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UTICAJ ZONE LOMA IZNAD PODZEMNE PROSTORIJE NA OPTEREĆENJE KONSTRUKCIJE SA VISEĆOM PODGRADOM

IMPACT OF A FAILURE ZONE ABOVE THE UNDERGROUND ROADWAY ON ROCKBOLTING STRUCTURE LOADING

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Ključne reči
- osobine stena
- podzemne prostorije
- viseća podgrada
- sidra

Izvod

U ovom radu je prezentovan razvoj numeričkog modela interakcije stenskog masiva i viseće podgrade ugrađene u boksit. Glavni cilj je bio modeliranje degradacije stene po konturi podzemne prostorije i uticaj ove pojave na opterećenje sidra. Rezultati ovakve analize se mogu koristiti za planiranje odgovarajućih mera u smislu sprečavanja dalje degradacije masiva ili ugradnje dopunske podgrade. Numeričko modeliranje je urađeno metodom konačnih elemenata, korišćenjem programa Phase2.

Keywords
- rock properties
- roadways
- rockbolting structure
- roof support

Abstract

Research in this article presents development of model of strata interaction with roof support installed in bauxite. The main task of this research is modelling of rock degradation over the surface of underground roadway and its impact on the loading of rockbolts. Results of such analysis can be used for planning appropriate measures for the prevention of rock degradation or installation of additional support. The numerical model is based on the finite element method, using Phase2 software.

UVOD

Prethodno obavljena istraživanja u Srbiji /9-12/ dala su povoljne rezultate vezane za primenu sidra kao glavnih oslonaca u podzemnim rudnicima. Istraživanja obavljena u RMU Rembas, /8/, obuhvatala su instalaciju sa smolom vezanim sidrom kao osloncem, u obliku punog stuba, koji je simetrično postavljen duž podzemnih prostorija sa rasponom od skoro 100 m. Jedan od zaključaka je bio da pojava degradacije stena duž konturne površine podzemnih prostorija predstavlja problem koji zahteva posebnu pažnju, s obzirom da su merenja ukazala na korelaciju između degradacije stena i povećanog opterećenja na sidru.

Fragmentacija stena je u najvećoj meri prouzrokovana velikim deformacijama. Deformacije počinju da se javljaju odmah nakon iskopavanja, i često se stabiliziraju reakcijama ugrađenih oslonaca, čime se sile dovode u ravnotežu. Međutim, u nekim slučajevima, početne karakteristike stene su pogoršane, što dovodi do degradacije. Degradacija stena, tj. njihovih osobina je bila predmet proučavanja, kako u Srbiji, tako i u inostranstvu, /1-3/, ali je prisutan nedostatak informacija vezan za uticaj na mehaničke konstrukcije, poput sidra, u oblasti podzemnih rudnika.

INTRODUCTION

Previous research conducted in Serbia /9-12/ provided favourable results to application of rockbolting as a primary support in underground mines. Research performed in RMU Rembas, /8/, included installation of full-column resin bonded rockbolting support, which was systematically installed in single roadway along the distance of almost 100 m. One of the conclusions was that occurrence of rock deterioration along the contour-surface of the roadway is the issue which requires special attention, since measurements indicated the correlation between deterioration of rock with increased loading of rockbolts.

Rock fragmentation is mainly induced by higher deformation. Deformation starts immediately after excavation, and it is commonly stabilized with reaction of the installed support, reaching the equilibrium of forces. However, in some cases initial properties of rock are reduced, causing its deterioration. Deterioration of rock, i.e. its properties was a subject of research both in Serbia and abroad, /1-3/, but there is a lack of information related to its impact on mechanical structures, such as rockbolts, in underground mining engineering.

Istraživanje prikazano u ovom radu predstavlja pokušaj da se analizira uticaj degradiranih stena na već postojeće oslonce (sidra), bez obzira na poreklo degradacije osobina stena. U tu svrhu je primenjen Hoek-Braun kriterijum loma, sa osnovnom idejom da se smanjenje laboratorijskih vrednosti određenih fizičkih i mehaničkih osobina izvrši istom metodom, kako bi se izbegla nasumičnost pri izboru faktora korekcije. Ovo će izvesno uticati na mogućnost pouzdanije primene rezultata ove analize na procenu bezbednosti rada.

OPIS OSLONCA-SIDRA

Sidro je proizvedeno od ugljeničnog čelika homogene strukture sa sledećim osobinama: sadržaj ugljenika (C) - max. 0,3%, mangan (Mn) - max. 1,6%, sumpor (S) - max. 0.05%, fosfor (P) - max 0,3%. Nominalni zatezni napon ovakvog sidra iznosi od 640 do 720 MPa, dok su maksimalni zatezni naponi 20% veći (približno 860 MPa). Sistem sidro-smola mora da izdrži smičuću silu od min. 250 kN.

Poprečni presek sidra je kružan, sa prečnikom 21.7 ± 0,2 mm. Površina sidra ima profil od 0.5 do 1.0 mm u visinu, u obliku spiralne žice sa korakom od 9 do 14 mm (čelik za armaturu). Sidro je isečeno pod uglom od 45° na jednom kraju u odnosu na osu, sa M24×3 hladno valjanim žicama minimalne dužine 150 mm na drugom kraju. Prihvatljivo odstupanje zavrtnjeva duž ose je 0,4%.

Treba napomenuti da se sklop sidra takođe sastoji od zavrtnja sa lomljivim čivijama, pločama i koničnim uloškom. Zavrtanj je napravljen od čelika kvaliteta 4.8 ili 5.6, visine 26 mm. Korišćena je žica M24×3 (7H). Lomljiva čivija je dimenzionisana tako da može da izdrži torziju koja se javlja tokom ugrađivanja sidra u smolu. Do smicanja u čiviji dolazi pri opterećenju torzijom od 96 do 175 Nm.

Ploča, koja se nalazi između zavrtnja i stene, je napravljena od ugljeničnog čelika debljine 8–10 mm, u obliku kvadrata sa stranicama 100–150 mm. Centralni deo ploče je zaobljen kako bi se obezbedilo ugrađivanje sidra u slučaju nepoklapanja osa (površina) sa uglom do ±18°. Druga funkcija zaobljenog dela je da primi energiju (opterećenje sidra), što znači da je predviđeno da se ovaj deo ispravi pri opterećenju od 140-200 kN. Pri većem opterećenju (iznad 210 kN), otvor u sredini ploče se deformiše i oslobađa opterećenje sidra, čime se sprečava lom žice zavrtnja.

Konični uložak je napravljen od livenog gvožđa, sa spoljnim prečnikom ϕ46,7 mm, unutrašnjim prečnikom ϕ25 mm i visinom od 21 mm. Svrha ove komponente je da ravnomerno rasporedi opterećenje sa ploče na zavrtanj i, samim tim, na žicu u slučaju nepoklapanja pri ugrađivanju sidra. Na sl. 1 je prikazan sklop žice, zavrtnja, smicajne čivije i ostalih detalja na kraju sidra.

Kontakt između sidra i stene se ostvaruje preko smole. Smola se dostavlja u kapsulama prečnika 24 mm. Kapsula sadrži dve komponente, poliesterske smole i katalizatora. Očvršćavanje smole se postiže mešanjem ovih komponenata.

Bitni parametri smole vezani za pravilnu ugradnju i pouzdanost sidra su vreme u stanju gela i vreme početnog otvrdnjavanja. Vreme u stanju gela je period tokom kojeg viskoznost smole ostaje nepromenjena, i počinje sa početkom mešanja. Vreme početnog otvrdnjavanja predstavlja

Research described in this paper is an attempt to analyse impact of deteriorated rock on the already installed support (rockbolts), regardless to origins of the deterioration of rock properties. For this purpose, Hoek-Brown failure criteria is applied, with the basic idea to reduce laboratory values of certain physical and mechanical properties by using the same method, in order to avoid arbitrariness in selecting correction factors. This will certainly affect the reliability of applying analysis results in evaluating operational safety.

DESCRIPTION OF THE ROCKBOLTING SUPPORT

The rockbolt is manufactured of homogenous structural carbon steel of following contents: carbon (C) – max. 0.3%, manganese (Mn) – max. 1.6%, sulphur (S) – max. 0.05%, phosphorus (P) – max. 0.3%. Nominal tensile load of these rockbolts is from 640 to 720 MPa, while the tensile strength is 20% higher (approx. 860 MPa). The rockbolt–resin system must withstand the shearing force of min. 250 kN.

Cross section of the rockbolt is circular, with diameter of 21.7 ± 0.2 mm. Surface of the rockbolt has a 0.5 to 1.0 mm profile height, in the shape of a helicoid thread pitch from 9 to 14 mm (rebar steel). Rockbolt is cut at angle of 45° at one end in relation to axis, while the M24×3 cold rolled thread with minimal length of 150 mm is at the other end. Acceptable bolt deviation along the axis is 0.4%.

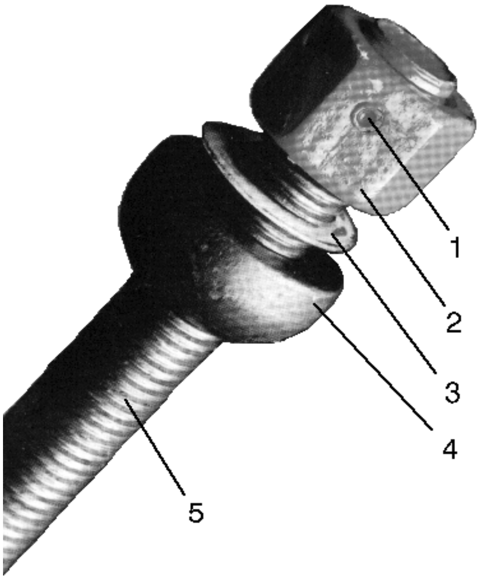
It should be mentioned that rockbolt assembly comprises also of nut with shear pin, plate and domed inlay. Nut is made of 4.8 or 5.6 quality steel, with 26 mm height. Nut thread is M24×3 (7H). Shear pin is sized in such manner to withstand torque during installation of the rockbolt through the resin. The pin is sheared when it is loaded with torque from 96 to 175 Nm.

The plate, located between the nut and the rock, is made of carbon steel of thickness 8–10 mm, squared shaped with sides 100–150 mm. Central part of the plate is domed in order to install the rockbolt in case of axes misalignment (surfaces) up to the angle of ±18°. A second function of the domed part is to consume the energy (rockbolt loading), meaning that this part is designed to flatten when loaded to 140–200 kN. At higher loads (above 210 kN), the hole at the centre of the plate will deform and release the loading of the bolt, thus preventing failure of the bolt thread.

The domed inlay is made of cast iron with outer diameter ϕ46.7 mm, inner diameter ϕ25 mm, and height of 21 mm. The purpose of this component is to equally distribute the load from the plate to nut and consequently to the thread in case of misaligned installation of the rockbolt. Figure 1 shows the assembly of the thread, nut, shear pin and other details at the end of the bolt.

Contact between the bolt and rock is achieved with resin. Resin is supplied in capsules 24 mm in diameter. The capsule contains two components, one of which is polyester resin and the other is the catalyst. Hardening of the resin is achieved by mixing these components.

Important parameters of resin related to proper installation and reliability of rockbolts are the gel time and initial curing time. Gel time is a period during which the viscosity of the resin remains unchanged, and starts at the beginning of components mixing. Initial curing time is a period of



Slika 1. Sklop zavrtnja sa lomljivom čivijom: 1 - lomljiva čivija; 2 - zavrtanj; 3 - podloška; 4 - konični umetak; 5 - sidro
Figure 1. Assembly at the end of the rockbolt: 1 – shear pin; 2 - nut; 3 - washer; 4 – domed inlay; 5 – bolt.

period otvrdnjavanja smole pre dostizanja dovoljne čvrstoće za naknadno zatezanje sidra okretanjem zavrtnja na njegovom kraju.

Osnovne mehaničke osobine očvrsle smole su pritisna čvrstoća od min. 80 MPa posle 24 č., modul elastičnosti od min. 11 GPa posle 24 č. i dilatacija od max. 0.12% posle 24 č.

GENERALISANI HOEK-BRAUN KRITERIJUM

Hoek-Braun kriterijum loma, /4/, za stenske mase je masovno prihvaćen i primenjen u velikom broju projekata širom sveta, posebno u dizajnu podzemnih iskopavanja u čvrstim stenama. Ovaj kriterijum je zasnovan na osobinama netaknutih stena i potom je uveo faktore na osnovu kojih se ove osobine umanjuju na osnovu zglobova u stenskim masama. Uzimajući u obzir da je Hoek-Braun kriterijum loma opšte prihvaćen i često korišćen u praksi, dati su samo glavni principi proračuna. Generalisani Hoek-Braun kriterijum se može izraziti kao:

$$\sigma_1' = \sigma_3' + \sigma_{ci}\left(m_b \frac{\sigma_3'}{\sigma_{ci}} + s\right)^a \qquad (1)$$

gde su σ_1' i σ_3' najveći i najmanji glavni napon pri lomu i σ_{ci} je jednoosna pritisna čvrstoća netaknute stene, i gde je m_b umanjena vrednost materijalne konstante m_i, koja je data kao:

$$m_b = m_i \exp\left(\frac{GSI - 100}{28 - 14D}\right) \qquad (2)$$

gde su s i a konstante stenske mase, definisane preko sledećih relacija:

$$s = \exp\left(\frac{GSI - 100}{9 - 3D}\right) \qquad (3)$$

gde GSI (indeks geološke čvrstoće) prestavlja vezu između kriterijuma loma i geoloških posmatranja u polju, dok je m_i materijalna konstanta za netaknutu stenu.

resin hardening before achieving sufficient strength to withstand post-tensioning of the rockbolt by turning the nut at its end.

Basic mechanical properties of hardened resin are compressive strength, min. 80 MPa after 24 h, elasticity modulus min. 11 GPa after 24 h and dilatation max. 0.12% after 24 h.

GENERALIZED HOEK-BROWN CRITERION

The Hoek-Brown failure criterion /4/ for rock masses is widely accepted and has been applied in a large number of projects around the world, especially for the design of underground excavations in hard rock. The criterion started from the properties of intact rock and then introduced factors to reduce these properties on the basis of the characteristics of joints in a rock mass. Considering that Hoek-Brown failure criterion is generally accepted and used in practice only main calculations principles is given. Generalized Hoek-Brown criterion is expressed as:

$$\sigma_1' = \sigma_3' + \sigma_{ci}\left(m_b \frac{\sigma_3'}{\sigma_{ci}} + s\right)^a \qquad (1)$$

where σ_1' and σ_3' are the major and minor effective principal stresses at failure and σ_{ci} is the uniaxial compressive strength of the intact rock, and m_b is a reduced value of the material constant m_i, given by

$$m_b = m_i \exp\left(\frac{GSI - 100}{28 - 14D}\right) \qquad (2)$$

where s and a are constants for the rock mass given by the following relationships:

$$s = \exp\left(\frac{GSI - 100}{9 - 3D}\right) \qquad (3)$$

where GSI (the Geological Strength Index) relates the failure criterion to geological observations in the field and m_i is a material constant for the intact rock.

$$a=\frac{1}{2}+\frac{1}{6}\left(e^{-GSI/15}-e^{-20/3}\right) \qquad (4)$$

Parametar D je faktor koji zavisi od stepena poremećenosti kojem je stenska masa izložena usled oštećenja izazvanih eksplozijama i relaksacijom napona. Vrednost varira od 0 za neporemećenu stensku masu na licu mesta do 1 za veoma poremećenu stensku masu.

Istraživanje opisano u ovom radu je zasnovano na geotehničkim podacima dobijenim tokom ispitivanja osobina stena u rudniku boksita Biočki Stan, Nikšić, /13/. Ovaj pristup je prihvaćen s obzirom da su rezultati ovih ispitivanja obezbedili neophodne ulazne parametre za modeliranje. Takođe, naše je mišljenje da je formacija boksita pogodna za modeliranje degradacije stena, koje se kasnije može primeniti i na druge vrste stena.

PONAŠANJE STENSKE MASE

Upoznavanje sa ponašanjem stenskih masa pod različitim uslovima prestavlja glavni zadatak mehanike stena. Kriterijum čvrstoće stenskog materijala predstavlja pokušaj da se opiše ovo ponašanje, na najpribližniji mogući način, primenom matematičkih jednačina. Iz ovih razloga, razvijen je veliki broj poznatih kriterijuma čvrstoće, obično zasnovanih na rezultatima troosnog ispitivanja. Primena nove verzije poznatog Hoek-Braun kriterijuma loma dovela je do proširenja i dodataka postojećim metodama, obezbeđujući na taj način visok kvalitet i pouzdanu primenu. Oblast na koju se ovaj kriterijum može primeniti je proširena na sva rudarska postrojenja, kako na površini, tako i pod zemljom, /15/.

Troosno ispitivanje je usmereno ka simuliranju uslova koji se mogu javiti u stenama koje okružuju podzemna postrojenja i u kojima bi takva postrojenja mogla biti izložena graničnim pritiscima i smičućim naponima. Primena troosnih ispitivanja u praksi rudarskog inženjerstva je postala jedan od najboljih načina da se utvrdi kriterijum čvrstoće koji, u smislu dobre početne baze, omogućava proračun stabilnosti podzemnih prostorija, /14/.

Simulacija vertikalnog i bočnog pritiska na ispitivanom uzorku, do vrednosti graničnog opterećenja, tj. granice loma, daje bolju predstavu o pritisku zemlje na većim dubinama, što je donedavno bilo predmet isključivo teoretskih razmatranja. Kompletna laboratorijska metoda troosnog pritiska je definisana standardima koji se danas koriste širom sveta, sa naglaskom na ISRM metodi.

U ovom poglavlju je prikazan Hoek-Braun kriterijum loma u formi u kojoj se koristi u praksi i daje rezultate koji se mogu primeniti u geotehničkom inženjerstvu. Iz ove perspektive smo primenili dobijene rezultate na numeričko modeliranje stenske mase za slučaj rudnika boksita Biočki Stan.

Na osnovu rezultata troosnog ispitivanja primene matematičkih modela Hoek-Braun kriterijuma, parametri stenske mase rudnika boksita Biočki Stan kod Nikšića potrebni za dalju analizu su prikazanu u tabeli 1.

Tabela 1. Ulazni parametri u matematički model za boksit

Jednoosna čvrstoća	σ_{ci} =	51,9 MPa
Hoek-Braun konstanta	m_i =	49,2
Indeks geološke čvrstoće	GSI =	50

$$a=\frac{1}{2}+\frac{1}{6}\left(e^{-GSI/15}-e^{-20/3}\right) \qquad (4)$$

The parameter D is a factor which depends upon the degree of disturbance to which the rock mass has been subjected by blast damage and stress relaxation. It varies from 0 for undisturbed in-situ rock masses to 1 for very disturbed rock masses.

Research described in this paper is based on geotechnical data obtained during testing of rock properties in the Biočki Stan bauxite mine, Nikšić, /13/. We accepted this approach since results of these tests provided necessary input parameters for modelling. Also, it is our opinion that bauxite formation is suitable for modelling of rock deterioration which later can be applied for other rock types.

THE BEHAVIOUR OF THE ROCK MASS

Knowing the behaviour of rock mass under different conditions is the main task of rock mechanics. The strength criterion of rock material is an attempt to describe this behaviour, as close as possible, using mathematical equations. Due to these reasons, a number of well-known strength criteria is developed, usually based on results of triaxial testing. Using a new version of the famous Hoek-Brown's fracture criterion, the certain additions and extensions are made, enabling its high quality and reliable applications. The area of application of this criterion is extended to all mining facilities, both underground and surface, /15/.

Triaxial testing is aimed to simulate the conditions that may occur in the rocks surrounding the underground facilities and these facilities could be exposed to the limit pressure and shearing stress. The application of triaxial tests in the mining engineering practice has become one of the most useful tests to determine the strength criteria which can, as a good starting base, enable the calculation of stability the underground roadway, /14/.

Simulating the vertical and side pressures on a test body to its limit load, i.e. to the point of fracture limit, a better picture can be created on ground pressure and at greater depths that until recently were only theoretical considerations. A complete laboratory triaxial compression method is defined by standards that are now used world wide, with an emphasis on the ISRM method.

This chapter shows the Hoek-Brown's failure criterion in a form that could be used in practice and gives results applicable in geotechnical engineering. From this perspective we have applied the obtained results to the numerical modelling of the rock mass in the case of the Biočki Stan bauxite mine.

Based on the results of triaxial testing and application of mathematical models of Hoek-Brown's criterion, the parameters of rock mass of the bauxite deposit Biočki Stan in Nikšić, necessary for further analysis are shown in Table 1.

Table 1. Input parameters for bauxite in numerical analyses.

Uniaxial strength	σ_{ci} =	51.9 MPa
Hoek-Brown constant	m_i =	49.2
Geological strength index	GSI =	50

Na osnovu laboratorijskih ispitivanja mehaničke čvrstoće, deformacionih karakteristika i ocene kvaliteta stenske mase, laboratorijske vrednosti dobijene za parametre stenske mase su date u tabeli 2.

Tabela 2. Fizičko-mehanički parametri dobijeni ispitivanjima u laboratoriji na uzorcima stene

Tip stene - boksit	γ (kN/m^3)	σ_c (MPa)	σ_i (MPa)	E (MPa)	E_d (MPa)	ν	GSI
	26,1	53,6	2,24	9660	5450	0,20	50

Simulacija troosnog ispitivanja daje krivu odnosa glavnih napona naprsle stenske mase, kao i napone pri lomu - normalnih i smičućih. Za analizu i procenu stabilnosti podzemnih prostorija i izabranih kriterijuma loma, korišćeni su parametri prikazani u tabeli 3. Ovako definisani parametri su korišćeni za modeliranje stenske mase i analizu stabilnosti podzemnih prostorija.

Tabela 3. Parametri modela za ispucalu stensku masu

Hoek-Braun konstanta	m_b	6,84
Hoek-Braun konstanta	S	0,0039
Pritisna čvrstoća stenske mase	σ_{cm}	11,48 MPa
Zatezna čvrstoća stenske mase	σ_{tm}	-0,02 MPa
Modul elastičnosti	E	7200 MPa
Poasonov koeficijent	ν	0,2
Ugao dilatacije	α	6°

MODELIRANJE

Analiza deformacija, rezultujućih napona i opterećenja sidra je izvršena primenom softverskog paketa Phase2, koji je zasnovan na metodama konačnih i graničnih elemenata.

Ovaj primer je vezan za izgradnju podzemne prostorije kružnog poprečnog preseka koja prolazi kroz boksit na dubini od 250 m. Prečnik prostorije je 3,5 m. Realna pretpostavka je da takva prostorija može da se osloni na 5 smolom vezanih sidara, dužine 2,4 m, sa dužinom vezivanja jednakom dužini sidra, sl. 2, /5, 8/.

Based on laboratory tests of mechanical strength, deformation characteristics and quality assessment of rock mass, the laboratory values are obtained for parameters of rock mass shown in Table 2.

Table 2. Physical and mechanical characteristics obtained by laboratory tests on samples of rock mass.

Rock type - bauxite	γ (kN/m^3)	σ_c (MPa)	σ_i (MPa)	E (MPa)	E_d (MPa)	ν	GSI
	26.1	53.6	2.24	9660	5450	0.20	50

Simulation of the triaxial testing produces the curve ratio of main stresses for cracked rock mass, as well as stresses at breakage - normal and shear stress. For the analysis and evaluating the stability of underground roadway and chosen fracture criteria, the parameters, shown in Table 3, are used. Parameters defined in this way are used in modelling of the rock mass and stability analysis of underground roadway.

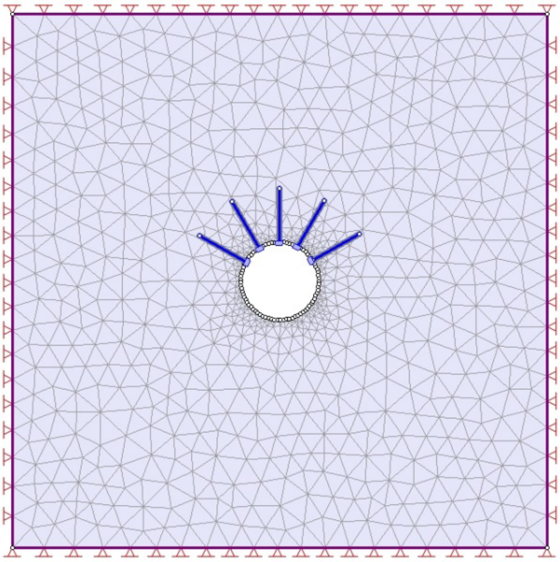
Table 3. Model parameters for fractured rock mass.

Hoek-Brown constant	m_b	6.84
Hoek-Brown constant	S	0.0039
Compressive strength of rock mass	σ_{cm}	11.48 MPa
Tensile strength of rock mass	σ_{tm}	-0.02 MPa
Elastic modulus	E	7200 MPa
Poisson's coefficient	ν	0.2
Dilatation angle	α	6°

MODELLING

Analysis of strain, induced stresses and loading of the rockbolts is performed with Phase2 software, based on the finite - and boundary element method.

This example is related to the development of roadway with circular cross-section through bauxite at a depth of 250 m. The diameter of the roadway is 3.5 m. The realistic assumption is that such a roadway can be supported with 5 resin bonded rockbolts, each 2.4 m long with bonding length equalling the length of the rockbolt, Fig. 2, /5, 8/.



σ_{ci} = 51,9 MPa
m_i = 49,2
GSI = 50

Hoek-Braun kriterijum:
m_b = 6,875
s = 0,0026
a = 0,506

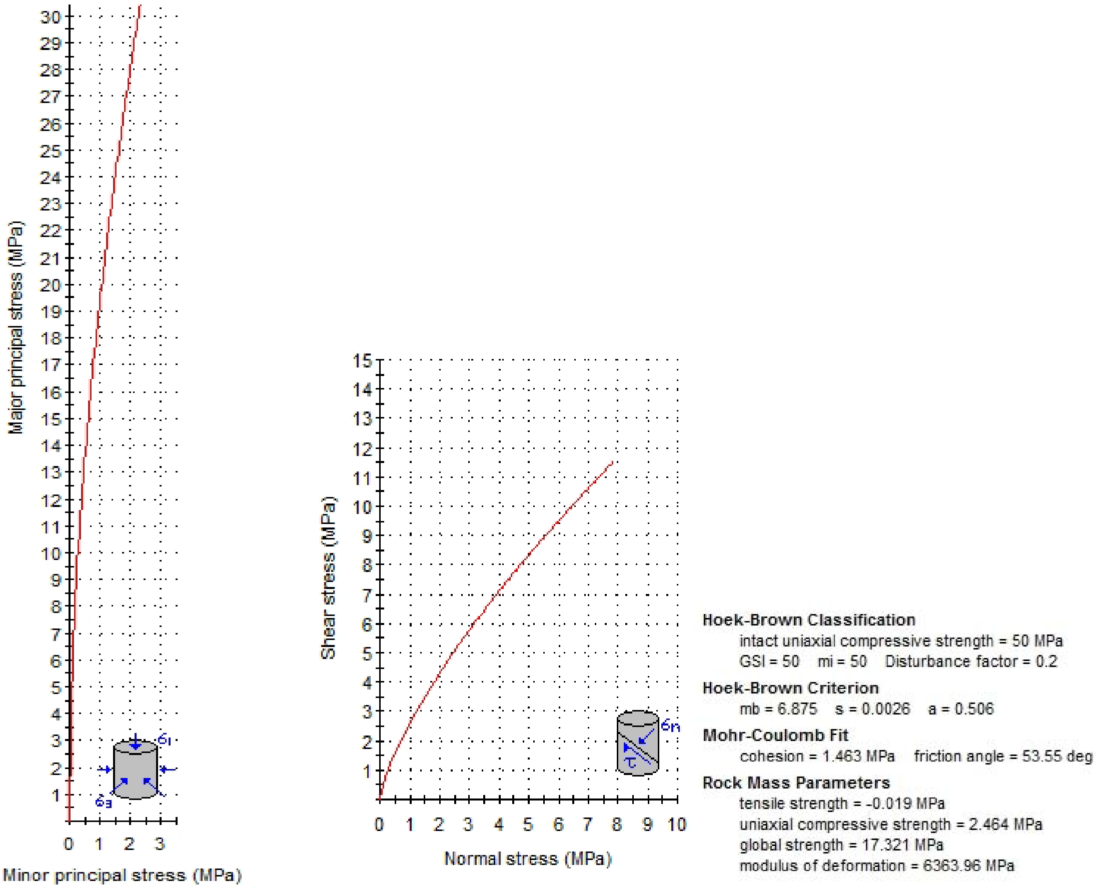
Sidra:
2,4 m, smolom vezan pun stub
prečnik: 22 mm
E = 200 GPa
prečnik bušotine: 27 mm

σ_{ci} = 51.9 MPa
m_i = 49.2
GSI = 50

Hoek-Brown criterion:
m_b = 6.875
s = 0.0026
a = 0.506

Bolts:
2.4 m, full-column resin bonded
diameter: 22 mm
E = 200 GPa
borehole diameter: 27 mm

Slika 2. Interpretacija podzemne prostorije kružnog profila podgrađene sa visećom podgradom
Figure 2. Interpretation of circular roadway supported with rockbolts.



Hoek-Brown Classification
intact uniaxial compressive strength = 50 MPa
GSI = 50 mi = 50 Disturbance factor = 0.2

Hoek-Brown Criterion
mb = 6.875 s = 0.0026 a = 0.506

Mohr-Coulomb Fit
cohesion = 1.463 MPa friction angle = 53.55 deg

Rock Mass Parameters
tensile strength = -0.019 MPa
uniaxial compressive strength = 2.464 MPa
global strength = 17.321 MPa
modulus of deformation = 6363.96 MPa

Slika 3. Karakteristike masiva dobijene softverom RockLab
Figure 3. Rock properties obtained by RockLab.

Parametri za stenu i modele korišćene za modeliranje u Phase2 softverskom paketu za ovaj primer, su zasnovani na prethodno opisanim geotehničkim podacima. Ulazni parametri su detaljno prikazani na slici ispod.

Ostali parametri potrebni za modeliranje su određeni korišćenjem RockLab softvera (sl. 3). Ovaj softver je takođe korišćen za verifikaciju geotehničkih podataka (tab. 1-3), i može se videti da je korelacija izuzetno precizna.

Treba napomenuti da su prihvaćene vrednosti najvećeg i najmanjeg glavnog napona (σ_1 i σ_3 u jedn. 1) 6 i 4 MPa, respektivno. Takođe, σ_z je usvojen za nivo od 6,5 MPa, koji odgovara dubini od 250 m (γ= 2,6 t/m^3). Sličan pristup za numeričko modeliranje usidrenih podzemnih prostorija je potvrđen od strane drugih istraživača, /7/.

Degradacija stena u blizini podzemnih otvora – prostorija se javlja iz nekoliko razloga. Glavni uzrok je koncentracija napona u stenama neposredno uz pod i svod, kao i uz bočne zidove. Ova koncentracija je prouzrokovana poremećajima u početnoj ravnoteži, do kojih dolazi tokom izgradnje podzemne prostorije, a koji dovode do koncentracije vertikalnih napona sa obe strane prostorije, dok se horizontalni naponi koncentrišu oko svoda i poda. Degradacija se manifestuje u formiranju oslabljenih zona u svodu podzemne prostorije. Ovo je primećeno u toku ranijih istraživanja /8/. Stene su u ovoj zoni veoma fragmentisane, pri čemu se degradirana zona dalje širi kroz stenski masiv oko podzemne prostorije. Degradacija kreće u rebrima prostorije, sa

Rock and model parameters used for the modelling in Phase2 software in this example are based on geotechnical data already described. Details on other input parameters are given below.

Other parameters required for modelling are calculated by using the RockLab software (Fig. 3). This software is also used for verification of geotechnical data (Tables 1-3), and it can be seen that correlation is very high.

It should be mentioned that accepted values for major and minor principal stresses (σ_1 and σ_3 in Eq. 1) are 6 and 4 MPa respectively. Also, σ_z is accepted at level of 6.5 MPa, which corresponds to the depth of 250 m (γ= 2.6 t/m^3). Similar approach for numerical modelling of rockbolted roadways has been confirmed by other researchers, /7/.

Rock deterioration in the proximity of underground openings – roadways occurs for several reasons. The major cause is stress concentration in immediate roof and floor rocks, as well as on the sides. This concentration is generated by disturbing initial equilibrium with development of the roadway, resulting in concentration of vertical stress in the sides of the roadway, while the horizontal stress is concentrated in the roof and the floor. Manifestation of deterioration is the creation of a deteriorated zone in the roof of the roadway. This is noted during previous research, /8/. Rock in this zone is very fragmented, while the deterioration zone propagates further on into the strata surrounding the roadway. Deterioration starts in the rib-sides of the roadway, with increasing deterioration depth toward the uvećanom dubinom degradacije prema svodu prostorije, i dostiže svoj maksimum u srednjoj liniji prostorije.

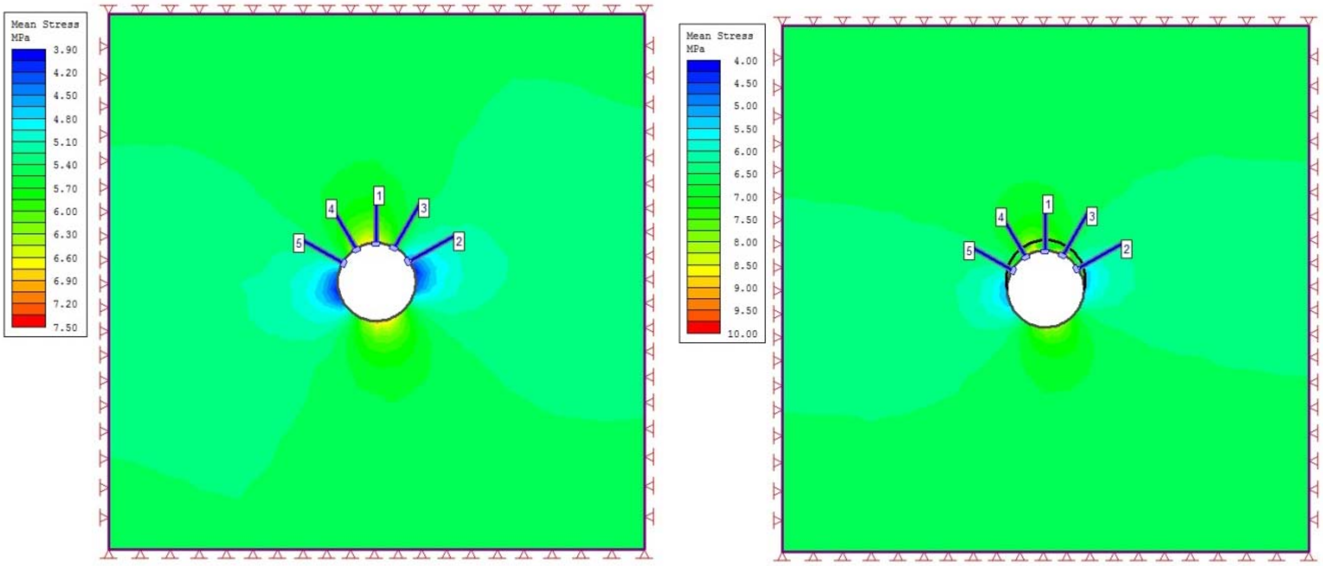
Stoga, razvijena su četiri modela prostorija kružnog oblika u stenskom masivu sa osobinama boksita (tabele 1 i 3). U prvom modelu nema zone degradacije stena (sl. 4a). Degradacija je uvedena u naredna tri modela, sa zajedničkom osobinom da u sva tri slučaja, zone počinju sa strane prostorije i dostižu maksimalnu dubinu u svodu iznad ose srednje linije. Degradacija stena je modelirana smanjenjem početnog indeksa geološke čvrstoće na 30 ± 5. Maksimalne debljine zone degradacije za modele su:

– 0,12 m za drugi model;
– 0,24 m za treći model i
– 0,48 m za četvrti model (sl. 4b).

roof of the roadway, achieving maximum depth at the centre line of the roadway.

Therefore, we developed four models of circular shaped roadway in strata with properties of bauxite (Tables 1 and 3). The first model had no zone of rock deterioration (Fig. 4a). Deterioration zone is introduced in subsequent three models, with common attribute that in each three cases the zone starts at the sides of the roadway, achieving maximal depth in the roof above the centre line axis. Rock deterioration is modelled by reducing initial geological strength index to 30 ± 5. Maximal thickness of the deterioration zone for the models is:

– 0.12 m in second model;
– 0.24 m in third model and
– 0.48 m in fourth model (Fig. 4b).



a) b)

Slika 4. Srednji napon u okolini podzemne prostorije: a) bez zone ispucale stene-početno stanje; b) zona ispucale stene u krovini prostorije (0,48 m po visini sidra broj 1)

Figure 4. Mean stress around the roadway: a) non deteriorated rock-initial state; b) deterioration zone above roadway (0.48 m along the bolt number 1).

Srednje vrednosti napona za podzemnu prostoriju za prvi i četvrti model su prikazane na sl. 4. Svi modeli su ukazali na relaksaciju napona u degradiranoj zoni, usled fragmentacije stena. Ovo je dovelo od preraspodele napona dalje u svodu.

Još jedna posledica preraspodele napona predstavljala je smanjenje efektivne dužine sidra, što je dovelo do povećanog opterećenja u sidru u delu neposredno iznad degradirane zone. Razlog za ovo leži u nedostatku prenosa opterećenja sa stene na sidru u degradiranoj zoni. Ova pojava je prikazana graficima aksijalnih sila duž sidra, koje su prikazane na sl. 5, za sva četiri modela.

Osno opterećenje sidra za slučaj bez poremećenih zona je prikazano na sl. 5a, odakle se može videti postepen porast opterećenja od vrednosti pre zatezanja, približno 20 kN na dubini od 0,75 m, praćen postepenim opadanjem do nule na kraju sidra. Slični oblici krive opterećenja su zabeleženi u ranijim istraživanjima, /6, 8/.

Naredni grafici, na kojima su prikazani modeli sa degradiranim zonama, ukazuju na porast aksijalnih sila u sidrima u odnosu na debljinu degradirane zone. Najzad, može se

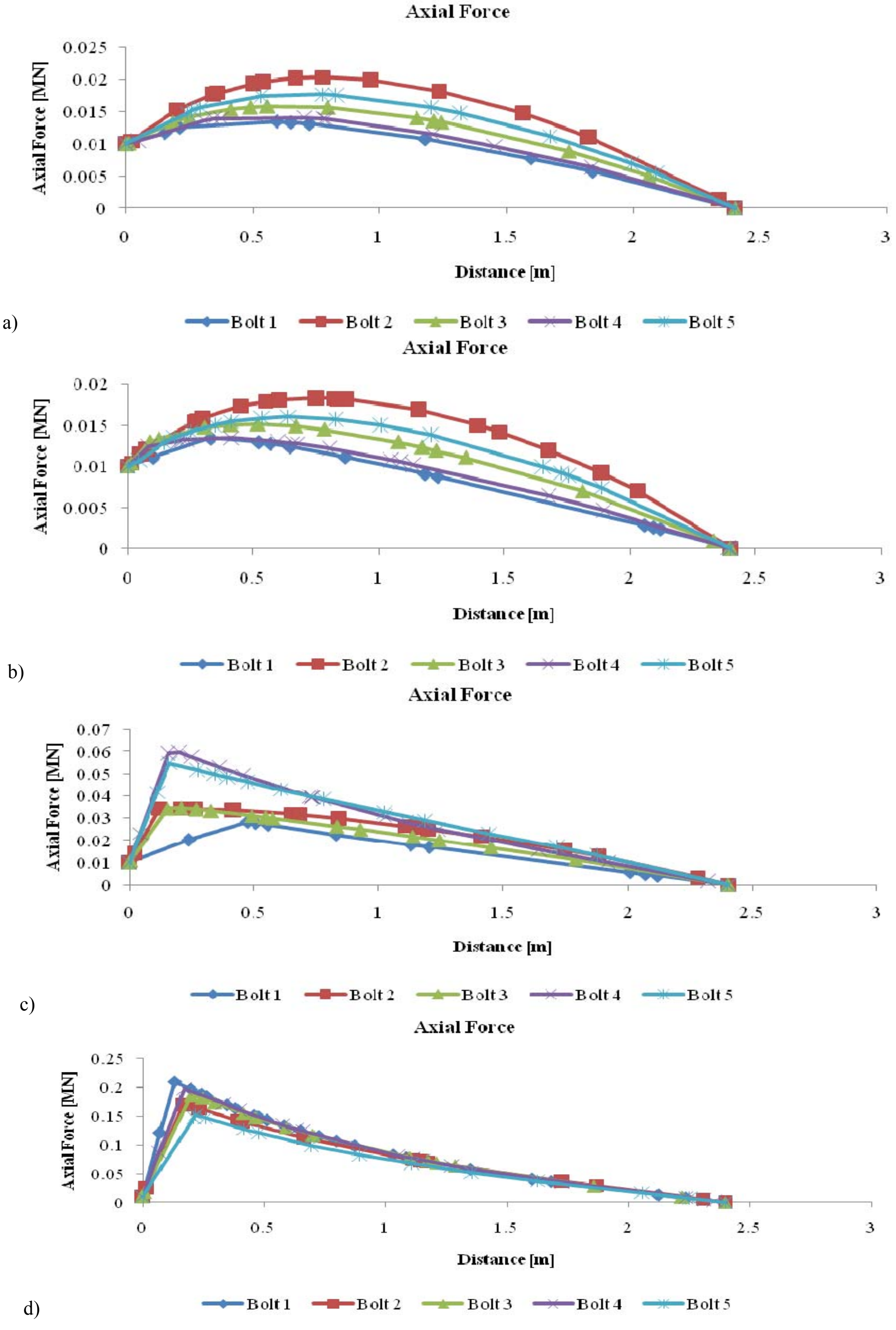
Mean stresses around the roadway for the first and fourth model are shown in Fig. 4. All models indicated stress relaxation in the deteriorated zone, due to rock fragmentation. This resulted in stress redistribution further into the roof.

Another consequence of stress redistribution is the reduced effective length of the rockbolt, resulting in increased loading of the rockbolt in the area immediately above the deteriorated zone. Reason for this is a lack of load transfer from the rock onto the bolt in the deteriorated zone. This is interpreted with graphs of axial force along the rockbolts, which are shown on Fig. 5, for all four models.

Axial loading of the rockbolts for case without disturbed zone is shown in Fig. 5a, where gradual increase of loading can be seen from the pre-tensioning value to approx. 20 kN at depth of 0.75 m, following a gradual decrease to zero at the end of the bolt. Similar shapes of load curves are recorded in previous researches, /6, 8/.

The following graphs, representing models with deteriorated zone, indicate an increase of axial forces in rockbolts in relation to the thickness of the deteriorated zone. Finally, videti da je u slučaju zone debljine 0,48 m (sl. 5d), maksimalna sila približno 210 kN, odnosno, da se približava vrednosti maksimalne čvrstoće sidra.

it can be seen that in case of zone with thickness of 0.48 m (Fig. 5d), the maximal force is approximately 210 kN, approaching the ultimate strength of the rockbolt.



Slika 5. Aksijalne sile duž sidara: a) bez zone poremećenog masiva; b) zona debljine 0,12 m; c) zona debljine 0,24 m; d) zona debljine 0,48 m

Figure 5. Axial force along the rockbolts: a) without disturbed zone; b) zone with 0.12 m thickness; c) zone with 0.24 m thickness; d) zone with 0.48 m thickness.

Može se zaključiti da bi dalje povećanje debljine degradirane zone rezultiralo lomom sidra, sa posledicama po stabilnost podzemne prostorije. Mere za sprečavanje loma moraju obuhvatiti stalno praćenje uslova u sidru, kao i merenje deformacija i određivanje napona u stenama oko podzemne prostorije. Ovime bi se omogućile pravovremene akcije, poput ugrađivanja dodatnih sidara ili pomoćnih oslonaca.

ZAKLJUČAK

Interakcija stena–sidro, opisana u ovom radu je korisna za razumevanje procesa degradacije stenske mase oko podzemnih prostorija i odgovora ugrađenih visećih podgrada. Ovde prikazano istraživanje potvrdilo je prethodne indikacije vezane za degradaciju osobina stena i povećano opterećenje na sidra, /8/. Pokazano je da prisustvo degradirane zone i njeno širenje dovodi do povećanja aksijalnog opterećenja u prethodno ugrađenim visećim podgradama. Ono čak može dovesti i do loma sidra. Stoga je neophodno uvesti praćenje uslova u steni i sidrima, kao i planiranje odgovarajućih mera u slučaju degradacije stena.

Primenom dorađenog Hoek-Braun kriterijuma loma, uvedeni su određeni dodaci i proširenja, i na taj način je omogućena pouzdanija ocena loma stene.

Identifikacija geoloških struktura i njihovog ponašanja pod uticajem napona prestavlja veliki iskorak u praksi bezbednog oslanjanja podzemnih prostorija. Onog trenutka kada se postigne razumevanje ovih faktora, konstruisanje odgovarajućih visećih podgrada postaje jednostavnije, kao i planiranje odgovarajućih mera za njihovo sprečavanje.

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It can be concluded that further increase of thickness of deterioration zone will result in failure of rockbolts, with consequences to the roadway stability. Measures for preventing failure must include permanent monitoring of rockbolt condition, as well as measurements of deformations and calculation of stresses in rock around the roadway. This would enable in-time actions, such as installation of additional rockbolts or installation of secondary support.

CONCLUSION

Interaction of the rock and rockbolts, described in this paper is useful for understanding the process of rock mass deterioration around an underground roadway and the response of installed roofbolting support. The presented research has confirmed previous indication related to deterioration of rock properties and increased loading of the rockbolts, /8/. It showed that the presence of the deterioration zone and its propagation generates increase of axial loading in already installed rockbolting support. It can even cause a failure of the rockbolt. Therefore it is necessary to introduce monitoring of rock and roofbolt conditions and to plan appropriate measures in case of rock deterioration.

By applying a revised Hoek-Brown fracture criterion, certain additions and extensions are made, enabling more reliable evaluation of rock failure.

Identification of geological structures and their behaviour under stress is a major step in safe roof support practice. Once an understanding of these factors is achieved, designing the appropriate roof support becomes easier as well as planning of suitable measures for their prevention.

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