupnim široj stručnoj javnosti. Štampaće se i stručni radovi za koje Redakcioni odbor oceni da su od šireg interesa.

*Ostali prilozi* su prikazi objekata, tj. njihove konstrukcije i iskustava-primeri u građenju i primeni različitih materijala, diskusije povodom objavljenih radova i pisma uredništvu, prikazi knjiga i zbornika radova, kao i obaveštenja o naučno-stručnim skupovima.

Autori uz rukopis predlažu kategorizaciju članka. Svi radovi pre objavljivanja se recenziraju, a o prihvatanju za publikovanje o njihovoj kategoriji konačnu odluku donosi Redakcioni odbor.

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 zbog eventualnog oštećenja ili gubitka rukopisa.

**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.**

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.

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 telefone, faks i adresu elektronske pošte, a za ostale autore poštansku adresu.

Uz sažetak (rezime) od oko 150 do 200 reči, na srpskom i engleskom jeziku daju se ključne reči (do deset). To je jezgrovit prikaz celog članka i čitaocima omogućuje uvid u njegove bitne elemente.

Rukopis se deli na poglavlja i potpoglavlja 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 definišu 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-belom tehničkom, u formatu koji obezbeđuje da pri smanjenju na razmere za štampu, po širini jedan do dva stupca (8cm ili 16.5cm), a po visini najviše 24.5cm, ostanu jasni i čitljivi, tj. da veličine slova i brojeva budu najmanje 1.5mm. Originalni crteži treba da budu kvalitetni i u potpunosti pripremljeni za presnimavanje. Mogu biti i dobre, oštre i kontrastne fotokopije. Koristiti fotografije, u crno-belom tehničkom, na kvalitetnoj hartiji sa oštrim konturama, koje omogućuju jasnu reprodukciju. Skraćenice u prilogima koristiti samo izuzetno uz obaveznu legendu. Prilozi se posebno označavaju arapskim brojevima, prema redosledu navođenja u tekstu. Objašnjenje tabela daje se u tekstu.

Potrebno je dati spisak svih skraćenica korišćenih u tekstu.

U popisu literature na kraju rada daju se samo oni radovi koji se pominju u tekstu. Citirane radove treba prikazati po azbučnom 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 navesti 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...». Neobjavljeni članci mogu se pominjati u tekstu kao «usmeno saopštenje».

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 prilogima.

Za detaljnija tehnička uputstva za pripremu rukopisa autori se mogu obratiti Redakcionom odboru časopisa.

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](mailto:folic@uns.ac.rs) ili [miram@uns.ac.rs](mailto:miram@uns.ac.rs) i [dimk@ptt.rs](mailto:dimk@ptt.rs)

Web sajt Društva i časopisa: [www.dimk.rs](http://www.dimk.rs)

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



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



**INŽENJERSKA KOMORA SRBIJE**

**MINISTARSTVO ZA NAUKU I TEHNOLOŠKI  
RAZVOJ SRBIJE**



**UNIVERZITET U BEOGRADU  
GRAĐEVINSKI FAKULTET**



**DEPARTMAN ZA GRAĐEVINARSTVO  
FAKULTET TENHIČKIH NAUKA NOVI SAD**



**INSTITUT IMS AD, BEOGRAD**



**UNIVERZITET CRNE GORE  
GRAĐEVINSKI FAKULTET - PODGORICA**