UDC 622
ISSN 2334-8836

Mining and Metallurgy Engineering Bor

2/2014

Published by: Mining and Metallurgy Institute Bor

MINING AND METALLURGY ENGINEERING BOR is a journal based on the rich tradition of expert and scientific work from the field of mining, underground and open-pit mining, mineral processing, geology, mineralogy, petrology, geomechanics, metallurgy, materials, technology, as well as related fields of science. Since 2001, is published twice a year, and since 2011 four times year.

Editor-in-chief

Academic Ph.D. Milenko Ljubojev, Principal Reasearch Fellow, Associate member of ESC
Mining and Metallurgy Institute Bor
E-mail: milenko.ljubojev@irmbor.co.rs
Phone: +38130/454-109, 435-164

Editor

Vesna Marjanović, B.Eng.

English Translation

Nevenka Vukašinović

Technical Editor

Suzana Cvetković

Preprinting

Vesna Simić

Printed in: Grafomedtrade Bor

Circulation: 200 copies

Web site

www.irmbor.co.rs

Journal is financially supported by

The Ministry of Education, Science and Technological Development of the Republic Serbia
Mining and Metallurgy Institute Bor

ISSN 2334-8836

Journal indexing in SCIndex and ISI.

Published by

Mining and Metallurgy Institute Bor
19210 Bor, Zeleni bulevar 35
E-mail: milenko.ljubojev@irmbor.co.rs
Phone: +38130/454-110

Scientific – Technical Cooperation with the Engineering Academy of Serbia

JOURNAL OF INTERNATIONAL IMPORTANCE, VERIFIED BY A SPECIAL DECISION ON THE MINISTRY OF EDUCATION, SCIENCE AND TECHNOLOGICAL DEVELOPMENT OF THE REPUBLIC SERBIA - M24

MINING AND METALLURGY ENGINEERING BOR je časopis baziran na bogatoj tradiciji stručnog i naučnog rada u oblasti rudarstva, podzemne i površinske eksploatacije, pripreme mineralnih sirovina, geologije, mineralogije, petrologije, geomehanike, metalurgije, materijala, tehnologije i povezanih srodnih oblasti. Izlazi dva puta godišnje od 2001. godine, a od 2011. godine četiri puta godišnje.

Glavni i odgovorni urednik

Akademik dr Milenko Ljubojev, naučni savetnik
Institut za rudarstvo i metalurgiju Bor
E-mail: milenko.ljubojev@irmbor.co.rs
Tel. 030/454-109, 435-164

Urednik

Vesna Marjanović, dipl.inž.

Prevodilac

Nevenka Vukašinović, prof.

Tehnički urednik

Suzana Cvetković, teh.

Priprema za štampu

Vesna Simić, teh.

Štamparija: Grafomedtrade Bor

Tiraž: 200 primeraka

Internet adresa

www.irmbor.co.rs

Izdavanje časopisa finansijski podržavaju

Ministarstvo za prosvetu, nauku i tehnološki razvoj Republike Srbije
Institut za rudarstvo i metalurgiju Bor

ISSN 2334-8836

Indeksiranje časopisa u SCIndeksu i u ISI.

Izdavač

Institut za rudarstvo i metalurgiju Bor
19210 Bor, Zeleni bulevar 35
E-mail: milenko.ljubojev@irmbor.co.rs
Tel. 030/454-110

Naučno - tehnička saradnja sa Inženjerskom Akademijom Srbije

ČASOPIS MEĐUNARODNOG ZNAČAJA VERIFIKOVAN POSEBNOM ODLUKOM MINISTARSTVA ZA PROSVETU, NAUKU I TEHNOLOŠKI RAZVOJ REPUBLIKE SRBIJE - M24

CONTENS

SADR@AJ

MINING AND METALLURGY INSTITUTE BOR ISSN: 2334-8836
UDK: 622

UDK: 622.271:504.06(045)=20 DOI:10.5937/MMEB1402001M

Miroslava Maksimović, Milenko Jovanović*, Goran Pačkovski*,*
*Vladan Marinković**

PRELIMINARY GEOLOGICAL EXPLORATION WORKS IN ORDER TO THE ENVIRONMENTAL MANAGEMENT IN THE AREA OF INACTIVE ECOLOGICAL MINING FIELD**

Abstract

Bor is otherwise a typical mining town, founded by the mine. Continued economic activity in the dominant area of extractive industry, related to the copper ore mining and processing, then for metallurgy and complementary industrial activities, what is of great importance for the town and the municipality. The northern part of the Timok magmatic complex and the Bor metallogenic zone, or the Bor mining region, covers the area in which the most significant ore fields are Bor, Veliki Krivelj Cerovo, Majdanpek, Blagojev Kamen and others. The largest technogenic formations were separated in the immediate vicinity of the Bor and Krivelj mine, and they are presented by formations originated by exploitation of mineral copper deposits (overburden) and mineral processing (flotation tailing dumps) in the immediate vicinity of Bor. Designed exploration works in the area of environmental inactive mining field were aimed to prepare the conditions for environment management, remediation of tailing dumps and landfills for disposal of mining waste in the Bor mining areas as well as the rehabilitation of ecological problems in the ore region of Bor. Exploration works included the study of the field: for disposal the tailings from Veliki Krivelj area of the Old Bor Tailing Dump (East), Saraka overburden dump, south-eastern overburden dump and RTH.

Keywords: *technogenic formations, inactive ecological exploitation field, ore mining, tailing dump, landfills for disposal of mining waste*

INTRODUCTION

Morphology of the terrain in the area of wider surrounding of exploration area affects the methods and conditions of exploration and exploitation, and the conditions of transport the ore and concentrate, and disposal of technogenic formations. Similarly is with the hydrological conditions, especially the waterways.

Intensive volcanic activity (the late Mesozoic and during Cenozoic) had a significant impact on the terrain relief in wider area of Bor, followed by strong tectonic movements. Tectonic movements, which are reflected in the breaking out, gravitational and reverse movements of blocks, as well as folding of the field, resulted in the primary modelling of geomorphologic forms, which were further modified by the influence of exogenous factors.

* *Mining and Metallurgy Institute Bor*

** *This work is the result of the Project TR37001 "The Impact of Mining Waste from RTB Bor on the Pollution of Surrounding Water Systems with the Proposal of Measures and Procedures for Reduction Harmful Effects on the Environment", funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia*

However, the formation of current look of relief was influenced by the economic activity in the mineral-raw material complex (Figures 1, 2, 3). The processes of exploitation, preparation, and processing of ore in Bor and its surroundings, caused the changes of relief and formation of some inverse morphological forms, such as the open pits and landfills (rock overburden, mining waste, flotation tailings, smelter slags, calcined pyrite).

Exploitation of the Bor deposit, since the beginning of the last century, has included 26 ore bodies, largely at the same time by the and underground mining (Figure 1). Thereby was obtained total of 146 270 000 tons of ore from which copper was extracted 2,437 million tons of metal copper, 139 140 kg of gold and 415 000 kg silver. It was also excavated 436,2 million tons of waste mass (overburden and associated rocks).

Figure 1 *The Old Bor Open Pit (August 2005)*

The exploitation of copper deposit at the old open pit in Bor (Figure 1), and later by the underground mining as well as enrichment of ore and production of concentrate in the Bor Flotation Plant, have caused the changes paleorelief in terms of degradation the natural terrain, creating the elevations of accumulated material of flotation tailings. Metallurgical treatment of concentrates resulted in the formation of slag landfill. The largest amount of slag is disposed at the site between the open pit and ore body "H" and former Pralište of the workshops at the old open pit, and this location is known as the "Slag Depot – 1" [I].

The first works on stripping the open pit Veliki Krivelj began in 1979. Excavation of copper ore began in 1982, and total were excavated and processed about 198 million tons of ore with about 689.000 tons of copper metal and approximately 179 million tons of tailings (Figure 2).

Figure 2 *View of the open pit Veliki Krivelj (2012)*

Processing of copper ore from the open pit Veliki Krivelj is performed in the Flotation Plant Veliki Krivelj. The designed capacity of the Veliki Krivelj Flotation Plant is 8 000 000 tons of dry ore per year, or expressed by hour capacity of 342.5 t/h of dry ore per section.

The tailing dump Veliki Krivelj is, due to different time of construction and use, divided into two parts - the fields. Field 1 is located between Dams 1 and 2, and Field 2 is the area between the Dams 2 and 3. The use of Field 1 began in December 1982 and it was temporarily suspended in September 1990. Field 2 has been used since September 1990 and today is active.

Figure 3 *Dam 2 of the Veliki Krivelj flotation tailing dump (2011)*

PRELIMINARY EXPLORATION WORKS

Preliminary exploration works are focused on testing the field for exploration, rehabilitation, remediation and reclamation: the Old Bor flotation tailing dump: landfill of tailings of the Veliki Krivelj dump, stability of the Dams 2 and 3 on Field 2, Saraka overburden dump, south-eastern overburden dump and RTH (Figure 4).

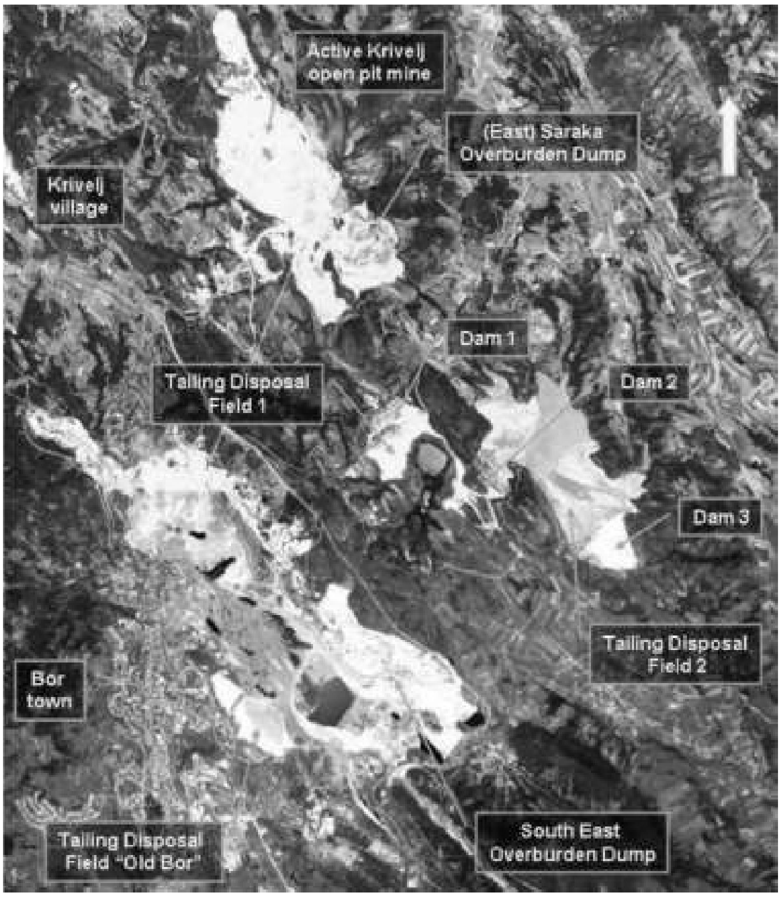


Figure 4 *Location plan of landfills and tailing dumps (2011)*

The basic aims of exploration are:

1. from landfills and remediation (mainly mining waste material),
2. stability of the dams,
3. water control (storm water, water refilling, water leakage, uncontrolled water leakage and sludge spilling),
4. closure and remediation of tailing dump in Bor, and partially re-planting of vegetation, and
5. monitoring and maintenance after construction.

Special attention is given to the rehabilitation/re-routing the bypass of the river (collector) that is now below the tailing dump Veliki Krivelj.

The objectives of this particular task are:

1. investigation of the location,
2. design works,
3. development the impacts on the environment,
4. development the plan of environment management,
5. preparation the monitoring plan for rehabilitation and remediation.

Specific objectives:

1. Implementation of environmental studies of the field and geological and hydrogeological explorations to obtain data for future remediation/reclamation of the land;
2. Elaborate of inputs for full assessment the impact on the environment, the projects of environmental management and remediation projects of the locations.

Preliminary geological works include: exploration drilling to take samples for determination the chemical composition, leaching tests, mining waste and flotation tailings, determination the geological structure of paleorelief, installation of piezometers to monitor the quality and level of water, taking samples for acid generation tests and neutralization of engineering-geological explorations to determine the stability of dams (Maksimović M., 2011., 2012.).

In addition to geological explorations in the field, further explorations include some specific activities that are relevant to the rehabilitation and reclamation of the subject areas. These activities include: sampling of surface soil (potential) surfaces of the mine landfills and tailing dumps for testing the acid generalization and neutralization; tests of biological reclamation, including small-scale tests on the ground with plants; tests for biological reclamation suitable for assessment the plant growth conditions.

In general, the field research began with detailed penetration testing the ground of landfill of the mine waste and flotation tailings to assess the composition of the soil. Further explorations were continued by exploration drilling. The final position and depth of the piezometers were selected on the basis of penetration tests and core drilling and soil stratigraphy as determined during drilling.

Static network test probes, up to 5 feet deep, were performed before the testing network of shear and core drilling.

In order to verify the effectiveness of the proposed stability and measures to reduce leakage, a comprehensive monitoring plan that was developed and implemented, consists of instrumental monitoring and visual inspection.

THE RESULTS OF CONDUCTED EXPLORATIONS AND TESTING

Flotation tailing dumps and dams on tailing dumps, over the years were built from materials of cyclone tailings, consisting of fine grained (silty) to coarse grained sand (loose material).

Stability of the dam is secured until the groundwater level within the body of the dam can be maintained below maximum safe level, especially taking into account the expected seismic conditions. The current efforts to control the groundwater levels are insufficient as evidenced by high amount of (contaminated) leakage that now appears through the dam (Maksimović M., 2011, 2012.).

For successful implementation the remediation Project, it is necessary that the current flow of leachate to be stopped.

Before taking actions, it is recommended to conduct firstly a rapid assessment of the risk to determine the potential impacts of possible collapse of dams and to evaluate the effectiveness and scope of the proposed remediation measures and remediation and reclamation of inactive landfills.

On the basis of realized explorations and testing, it was determined that the following measures have to be taken:

- Plan of vegetation should be adopted for the slopes of dams to prevent the future surface erosions the filling of dams;
- Redesign of the drainage system to prevent leakage and improve the stability of the systematic and effective lowering the groundwater levels within dams and in their immediate vicinity.

CONCLUSION

The exploration area, located in the area of environmental inactive mining field, is the space, in which the presence of hazardous and harmful substances is confirmed caused by human activity in concentrations that may cause a significant risk to the human health and environment.

The area of environmental inactive mining field was explored by the exploration drill holes from the field surface. The realized geological explorations provided the preliminary data on geological structure, physico-mechanical and hydrological characteristics of the areas of ecological inactive mining field.

Based on the results of realized explorations and testing, the further measures were proposed for rehabilitation of the subject area, and reduction of pollution. Further explorations will get the results to take measures to stop further pollution and environmental degradation to a level that is safe for the future use of the site including landscaping, rehabilitation and reclamation.

REFERENCES

[1] Maksimović M., Nikolić K., et al., Elaborate on Reserves of the Copper Deposit Bor (Ore Bodies “Brezanik”, “Tilva Roš“ and “P2A”), state on 31/12/2004–textual part, Fund of Technical Documentation, Geology Department, MMI, Bor; 2005, p.144.

[2] Maksimović M.: Project of Detailed Geological Explorations of Copper and Other Useful Components in the Area of the Old Flotation Tailing Dump in Bor (Field 1 and Field 2), in 2011/12, Fund of Technical Documentation, Geology Department, MMI Bor; 2011, p. 44.

[3] Maksimović M.: Project of Explorations and Testing the Flotation Tailing Dumpsand Open Pit Waste Dumps Bor, in the Area of Inactive Ecological Exploitation Field Related to the Activities of Remediation by the World Bank, Fund of Technical Documentation, Geology Department, MMI Bor; 2011, p. 55.

[4] Maksimović M.: Project of Geological-Ecological Exploration and Testing Within the Endangered Ecological Zone – Tailing Dumps in Bor (Dam 2), Fund of Technical Docu-mentation, Geology Department, MMI Bor; 2012, p. 20.

[5] Maksimović M.: Elaborate on Realized Geological Explorations and Testing the Flotation Tailing Dumps and Open Pit Waste Dumps Bor, in the Area of Inactive Ecological Exploitation Field Related to the Activities of Remediation by the World Bank, in the period 2011/12, Fund of Technical Documentation, Geology Department, MMI Bor; 2012, p. 83.

[6] Report of the Consulting Company Witteveen + Bos, according to the Project of the World Bank "Bor Regional Development", the component A - remediation of the flotation tailing dumps and relocation the Krivelj collector, Fund of Technical Documentation, Geology Department, MMI Bor; 2012, p. 50.

UDK: 622.271:504.06(045)=861 DOI:10.5937/MMEB1402001M

Miroslava Maksimović, Milenko Jovanović*, Goran Pačkovski*, Vladan Marinković**

PRELIMINARNI GEOLOŠKI ISTRAŽNI RADOVI U CILJU UPRAVLJANJA ŽIVOTNOM SREDINOM NA PROSTORU NEAKTIVNOG EKOLOŠKOG EKSPLOATACIONOG POLJA**

Izvod

Bor je inače tipični rudarski grad, nastao uz rudnik. Nastavak privređivanja u dominantnoj oblasti ekstraktivne industrije, vezanoj za eksploataciju i preradu rude bakra, zatim za metalurgiju i komplementarne industrijske delatnosti, od izuzetnog je značaja za grad i opštinu. Severni deo timočkog magmatskog kompleksa i borske metalogenetske zone, odnosno borski rudni reon, obuhvata prostor u kome su najznačajnija rudna polja Bor, Veliki Krivelj, Cerovo, Majdanpek, Blagojev Kamen i dr.

Najveće tehnogene tvorevine izdvojene su u neposrednoj okolini Borskog i Kriveljskog rudnika, i predstavljene su tvorevinama koje su nastale eksploatacijom rudnih ležišta bakra (raskrivka) i pripremom mineralnih sirovina (flotacijska jalovišta), u neposrednoj okolini Bora.

Projektovani istražni radovi na prostoru neaktivnog ekološkog eksploatacionog polja imali su za cilj da se pripreme uslovi za upravljanje životnom sredinom, remedijacijom jalovišta i deponija za odlaganje rudničkog otpada u Borskoj rudarskoj oblasti, kao i sanacija ekoloških problema u rudnom reonu Bor. Istražni radovi obuhvatili su istraživanje terena: za odlaganje jalovine Veliki Krivelj, prostora Starog Borskog jalovišta, (Istok) Saraka deponija jalovine, jugo-istočne deponije jalovine i RTH.

Ključne reči: *tehnogene tvorevine, neaktivno ekološko eksploataciono polje, eksploatacija rude, jalovišta, deponije za odlaganje rudničkog otpada*

UVOD

Morfologija terena na području šire okoline istražnog prostora, bitno utiče na način i uslove istraživanja i eksploatacije, te uslove transporta rude i koncentrata, i načina odlaganja tehnogenih tvorevina. Slično je i sa hidrološkim uslovima, a pre svega vodenim tokovima.

Na reljef terena, u širem području Bora, znatan uticaj imala je intenzivna vulkanska aktivnost (krajem mezozoika i tokom kenozoika), praćena snažnim tektonskim pokretima. Tektonski pokreti, koji se ogledaju u razlamanju, gravitacionim i reversnim pokretima blokova, kao i u nabiranju terena, uticali su na primarno modeliranje geomorfoloških oblika, koji su dalje modifikovani uticajem egzogenih faktora.

Međutim, na formiranje sadašnjeg izgleda reljefa uticala je i privredna aktivnost u mineralno-sirovinskom privrednom kompleksu (slike 1, 2, 3). Procesi eksploatacije, pripreme, i prerade ruda u Boru i okolini, uslovili su promene reljefa i nastajanje pojedinih inverznih morfoloških oblika, kao

* *Institut za rudarstvo i metalurgiju Bor*

** *Ovaj rad je rezultat Projekta br TR: 37001 „Uticaj rudarskog otpada iz RTB Bor na zagađenje vodotokova, sa predlogom mera i postupaka za smanjenje štetnog dejstva na životnu sredinu“, finansiranog od strane Ministarstva prosvete, nauke i tehnološkog razvoja Republike Srbije.*

što su površinski kopovi i deponije (stenske otkrivke, rudničke jalovine, flotacijske jalovine, topioničke šljake, piritnih ogoretina).

Eksploatacija borskog ležišta, od početka prošlog veka, zahvatila je 26 rudnih tela, dobrim delom u isto vreme površinskom i podzemnom eksploatacijom, (slika 1). Pri tome je dobijeno ukupno 146.270.000 t rude bakra iz koje je estrakovano 2.437.000 tona metala bakra, 139.140 kg zlata i 415.000 kg srebra. Takođe je otkopano i 436.200.000 tona jalove mase (otkrivke i pratećih stena).

Sl. 1. *Stari borski površinski kop (avgust 2005)*

Eksploatacija ležišta bakra, starim površinskim kopom u Boru (slika 1.10), a kasnije i podzemnom eksploatacijom, kao i obogaćivanje rude i dobijanje koncentrata u borskoj flotaciji, uslovile su izmene paleoreljefa, u smislu degradacije prirodnog reljefa, uz stvaranje uzvišenja od nagomilanih materijala flotacijske jalovine. Metalurška prerada koncentrata uslovila je stvaranje deponija šljake. Najveća količina šljake odložena je na lokalitetu između površinskog kopa rudnog tela „H“ i bivšeg prališta radionice starog površinskog kopa, pa je ova lokacija poznata kao „Depo šljake – 1. (Maksimović M., Nikolić K., 2005.).

Prvi radovi na raskrivanju na površinskom kopu Veliki Krivelj počeli su 1979. godine. Otkopavanje rude bakra počelo je 1982. godine i ukupno je otkopano i prerađeno oko 198 miliona tona rude sa oko 689.000 tona metala bakra i oko 179 miliona tona jalovine. (slika 2)

Sl. 2. *Izgled PK Veliki Krivelj (2012)*

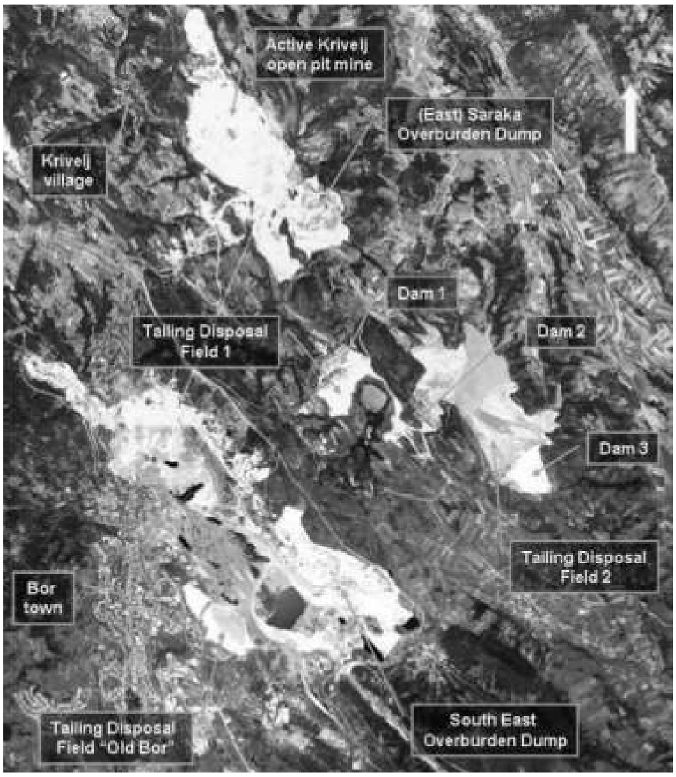
Prerada rude bakra površinskog kopa Veliki Krivelj obavlja se u pogonu Flotacija Veliki Krivelj. Projektovani kapacitet Flotacije Veliki Krivelj je 8.000.000 tona suve rude godišnje, ili iskazano preko časovnog kapaciteta 342,5 t/h suve rude po sekciji.

Jalovište Flotacije Veliki Krivelj je, zbog različitog vremena izgradnje i korišćenja podeljeno u dva dela – polja. Polje 1 zauzima prostor između brana 1 i 2, a polje 2 prostor između brana 2 i 3. Korišćenje polja 1 je započelo u decembru 1982. g., a privremeno prekinuto septembra 1990. g. Polje 2 se koristi od septembra 1990. g. i danas je aktivno.

Sl. 3. *Brana 2 kriveljskog flotacijskog jalovišta (2011)*

PRELIMINARNI ISTRAŽNI RADOVI

Preliminarni istražni radovi usmereni su na ispitivanje terena za istraživanje, sanaciju, remedijaciju i rekultivaciju: Starog Borskog flotacijskog jalovišta: deponije jalovine odlagališta Veliki Krivelj, stabilnost Brane, 2 i 3 na polju 2, Saraka deponije jalovine, jugo-istočne deponije jalovine i RTH. (slika 4).



Sl. 4. *Situacioni plan deponija i odlagališta jalovine (2011)*

CILJ ISTRAŽIVANJA

Osnovni ciljevi istraživanja su:

1. Mere suzbijanja isticanja otpadnih voda sa deponija i remedijacije (uglavnom materijal rudničke jalovine).
2. Stabilnost brana,
3. Upravljanje vodom (atmosferske vode, vode iz pretakanja, curenje vode, nekontrolisanje curenje vode i izlivanje mulja),
4. Zatvaranje i remedijacija deponija jalovine u Boru, i delimično ponovno obnavljanje (sađenje) vegetacije i,
5. Monitoring i održavanje posle izgradnje.

Posebna pažnja posvećena je rehabilitaciji/preusmeravanju baj-pasa reke (kolektor) koji je sada ispod jalovišta Veliki Krivelj.

Ciljevi ovog posebnog zadatka su:

1. ispitivanje lokacije,
2. projektni radovi,
3. razvoj uticaja na životnu sredinu,
4. izrada plana upravljanja životnom sredinom,
5. priprema plana monitoringa za rehabilitaciju i remedijacija.

Specifični ciljevi

1. Sprovođenje ekološkog ispitivanja terena i geološka i hidrogeološka istraživanja radi dobijanja podataka za buduću remedijaciju/rekultivaciju zemljišta;
2. Elaborat ulaza za punu procenu uticaja na životnu sredinu, projekti upravljanja zaštitom životne sredine i projekti sanacije lokacija.

Preliminarni geološki radovi obuhvataju: istražno bušenje radi uzimanja uzoraka za utvrđivanja hemijskog sastava, testove luženja, rudničke i flotacijske jalovine, utvrđivanje geološke građe paleoreljefa, ugradnju piezometara radi praćenja kvaliteta i nivoa voda, uzimanje uzoraka za testove generacije kiseline i neutralizacije inženjersko-geološka ispitivanja radi utvrđivanja stabilnosti brana (Maksimović M., 2011., 2012.).

Pored geoloških istraživanja na terenu, dalja istraživanja obuhvataju neke specifične aktivnosti koje su relevantne za sanaciju i rekultivaciju predmetnih prostora. Ove aktivnosti su: uzorkovanje površinskog zemljišta (potencijalnih) površina deponija rudničke i flotacijske jalovine radi izrade testova generalizacije kiselina i neutralizacije; testova biološke rekultivacije uključujući i testove malog obima na terenu sa biljkama; testove biološke rekultivacije za procenu podobnosti za uslove rasta biljaka.

Uopšteno, istraživanje terena počela su sa detaljnijim testovima prodiranja osnove odlagališta rudničke i flotacijske jalovine radi procene sastava tla. Dalji istraživanja nastavljena su istražnim bušenjem. Finalni položaj i dubina piezometara su odabrani na osnovu testova prodiranja i jezgrenog bušenja i stratigrafije zemljišta koja je utvrđena tokom bušenja.

Mreža testova statičkog sondiranja, do 5 metara dubine, izvedena je pre mreže testiranja smicanja i jezgrenog bušenja.

U cilju provere efikasnosti predložene stabilnosti i mera za smanjenje curenja, sveobuhvatan plan monitoringa koji je urađen i sproveden, sastoji se od instrumentalnog praćenja i vizuelne inspekcije.

Rezultati izvedenih istraživanja i ispitivanja

Flotacijska jalovišta i same brane na jalovištima, su godinama građene od materijala ciklonske jalovine, koji se sastoji od finozrnastog (alevritskog) do krupno-zrnastog peska (rastresitog materjala).

Stabilnost brana je osigurana sve dok se nivo podzemnih voda unutar tela brana može održavati ispod bezbednog maksimalnog nivoa, posebno uzimajući u obzir očekivane seizmičke uslove. Sadašnji napori da se kontroliše nivo podzemnih voda su nedovoljni što dokazuje visok iznos (kontaminiranog) curenja koja se sada pojavljuju kroz brane. (Maksimović M., 2011, 2012.)

Za uspešnu realizaciju Projekta remedijacije neophodno je da trenutni priliv procednih voda bude zaustavljen.

Pre preduzimanja mera, preporučuje se da se prvo sprovede brza procena rizika radi utvrđivanja eventualnih uticaja mogućeg propadanja brana i da se proveri efikasnost i obim predloženih mera sanacije aktivnih jalovišta i remedijacije i rekultivacije neaktivnih deponija.

Na osnovu izvedenih istraživanja i ispitivanja utvrđeno je da treba preduzeti sledeće mere:

- Plan vegetacije treba da bude donešen za kosine brana u cilju sprečavanja buduće površinske erozije ispune brane;

- Redizajn drenažnog sistema za sprečavanje curenja i poboljšanje stabilnosti kroz sistematsko i efikasno spuštanje nivoa podzemnih voda unutar brana i u njihovoj neposrednoj blizini.

ZAKLJUČAK

Istražni prostor koji se nalazi na području neaktivnog ekološkog eksploatacionog polja je prostor, na kome je potvrđeno prisustvo, opasnih i štetnih materija uzrokovano ljudskom aktivnošću, u koncentracijama koje mogu izazvati značajan rizik po ljudsko zdravlje i životnu sredinu.

Područje neaktivnog ekološkog eksploatacionog polja istraživan je istražnim bušotinama sa površine terena. Izvedenim geološkim istraživanjima dobijeni su preliminarni podaci o geološkoj gradi, fizičko-mehaničkim i hidrogeološkim osobinama, područja neaktivnog ekološkog eksploatacionog polja.

Na osnovu rezultata izvršenih istraživanja i ispitivanja predložene su dalje mere radi sanacije predmetnog prostora, i smanjenja zagađenja. Daljim istraživanjima dobiće se rezultati za preduzimanja mera za zaustavljanje zagađenja i dalje degradacije životne sredine do nivoa koji je bezbedan za buduće korišćenje lokacije uključujući uređenje prostora, revitalizaciju i rekultivaciju.

LITERATURA

[1] Maksimović M., Nikolić K. i dr.: Elaborat o rezervama ležišta bakra Bor (rudna tela “Brezanik”, “Tilva Roš“ i “P2A”), stanje 31.12.2004.-tekstualni deo, Fond stručne dokumentacije, Odeljenje za geologiju IRM, Bor; 2005, s. 144.

[2] Maksimović M.: Projekat detaljnih geoloških istraživanja bakra i drugih korisnih komponenti na prostoru Starog flotacijskog jalovišta u Boru (Polje 1 i Polje 2), u 2011/12. godini, Fond stručne dokumentacije Odeljenje za geologiju IRM, Bor; 2011, s. 44.

[3] Maksimović M.: Projekat istraživanja i ispitivanja flotacijskih i kopovskih jalovišta Bor, na području neaktivnog ekološkog eksploatacionog polja, vezano za aktivnosti na remedijaciji od strane Svetske banke, Fond stručne dokumentacije Odeljenje za geologiju IRM, Bor; 2011, s. 55.

[4] Maksimović M.: Projekat geološko-ekološkog istraživanja i ispitivanja u okviru ugrožene ekološke zone – Jalovišta u Boru (Brana 2), Fond stručne dokumentacije Odeljenje za geologiju IRM, Bor; 2012, s. 20.

[5] Maksimović M.: Elaborat o izvršenim geološkim istraživanjima i ispitivanjima flotacijskih i kopovskih jalovišta Bor, na području neaktivnog ekološkog eksploatacionog polja, vezano za aktivnosti na remedijaciji od strane Svetske banke, u periodu 2011/12. Godine, Fond stručne dokumentacije Odeljenje za geologiju IRM, Bor; 2012, s. 83.

[6] Izveštaj konsultantske kuće Witteveen + Bos, po Projektu Svetske banke ”Bor regional development“, komponenta A-remedijacija flotacijskih jalovišta i izmeštanje kriveljskog kolektora., Fond stručne dokumentacije Odeljenje za geologiju IRM, Bor; 2012, s. 50.

MINING AND METALLURGY INSTITUTE BOR ISSN: 2334-8836
UDK: 622

UDK: 661.013.14:551.49(045)=20 DOI:10.5937/MMEB1402013K

Srđan Kostić, Dejan Vasović**, Ruža Okrajnov Bajić**

NEW FRESH CONCRETE CHEMICAL ADMIXTURE FOR TUNNEL LINING DESIGN IN THE EXTREME WINTER CONDITIONS***

Abstract

A new type of calcium-nitrate and urea-based chemical admixture is proposed, in order to maintain the compressive strength of fresh concrete exposed to very low temperatures (below to – 25^{0}C), including a sudden transition to positive temperatures at an early age. The applied admixture has no negative effect on compressive strength of specimens cured in water at 20^{0}C. When it is cured under three different frost regimes, concrete specimens with admixture show over three times higher compressive strength, in comparison to specimens without admixture. The implications of such improved concrete composition are discussed in reference to the tunnel lining design.

Keywords*: frost protection, compressive strength, anti-freezing admixture, tunnel lining*

INTRODUCTION

Tunnel advance in weak rock masses requires an appropriate lining design, in order to prevent high inward displacements of rock masses, tunnel roof collapse or jamming/damage of tunnel boring machines, before the final support is installed. The process of supporting the rock mass usually initiates with adequate distribution of rock bolts, modifying the properties of rock mass in much the same way as reinforcement does in concrete. In the same time, since the final support is typically installed after some time elapsed from the excavation, and at some distance from the excavation point (using the "longitudinal arch" effect), a thin layer of shotcrete (sprayed concrete) is usually installed with the main task to reduce displacement and number of yielded bolt elements (regarding the elastic-perfectly plastic behavior of rock mass) [1]. Properties of such shotcrete are determined according to specific tunnel design and geological conditions. However, an important issue that has to be considered is the time - dependent properties of the shotcrete layer. For example, if the tunnel lining, consisting of rock bolts and shotcrete with steel lattice girders, is installed right behind the tunnel face and

* *Department of Geology, University of Belgrade Faculty of Mining and Geology, Djušina 7, 11000 Belgrade, srdjan.kostic@rgf.bg.ac.rs*
** *Department of Architectural Technologies, University of Belgrade Faculty of Architecture, Belgrade, Serbia*
*** *This research was partly supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Project No. 176016).*

activated immediately, the rock-bolts and lattice girders respond to the deformation of the rock mass surrounding the tunnel as soon as the tunnel advances. However, the shotcrete is only one day old at this stage, and it has not yet developed its full capacity, so the current load may be sufficient to induce failure in the shotcrete. Considering this, it is important to assure that shotcrete reaches the expected short-term value of compressive strength by protecting it from the unfavorable outdoor conditions, e.g. sudden freezing and thawing cycles. It should be noted that for tunnel advance in frost conditions, it is not necessary to use the shotcrete mixture which provides freeze/thaw resistant hardened concrete, but to have a fresh concrete mixture resistant to possible freezing [2-3]. According to [4], concrete has to be protected against freezing until the degree of saturation is significantly reduced due to hydration process, corresponding to the time when concrete reaches a compressive strength of 3.5 MPa [5], which is typically achieved in the first 24 h for concrete mixtures with W/C ratio below 0.6 and exposed to t=20ºC. If concrete is exposed to freezing before this time, its compressive strength will be sig-nificantly reduced [6]. Considering this, it is of special interest to investigate the frost resistance of fresh concrete in winter months, when minimum recorded daily temperatures may reach even below -10ºC with up to 15 days with the average daily temperature below zero [7]. In such cases, water freezing in fresh concrete could permanently damage the structure of newly formed cement matrix.

Even though, there are many previous studies on the impact of low temperatures on compressive strength of concrete [8-11], none of them investigate the influence of severe frost on fresh concrete, with temperatures down to -25ºC, including the effect of quick temperature changes, with amplitude up to 45ºC in just several days. The main motivation for performing such research lies in the justified need for an anti-freeze admixture, considering the real temperature regimes recorded in Belgrade, with frequent cases of severe frost. Such extreme frost conditions could have happened during the TBM excavation of hydrotechnical tunnel in Višnjica near Belgrade, leading to the possible machine jamming.

The aim of research is to develop a reliable admixture, which could enable tunnel lining without frost protection even in such severe climate conditions. Considering this, the impact of different amount of proposed chemical admixture (4% and 8%) is investigated on compressive strength of fresh concrete under three different frost regimes: one-day frost (-10ºC), three-day frost (-10ºC, -5ºC and -15ºC), and seven-day frost (oscillating from 0ºC up to -25ºC).

DURATION OF FROST IN REAL CONDITIONS

In order to motivate a need for field application of such an anti-freeze admixture, a review on the climatic properties in Belgrade for period 1993-2012 is given according to the observations made by the Republic Hydrometeorological Service of Serbia [7]. In order to justify the testing of concrete under the first and second frost regime, the extreme examples of sudden warming for December, January, February and March in the period 1993-2012 were analyzed. Maximum temperature amplitudes (up to 16.8ºC in February 1996) are shown in Figure 1 only for those days with sudden transition from negative to positive temperatures in two consecutive days.

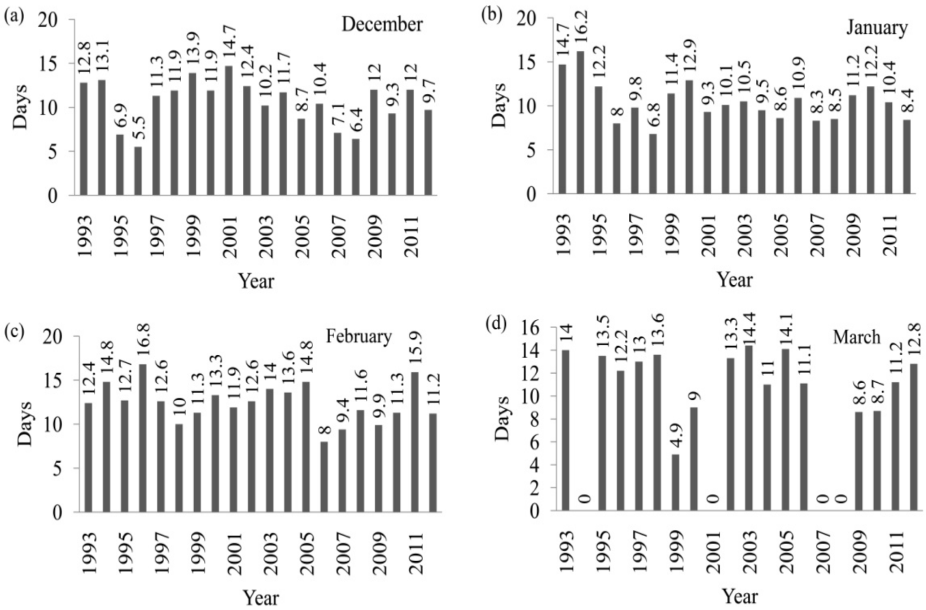


Figure 1 *Maximum daily temperature amplitude with sudden transition from negative to the positive values for two consecutive days in the period 1993-2012 for the following months: (a) December, (b) January, (c) February; (d) March. Zero value is assigned for months without a transition from negative to positive temperature*

On the other hand, maximum number of consecutive days with frost is shown in Figure 2 (14 days in January 2009 and February 2012), which legitimizes the testing of concrete in the third frost regime, with seven-day continuous frost.

EXPERIMENTAL PART

In the first phase of research, the concrete compressive strength was determined with and without admixture after curing in water at the room temperature (20ºC). The second stage of the study comprises the analysis of admixture effect (4% and 8%) on compressive strength of concrete specimens and after that they were exposed to three different frost regimes. The main constitutive elements of concrete were (Table 1): cement (CEM I 42.5 R, Lafarge Cement Factory Beočin, Serbia), andesite aggregate (crushed, quarry Šumnik, Serbia) and admixture ("T-25 ºC"). Cubic concrete specimens (10x10 cm) were formed in a laboratory counter-current concrete mixer, with the mixing period of 3 minutes for all mixtures. Casting was performed at a vibrating table until a complete consolidation was achieved.

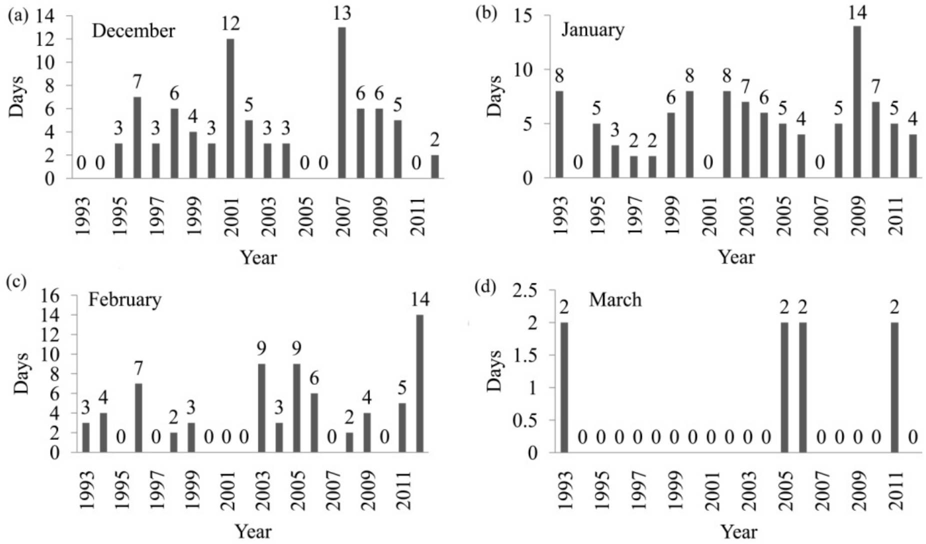


Figure 2 *Number of consecutive days with the temperature below 00C in the period 1993-2012 for the following months: (a) December, (b) January, (c) February; (d) March (only two or more days are taken into account)*

Table 1 *Proportions of concrete mixtures*

constituent per 1m^3 of concrete	admixture 0%	admixture 4%	admixture 8%
cement: CEM I 42,5 R	417 kg	411 kg	408 kg
andesite aggregate 0 - 2 mm (30%)	574 kg	567 kg	563 kg
andesite aggregate 2 - 4 mm (10%)	192 kg	189 kg	188 kg
andesite aggregate 4 - 8 mm (10%)	192 kg	189 kg	188 kg
andesite aggregate 8 -11 mm (20%)	383 kg	378 kg	375 kg
andesite aggregate 11 -16 mm (30%)	575 kg	568 kg	563 kg
admixture	-	16,4 kg	32,6 kg
water	167 kg	148 kg	139 kg
W/C ratio	0.40	0.36	0.34
unit weight	2500 kg/m^3	2467 kg/m^3	2456 kg/m^3

Concrete specimens for the first set of tests (isothermal curing conditions) were prepared as described above and cast in steel moulds. After 24 hours, the reference samples were taken out of the moulds and cured under the same conditions in water at 20ºC. The compressive strength was determined after 3, 7 and 28 days. In the second phase of the experimental part of the research, test specimens were made in the same way as in the previous test (10x10 cm cubes). The temperature of mixtures during casting was 20ºC. Immediately upon casting, metal moulds with fresh concrete were put in the acclimatization chamber at -10ºC, and exposed to three different frost regimes: (a) frost regime 1 simulates temporary one-day frost, with specimens exposed to -10ºC on the first day and cured in water at 20ºC during the following day; (b) frost regime 2 simulates several-day frost, with first-day exposure to -10ºC, second-day exposure to -5ºC, third-day exposure to -15ºC and, during the fourth day, the specimens were cured in water at 20ºC; (c) frost regime 3 simulates a long, seven-day period of frost, with first-day exposure to -10ºC, second-day exposure to -5ºC, third-day exposure to -15ºC, fourth-day exposure to -25ºC, fifth-day exposure to -10ºC and sixth-day and seventh-day exposure to -5ºC. From the eighth to twenty-eighth day, test specimens were cured in water at 20ºC.

EXPERIMENTAL RESULTS

Results of the first phase of research are shown in Table 2. It is clear that concrete compressive strength with admixture after 3 days is larger when compared to the specimens without admixture. However, after 7 days, a slightly larger compressive strength is observed for the concrete with 4% of admixture, while significantly lower strength is determined for the concrete with 8% of admixture. On the other side, after 28 days compressive strength increases for the concrete with 4% of admixture and then slightly drops for samples with 8% of admixture, but it is still higher when compared to the specimens without admixture. The testing proved that the addition of admixture had no negative effect on the concrete hardening after 28 days.

Table 2 *Properties of concrete samples with different % of admixture cured in water at 20ºC**

Sp. No.	Age (days)	0% admixture		4% admixture		8% admixture	
		γ (kg/m^3)	σ_c (MPa)	γ (kg/m^3)	σ_c (MPa)	γ (kg/m^3)	σ_c (MPa)
1	3	2470	52.0	2405	57.5	2490	61.0
2		2460	52.0	2420	58.0	2480	62.0
3		2460	51.0	2490	54.5	2480	65.0
4	7	2470	77.4	2470	74.5	2420	66.2
5		2580	73.8	2450	78.0	2460	64.0
6		2450	72.0	2450	72.0	2440	68.5
7	28	2460	88.5	2450	93.0	2470	83.7
8		2470	70.6	2470	84.0	2470	96.5
9		2440	81.0	2450	90.0	2430	81.6

**Sp. No. denotes specimen number, γ represents unit weight and σ_c denotes compressive strength of concrete.*

In the second stage of analysis, concrete compressive strength was determined under the various frost regimes up to -25ºC. Firstly, the effects of water freezing in fresh concrete without chemical admixtures are tested (Table 3).

Table 3 *Properties of concrete samples without admixture*

Sp. No.	frost regime	age (days)		equivalent age (t_e)*	concrete without admixture			
		< 0°C	= 20°C		γ (kg/m³)	average	σ_c (MPa)	average
1	1	1	1	1	2455	2478	7.9	8.2
2	1	1	1	1	2500		8.5	
3	2	3	1	1	2430	2420	10.1	10.2
4	2	3	1	1	2410		10.4	
5	3	7	1	0.83	2410	2400	11.8	12.1
6	3	7	1	0.83	2390		12.4	
7	3	7	1	0.83	2355		16.7	
8	3	7	3	2.83	2530	2425	19.0	17.6
9	3	7	3	2.83	2390		17.1	
10	3	7	3	2.83	2390		21.0	
11	3	7	7	6.83	2410	2397	21.8	21.5
12	3	7	7	6.83	2390		21.8	
13	3	7	7	6.83	2525		31.0	
14	3	7	28	27.83	2410	2440	28.0	29.3
15	3	7	28	27.83	2385		29.0	

**equivalent age (t_e) is determined according to the Saul model [12]*

The results of experimental research on concrete specimens with 4% and 8% of admixture are shown in Tables 4 and 5. In both cases, compressive strength of concrete specimens is much higher, even over three times (for frost regime 1 from 8.2 MPa to 25.9 MPa with 4% of admixture), when compared to the concrete strength without the admixture (Table 3).

Table 4 *Properties of concrete samples with 4% admixture*

Sp. No.	frost regime	age (days)		equivalent age (t_e)	concrete with 4% admixture			
		< 0°C	= 20°C		γ (kg/m³)	average	σ_c (MPa)	average
1	1	1	1	1	2440	2445	25.8	25.9
2	1	1	1	1	2450		26.0	
3	2	3	1	1	2470	2460	15.2	15.6
4	2	3	1	1	2450		16.1	
5	3	7	1	0.83	2440	2445	26.0	25.2
6	3	7	1	0.83	2450		24.3	
7	3	7	1	0.83	2380		31.0	
8	3	7	3	2.83	2380	2390	31.5	31.5
9	3	7	3	2.83	2410		32.0	
10	3	7	3	2.83	2370		45.0	
11	3	7	7	6.83	2410	2390	39.5	43.1
12	3	7	7	6.83	2390		44.8	
13	3	7	7	6.83	2440		50.7	
14	3	7	28	27.83	2460	2453	53.8	53.6
15	3	7	28	27.83	2460		56.4	

Table 5 *Properties of concrete samples with 8% admixture*

Sp. No.	frost regime	age (days)		equivalent age (t_e)	concrete with 8% admixture			
		< 0°C	= 20°C		γ (kg/m³)	average	σ_c (MPa)	average
1	1	1	1	1	2440	2440	17.0	17.6
2	1	1	1	1	2440		18.1	
3	2	3	1	1	2430	2445	24.0	23.8
4	2	3	1	1	2460		23.7	
5	3	7	1	0.83	2430	2435	38.7	39.4
6	3	7	1	0.83	2440		40.2	
7	3	7	1	0.83	2410		41.0	
8	3	7	3	2.83	2385	2402	40.0	40.5
9	3	7	3	2.83	2410		40.5	
10	3	7	3	2.83	2410		46.3	
11	3	7	7	6.83	2420	2403	46.5	47.9
12	3	7	7	6.83	2380		51.0	
13	3	7	7	6.83	2430		56.1	
14	3	7	28	27.83	2450	2443	69.4	61.0
15	7	7	28	27.83	2450		57.4	

It is necessary to emphasize that the difference in behaviour of concrete specimens with 4% and 8% admixture is rather small, indicating that further increase in admixture dosage would not significantly increase the concrete compressive strength. On the other hand, even though there is a significant increase of compressive strength when compared with the case without admixture (Tables 3, 4 and 5), the recorded values are still lower in comparison to the concrete specimens cured under isothermal conditions (Table 2). In order to compare the compressive strength of concrete samples under different frost regimes (with and without chemical additives) to the compressive strength of concrete specimens cured under isothermal conditions, the compressive strength of concrete is estimated after the following days: 0.83, 1, 2.83, 6.83 and 27.83, which represent the equivalent age for all tested cases (fourth column in Tables 3, 4 and 5). The compressive strength at target days was estimated using the Plowman model (Figure 3), which expresses the relationship between compressive strength of concrete cured under isothermal conditions and maturity by the Saul:

$$S_p = a + b \times \log M_s ,$$

where

- S_p - is the strength prediction value by the Plowman equation [13],
- M_s - is the maturity by the Saul model [12] and
- a and b are constants.

Maturity of concrete M_s was determined on the basis of equivalent age, which takes into account the combined effect of time and curing temperature on strength development [14]:

$$t_e = \left(\sum_{1}^{n} (T - T_0) \times \Delta t_i \right) / \left(T_r - T_0 \right),$$

where

- t_e - is the equivalent age,
- T - is temperature at which concrete hardens in the time interval Δt_i,
- T_0 - indicates the reference temperature (–10ºC),
- T_r - represents the concrete curing temperature (20 ºC), and
- Δt_i - represents the observed time interval.

It is obvious, based on Figure 3, that the Plowman model gives a reasonable estimation of experimental results, with high coeficient of correlation (r > 0.8) and small root mean squared error ($RMSE \leq$ 7.14). Thus the values of compressive strength at target days could be read from these diagrams with reliable accuracy (fourth column in Tables 3, 4 and 5).

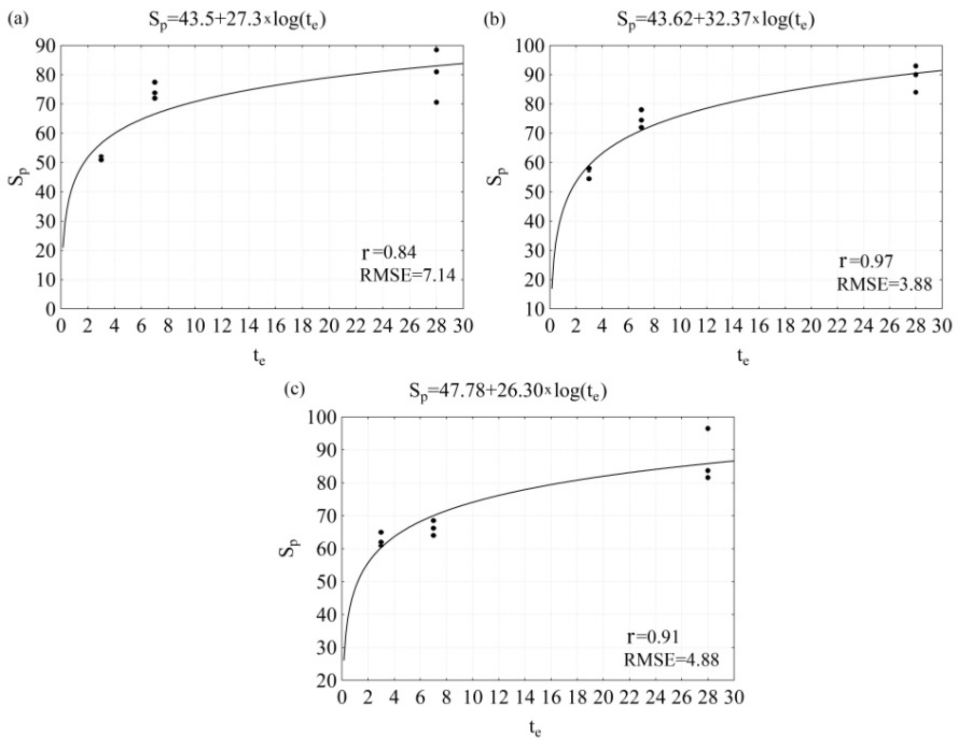


Figure 3 *Regression results of the Plowman model for concrete specimens with different amount of admixture, cured under the isothermal conditions (in water at 200C): (a) 0% of admixture; (b) 4% of admixture; (c) 8% of admixture*

Comparison of concrete compressive strength cured under isothermal conditions and after different frost regimes is shown in Table 6. It is clear that concrete specimens with 8% of admixture achieve 86.3% of the target compressive strength, for the third frost regime with seven days of frost and only one day of thawing. The same specimens achieve 71.1% of the target compressive strength for the third frost regime with seven days of frost and 21 days of thawing. In all other cases, the concrete specimens achieve less than 70% of the compressive strength of reference samples cured under isothermal conditions.

Table 6 *Decrease of compressive strength of concrete with and without admixture cured under the isothermal conditions and exposed to different temperature regimes*

equivalent age (t_e)	σ_c (MPa) with 0% admixture			σ_c (MPa) with 4% admixture			σ_c (MPa) with 8% admixture		
	Isothermal	After different frost regimes	% of isothermal σ_c achieved	Isothermal	After different thermal regimes	% of isothermal σ_c achieved	Isothermal	After different thermal regimes	% of isothermal σ_c achieved
0.83	41.29	12.1	29.3	41.00	25.2	61.5	45.65	39.4	86.3
1	43.50	8.2-10.2	18.9-23.5	43.62	15.6-25.9	35.8-59.4	47.78	17.6-23.8	36.8-49.8
2.83	55.83	17.6	31.5	58.24	31.5	54.1	59.66	40.5	67.9
6.83	66.28	21.5	32.4	70.63	43.1	61.0	69.73	47.9	68.7
27.83	82.94	29.3	35.3	90.38	53.6	59.3	85.77	61.0	71.1

CONCLUSION

This work analyzes the effect of chemical admixture on compressive strength of concrete specimens under differrent frost regimes. In all three cases, concrete with admixture achieved considerably higher compressive strength (even 200% higher for some regimes), when compared to the samples without admixture. The results of this analysis confirm that the use of chemical admixtures prevent breakage of fresh shotcrete tunnel lining even in such severe winter conditions.

It should be noted that comparison of recorded concrete compressive strength (Table 6) was carried out using the regression analysis, which could lead to ambiguous interpretations. However, relatively high value of correlation coefficient (r>0.8) points out that possible error in estimated value lies in the range of a measurement error. On the other side, the present analysis was limited by the small number of concrete samples: for some regimes three concrete samples are tested, as it is common in laboratory testing, while in the other cases, properties of only two specimens were determined. However, even with large number of samples the significantly different results should not be expected from the standpoint of the achieved compressive strength.

Regarding the future research, further analysis of the proposed admixture effect should be carried out especially regarding the target of compressive strength. Certainly, this should be related to the economic benefits, aiming at low-cost percentage of admixture with maximum concrete compressive strength. These experiments would certainly be performed *in situ*, at excavated contour, which would also involve the impact of progressive inward displacement of rock masses on the development of shotcrete compressive strength. In that way, the effect of chemical admixture on the stability of fresh shotcrete tunnel lining would be evaluated more closely.

REFERENCES

[1] Hoek, E., Carranza-Torres, C., Diederichs, M., The 2008 Kersten Lecture: Integration of Geotechnical and Structural Design in Tunneling, Proceedings, 56th Annual Geotechnical Engineering Conference, Minneapolis, 2008; pp. 53;

[2] Aitcin, P. C. The Durability Characteristics of High Performance Concrete: A Review. Cement Concrete Comp. 2003; 25: pp. 409-420;

[3] Neville, A. M. Properties of Concrete. 5th ed. Edinburgh: Pearson Education Limited; 2012;

[4] ACI 306 Committee, Guide to Cold Weather Concreting, ACI 306R-10, Farmington Hills, Michigan: American Concrete Institute; 2010;

[5] Powers, T. C. Prevention of Frost Damage to Green Concrete. RILEM 1962;14: 120-124;

[6] Kosmatka, S. H., Kerkhoff, B., Panarese, W. C. Design and Control of Concrete Mixtures. 14th ed. Skokie, Illinois: Portland Cement Association; 2003;

[7] Yearbooks of Hydrometeorological Service of Serbia, 1993-2012;

[8] Nmai, C. K. Cold Weather Concreting Admixtures, Cement Concrete Comp. 1998; 20:121-128;

[9] Husem, M., Gozutok, S., The Effects of Low Temperature Curing on the Compressing Strength of Ordinary and High Performance Concrete, Constr. Build. Mater. 2005;19: 49-53;

[10] Barna, L. A., Seman, P. M., Korhonen, C. J., Energy-efficient Approach to Cold-weather Concreting, Journal of Materials in Civil Engineering, Special Issue: Energy Efficient and Environmentally Friendly Paving Materials 2011; 23: pp. 1544–1551;

[11] Cullu, M., Arslan, M., The effects of Antifreeze Use on Physical and Mechanical Properties of Concrete Produced in Cold Weather, Composites: Part B 2013; 50:pp. 202–209;

[12] Saul, A. G. A. Principles Underlying the Steam Curing of Concrete at Atmospheric Pressure, Mag. Concr. Res. 1951; 2: pp. 127–140;

[13] Plowman, J. M. Maturity and the Strength of Concrete. Mag. Concr. Res. 1956;8: pp. 13 – 22;

[14] Yi, S. T., Moon, Y. H., Kim, J. K., Long-term Strength Prediction of Concrete with Curing Temperature, Cement Concrete Res. 2005; 35; pp. 1961–1969.

INSTITUT ZA RUDARSTVO I METALURGIJU BOR ISSN: 2334-8836
UDK: 622

UDK: 666.013.14:551.49(045)=861 DOI:10.5937/MMEB1402013K

Srđan Kostić, Dejan Vasović**, Ruža Okrajnov Bajić**

NOVI HEMIJSKI DODATAK SVEŽEM BETONU ZA IZVOĐENJE TUNELSKE OBLOGE U EKSTREMNIM ZIMSKIM USLOVIMA***

Izvod

U radu se predlaže novi tip hemijskog dodatka betonu na bazi kalcijum-nitrata i uree, sa ciljem održavanja čvrstoće na pritisak svežeg betona izloženog vrlo niskim temperaturama (do -25^{0}C), uključujući i uticaj iznenadnih velikih temperaturnih amplituda (prelaze od negativnih ka pozitivnim temperaturama). Primenjeni dodatak ne utiče nepovoljno na čvrstoću na pritisak uzoraka betona negovanih u izotermalnim uslovima na temperaturi od 20^{0}C. Kada se svež beton izloži uticaju različitih režima mraza, uzorci sa dodatkom pokazuju gotovo tri puta veću pritisnu čvrstoću u poređenju sa uzorcima bez dodatka. Primena betona sa predloženim aditivom u praksi razmatra se u odnosu na postojanost i stabilnost tunelske obloge sa prskanim betonom.

Ključne reči: *zaštita od mraza, čvrstoća na pritisak, dodatak protiv zamrzavanja, obloga tunela*

UVOD

Izvođenje tunela u „slabim” stenskim masama zahteva pravilno projektovanje tunelske obloge, radi sprečavanja velikih pomeranja po konturi iskopa, provaljivanja krovine ili zaglavljivanja, odnosno oštećenja tunelske mašine pre postavljanja finalne podgrade. Proces podgrađivanja stenske mase obično započinje ugradnjom ankera odgovarajućih svojstava, i u tačno određenom rasporedu, sa ciljem poboljšanja mehaničkih svojstava stenske mase. S obzirom na to da se izvođenju finalne podgrade pristupa tek nakon određenog vremena od iskopa, kao i na određenoj udaljenosti od čela (koristeći longitudinalni efekat luka), najpre se postavlja tanak sloj prskanog betona (torkreta) po konturi iskopa, sa ciljem redukovanja pomeranja stenske mase i broja deformisanih ankera (pod pretpostavkom elastičnog-idealno plastičnog ponašanja stenske mase) [1]. Svojstva takvog betona se određuju prema zahtevima projekta i lokalnim geološkim uslovima, pri čemu je neophodno imati u vidu i vremenski promenljivo ponašanje betona. Naime, ukoliko se obloga tunela,

* *Departman za geologiju, Univerzitet u Beogradu Rudarsko-geološki fakultet, Đušina 7, 11000 Beograd, srdjan.kostic@rgf.bg.ac.rs*

** *Departman za arhitektonske tehnologije, Univerzitet u Beogradu Arhitektonski fakultet, Beograd*

*** *Izvedeno istraživanje je podržano od strane Ministarstva prosvete, nauke i tehnološkog razvoja Republike Srbije (Projekat br. 176016).*

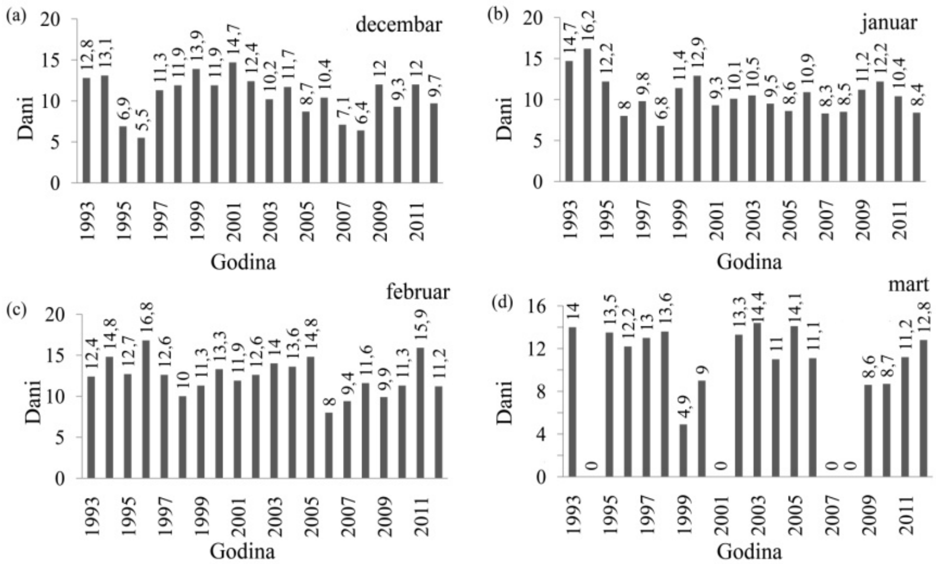
sastavljena od ankera i prskanog betona sa čeličnim rešetkastim nosačima, postavlja neposredno iza čela iskopa, ankeri i rešetkasti nosači će "odgovoriti" na deformaciju stenske mase po konturi iskopa istovremeno sa daljim napredovanjem tunela. Međutim, u ovom stadijumu, starost prskanog betona je vrlo mala, i beton nije uspeo da razvije svoju punu nosivost, tako da trenutno opterećenje od stenske mase u ovoj fazi iskopa može da dovede do njegovog loma. Shodno tome, neophodno je pristupiti zaštiti betona od nepovoljnih spoljašnjih uslova, poput iznenadnog zamrzavanja i otkravljivanja, kako bi dostigao očekivanu vrednost pritisne čvrstoće u tako kratkom vremen-skom intervalu. Neophodno je naglasiti da, u ovom slučaju, izvođaču radova nije potrebna smeša betona koja daje očvrsli beton otporan na zamrzavanje/otkravljivanje, već sveža smeša betona koja je otporna na moguće zamrzavanje [2-3]. Prema Uputstvu Američkog Instituta za beton [4], potrebno je pristupiti zaštiti betona od zamrzavanja sve dok ne dostigne čvrstoću na pritisak od 3,5 MPa [5], što obično iznosi 24 h za smešu betona sa vodocementnim (VC) faktorom ispod 0,6, kada je beton izložen temperaturi t=20ºC. Ukoliko se beton izloži zamrzavanju pre nego što dostigne čvrstoću od 3,5M Pa, njegova konačna čvrstoća na pritisak biće značajno umanjena [6]. Shodno tome, od posebnog je interesa proučavanje otpornosti na mraz svežeg betona za vreme zimskih meseci, sa prosečnom dnevnom temperaturom ispod 0^0C i do 15 dana uzastopno, i sa minimalnim dnevnim temperaturama ispod -10ºC [7]. U takvim uslovima, zamrzavanje vode u svežem betonu može dovesti do trajnog oštećenja strukture novoformiranog cementnog matriksa.

I pored velikog broja prethodnih istraživanja o uticaju niskih temperatura na pritisnu čvrstoću betona [8-11], do sada nisu vršena istraživanja uticaja „oštrog'' mraza na svojstva svežeg betona, sa temperaturama i do -25ºC, uključujući i efekat brzih temperaturnih promena, sa amplitudom i do 45ºC za samo nekoliko dana. Uzimajući u obzir niske temperature zabeležene na području Beograda sa čestim slučajevima oštrog mraza, postoji realna potreba za jednom funkcionalnom antifriz smešom svežeg betona. Ovakvi oštri klimatski uslovi mogli su se očekivati i pri mašinskom iskopu hidrotehničkog tunela u Višnjici, što je moglo dovesti i do zaglavljivanja tunelske mašine.

Osnovni cilj istraživanja je razvoj pouzdanog aditiva, koji bi omogućio izvođenje tunelske obloge bez zaštite od mraza čak i u takvim surovim klimatskim uslovima. Shodno tome, u radu se analizira uticaj različite količine predloženog hemijskog aditiva (4% i 8%) na pritisnu čvrstoću svežeg betona pri različitim režimima mraza: jednodnevni mraz (-10ºC), trodnevni mraz (-10ºC, -5ºC i -15ºC), i sedmodnevni mraz (sa oscilacijama temperature između 0ºC i -25ºC).

TRAJANJE MRAZA U REALNIM USLOVIMA

U cilju potvrde realne potrebe za praktičnom primenom antifriz aditiva za prskani beton, najpre je izvršena analiza klimatskih karakteristika na području Beograda u periodu 1993-2012. g. na osnovu podataka Republičkog Hidrometeorološkog zavoda [7]. Analiza ekstremnih slučajeva iznenadnog otopljavanja za decembar, januar, februar i mart izvedena je sa ciljem definisanja prvog i drugog režima mraza. Na slici 1 prikazana je maksimalna zabeležena temperaturna amplituda samo za one dane sa prelazom iz negativnih u pozitivne temperature za dva uzastopna dana (maksimalna vrednost od 16,8ºC zabeležena je tokom februara 1996.g.).

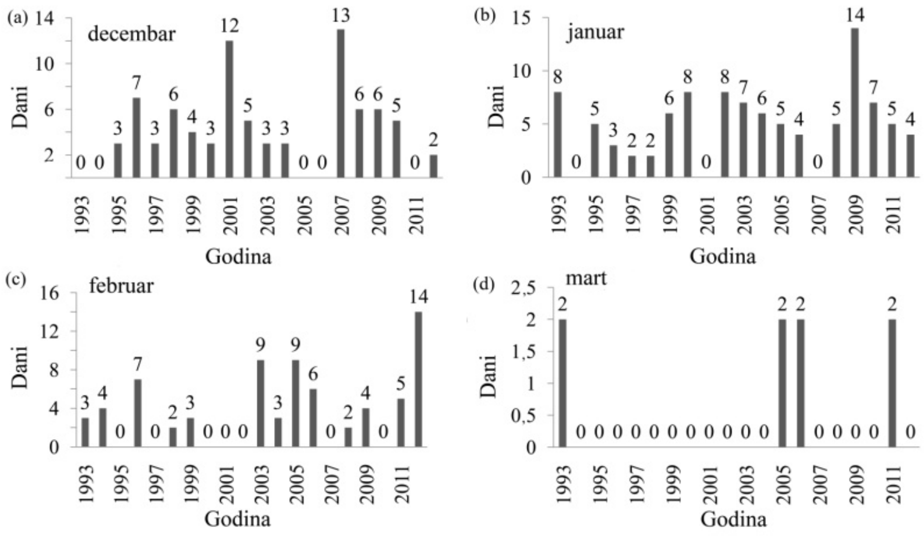


Sl. 1. *Maksimalne dnevne temperaturne amplitude sa iznenadnim prelazom od negativnih ka pozitivnim vrednostima za dva uzastopna dana u periodu 1993-2012.g. za: (a) decembar, (b) januar, (c) februar; (d) mart. Nulta vrednost se dodeljuje za mesece/godine u kojima nije zabeležen prelaz od negativnih ka pozitivnim temperaturama za dva uzastopna dana*

Treći režim mraza, kojem su izloženi uzorci betona, definisan je na osnovu maksimalnog broja uzastopnih dana sa mrazom za decembar, januar, februar i mart, prikazanih na slici 2 (14 dana tokom januara 2009. g. i februara 2012. g.).

EKSPERIMENTALNA PROCEDURA

U prvoj fazi istraživanja, pritisna čvrstoća betona određivana je na uzorcima sa i bez hemijskog aditiva nakon nege u vodi u izotermalnim uslovima (20°C). U drugoj fazi istraživanja, pristupa se analizi efekta 4% i 8% hemijskog aditiva na pritisnu čvrstoću uzoraka betona, nakon njihovog izlaganja različitim režimima mraza. Pri tome, osnovni sastavni elementi betona su (Tabela 1): cement (CEM I 42,5 R, Lafarge Cement, Beočin), agregat (drobljeni kamen, kamenolom Šumnik) i aditiv ("T-25ºC"). Uzorci betona oblika kocke (10x10 cm) pravljeni su u laboratorijskoj mešalici, sa periodom mešanja od 3 minuta za sve smeše. Livenje je obavljeno na vibracionom stolu dok nije postignuta potpuna konsolidacija.



Sl. 2. *Broj uzastopnih dana sa temperaturom ispod 0ºC u periodu 1993-2012.g. za: (a) decembar, (b) januar, (c) februar; (d) mart (samo dva i više dana je uzimano u obzir)*

Tabela 1. *Sastav smeša betona*

komponenta po 1m^3 betona	aditiv 0%	aditiv 4%	aditiv 8%
cement: CEM I 42,5 R	417 kg	411 kg	408 kg
agregat andezita 0 - 2 mm (30%)	574 kg	567 kg	563 kg
agregat andezita 2 - 4 mm (10%)	192 kg	189 kg	188 kg
agregat andezita 4 - 8 mm (10%)	192 kg	189 kg	188 kg
agregat andezita 8 -11 mm (20%)	383 kg	378 kg	375 kg
agregat andezita 11 -16 mm (30%)	575 kg	568 kg	563 kg
aditiv	-	16,4 kg	32,6 kg
voda	167 kg	148 kg	139 kg
V/C	0,40	0,36	0,34
zapreminska težina	2500 kg/m^3	2467 kg/m^3	2456 kg/m^3

Uzorci betona za prvu fazu testiranja (u izotermalnim uslovima nege) pripremljeni su prema prethodno opisanoj proceduri, i izliveni u čelične kalupe. Nakon 24 h, referentni uzorci su izvađeni iz kalupa i negovani pod istim uslovima u vodi na temperaturi od 20ºC. Čvrstoća na pritisak je određena nakon 3, 7 i 28 dana. U drugoj fazi istraživanja uzorci su pripremljeni na siti način kao zaprethodnu fazu. Temperatura smeša za vreme livenja iznosila je 20ºC. Odmah nakon livenja, metalni kalupi sa svežim betonom stavljeni su u aklimatizacionu komoru na temperature -10^{o}C, a potom su izlagani promeni temperature definisanoj sa tri različita režima mraza: (a) režim mraza 1 simulira jednodnevni mraz, pri čemu su uzorci betona izloženi temperaturi od -10ºC u toku jednog dana, a potom, drugog dana, uzorci su izloženi temepraturi od 20ºC; (b) režim mraza 2 simlira višednevni mraz, pri čemu se uzorci betona izlažu temperaturi od -10ºC tokom prvog dana, a potom blagom porastu temperature do -5ºC tokom drugog dana, potom temperaturi od -15ºC tokom trećeg dana, a tokom četvrtog dana uzorci se neguju u vodi na temperaturi od 20ºC; (c) režim mraza 3 simulira duži sedmodnevni mraz sa temperaturom prvog dana od -10ºC, drugog dana od -5ºC, trećeg dana od -15ºC, četvrtog dana od -25ºC, petog dana od -10ºC i šestog dana od -5ºC. U periodu od 8. do 28. dana uzorci betona se neguju u vodi na temperaturi od 20ºC.

EKSPERIMENTALNI REZULTATI

Rezultati prve faze istraživanja prikazani su u Tabeli 2. Jasno je da je pritisna čvrstoća betona sa aditivom nakon 3 dana veća od čvrstoće uzoraka bez aditiva. Međutim, nakon sedam dana, nešto veća pritisna čvrstoća zabeležena je za uzorak betona sa 4% aditiva, dok je značajno manja čvrstoća zabeležena za uzorak sa 8% aditiva. Sa druge strane, nakon 28 dana čvrstoća na pritisak za uzorak betona sa 4% aditiva se povećava, a sa 8% aditiva se nešto smanjuje, ali je i dalje veća u poređenju sa čvrstoćom uzoraka bez aditiva. Izvedeno istraživanje je pokazalo da aditiv ne utiče nepovoljno na očvšćavanje betona nakon 28 dana.

Tabela 2. *Svojstva uzoraka betona sa različitom količinom hemijskog aditiva, negovanih u vodi na temperaturi od 20ºC.**

uzorak broj	starost (dani)	0% aditiva		4% aditiva		8% aditiva	
		γ (kg/m^3)	σ_c (MPa)	γ (kg/m^3)	σ_c (MPa)	γ (kg/m^3)	σ_c (MPa)
1	3	2470	52,0	2405	57,5	2490	61,0
2		2460	52,0	2420	58,0	2480	62,0
3		2460	51,0	2490	54,5	2480	65,0
4	7	2470	77,4	2470	74,5	2420	66,2
5		2580	73,8	2450	78,0	2460	64,0
6		2450	72,0	2450	72,0	2440	68,5
7	28	2460	88,5	2450	93,0	2470	83,7
8		2470	70,6	2470	84,0	2470	96,5
9		2440	81,0	2450	90,0	2430	81,6

** γ označava zapreminsku težinu, a σ_c je čvrstoća na pritisak uzorka betona.*

U drugoj fazi istraživanja, pritisna čvrstoća betona određena je nakon izlaganja uzoraka različitim režimima mraza, sa temperaturom do -25ºC. Postupak ispitivanja se sastojao u sledećem. Najpre je ispitan efekat zamrzavanja na uzorke svežeg betona bez hemijskog aditiva (Tabela 3).

Tabela 3. *Zapreminska težina i čvrstoća na pritisak uzoraka betona bez hemijskog aditiva*

uzorak broj	režim mraza	starost (dani)		ekvivalentna starost (t_e)*	svojstva betona bez aditiva			
		< 0°C	= 20°C		γ (kg/m^3)	srednja vrednost	σ_c (MPa)	srednja vrednost
1	1	1	1	1	2455	2478	7,9	8,2
2	1	1	1	1	2500		8,5	
3	2	3	1	1	2430	2420	10,1	10,2
4	2	3	1	1	2410		10,4	
5	3	7	1	0,83	2410	2400	11,8	12,1
6	3	7	1	0,83	2390		12,4	
7	3	7	1	0,83	2355		16,7	
8	3	7	3	2,83	2530	2425	19,0	17,6
9	3	7	3	2,83	2390		17,1	
10	3	7	3	2,83	2390		21,0	
11	3	7	7	6,83	2410	2397	21,8	21,5
12	3	7	7	6,83	2390		21,8	
13	3	7	7	6,83	2525		31,0	
14	3	7	28	27,83	2410	2440	28,0	29,3
15	3	7	28	27,83	2385		29,0	

**ekvivalentno vreme (t_e) određeno je na osnovu Solovog modela [12]*

Rezultati eksperimentalne analize pritisne čvrstoće uzoraka betona sa 4% i 8% aditiva prikazani su u Tabelama 4 i 5. U oba slučaja, čvrstoća na pritisak uzoraka betona je mnogo veća, skoro i do tri puta (za režim mraza 1 od 8,2 MPa do 25,9 MPa sa 4% aditiva) u poređenju sa pritisnom čvrstoćom na uzorcima betona bez aditiva (Tabela 3).

Tabela 4. *Svojstva uzoraka betona sa 4% hemijskog aditiva*

uzorak broj	režim mraza	starost (dani)		ekvivalentna starost (t_e)	svojstva betona sa 4% aditiva			
		< 0°C	= 20°C		γ (kg/m^3)	srednja vrednost	σ_c (MPa)	srednja vrednost
1	1	1	1	1	2440	2445	25,8	25,9
2	1	1	1	1	2450		26,0	
3	2	3	1	1	2470	2460	15,2	15,6
4	2	3	1	1	2450		16,1	
5	3	7	1	0,83	2440	2445	26,0	25,2
6	3	7	1	0,83	2450		24,3	
7	3	7	1	0,83	2380		31,0	
8	3	7	3	2,83	2380	2390	31,5	31,5
9	3	7	3	2,83	2410		32,0	
10	3	7	3	2,83	2370		45,0	
11	3	7	7	6,83	2410	2390	39,5	43,1
12	3	7	7	6,83	2390		44,8	
13	3	7	7	6,83	2440		50,7	
14	3	7	28	27,83	2460	2453	53,8	53,6
15	3	7	28	27,83	2460		56,4	

Neophodno je naglasiti da je razlika u ponašanju uzoraka betona sa 4% i 8% aditiva vrlo mala, što ukazujena činjenicu da dalje dodavanje hemijskog aditiva ne bi doprinelo značajnijem povećanju čvrstoće na pritisak uzoraka betona. S druge strane, iako se zapaža značajno povećanje pritisne čvrstoće u poređenju sa uzorcima bez aditiva (Tabele 3, 4 i 5), registrovane vrednosti su i dalje niže u odnosu na pritisnu čvrstoću uzoraka betona negovanih u izotermalnim uslovima (Tabela 2).

Tabela 5. *Zapreminska težina i čvrstoća na pritisak uzoraka betona sa 8% hemijskog aditiva*

uzorak broj	režim mraza	starost (dani)		ekvivalentna starost (t_e)	svojstva betona sa 8% aditiva			
		< 0°C	= 20°C		γ (kg/m^3)	srednja vrednost	σ_c (MPa)	srednja vrednost
1	1	1	1	1	2440	2440	17,0	17,6
2	1	1	1	1	2440		18,1	
3	2	3	1	1	2430	2445	24,0	23,8
4	2	3	1	1	2460		23,7	
5	3	7	1	0,83	2430	2435	38,7	39,4
6	3	7	1	0,83	2440		40,2	
7	3	7	1	0,83	2410		41,0	
8	3	7	3	2,83	2385	2402	40,0	40,5
9	3	7	3	2,83	2410		40,5	
10	3	7	3	2,83	2410		46,3	
11	3	7	7	6,83	2420	2403	46,5	47,9
12	3	7	7	6,83	2380		51,0	
13	3	7	7	6,83	2430		56,1	
14	3	7	28	27,83	2450	2443	69,4	61,0
15	7	7	28	27,83	2450		57,4	

U cilju poređenja čvrstoće na pritisak uzoraka betona nakon izlaganja različitim režimima mraza (sa i bez aditiva) i pritisne čvrstoće uzoraka negovanih u izotermalnim uslovima, procena pritisne čvrstoće uzoraka betona izvedena je za sledeće dane: 0,83; 1; 2,83; 6,83 i 27,83, što predstavlja ekvivalentnu starost za sve ispitivane slučajeve (četvrta kolona u tabelama 3, 4 i 5). Čvrstoća na pritisak uzoraka betona za navedene dana ocenjena je koristeći Ploumanov model (Slika 3), koji daje vezu između čvrstoće betona negovanog u izotermalnim uslovima i zrelosti betona po Solu:

$$S_p = a + b \times \log M_s$$

gde je:

- S_p - predviđena vrednost čvrstoće na osnovu Ploumanove jednačine [13],
- M_s - je zrelost betona na osnovu Solovog modela [12], a
- a i b su konsatnte.

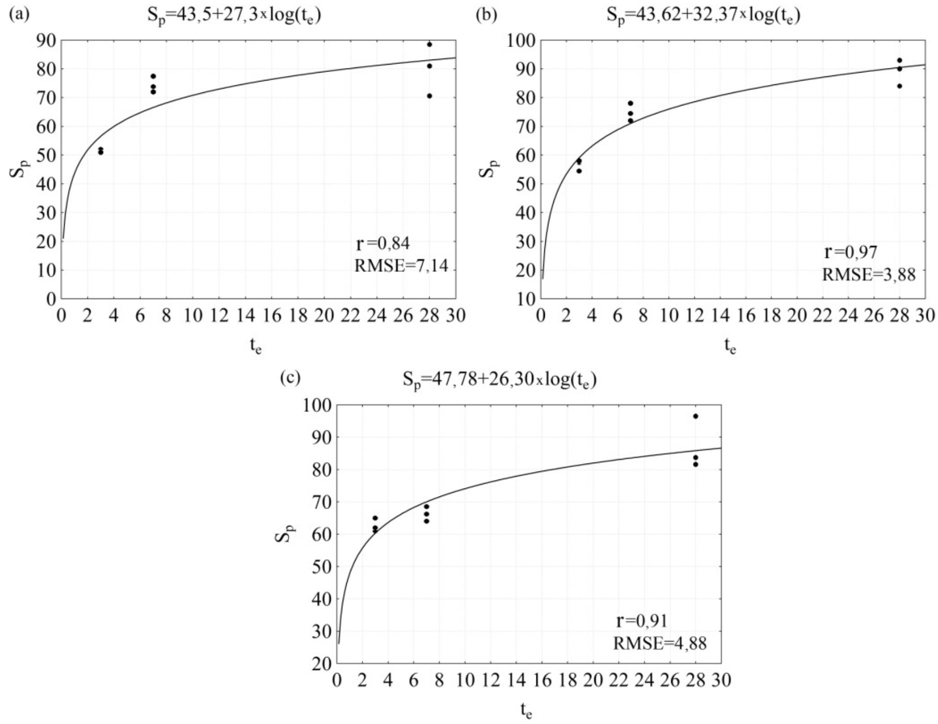
Zrelost betona M_s određena je na osnovu ekvivalentne starosti, uzimajući u obzir spregnuti uticaj proteklog vremena i temperature na razvoj čvrstoće [14]:

$$t_e = \left(\sum_{1}^{n} (T - T_0) \times \Delta t_i \right) / \left(T_r - T_0 \right),$$

gde je:

- t_e - ekvivalentna starost,
- T - je temperatura očvršćavanja betona u vremenskom intervalu Δt_i,
- T_0 - označava referentnu temperaturu (–10ºC),
- T_r - je temperatura nege betona (20ºC), a
- Δt_i - je posmatrani vremenski interval.

Očigledno je, na osnovu slike 3, da Ploumanov model daje zadovoljavajuću procenu eksperimentalnih rezultata, sa visokim koeficijentom korelacije (r>0,8) i niskom vrednošću srednje kvadratne greške ($RMSE$≤7,14). Prema tome, vrednosti čvrstoće na pritisak za ekvivalentnu starost mogu da se očitaju sa ovih dijagrama sa zadovoljavajućom tačnošću (četvrta kolona u tabelama 3, 4 i 5).



Sl. 3. *Rezultati predviđanja čvrstoće na pritisak uzoraka betona pomoću Ploumanovog modela sa različitom količinom aditiva, negovanih u izotermalnim uslovima (u vodi na temperaturi 20ºC): (a) 0% aditiva; (b) 4% aditiva; (c) 8% aditiva*

Poređenje čvrstoće na pritisak betona negovanog u izotermalnim uslovima i nakon izlaganja različitim režimima mraza prikazano je u Tabeli 6. Jasno je da uzorci betona sa 8% aditiva postižu 86,3% željene pritisne čvrstoće, za režim mraza 3 sa sedmodnevnim mrazom i samo jednim danom otkravljivanja.

Isti uzorci postižu 71,1% željene pritisne čvrstoće za režim mraza 3 sa sedmodnevnim mrazom i 21 danom otkravljivanja. U svim drugim slučajevima, uzorci betona postižu manje od 70% pritisne čvrstoće referentnih uzoraka negovanih pod izotermalnim uslovima u vodi na temperaturi od 20ºC.

Tabela 6. *Smanjenje čvrstoće na pritisak uzoraka betona sa i bez hemijskog aditiva, negovanih u izotermalnim uslovima, i pri delovanju različitih temperaturnih režima*

ekvivalentna starost (t_e)	σ_c (MPa) sa 0% aditiva			σ_c (MPa) sa 4% aditiva			σ_c (MPa) sa 8% aditiva		
	Izotermalni uslovi	Nakon različitih režima mraza	% postignute izotermalne čvrstoće σ_c	Izotermalni uslovi	Nakon različitih režima mraza	% postignute izotermalne čvrstoće σ_c	Izotermalni uslovi	Nakon različitih režima mraza	% postignute izotermalne čvrstoće σ_c
0,83	41,29	12,1	29,3	41,00	25,2	61,5	45,65	39,4	86,3
1	43,50	8,2-10,2	18,9-23,5	43,62	15,6-25,9	35,8-59,4	47,78	17,6-23,8	36,8-49,8
2,83	55,83	17,6	31,5	58,24	31,5	54,1	59,66	40,5	67,9
6,83	66,28	21,5	32,4	70,63	43,1	61,0	69,73	47,9	68,7
27,83	82,94	29,3	35,3	90,38	53,6	59,3	85,77	61,0	71,1

ZAKLJUČAK

U radu se analizira efekat hemijskog aditiva na čvrstoću na pritisak uzoraka betona nakon izlaganja različitim režimima mraza. U sva tri ispitana slučaja, uzorci betona sa hemijskim aditivom dostigli su znatno višu pritisnu čvrstoću (čak i do 200% veću) u odnosu na uzorke bez hemijskog aditiva. Rezultati analize potvrđuju da se primenom hemijskog aditiva može sprečiti lom svežeg prskanog betona čak i takvim oštrim zimskim uslovima.

Naglasimo da je poređenje pritisnih čvrstoća zabeleženih pri različitim temperaturnim uslovima (Tabela 6) izvedeno korišćenjem regresione analize (Ploumanov model), što može dovesti do nepouzdanih interpretacija. Međutim, relativno visoka vrednost koeficijenta korelacije (r>0.8) ukazuje na to da je moguća greška u proceni pritisne čvrstoće u intervalu greške merenja. S druge strane, izvedena analiza je u znatnoj meri ograničena malim brojem ispitanih uzoraka betona: u pojedinim slučajevima ispitivana su po tri uzorka, što je i uobičajeno u laboratorijskoj praksi, dok su, u drugim slučajevima, svojstva betona određivana na samo dva uzorka. Međutim, čak i sa većim brojem uzoraka, ne bi trebalo očekivati značajnije promene u pogledu dostignute pritisne čvrstoće sa dodatim hemijskim aditivom.

U pogledu pravca daljih istraživanja, izvedena analiza bi trebalo biti proširena dodatnim analizama efekta predloženog hemijskog aditiva, pre svega u odnosu na postizanje željene čvrstoće na pritisak betona. Naravno, buduća istraživanja bi morala uzeti u obzir i ekonomske efekte, sa ciljem određivanja najpovoljnijeg procenta aditiva, koji obezbeđuje najveću pritisnu čvrstoću betona. Ovi opiti bi morali da budu izvedeni u realnim uslovima, *in situ*, postavljanjem svežeg betona po konturi iskopa, čime bi se obuhvatio i uticaj pomeranja stenske mase ka tunelskom otvoru na razvoj čvrstoće mladog prskanog betona. Na taj način, bila bi izvršena još realnija procena efekta hemijskog aditiva na stabilnost i postojanost svežeg prskanog betona.

LITERATURA

[1] Hoek, E., Carranza-Torres, C., Diederichs, M. The 2008 Kersten Lecture: Integration of Geotechnical and Structural Design in Tunneling. Proceedings of 56th Annual Geotechnical Engineering Conference, Minneapolis, 2008; 53 p.

[2] Aitcin, P. C. The Durability Characteristics of High Performance Concrete: a Review. Cement Concrete Comp. 2003; 25: p. 409-420.

[3] Neville, A. M. Properties of Concrete. 5th ed. Edinburgh: Pearson Education Limited; 2012.

[4] ACI 306 Committee. Guide to Cold Weather Concreting, ACI 306R-10. Farmington Hills, Michigan: American Concrete Institute; 2010.

[5] Powers, T. C. Prevention of Frost Damage to Green Concrete. RILEM 1962; 14: p. 120-124.

[6] Kosmatka, S. H., Kerkhoff, B., Panarese, W. C. Design and Control of Concrete Mixtures. 14th ed. Skokie, Illinois: Portland Cement Association; 2003.

[7] Yearbooks of Hydrometeorological Service of Serbia, 1993-2012.

[8] Nmai, C. K. Cold Weather Concreting Admixtures. Cement Concrete Comp. 1998; 20:121-128.

[9] Husem, M., Gozutok, S. The Effects of Low Temperature Curing on the Compressing Strength of Ordinary and High Performance Concrete. Constr. Build. Mater. 2005;19:49-53.

[10] Barna, L. A., Seman, P. M., Korhonen, C. J. Energy-efficient Approach to Cold-Weather Concreting. Journal of Materials in Civil Engineering, Special Issue: Energy Efficient and Environmentally Friendly Paving Materials 2011; 23: 1544–1551.

[11] Cullu, M., Arslan, M. The Effects of Antifreeze Use on Physical and Mechanical Properties of Concrete Produced in Cold Weather. Composites: Part B 2013; 50:p. 202–209.

[12] Saul, A. G. A. Principles Underlying the Steam Curing of Concrete at Atmospheric Pressure. Mag. Concr. Res. 1951; 2: p. 127 – 140.

[13] Plowman, J. M. Maturity and the Strength of Concrete. Mag. Concr. Res. 1956;8: p. 13 – 22.

[14] Yi, S. T., Moon, Y. H., Kim, J. K. Long-term Strength Prediction of Concrete With Curing Temperature. Cement Concrete Res. 2005; 35; p. 1961–1969.

UDK: 622.831.3(045)=20
DOI:10.5937/MMEB1402033Z

Dragan Zlatanović, Milenko Ljubojev**, Zoran Stojanović**, Goran Stojanović*

DETERMINING THE STRESS OF ROCK MASSIF***

Abstract

Defining the stress rock massif is essential for design of underground facilities and methods of mining in the mines. Assessment the value of stress state of rock massif and rock strength in the various loads allows rational design. This is of particular importance when sizing columns, determining the extent of excavation, the cross-sections of underground rooms in problems with rock bursts and others. This paper briefly gives the basic methods of determining the rock massif stress as part of a study that is aimed to facilitate development of engineering-geological and geomechanical model of the rock massif along the tunnel route under the flotation tailing dump Veliki Krivelj and underground facilities in Jama Bor as the numerical analysis could be applied of the stress-strain state of rocks around the built facilities.

Keywords: *stress of rock massif, "in situ" measuring of stress, probe for stress measuring*

INTRODUCTION

To solve the problem of stability of built room, in addition to knowledge of the theory of elasticity, it is necessary to know the stresses acting in the rock massif, the properties and composition of the massif. Experimental studies have shown that the stress state of the rock massif is very complex. At relatively shallow depths of exploitation, the additional stresses are sometime, due to the stress concentration at the measuring point, up to 20 times higher than predicted by calculation based on the weight of the rocks (the effect of gravitational forces only). With increasing depth of exploitation, the stress also increases in the rock massif, and thus the importance of studying this problem.

The primary stress state refers to the undisturbed rock massif. Based on previous studies and conducted measurements the primary stress in the world, and using a well-known theory, it was concluded that the vertical component of the primary stress in most cases depends on the force of many lying masses in comparison to the observed point in the earth's crust, Figure 1.

* *Innovation Center of Mechanical Engineering Faculty, Belgrade, dr.dragan.zlatanovic@gmail.com*
** *Mining and Metallurgy Institute Bor, milenko.ljubojev@irmbor.co.rs*
*** *This work is the result of the Project 33021 "Investigation and Monitoring the Changes of Stress-strain State in the Rock Mass "In-situ" around the Underground Rooms with Development a Model with Special Reference on the Tunel of the Krivelj River and Jama Bor", funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia.*

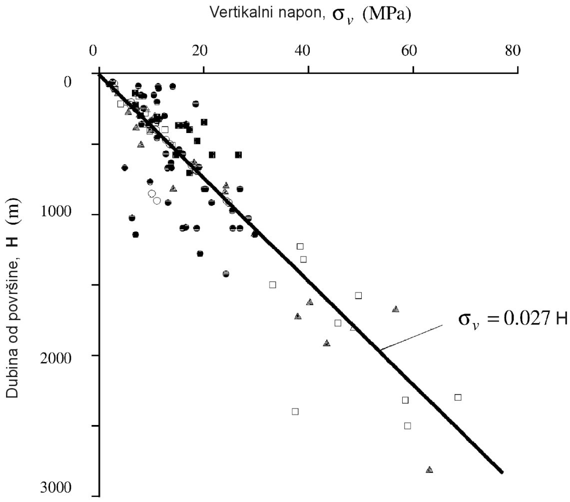


Figure 1 *Measurevertical stress for the needs of design in mining in the world (by Hoek-Brown, 1978)*

It is represented by equation:

$$\sigma_V = \gamma \cdot H$$

where:

σv - vertical component of normal stress;

γ - bulk density in natural state *(on average 27 kN/m³)*

H - depth of the observed place from surface.

The size of horizontal component of stress has influenced by tectonics, residual stresses due to erosion, gravity, morphology of rocks themselves. It starts from the engineering-geological conditions in general, and then the properties of each lithologic members, the presence of water, the temperature, the tectonic movements that have occurred or are still ongoing. From the point of hydrostatics, the vertical and horizontal components are equal or nearly equal, so that the ratio of the horizontal and vertical stresses in the rock massif "k" can be represented by the following equation:

$$k = \frac{\sigma_H}{\sigma_V} \approx 1$$

where:

k - coefficient of horizontal and vertical stress ratio in the rock massif,

σ_v - vertical component of normal stress

σ_H - horizontal component of normal stress.

Assuming that the rock is elastic and continuous environment, Terzaghi concluded that the rock is deformed by the effect of vertical stress, and the result of that is deformation in horizontal direction. Horizontal deformation is prevented by the presence of surrounding rocks, and by the theory of elasticity, it follows:

$$\sigma_H = \frac{\nu}{1-\nu} \cdot \sigma_V$$

where:

ν - Poisson's ratio

Of the newest approaches was given by Sheorey (1994). He developed an elastic-static-thermal stress model of the Earth. He proposed a simplified equation with which it is possible to estimate the ratio of horizontal and vertical stresses.

$$k = 0.25 + 7 \cdot E_h \cdot \left(0.001 + \frac{1}{H}\right)$$

where:

E_h - mean value of deformation module of lying masses measured in horizontal direction, GPa

H - depth of the observed place from surface, m

A graphical presentation of this equation is shown in Figure 2. It should be noted that the curve showing the ratio of stress k is also the same with the other authors who measured the stress "in situ", among others, Hoek and Brown (1978), Harget (1988) and others.

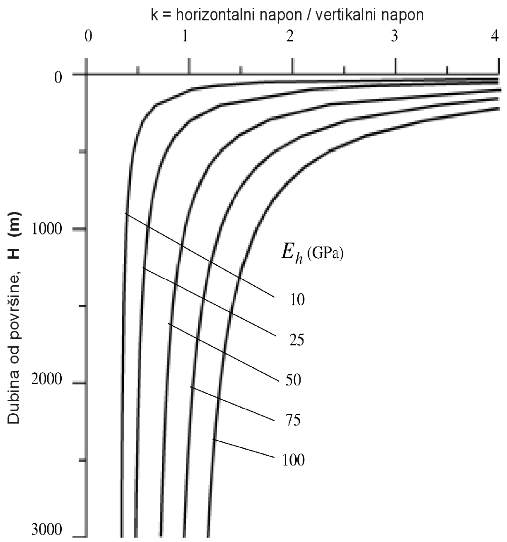


Figure 2 *Ratio of horizontal and vertical stress for various deformation modules based on the Sheorey equation*

In any case, it should be noted that there is no theoretical approach that would fully satisfy the needs of analyzing the primary stress state. Such complex solutions are still required in the experimental study. Thus, the collected and processed data have led to the establishment a relatively realistic legality between these two components. In practice, it is recognized that the values of horizontal component are determined based on the following relationships:

$$\sigma_H = k \cdot \sigma_V$$

where:

- for rock massives that behave elastically:

$$\sigma_H = \frac{\nu}{1-\nu} \cdot \sigma_V$$

- for rock massives that behave plastically:

$$\sigma_H = \frac{1-\sin\varphi}{1+\sin\varphi} \cdot \sigma_V$$

where:

φ - angle of internal friction

ν - Poisson's ratio

However, it should be noted that it can be concluded from the all stated above that data on components of the primary stress, despite all theoretical considerations, can be only defined in the field by direct measuring "in situ" [1].

The secondary stress states occur, mainly, as the result of human activities in the rock, which disrupts the natural balance and leads to changes in the intensity and redistribution of the primary stress state.

In addition, on the basis of theoretical and experimental research, three characteristic zones of the secondary stress can occur in the rock massif:

- Zone of released stresses (plastic zone),
- Zone of increased stresses (elastic zone),
- Intact zone (zone of the primary stresses).

In the case of the secondary stress state, in addition to the above mentioned factors for the primary stress state, the new influential factors are added such as: the quality of rock material, size and shape of the underground facility, as well as the manner and speed of execution the works. These factors have the greatest impact on the character of stress changes; however, it should be always kept in mind that the changes that occur in rock material have progressive character. If these changes are not prevented on time or intentionally prolonged, it can lead to unintended consequences - demolitions.

PROBLEMS RELATED TO THE MEASURINGOF STRESS "IN SITU"

There are at least three main areas of difficulties when measuring the stress of rock massif. They must be understood in order to create an optimal plan of measuring, and more importantly correctly interpret the measuring results.

Those areas are:

a) interaction of stress - rock massif,
b) measurement methodology, and
c) reduction of data - calculation.

Structural properties of rock massif affect any method of stress measuring. The impact of natural properties of the rocks is analyzed on the existing stress field before the start of measuring.

The degree of disturbance the stress field depends on the size of studied site. It may be regional, local or at the level of measuring point size. This means that disturbance of stress field will come from the impact of faults, major discontinuities, fractures and cracks, and even of micro-cracks. As the result of these disorders, it is normal to expect that the value of "in situ" stress is highly variable when measured along one direction through the rock massif.

In engineering practice, the general requirement is knowledge of the total stress state as well as its variations in a particular location, which is the sum of all local impacts. It is far easier to measure the local stress field than to isolate only, for example, tectonic stress component of undisturbed rock massif. All this must be borne in mind when making a measurement program and making interpretation of measured values.

Measurement in a discontinuous rock massif is far more sensitive because it is measured in larger volume in order to eliminate the local irregularities of stress field. Dispersion the measuring results is reduced by increasing the mass volume of measurement area. This leads to the concept of a representative elementary volume [2].

Therefore, it is necessary to understand a degree of expected dissipation the measured stress values. This means that in development the program for stress measuring of rock massif, these factors must be taken into account as they affect the results. The key problem lies in the use of information on the structure of rock massif and other relevant data in order to get a realistic view on stress field.

In addition to dissipation the measuring results due to the natural factor, it must be borne in mind that the applied measuring technique also has an impact.

ANALYSIS OF SOME MEASURING METHODS

The most common way of measuring the stress of rock massif consists in measuring the deformation of massive by disburdening. So, the stress of rock massif is determined indirectly. It is necessary to have a measured size (deformation) and legality of its link with stress. In the majority of cases, the Hook's law is used, because it is assumed that in the first moments of mass disburdening, the greatest part of deformation is "fall of" to the elastic:

$$\sigma = \varepsilon \cdot E$$

where:

σ - stress, MPa

ε - deformation, μmm/mm

E - elasticity modulus, MPa.

This means that the stress can be calculated by the modulus of elasticity and measured deformation. In fact, it is the basis of most methods of determining the stress of rock massif.

Selection of method and measuring instruments

Measuring methods that meet minimum requirements are reduced to the principle of disburdening a part of rock massif with incorporated instrument and measuring:

a) deformation of drill hole sides,
b) deformation of drill hole bottom, and
c) hydraulic fracture.

Deformation of drill hole sides

Instruments for measuring the deformations of drill hole sides are in the shape of probe, which can be cemented by volume in a drill hole, or only in contact over some parts with a drill hole side. The first type consists of so-called instruments soft type - deformometers, and the other probes that are used repeatedly and moved by depth of drill hole; their bodies are typically made of metal or hard plastic, and the measuring detail both of measuring tape or some of inductive sensors. In addition to these two types, there are probes with optical tapes (photoelastic tapes - Photostress gage).

Deformation of drill hole bottom

Instruments for measuring the deformations at the bottom of drill hole are known under the name "Doorstoper". All of these instruments for monitoring the changes in the rock massif deformation caused by disburdening, use various types of sensors. The main task of the sensors is to convert the changes of mechanical sizes (μmm/mm) into an electrical signal (millivolt - milliamp), which can then be registered by sensitive electronic instruments.

Hydraulic fracture

The instrument that uses the principle of hydraulic fracture of rock massif, is one of reliable instruments, which is particularly important because there is no need for special preparation the measuring points for its use.

SELECTED SYSTEM FOR MEASURING THE MASS STRESS

Having primarily in mind the problems with procurement some of commercial instrument for measuring the stress in mass, the instruments can be used that are designed and made in some scientific organization, faculty or institute. These instruments are based on known theoretical principles of stress measuring as well as the experiences gained in the past period of exploration.

According to the set objective of the Project and required physical-mechanical and stress-deformation testing of rocks along the route of the new tunnel under the flotation tailing dump Veliki Krivelj in Bor as well as the underground facilities in Jama Bor, a special probe-transmitter was made.

The probe acts as a hydraulic cushion and it is permanently installed in the side of the room. The probe is placed into a special metal box with other measuring technique [3].

Figure 3 *Measuring probe with additional tools for measuring the stress states*

This equipment is of domestic production, made of local materials in the Mining and Metallurgy Institute in Bor (MMI). It can be applied in various mining and construction structures and, if necessary, it can be serially produced in various measuring ranges.

CONCLUSION

In contrast to most branches of structural engineering in which the engineer-designer is able to choose the construction material with a known initial stress state, the mining engineer has no ability to choose the location of construction, and mechanical properties and initial stress state in his construction material are unknown.

Due to this fact, definition and measuring the stress state in the vicinity of underground facilities becomes of primary importance for their design in each lithological environment.

The mentioned research enables development of engineering-geological and geomechanical model of rock material of the new tunnel route and modeling the designed rooms in the underground mine Jama Bor as the numerical analysis of the stress-strain states of rocks around the facilities could be applied.

REFERENCES

[1] M. Ljubojev, M. Avdić, L. Đurđevac Ignjatović: State around the mine workings; The 44th International October Conference on Mining and Metallurgy 1-3 October 2012, Bor; pp. 245-248, Serbia

[2] M. Ljubojev, D. Ignjatović, L. Đurđevac-Ignjatović, D. Tašić: Probe for measuring stress-strain state in rock massif, 45rd International October conference on Mining and Metallurgy. Bor Lake, 16-19 October 2013, pp. 285-288

[3] Godišnji izveštaj o realizaciji projekta TR 33021 za 2013 godinu

[4] D. Ignjatović, L. Đurđevac-Ignjatović, M. Ljubojev, I. Ivanov: Testing the Carrying Capacity of Anchor in the Ore Body „T1“, Mining and Metallurgy Enginering Bor 1/2014, pp. 1-6.

[5] D. Ignjatović, L. Đurđevac-Ignjatović, M. Ljubojev: Effect of Discplacement the Flotation Dam 2 on the Route of Future Collector of the Krivelj River, Tested Using the Software Phase2 v8.0, Mining and Metallurgy Enginering Bor 4/2013, pp. 17-22.

INSTITUT ZA RUDARSTVO I METALURGIJU BOR | ISSN: 2334-8836
UDK: 622

UDK: 622.272.83(045)=861 DOI:10.5937/MMEB1402033Z

Dragan Zlatanović, Milenko Ljubojev**, Zoran Stojanović**, Goran Stojanović*

ODREĐIVANJE NAPONA STENSKOG MASIVA***

Izvod

Definisanje napona u stenskoj masi je od bitnog značaja za projektovanje podzemnih objekata i metoda otkopavanja u rudnicima. Procena vrednosti naponskog stanja stenskog masiva i otpornosti stena na razna opterećenja omogućuje racionalno projektovanje. Ovo ima poseban značaj kod dimenzionisanja stubova, određivanja raspona otkopa, poprečnih profila podzemnih prostorija, kod problema gorskih udara i dr.

U ovom radu se, u najkraćim crtama, daju osnovni postupci o određivanju napona stenskog masiva kao deo istraživanja koje ima za cilj da omogući izradu inženjersko-geološkog i geomehaničkog modela stenskog masiva duž trase tunela ispod flotacijskog jalovišta Veliki Krivelj u Boru kao i podzemnih objekata u Jami Bor, kako bi se mogla primeniti numerička analiza o naponsko-deformacionom stanju stena oko izgrađenih prostorija.

Ključne reči: *napon stenskog masiva, merenje napona „in situ“, sonda za merenje napona*

UVOD

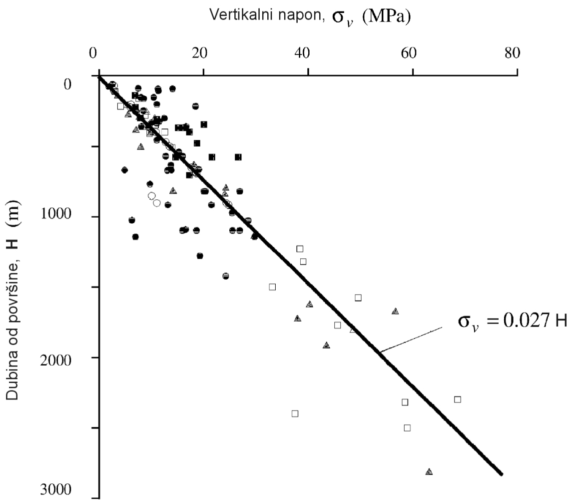
Za rešavanje problema stabilnosti izrađene prostorije, pored poznavanja teorije elastičnosti, neophodno je znati i napone koji deluju u stenskom masivu, svojstva i sastav masiva. Eksperimentalna istraživanja su pokazala da je naponsko stanje stenskog masiva vrlo složeno. Na relativno malim dubinama eksploatacije, dopunska naprezanja su nekad, zbog koncentracije napona na mernom mestu i do 20 puta veća nego što to predviđa proračun na osnovu težine stena (uticaj samo gravitacionih sila). Porastom dubine eksploatacije raste i napon u masivu, a time i važnost izučavanja ovog problema.

Primarno naponsko stanje se odnosi na neporemećen stenski masiv. Na osnovu dosadašnjih ispitivanja i izvršenim merenjima primarnih napona u svetu, a koristeći poznate teorije, došlo se do zaključka da vertikalna komponenta primarnih napona u većini slučajeva zavisi od sile više ležećih masa u odnosu na posmatranu tačku u zemljinoj kori, slika 1.

* *Inovacioni Centar Mašinskog fakulteta, Beograd, dr.dragan.zlatanovic@gmail.com*

** *Institut za rudarstvo i metalurgiju, Bor, milenko.ljubojev@irmbor.co.rs*

*** *Ovaj rad je proistekao kao rezultat projekta 33021 „Istraživanje i praćenje promena naponsko deformacijskog stanja u stenskom masivu „in-situ“ oko podzemnih prostorija sa izradom modela sa posebnim osvrtom na tunel Kriveljske reke i Jame Bor“, koga finansira Ministarstvo prosvete, nauke i tehnološkog razvoja Republike Srbije.*



Sl. 1. *Izmereni vertikalni napon za potrebe projektovanja u rudarstvu u svetu (po Hoek-Brown-u, 1978)*

Predstavlja se jednačinom:

$$\sigma_V = \gamma \cdot H$$

gde su:

σ_v - vertikalna komponenta normalnog napona;

γ - zapreminska težina u prirodnom stanju *(u proseku 27 kN/m^3)*

H - dubina posmatranog mesta od površine.

Na veličinu horizontalne komponente napona značajan uticaj imaju tektonika, zaostali naponi usled erozije, gravitacija, morfologija samih stena. Polazi se od inženjersko-geoloških uslova u celini, zatim od svojstva svakog litološkog člana, od prisustva vode, od temperature, tektonskih pokreta koji su se dogodili ili još uvek traju. Sa stanovišta hidrostatike, vertikalne i horizontalne komponente su jednake ili približno jednake, tako da koeficijent odnosa horizontalnog i vertikalnog napona u stenskoj masi "k" može da se predstavi sledećom jednačinom:

$$k = \frac{\sigma_H}{\sigma_V} \approx 1$$

gde su:

k - koeficijent odnosa horizontalnog i vertikalnog napona u stenskoj masi,

σ_v - vertikalna komponenta normalnog napona,

σ_H - horizontalna komponenta normalnog napona.

Polazeći od pretpostavki da je stena elastična i kontinualna sredina, Terzaghi je zaključio da se stena dejstvom vertikalnog napona deformiše, pa je posledica toga deformacija u horizontalnom pravcu. Horizontalna deformacija je sprečena prisustvom okolnih stena, a po teoriji elastičnosti proizilazi:

$$\sigma_H = \frac{\nu}{1-\nu} \cdot \sigma_V$$

gde je

ν - Poissonov koeficijent

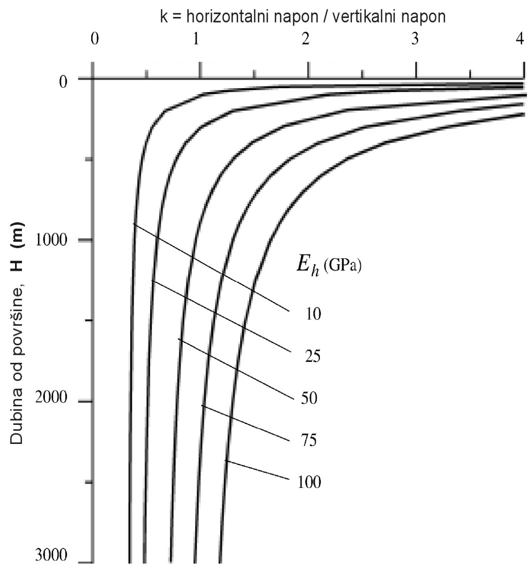
Jedan od najnovijih prilaza je dao Sheorey (1994). On je razvio elasto-statičko-termički model napona Zemlje. Predložio je pojednostavljenu jednačinu sa kojom je moguće proceniti odnos horizontalnog i vertikalnog napona.

$$k = 0{,}25 + 7 \cdot E_h \cdot \left(0{,}001 + \frac{1}{H}\right)$$

gde su:

- E_h - srednja vrednost modula deformacije višeležećih masa merene u horizontalnom pravcu, GPa
- H - dubina posmatranog mesta od površine, m

Grafički prikaz ove jednačine dat je na slici 2. Treba napomenuti da kriva koja prikazuje odnos napona k je slična i sa drugima autorima koji su merili napon »in situ«, između ostalih, Hoek i Brown (1978), Harget (1988) i drugi



Sl. 2. *Odnos horizontalnog i vertikalnog napona za različite module deformacija bazirane na Sheorey-ovoj jednačini*

U svakom slučaju treba reći da ne postoji ni jedan teoretski pristup koji bi u potpunosti zadovoljio potrebe za analiziranjem primarnog naponskog stanja. Takva kompleksna rešenja su dalje tražena u eksperimentalnom istraživanju. Tako prikupljeni i obrađeni podaci su doveli do uspostavljanja relativno realne zakonitosti između ove dve komponente. U praksi je prihvaćeno da se veličina horizontalne komponente određuje na osnovu sledećih veza:

$$\sigma_H = k \cdot \sigma_V$$

gde je:

- za stenske mase koje se ponašaju elastično:

$$\sigma_H = \frac{\nu}{1-\nu} \cdot \sigma_V$$

- za stenske mase koje se ponašaju plastično:

$$\sigma_H = \frac{1-\sin\varphi}{1+\sin\varphi} \cdot \sigma_V$$

gde su:

φ - ugao unutrašnjeg trenja,

ν - Poissonov keoficijent.

Ipak, treba reći da se iz svega do sada rečenog može zaključiti da podatke o komponentama primarnog napona je, pored svih teorijskih razmatranja jedino možemo odrediti na terenu, direktnim merenjem “in situ”.[1]

Sekundardna naponska stanja javljaju se, uglavnom, kao rezultat čovekovog delovanja u steni, čime se narušava prirodna ravnoteža i dolazi do promene inteziteta i preraspodele primarnog naponskog stanja.

Pri tome se, na osnovu teoretskih i eksperimentalnih istraživanja, u stenskom masivu se mogu javiti tri karakteristične zone sekundarnih napona:

- Zona oslobođenih napona (plastična zona),
- Zona povećanih napona (elastična zona),
- Intaktna zona (zona primarnih napona).

U slučaju sekundarnog naponskog stanja, pored već nabrojanih faktora za primarno naponsko stanje, dodaju se novi uticajni fakori kao što su: kvalitet stenskog materijala, veličina i oblik podzemnog objekta, kao i način i brzina izvođenja radova. Ovi faktori najviše utiču na karakter promene napona s'tim što, uvek treba imati na umu da su promene koje se dešavaju u stenskom materijalu progresivnog karaktera. Ukoliko se ove promene ne spreče na vreme ili svesno produže, može doći do neželjenih posledica – zarušavanja.

PROBLEMI VEZANI ZA MERENJE NAPONA "IN SITU"

Postoji najmanje tri glavne oblasti teškoća kod merenja napona stenske mase. One se moraju razumeti da bi se napravio optimalni plan merenja, a što je još važnije korektno interpretirali rezultati merenja.

Te oblasti su:

a) interakcija napon - stenski masiv,
b) metodologija merenja i
c) redukcija podataka, proračun.

Strukturna svojstva stenskog masiva utiču na bilo koju metodu merenja napona. Analizira se uticaj prirodnih svojstava stene na postojeće naponsko polje pre početka merenja.

Stepen poremećaja naponskog polja zavisi od veličine izučavanog lokaliteta. On može biti regionalni, lokalni ili na nivou veličine mernog mesta. To znači da će do poremećaja naponskog polja doći od uticaja raseda, glavnih diskontinuiteta, pukotina i prslina, pa čak i od mikroprslina. Kao rezultat ovih poremećaja normalno je i očekivati da je vrednost "in situ" napona vrlo promenljiva kada se meri duž jednog pravca kroz stensku masu.

U inženjerskoj praksi, opšti zahtev je znanje ukupnog naponskog stanja kao i njegove varijacije na određenoj lokaciji, koja je ujedno i zbir svih lokalnih uticaja. Daleko lakše je meriti lokalno polje napona nego izolovati samo npr. tektonsku komponentu napona neporemećenog stenskog masiva. Sve ovo se mora imati u vidu kada se pravi program merenja i vrši interpretacija izmerenih veličina.

Merenje u diskontinualnoj stenskoj masi daleko je osetljivije jer se meri u većoj zapremini u cilju eliminisanja lokalnih neregularnosti naponskog polja. Rasipanje rezultata merenja se smanjuje povećanjem zapremine masiva merne oblasti. To vodi ka konceptu reprezentativne elementarne zapremine. [2]

Zato je potrebno razumeti stepen očekivanih rasturanja merenih vrednosti napona. To znači da se pri izradi programa merenja napona stenske mase mora voditi računa o ovim faktorima jer će oni uticati na rezultate. Ključni problem se sastoji u korišćenju informacija o strukturi stenske mase i drugih relevantnih podataka kako bi se došlo do realne slike o naponskom polju.

Pored rasipanja rezultata merenja zbog prirodnih faktora mora se imati u vidu da i primenjena merna tehnika ima uticaja.

ANALIZA POJEDINIH METODA MERENJA

Najčešći način merenja napona stenske mase sastoji se u merenju deformacija masiva rasterećenjem. Znači, napon stenske mase određuje se indirektno. Potrebno je imati neku izmerenu veličinu (deformaciju) i zakonitost njene veze se naponom. U većini slučajeva koristi se Hook-ov zakon, jer se pretpostavlja da u prvim momentima rasterećenja masiva, najveći deo deformacija "otpada" na elastične:

$$\sigma = \varepsilon \cdot E$$

gde su:

σ - napon, MPa,

ε - deformacija, μmm/mm,

E - modul elastičnosti, MPa.

To znači de se preko modula elastičnosti i izmerene deformacije može izračunati napon. U suštini to je osnova većine metoda određivanja napona stenske mase.

Izbor metode i instrumenata za merenje

Metode merenja koje ispunjavaju minimum zahteva svode se na princip rasterećenja dela stenskog masiva sa ugrađenim instrumentom i merenju:

a) deformacija bokova bušotine,
b) deformacija dna bušotine i
c) hidraulički lom.

Deformacija bokova bušotine

Instrumenti za merenje deformacija bokova bušotine su u obliku sondi, koje mogu biti ucementirane po obimu u bušotini ili samo u kontaktu preko pojedinih delova sa bokom bušotine. Prvu vrstu čine instrumenti tzv. mekog tipa - deformometri, a drugu sonde koje se koriste više puta i pomeraju po dubini bušotine, tela su im po pravilu od metala ili tvrde plastike, a merni detalj ili od mernih traka ili je to neki od induktivnih davača. Pored ova dva tipa imamo i sonde sa optičkim trakama (foto-elastične trake - Photostress gage).

Deformacija dna bušotine

Instrumenti za merenje deformacija na dnu bušotine su poznati pod imenom “Doorstoper”. Svi ovi instrumenti za praćenje promena deformacija stenskog masiva, izazvanih rasterećenjem, koriste senzore raznih vrsta. Osnovni zadatak senzora je da pretvore promene mehaničkih veličina (μmm/mm) u električni signal (milivolt - miliamper) koji se zatim može registrovati osetljivim elektronskim instrumentima.

Hidraulički lom

Instrument koji koristi princip hidrauličkog loma stenske mase, je jedan od pouzdanih instrumenata, a što je naročito važno, jer za njegovu upotrebu nisu potrebni specijalne pripreme mernih mesta.

ODABRANI SISTEM ZA MERENJE NAPONA MASIVA

Imajući prvenstveno u vidu probleme oko nabavke nekog od komercijalnih instrumenata za merenje napona u masivu, mogu se upotrebiti instrumenti koji su konstruisani i izrađeni u nekoj naučnoj orga-nizaciji, fakultetu ili institutu. Ovi instru-menti su bazirani na poznatim teoretskim principima merenja napona kao i na iskust-vima stečenim u ranijem periodu istra-živanja.

Shodno postavljenom cilju Projekta i potrebnih fizičko-mehaničkih i naponsko-deformacionih ispitivanja stena duž trase novog tunela ispod flotacijskog jalovišta Veliki Krivelj u Boru kao i podzemnih objekata u Jami Bor, izrađena je specijalna sonda-transmiter.

Sonda ima ulogu hidrauličnog jastuka i trajno se ugrađuje u bok prostorije. Sonda se smešta u specijalni metalni sanduk sa ostalom mernom tehnikom.[3]

Sl. 3. *Merna sonda sa dodatnim alatima za merenje naponskih stanja*

Ova oprema je domaće proizvodnje, izrađena od domaćih materijala u Institutu za rudarstvo i metalurgiju u Boru (IRM). Može se primenjivati u raznim rudarskim i građevinskim objektima i po potrebi se može serijski proizvoditi u različitim mernim opsezima.

ZAKLJUČAK

Nasuprot većini grana konstruktivnog inženjerstva u kojima je inženjer- projektant u mogućnosti da bira konstruktivni materijal sa poznatim početnim stanjem napona, rudarski inženjer nema mogućnost izbora lokacije gradnje, a mehaničke karakteristike i početno naponsko stanje u njegovom konstruktivnom materijalu su nepoznati.

Zbog ove činjenice definisanje i merenje naponskog stanja u okolini podzemnih objekata postaje od primarnog značaja za njihovo projektovanje u svakoj litološkoj sredini.

Navedena istraživanja omogućavaju izradu inženjersko-geološkog i geomehaničkog modela stenskog materijala trase novog tunela i u modeliranju projektovanih prostorija u Jami Bor, kako be se mogla primeniti numerička analiza o naponsko-deformacionom stanju stena oko izgrađenih objekata.

LITERATURA

[1] M. Ljubojev, M. Avdić, L. Đurđevac Ignjatović: State around the mine workings; The 44th International October Conference on Mining and Metallurgy 1-3 October 2012, Bor; pp. 245-248, Serbia

[2] M. Ljubojev, D. Ignjatović, L. Đurđevac-Ignjatović, D. Tašić: Probe for measuring stress-strain state in rock massif, 45rd International October conference on Mining and Metallurgy. Bor Lake, 16-19 October 2013, pp. 285-288

[3] Godišnji izveštaj o realizaciji projekta TR 33021 za 2013 godinu

[4] D. Ignjatović, L. Đurđevac-Ignjatović, M. Ljubojev, I. Ivanov: Ispitivanje nosivosti ankera u rudnom telu „T1", Mining and Metallurgy Enginering Bor 1/2014, str. 7-12.

[5] D. Ignjatović, L. Đurđevac-Ignjatović, M. Ljubojev: Uticaj pomeranja flotacijske brane 2 na trasu budućeg kolektora Kriveljske reke, testiran pomoću softvera Phase2 v8.0, Mining and Metallurgy Enginering Bor 4/2013, str. 23-28.

UDK: 622.271:681.33(045)=20
DOI:10.5937/MMEB1402045R

Radmilo Rajković[*], Zoran Vaduvesković[*], Lazar Stojanović[**], Daniel Kržanović[*]

ALGORITHM OF OPTIMIZATION THE OPEN PITS USING THE COMPUTER PROGRAMS WHITTLE AND GEMCOM[***]

Abstract

The world mining companies in assessment the financial sustainability and defining the optimal strategy for development of mine, to the aim of rational and economical utilization the mineral deposits, use the computer programs for optimization and design. Among the leading programs in this field are Whittle and Gemcom. This work an algorithm of work with the necessary input data, procedure of work and output results in design the open pits, using the computer programs Whittle and Gemcom, for optimal utilization the deposit, what is a necessary precondition for responsible management of mineral resources.

Keywords: *open pit, design, optimization, computer software Whittle and Gemcom*

INTRODUCTION

Natural mineral resources of a country present the base of its economic and social prosperity. In the economic value of mineral resources at its disposal, Serbia does not belong to the rich countries. Therefore there is an obligation to carry out the mining activity according to the principles of rational management of mineral resources.

The application of software for design in mining [1-13, 15] presents nowadays the standard in the world, primarily because it allows fast and with high accuracy assessment the most suitable solutions for mining the mineral resources, in terms of their rational utilization from deposits to achieve maximum profit.

For rational and economical utilization the deposit with a large number of data, used for calculation of reserves, as well as determining the optimal open pit contour and dynamics of excavation and disposal, the advantage of computer technology is indisputable, compared to other methods of calculation. This advantage is reflected in the following:

- Due to the size of deposit, the state of open pits and production capacity (large amounts of excavation), the designs and design modifications are very complex with optimal working and final contours of the open pit. Digital model with calculated reserves by mini-blocks, facilitates and accelerates this process, as it is possible in a short period of time to see large number

[*] *Mining and Metallurgy Institute Bor, radmilo.rajkovic@irmbor.co.rs*
[**] *COMSAR ENERGY Republika Srpska d.o.o.*
[***] *This work is the result of the Project TR37001 "The Impact of Mining Waste from RTB Bor on the Pollution of Surrounding Water Systems with the Proposal of Measures and Procedures for Reduction Harmful Effects on the Environment", funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia*

of variants and to find the best solution.

- The results obtained by design and economic analyzing on digital models have satisfactory quality, i.e. they are accepted in the world as satisfactory.
- Potential concessionaires require that the deposit has to be present in a digital form.

WORK PROCEDURES IN THE PROGRAMS WHITTLE AND GEMCOM

The first step in working with programs Whittle and Gemcom is a construction of digital 3D block - deposit model [16-19], Figure 1. Block - model of deposit is a set of individual blocks. Each single block is defined by the following parameters:

- Sizes of the block;
- Spatial position of the block;
- Type of material from which the block is made;
- Bulk density of material in the block;
- Contents of individual components in the block (copper, gold, silver,...).

The block model is constructed in the program Gemcom based on geological parameters that may be imported from the Excel application of Office.

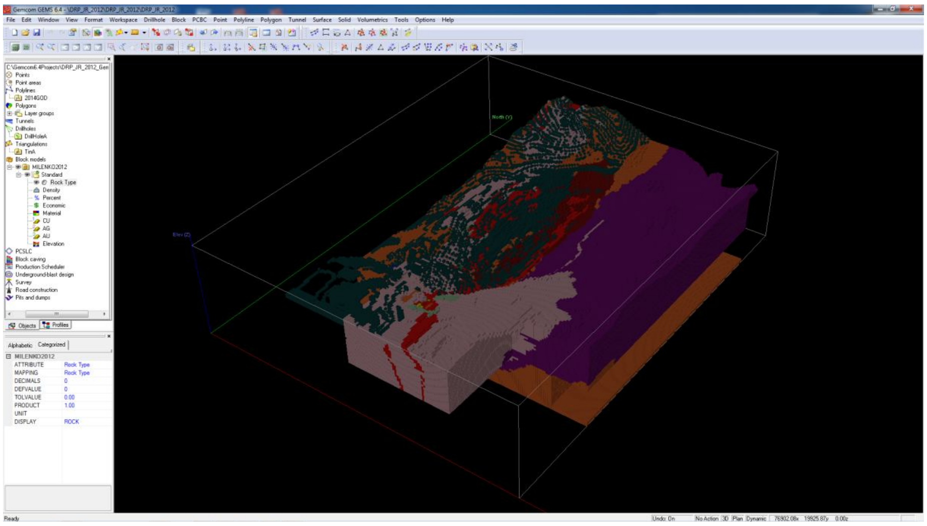


Figure 1 *Block – model of deposit in the program Gemcom 6*

The second step in working with these programs is the construction of 3D field model [14]. The field model can be imported from the program AutoCAD. If the situational map of the field in AutoCAD is done in 3D (each point has X, Y and Z coordinates), a direct import is done in the program Gemcom. If situational map of the field in AutoCAD is not done in 3D (all points have zero Z elevation), the real Z elevation have to be assigned to the points, and then import in the program Gemcom is done.

After preparation and processing of data in Gemcom, the export block-model is done with topography in the program Whittle.

In Whittle [1, 2-5, 7, 9, 10-13], a construction of possible open pits is made based on the Lerches and Grossman algorithm. The Lerches and Grossman algorithm is a procedure for determining the optimal open pit like the one with the highest value for the corresponding set of costs and factors of return.

For optimization in the program Whittle, the following input parameters are needed:

- Angle of general open pit slope for each region
- Operating costs of mining (OPEX), $/t
- Dilution of ore and loss in excavation
- Operating processing costs, $/t
- Cut-off grade for all elements
- Recovery of processing for all elements
- Selling price for each element individually, $/t
- Selling costs for each element individually, $/t
- Initial capital costs, $
- Residual value, $
- Costs of equipment replacement, $
- Discount rate,%
- Annual capacity of excavation mining
- Annual capacity of mining the mineral resources
- Annual capacity of the final product, optionally (typically not limiting)
- Defined criteria for selection the final open pit outline (maximum profit, service life, spatial limits due to the existing facilities, etc.

After optimization, the set of open pits is obtained; each with different amounts of excavation and different value, Figure 2.

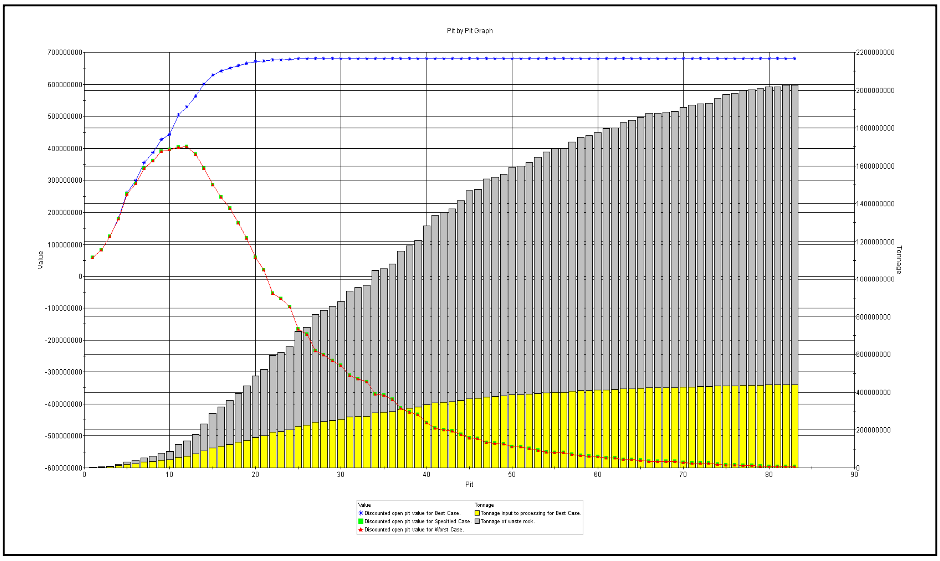


Figure 2 *Diagram of the open pits with different value and amounts of excavation in Whittle*

The open pits obtained in this manner do not have benches and transport routes. The export into Gemcom is done by selection the optimum open pit and push backs, where detailed open pits with benches and transport routes are constructed, which are exported back to Whittle that defines the dynamics of excavation [6, 8], Figure 3.

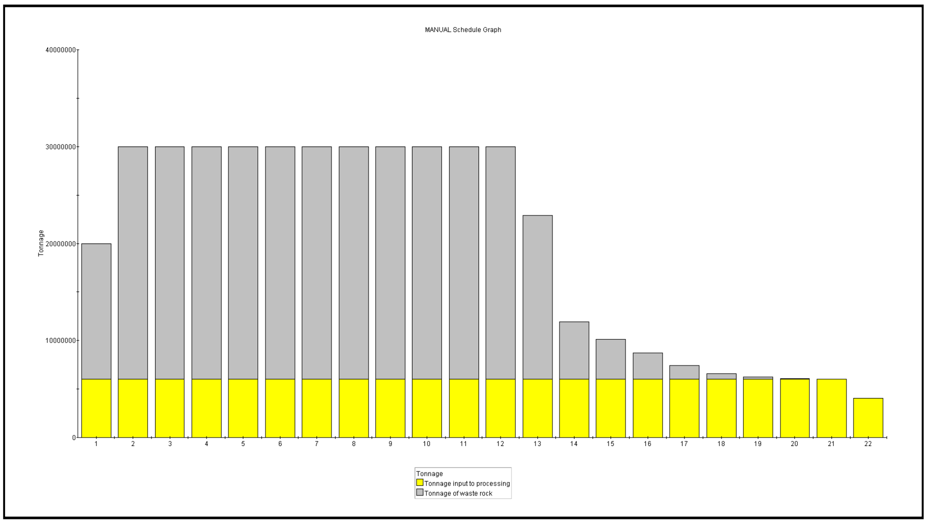


Figure 3 *Diagram of amounts of excavation by periods of exploitation in Whittle*

The obtained contours of the open pits by periods of exploitation in Whittle do not also have benches and transport routes, and they are exported to Gemcom, where detailed open pits with benches and transport roads are constructed for each period of exploitation, Figure 4.

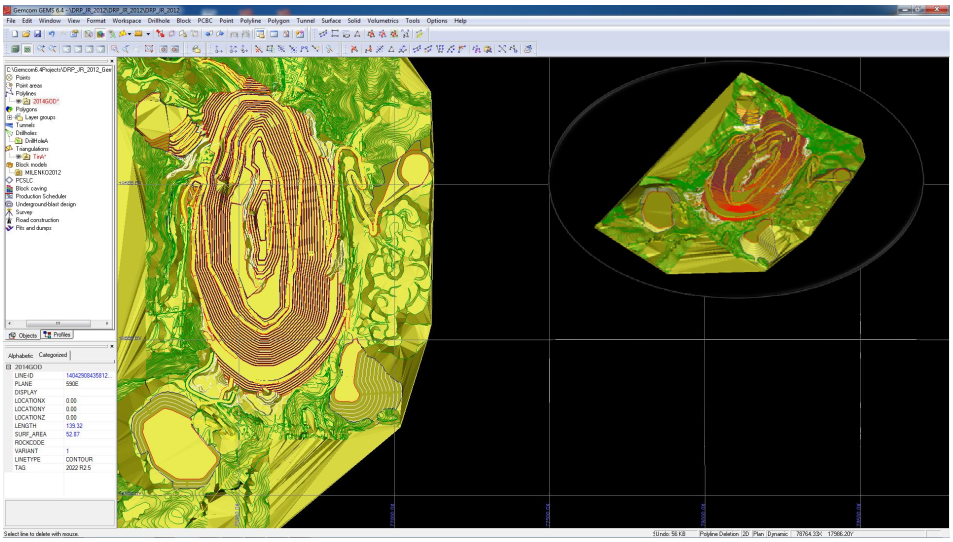
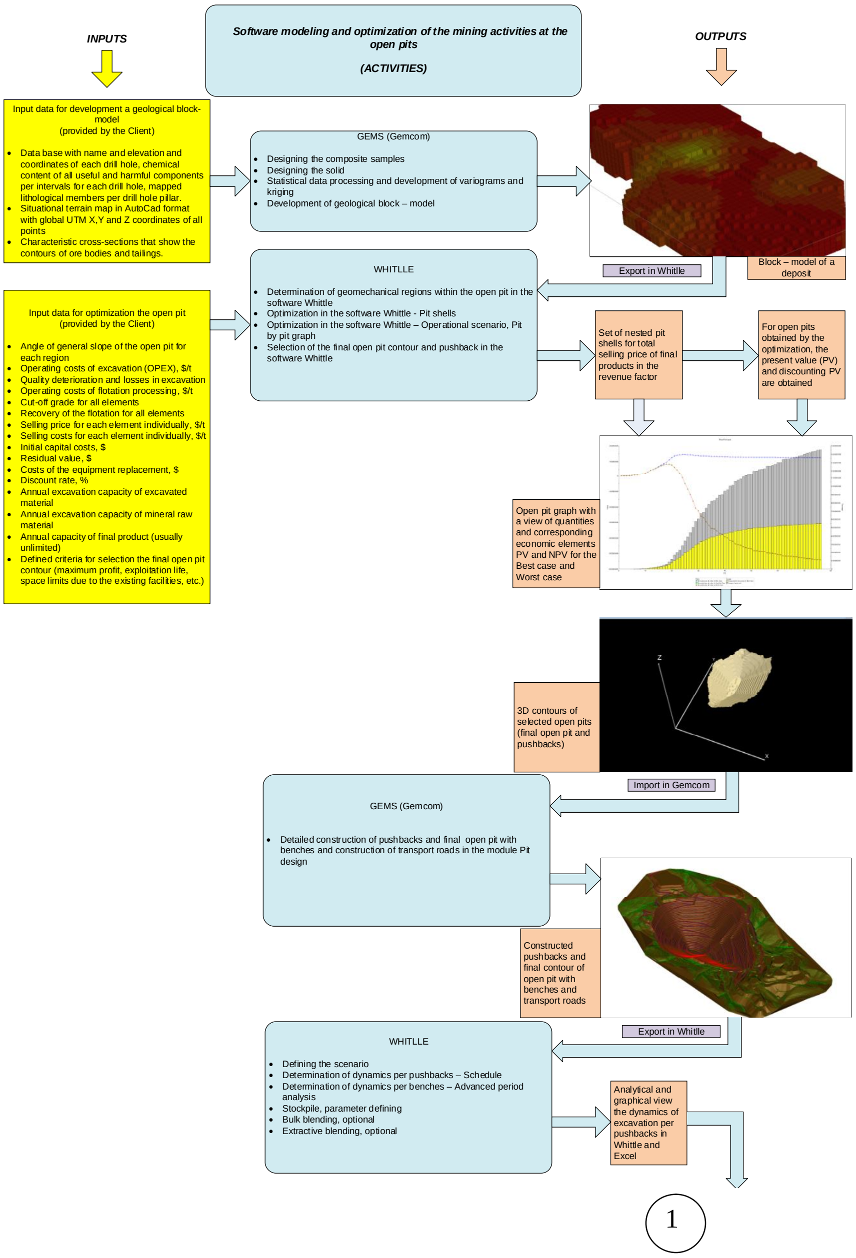


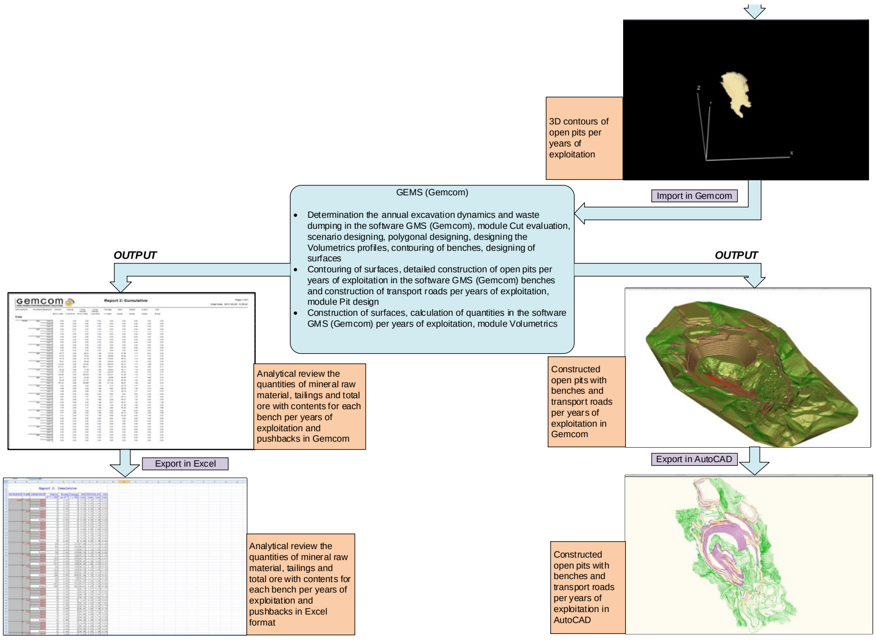
Figure 4 *2D and 3D view of the open pit in Gemcom*

Output data are analytical dynamics that can be exported from Gemcom to the Office application Excel and dynamic graphics that can be exported from Gemcom to AutoCAD. The final results of optimazation are:

1. Analytical view the amount of mineral resources, waste and total excavation with contents for each bench by years of exploitation and operations in Excel format;
2. Constructed open pits with benches and transport roads by years of exploitation in AutoCAD.

The algorithm of design in the software Whittle and Gemcom is given in the next text.





CONCLUSION

An important factor in the use of computer programs for design the open pits is relatively easy and quick change of parameters related to the geological interpretation of deposit by entering the new data into the base of drill holes, the variation of techno - economic parameters of optimization as well as the ability of changing and comparison of several scenarios for mining.

It is also considerably much less time of design development in relation to the classic design, which in today's market conditions is of great importance in obtaining the jobs and favorable conclusion of financial contracts.

Both for the geological interpretation of deposit and design of open pit, a designer is still the most important. However, using the computer software the designer's job is much easier in terms of time and quality due to the accurate analysis in order to select the best solutions.

Quality of developed design documentation using the computer programs Whittle and Gemcom is certainly one of the main reasons why the use of these and similar programs has become a necessity and standard in design the open pits.

REFERENCES

[1] D. Kržanović, M. Mikić, R. Rajković, M. Žikić, Z. Vaduvesković: Concept of Development the Copper Mine Majdanpek in the Period from 2013 to 2034; pp. 161-164; Mining 2013 Plans for Development and Improvement of Mining; Veliko Gradište, Srebrno jezero, 28-31 May 2013

[2] R. Rajković, D. Kržanović, M. Mikić: Application the Software Package Whittle for Determining the Mineable Reserves of the Vopper Deposit South Mining District Majdanpek, Serbia; Mining Engineering, 3/2012; pp. 115-130;

[3] D. Kržanović, R. Rajkovic, M. Mikić: Application of Software Packages Gemcom and Whittle for Design in

Mining Aimed to Rational and Cost Effective Utilization the Copper Deposit Veliki Krivelj near Bor, Serbia; Mining Engineering, 3/2012; pp. 85 – 98.

[4] D. Kržanović, M. Mikić, R. Rajković: Analysis of as Long Term Development the Marl Open Pit Trešnja Operating with the Company Holcim Serbia LTD. Using the Software Whittle and Gemcom. 44th International October Conference on Mining and Metallurgy. Proceedings, October 2012, Bor, Serbia, pp. 95-101.

[5] D. Kržanović, R. Rajković, M. Žikić: Application the Software Packages Whittle and Gemcom for Calculation the Balance Reserves of Copper Ore in the South Mining District Deposit Majdanpek; Mining Engineering, 4/2011; pp. 81 – 92.

[6] R. Rajković, D. Kržanović, B. Rajković; Dynamics of excavation on "Deo Donja Bela Reka" deposit in software Gemcom 6.1.3.; 40th International October Conference on Mining and Metallurgy IOCMM 2009; Kladovo, Serbia, 04 – 06 October 2009; Pages 111-116.

[7] D. Kržanović, R. Rajković, M. Mikić; Potentiality of Exploitation Copper Ore at the Locality Cerovo – Cementacija Kraku Bugaresku; 41th International October Conference on Mining and Metallurgy IOCMM 2009; Kladovo, Serbia, 04 – 06 October 2009; pp. 117-122.

[8] R. Rajković, M. Ignjatović, V. Marinković: Determination of Mining Dynamics Using Gemcom 6.1 Program; Second International Symposium Mining Energetic 08; Tara, Serbia, 15 - 18 September 2008; pp. 379-384.

[9] D. Kržanović, M. Žikić, N. Vušović, R. Pantović, S. Stojadinović, Optimum Development of the Open Pit South Mining District in Majdanpek for Annual Capacity of Copper Ore Mining of 8 500 000 t, 44rd International October Conference on Mining and Metallurgy, Bor, 2012;

[10] D. Kržanović, M. Žikić, R. Pantović, Important Improvement of Utilization the Available Geological Reserves of the South Mining District Deposit in Majdanpek in the New Defined Optimum Contour of the Open Pit Using the Whittle and Gemcom Software, Mining Engineering, 2012;

[11] D. Kržanović, M. Žikić, Z. Vaduvesković, Innovated Block Model of the Copper Ore Deposit South Mining District Deposit as a Basis for Analysis the Optimum Development of Open Pit Using the Software Packages Whittle and Gemcom, Mining Engineering, 2011;

[12] Z. Vaduvesković, D. Đokić, D. Kržanović, R. Rajković: Selection of the Most Favorable Variant of the Ope Pit Contour in the Deposit "Veliki Krivelj"; Mining Engineering, 1/2004, pp. 52-60.

[13] Z. Vaduvesković, D. Kržanović, R. Rajković: Analysis the Possibilities for Cost Effective Copper Production at the Open Pit "Veliki Krivelj"; Mining Engineering, 1-2/2003, pp. 55-63.

[14] R. Rajković, V. Marinković, R. Lekovski: Digital 3D Terrain Model; Mining Engineering, 3/2011; pp. 25-40.

[15] R. Rajković, S. Pavlović, B. Rajković; Dynamics of Depositing on Dump II of Jazovnik Limestone Open Pit by Software Gemcom 6.2; 42nd International October Conference on Mining and Metallurgy; pp. 162-169.

[16] V. Marinković, R. Rajković, D. Kržanović, G. Pačkovski, D. Mitić: 2D and 3D Models, Similarity and Differences, Copper, 34 (1/2009).

[17] R. Rajković, D. Kržanović, V. Marinković: The Geological Interpretation of Ore Deposit „Deo" Donja Bela Reka with Block-model in Software

Gemcom 6.1.3; Mining Engineering 1/2009; pp. 1-6.

[18] D. Kržanović, R. Rajković, V. Marinković: Geological Characteristics, Modeling and Technical Solution of Excavation Technogenic Copper Deposit „Depo Šljake 1“ in Bor; Mining Engineering, 1/2009; pp. 7-16.

[19] R., Rajković, V. Marinković, M. Ignjatović: Calculation of Geological Reserves of the Coal Deposit by the Use of Computer Program Gemcom 1; First International Symposium Mining Energetic 07; Vrnjačka Banja, Serbia, 21 - 24 November 2007; pp. 201-206.

ISSN: 2334-8836
UDK: 622

UDK: 622.271:681.33(045)=861 DOI:10.5937/MMEB1402045R

Radmilo Rajković, Zoran Vaduvesković*, Lazar Stojanovic**, Daniel Kržanović**

ALGORITAM OPTIMIZACIJE POVRŠINSKIH KOPOVA U RAČUNARSKIM PROGRAMIMA WHITTLE I GEMCOM***

Izvod

Svetske rudarske kompanije kod procene finansijske održivosti i definisanja optimalne strategije za razvoj rudnika u cilju racionalnog i ekonomičnog iskorišćenja ležišta mineralnih sirovina, koriste računarske programe za optimizaciju i projektovanje. Među vodećim programima iz ove oblasti su Whittle i Gemcom.

Ovde je prikazan algoritam rada sa potrebnim ulaznim podacima, procedurom rada i izlaznim rezultatima pri projektovanju površinskih kopova računarskim programima Whittle i Gemcom, čime se postiže optimalno iskorišćenje ležišta, što je nužan preduslov odgovornog upravljanja mineralnim sirovinama.

Ključne reči: *površinski kop, projektovanje, optimizacija, računarski programi Whittle i Gemcom*

UVOD

Prirodna rudna bogatstva jedne zemlje predstavljaju osnovu njenog ekonomskog i društvenog prosperiteta. Po ekonomskoj vrednosti rudnih bogatstava kojim raspolaže, Srbija ne pripada bogatim zemljama. Zato postoji obaveza da se rudarska delatnost obavlja po principima racionalnog upravljanja mineralnim resursima.

Primena softvera za projektovanje u rudarstvu [1-13, 15], predstavlja danas standard u svetu, pre svega zato što omogućava brzo i sa velikom tačnošću sagledavanje najpovoljnijih varijanti eksploatacije mineralnih sirovina, sa aspekta njihovog racionalnog iskorišćenja iz ležišta uz postizanje maksimalnog profita.

Za racionalno i ekonomično iskorišćenje ležišta, sa velikim brojem podataka koji se koriste za proračun rezervi, kao i određivanje optimalne konture kopa i dinamike otkopavanja i odlaganja, neosporna je prednost računarske tehnike, u odnosu na proračune drugim metodama. Ova prednost se ogleda u sledećem:

- Zbog veličine ležišta, stanja površinskih kopova i kapaciteta proizvodnje (velike količine iskopina), jako su složena projektovanja i izmene projekata sa optimalnim radnim i završnim konturama površinskog kopa. Digitalni model, sa proračunatim rezervama po mini-blokovima, olakšava i ubrzava taj proces, jer je moguće u kratkom vremenskom periodu sagledati veliki broj varijanti i iznaći najbolja rešenja.

* *Institut za rudarstvo i metalurgiju Bor, radmilo.rajkovic@irmbor.co.rs*
** *COMSAR ENERGY Republika Srpska d.o.o.*
*** *Ovaj rad je proistekao iz projekta TR37001 „Uticaj rudarskog otpada iz RTB Bor na zagađenje vodotokova, sa predlogom mera i postupaka za smanjenje štetnog dejstva na životnu sredinu“, koji je finansiran sredstvima Ministarstva prosvete, nauke i tehnološkog razvoja Republike Srbije*

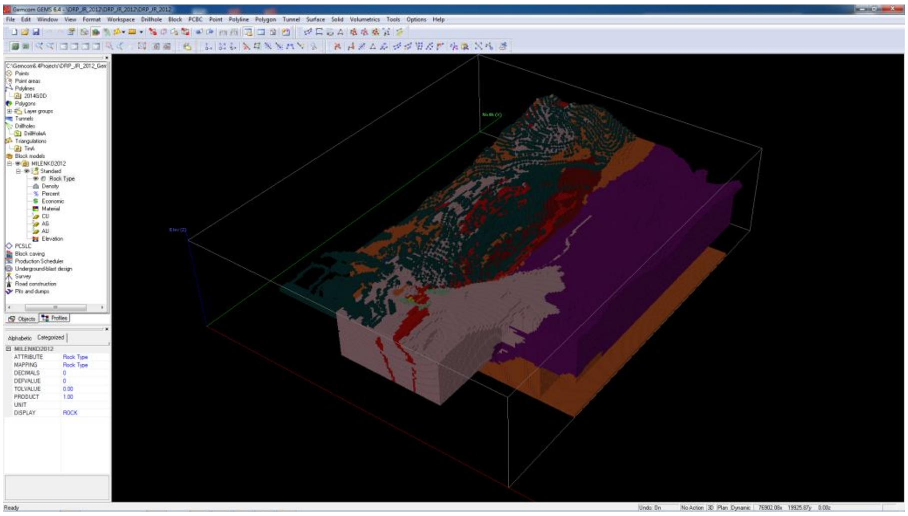
- Rezultati koji se dobijaju projektovanjem i ekonomskim sagledavanjem, na digitalnim modelima, zadovoljavajućeg su kvaliteta, odnosno u svetu su prihvaćeni kao zadovoljavajući.
- Potencijalni koncesionari zahtevaju da ležište bude prikazano u digitalnom obliku.

POSTUPAK RADA U PROGRAMIMA WHITTLE I GEMCOM

Prvi korak pri radu sa programima Whittle i Gemcom je konstrukcija digitalnog 3D blok – modela ležišta [16-19], slika 1. Blok – model ležišta je skup pojedinačnih blokova. Svaki pojedinačni blok je definisan sledećim parametrima:

- Dimenzije bloka;
- Prostorni položaj bloka;
- Vrsta materijala od koga je blok sačinjen;
- Zapreminska masa materijala u bloku;
- Sadržaji pojedinačnih komponenti u bloku (bakar, zlato, srebro, ...).

Blok model se konstruiše u programu Gemcom na osnovu geoloških parametara koji se mogu importovati iz Office aplikacije Excel.



Sl. 1. *Blok – model ležišta u programu Gemcom 6*

Drugi korak pri radu sa ovim programima je konstrukcija 3D modela terena [14]. Model terena se može importovati iz programa AutoCAD. Ukoliko je situaciona karta terena u AutoCad-u rađena u 3D (svaka tačka ima X, Y i Z koordinatu) vrši se direktni import u program Gemcom. Ukoliko situaciona karta terena u AutoCAD-u nije rađena u 3D (sve tačke imaju Z elevaciju nula) prethodno se moraju dodeliti realne Z elevacije tačkama pa se tek onda vrši import u program Gemcom.

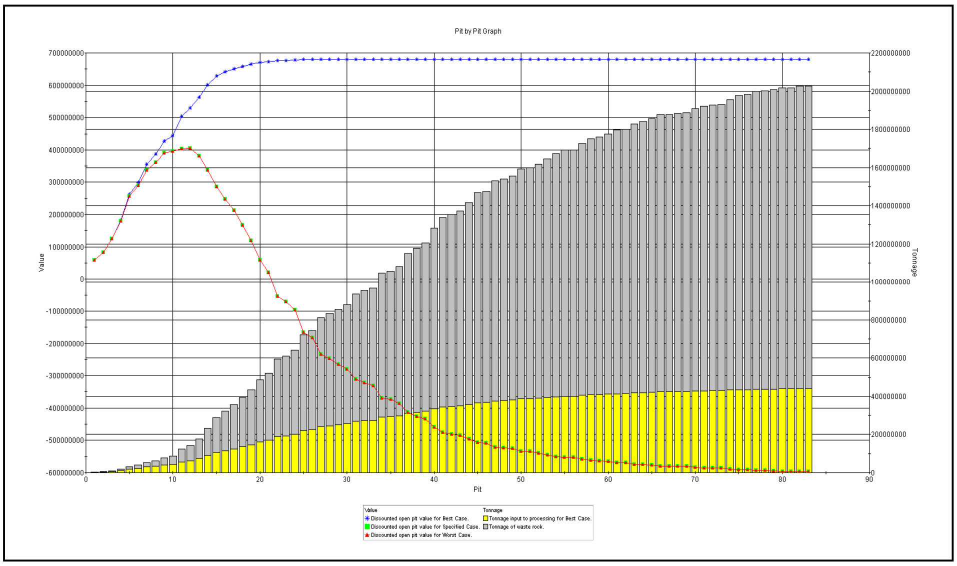
Nakon pripreme i obrade podataka u programu Gemcom, vrši se export blok – modela sa topografijom u program Whittle.

U programu Whittle [1, 2-5, 7, 9, 10-13] vrši se konstrukcija mogućih kopova koja se bazira na Lerches and Grossman algoritmu. Lerches and Grossman algoritam je postupak za određivanje optimalnog kopa kao onog sa najvećom vrednošću za odgovarajući set troškova i faktora povraćaja.

Za optimizaciju i programu Whittle potrebni su sledeći ulazni parametri:

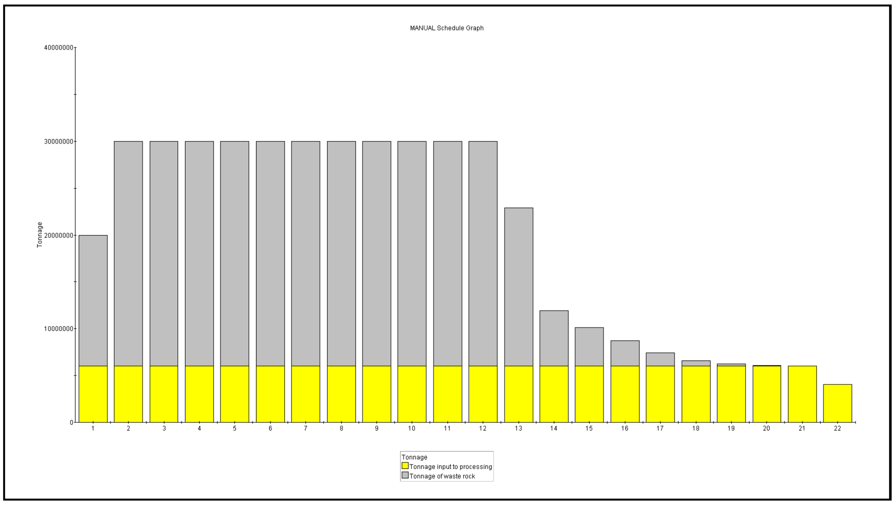
- Ugao generalne kosine kopa za svaki region
- Operativni troškovi otkopavanja (OPEX), $/t
- Osiromašenje i gubici pri otkopavanju
- Operativni troškovi prerade, $/t
- Granični sadržaj (cut off) za sve elemente
- Iskorišćenje na preradi za sve elemente (recovery)
- Prodajna cena za svaki element pojedinačno, $/t
- Troškovi prodaje za svaki element pojedinačno, $/t
- Inicijalni kapitalni troškovi, $
- Ostatak vrednosti, $
- Troškovi zamene opreme, $
- Diskontna stopa, %
- Godišnji kapacitet otkopavanja iskopine
- Godišnji kapacitet otkopavanja mineralne sirovine
- Godišnji kapacitet finalnog proizvoda, opciono (obično se ne ograničava)
- Definisani kriterijumi za izbor konačne konture kopa (maksimalni profit, vek eksploatacije, prostorna ograničenja zbog postojećih objekata, i sl.)

Nakon optimizacije dobija se set kopova od kojih svaki ima različite količine iskopine i različitu vrednost, slika 2.



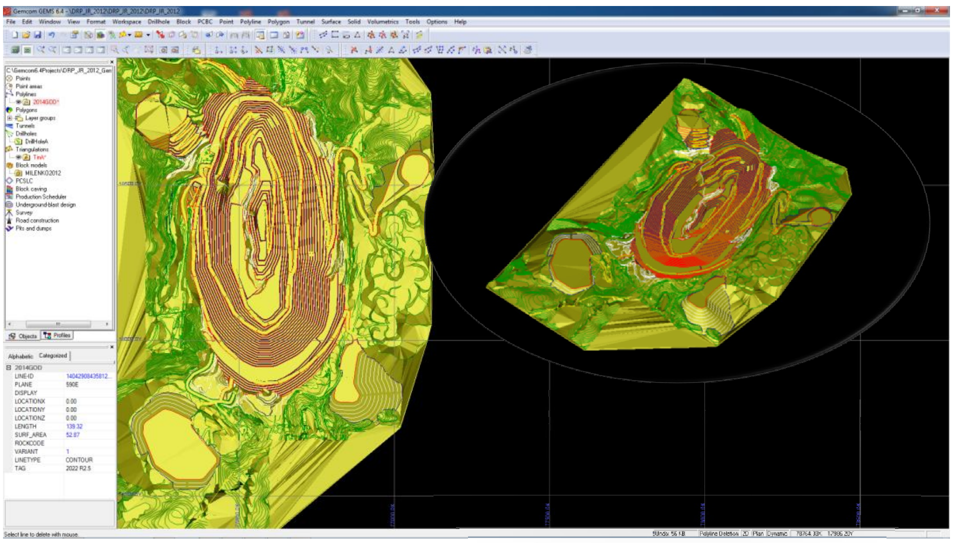
Sl. 2. *Dijagram kopova sa različitom vrednošću i količinama iskopine u programu Whittle*

Kopovi dobijeni na ovaj način nemaju etaže i transportne puteve. Po odabiru optimalnog kopa i međuzahvata (push backs) vrši se eksport u program Gemcom, gde se konstruišu detaljni kopovi sa etažama i transportnim putevima, koji se exportuju nazad u program Whittle u kome se na osnovu njih definiše dinamika otkopavanja [6, 8], slika 3.



Sl. 3. *Dijagram količina iskopine po periodima eksploatacije u programu Whittle*

Dobijene konture kopova po periodima eksploatacije u programu Whittle takođe nemaju etaže i transportne puteve, pa se eksportuju u program Gemcom, gde se konstruišu detaljni kopovi sa etažama i transportnim putevima za svaki period eksploatacije, slika 4.

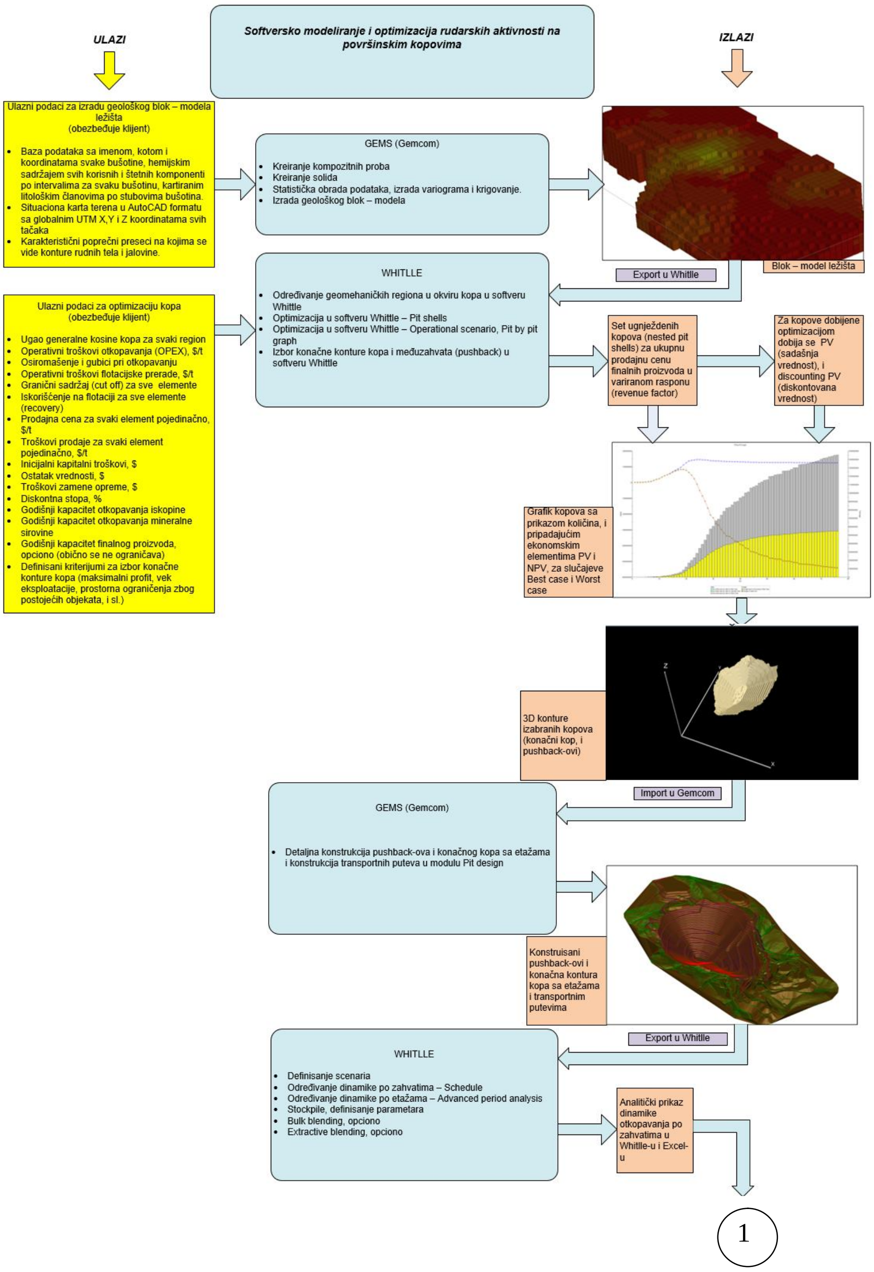


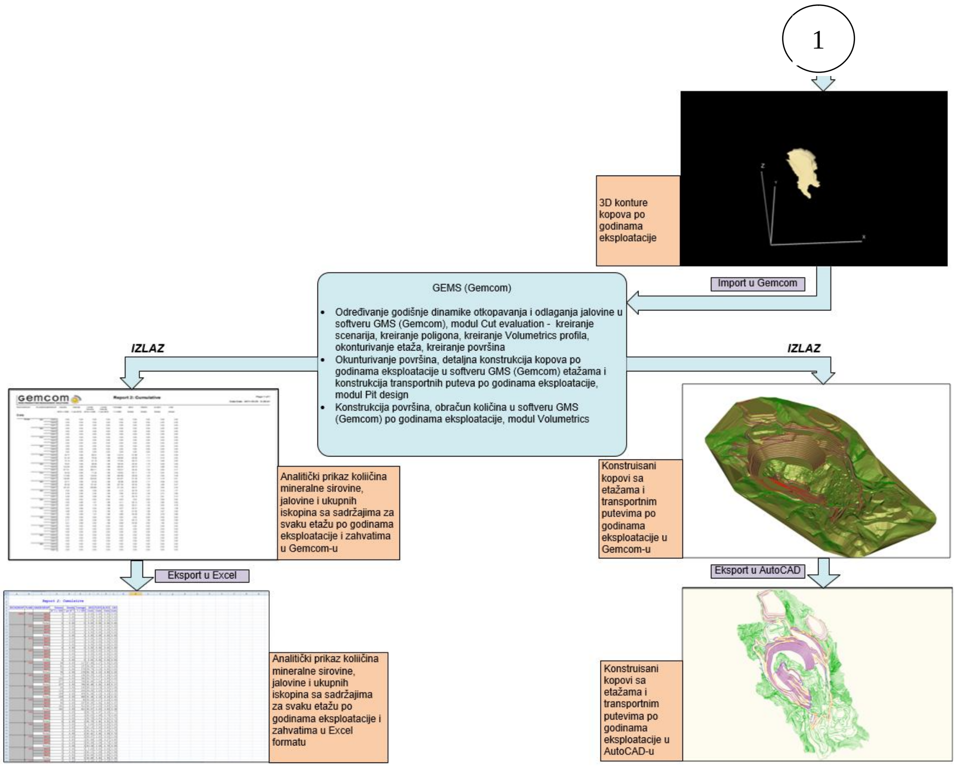
Sl. 4. *2D i 3D prikaz kopa u programu Gemcom*

Izlazni podaci su analitička dinamika koja se iz programa Gemcom može eksportovati u Office aplikaciju Excel, i grafička dinamika koja se iz programa Gemcom može eksportovati u program AutoCAD. Konačni rezultati optimizacije su:

1. Analitički prikaz količina mineralne sirovine, jalovine i ukupnih iskopina sa sadržajima za svaku etažu po godinama eksploatacije i zahvatima u Excel formatu;
2. Konstruisani kopovi sa etažama i transportnim putevima po godinama eksploatacije u AutoCAD-u.

U daljem tekstu dat je algoritam projektovanja u programima Whittle i Gemcom.





ZAKLJUČAK

Važan činilac upotrebe računarskih programa za projektovanje površinskih kopova je relativno laka i brza promena parametara vezanih za geološku interpretaciju ležišta unošenjem novih podataka u bazu bušotina, varijacija tehno – ekonomskih parametara optimizacije, kao i mogućnost promene i upoređivanja više scenarija dinamike otkopavanja.

Takođe je značajno mnogo kraće vreme izrade projekata u odnosu na klasično projektovanje, što je u današnjim tržišnim uslovima od izuzetnog značaja pri dobijanju poslova i sklapanju povoljnih finansijskih ugovora.

Kako za geološku interpretaciju ležišta tako i za projektovanje površinskih kopova i dalje je najvažniji projektant. Međutim upotrebom računarskih programa posao projektanta je znatno olakšan sa aspekta vremena i kvaliteta usled mogućnosti brze analize u cilju odabira najboljih rešenja.

Kvalitet urađene projektne dokumentacije računarskim programima Whittle i Gemcom svakako je jedan od osnovnih razloga zašto je primena ovih i sličnih programa postala neminovnost i standard u projektovanju površinskih kopova.

LITERATURA

[1] D. Kržanović, M. Mikić, R. Rajković, M. Žikić, Z. Vaduvesković: Concept of development the copper mine Majdanpek in the period from 2013 to 2034; Pages 161-164; Mining 2013 Plans for development and improvent of mining; Veliko Gradište, Srebrno jezero, 28-31 maj 2013;

[2] R. Rajković, D. Kržanović, M. Mikić: Primena softverskog paketa Whittle za odredjivanje eksploatacionih rezervi ležišta bakra Severni revir - Majdanpek -Srbija, Rudarski radovi 3/2012; str. 115-122.

[3] D. Kržanović, R. Rajkovic, M. Mikić: Primena softverskih paketa za projektovanje u rudarstvu Gemcom i Whittle u cilju racionalnog i ekonomičnog iskorišđćenja ležišta bakra Veliki Krivelj kod Bora, Srbija, Rudarski radovi 3/2012; str. 85-90.

[4] D. Kržanović, M. Mikić, R. Rajković: Analysis of as Lonf Term Development the Marl Open Pit Trešnja Operating with the Company Holcim Serbia LTD. using the Software Whittle and Gemcom. 44th International October Conference on Mining and Metallurgy. Proceedings, Oktobar 2012, Bor, Serbia, str. 95-101.

[5] D. Kržanović, R. Rajković, M. Žikić: Primena softverskih paketa Whittle i Gemcom za proračun bilansnih rezervi rude bakra u ležištu Južni revir Majdanpek, Rudarski radovi 4/2011; str. 81 - 86.

[6] R. Rajković, D. Kržanović, B. Rajković, Dynamics of excavation on "Deo Donja Bela Reka" deposit in software Gemcom 6.1.3.; 40th International October Conference on Mining and Metallurgy IOCMM 2009; Kladovo, Serbia, 04 – 06 October 2009; str. 111-116.

[7] D. Kržanović, R. Rajković; M. Mikić; Potentiality of exploitation copper ore at the Locality Cerovo – Cementacija Kraku Bugaresku; 41th International October Conference on Mining and Metallurgy IOCMM 2009; Kladovo, Serbia, 04 – 06 October 2009; str. 117-122.

[8] R. Rajković, M. Ignjatović, V. Marinković, Determination of Mining Dynamics Using Gemcom 6.1 Program; Second International Symposium Mining Energetic 08; Tara, Serbia, 15 - 18. September 2008; str. 379-384.

[9] D. Kržanović, M. Žikić, N. Vušović, R. Pantović, S. Stojadinović, Optimum Development of the Open Pit South Mining District in Majdanpek for Annual Capacity of Copper Ore Mining of 8 500 000 t, 44rd International October Conference on Mining and Metallurgy, Bor, 2012

[10] D. Kržanović, M. Žikić, R. Pantović, Bitno poboljšanje iskorišćenja raspoloživih geoloških rezervi ležišta Južni revir Majdanpek u novo definisanoj optimalnoj konturi kopa primenom softverskih paketa Whittle i Gemcom, Rudarski radovi 1/2012, str. 21-28.

[11] D. Kržanović, M. Žikić, Z. Vaduvesković, Inovirani blok model ležišta rude bakra Južni revir - Majdanpek kao osnova za analizu optimalnog razvoja površinskog kopa primenom softverskih paketa Whittle i Gemcom, Rudarski radovi 3/2011, str. 61-68.

[12] Z. Vaduvesković, D. Đokić, D. Kržanović, R. Rajković: Izbor najpovoljije varijante konture kopa na ležištu "Veliki Krivelj"; Rudarski radovi 1/2004, str. 52-60.

[13] Z. Vaduvesković, D. Kržanović, R. Rajković, Analiza mogućnosti rentabilne proizvodnje bakra na površinskom kopu "Veliki Krivelj"; Rudarski radovi 1-2/2003, str. 55-63.

[14] R. Rajković, V. Marinković, R. Lekovski: Digitalni 3D model terena, Rudarski radovi 3/2011, str. 25-32.

[15] R. Rajković, S. Pavlović, B. Rajković; Dynamics of Depositing on Dump II of Jazovnik Limestone Open Pit by

Software Gemcom 6.2; 42. International October Conference on Mining and Metallurgy; str. 162-169.

[16] V. Marinković, R. Rajković, D. Kržanović, G. Pačkovski, D. Mitić: 2D i 3D modeli, sličnosti i razlike, Bakar 34 (1/2009), str. 1-8.

[17] R. Rajković, D. Kržanović, V. Marinković: Geološka interpretacija ležišta „Deo“ Donja Bela Reka programom Gemcom 6.1.3, Rudarski radovi 1/2009, str. 1-6.

[18] D. Kržanović, R. Rajković, V. Marinković: Geološke karakteristike, modeliranje i tehničko rešenje otkopavanja tehnogenog ležišta bakra „Depo šljake 1“ u Boru, Rudarski radovi 1/2009, str. 7-16.

[19] R. Rajković, V. Marinković, M. Ignjatović; Calculation of Geological Reserves of the Coal Deposit by the Use of Computer Program Gemcom 1; First International Symposium Mining Energetic 07; Vrnjačka Banja, Serbia, 21-24. November 2007, str. 201-206.

UDK: 622.271:681.325(045)=20
DOI:10.5937/MMEB1402061K

Vedran Kostić, Zoran Vaduvesković**

COMPARATIVE OPTIMIZATION OF MINING THE KRAKU BUGARESKU CEMENTATION DEPOSIT USING WHITTLE AND NPV SCHEDULER SOFTWARE

Abstract

The paper is aimed to present a method of determining the final pit contour with maximum discounted profit, to determine the stages of excavation (Pushbacks) and mining schedule for the final pit using the software packages for strategic planning of open pit mining - Whittle and NPV Scheduler, in the case of optimization the Kraku Bugaresku Cementation deposit. In both cases the same techno - economic parameters were used and the same initial topography. The aim or intention of the authors was not to judge or advertise the aforementioned software packages, but to demonstrate the optimization procedure in a specific case, with reference to the basic differences. Comparison of the obtained results is also a verification of correctness of the optimization results.

Keywords: *optimization, optimal pit contour, pushbacks, mining schedule, software, NPV*

INTRODUCTION

The "Cerovo" deposit is located in the ore field Mali Krivelj - Cerovo, about fifteen kilometers northwest of the town of Bor.

Figure 1 *Cerovo Cementation 1*

* *Mining and Metallurgy Institute Bor, Serbia*

There are the following ore bodies on the site: "Cerovo - Cementation 1", "Cerovo - Cementation 2", "Cerovo - Cementation 3", "Cerovo - Cementation 4", “Drenova” and "Cerovo - Primary".

In 1990, the work began at the opening the open pit Cementation 1, and the pre-stripping period was dictated by the length of investment period for construction the facilities of Flotation Plant and hydro-transport system for ore pulp to the Flotation Plant in Bor, i.e. the infrastructure facilities of the mine. This period lasted more than 2 years. The Kraku Bugaresku Cementation deposit is a cementation zone of the secondary enrichment and the main oxide minerals are azurite, malachite, and even native copper as occurrence. The main holder of copper bearing mineralization of sulfide minerals is chalcopyrite accompanied by bornite, since pyrite is the most present mineral in the ore. Chalcocite, covellite and azurite are also presented to a lesser extent. [9]

The main problem with the Kraku Bugaresku Cementation deposit is a significant participation of oxide minerals in total ore what reduces the copper recovery in the flotation process of concentrate preparation, and by that the final effects of valorization the total production. In the process of flotation concentration, higher copper recovery can be achieved in the processing of sulfide ore than it is the case in processing of oxide ore. [7] In the world today, the hydrometallurgical processing technology, leaching and SX/EW (solvent extraction and electrochemical separation by electrowinning) are successfully used for the processing of oxide ores, which is particularly actual for low grade heaps like dumps or specially formed oxide ore heap piles. [4, 5] The leaching-SX/SW technology implies that copper from heap is recovered with a solution of sulfuric acid which, after the percolation through the pile, is collected, purified and, in the process of solvent extraction the copper ions are transferred from aqueous into organic phase. The aqueous phase is returned to the leaching process while the organic phase is sent to the process of re-extraction, where in copper is transferred into copper-sulfate solution from which it is further recovered in the process of electro-winning. The resultant copper cathode purity is 99.99 % Cu. [5]

In order to test the possibility and effects of two methods of processing ore at the deposit Kraku Bugaresku Cementation, it was necessary to revise the block model in the software *GEOVIA Gems* to clearly separate the zone of sulfide and oxide ore and enable optimization in the case of two processing methods, i.e. flotation of sulfide (Mill) ore and leaching of oxide ore (Leach). Therefore, the deposit Cerovo Cementation is a separate zone of sulfide ore with participation of oxide minerals by 10% and the oxide ore zone with participation of oxide minerals higher than 10%.

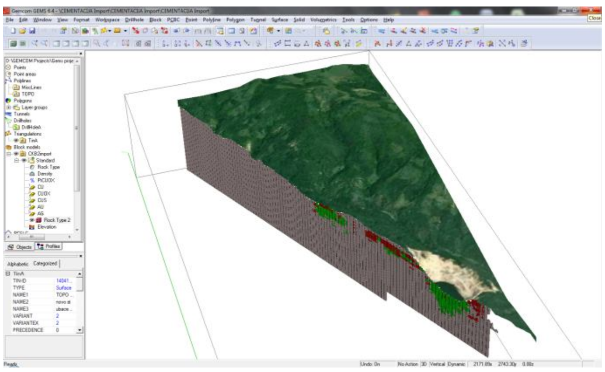
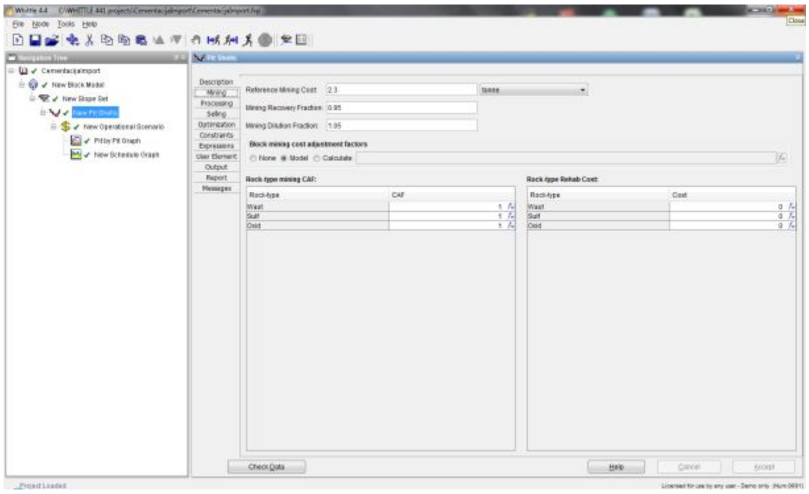


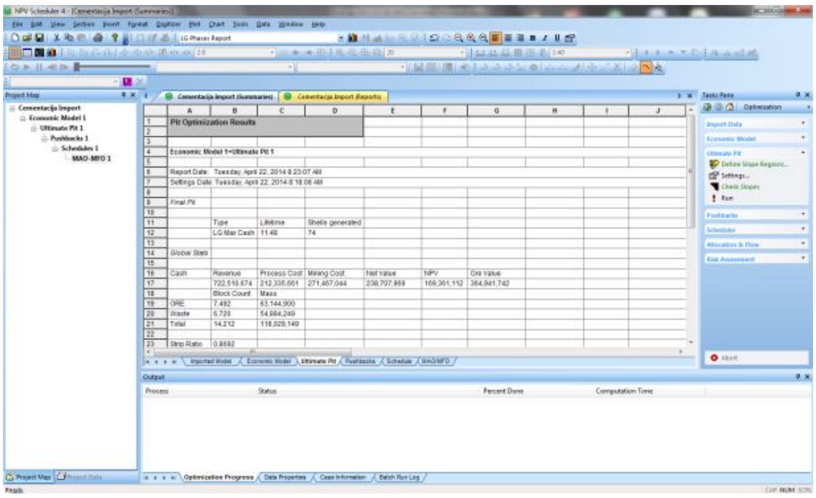
Figure 2 *View of a block model in GEMS with an oxide (red) and sulfide (green) ore zones*

Description the Software Packages Whittle and NPV Scheduler

Software packages *Whittle* from the company GEOVIA and *NPV Scheduler* (NPVS) from the company DATAMINE, are used for strategic planning in the open pit mining, in determining the optimal open pit contour, selection of appropriate open pit mine stages (Phases-Pushbacks) and defining the mining schedule in order to achieve the optimum techno-economic parameters and improved financial results (Figure 3).



a.



b.

Figure 3 *"Windows" of Whittle (a) and NPVS (b) software*

Input Data for Determining the Final Pit Contour and Mining Schedule

The scenario considered in this work involves limited processing of sulfide ore in the flotation (Mill) with maximum of 2.5 mt/year in the first two years, with the expansion of the flotation processing capacity to 5.5 mt/year in the coming years. Processing of oxide ore by leaching (Leach) would not be limited annually, but would be adapted to the amounts of oxide ore that must be excavated within the total excavated rock as to allow for excavation of necessary amounts of sulfide ore for the planned capacity of flotation processing (2.5 mil.t or 5.5 mil.t). Table 1 shows the input economic-technological parameters used as the basis for the optimization process in both softwares. [1]

Table 1 *Input parameters for optimization in Whittle and NPVS*

Economic cut-off grade of copper	**0.15% Cu**
Metal prices	
copper	5 000 $/t
gold	30 000 $/kg
silver	400 $/t
Mining costs	2.3 $/t
Mineral processing costs	
flotation (Mill)	4 $/t
leaching (Leach)	1 $/t
Additional copper recovery costs	
flotation	450 $/t
leaching	100 $/t
Additional metal recovery costs	
gold	150 $/kg
silver	15 $/kg
Mining recovery	95%
Dilution from mining	5%
Metal recoveries	
copper (flotation and metallurgical treatment)	78.8%
copper (leaching and SX/EW)	75%
gold (in both processes)	50%
silver (in both processes)	40%
Discount rate	10%
Slope angle of open pit	37°

Mining layout as of 01. 04. 2014 was taken for the initial topography.

Selection the Optimal Open Pit Contour and Phase Determining

Both softwares are based on the Lerch-Grossman optimization algorithm. The essence of this algorithm is that, for a given techno-economic parameters, the most economical open pit contour is formed by movement from the lowest acceptable economic block to the highest block in the model, while respecting the defined pit slope angles. In order to determine the most economical direction of open pit development, and determination the appropriate stages when planning a mine schedule, software have an option of scaling the metal prices using a coefficient (*revenue factor*) resulting in a series of pits (*nested pits*) from the smallest (for the lowest price of metal) to the largest (depending on the increase of metal price). [2, 3, 4] Open pit with the coefficient of 1.0 (100 % revenue factor) is an open pit with unscaled selling price of metal. For selection the optimal open pit contour, in this case the pit contour with maximum discounted profit or NPV (net present value), it is necessary to determine the discount rate and define the annual production of ore.

In the Whittle software, NPV values are estimated based on the so-called *Best Case* and *Worst Case* Scenarios. The Best Case scenario is where the final pit is mined through all previously defined stages, one by one, in the form of pushbacks. The Worst Case is a scenario in which the final pit is mined without pushbacks, i.e.by benches within the final pit. These cases are uneconomical (Worst Case) and technologically unattainable in practice (Best Case), and therefore it is necessary to seek the adequate phases and, for them, the optimal final pit. In Whittle, this is referred to as the *Specified Case*. [8]

Figures 4 and 5 show the graphs for estimated NPV values in Whittle and NPVS.

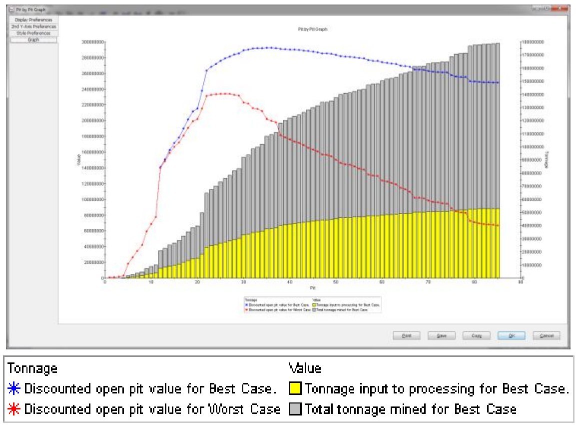


Figure 4 *NPV estimation "Pit by Pit graph" in Whittle*

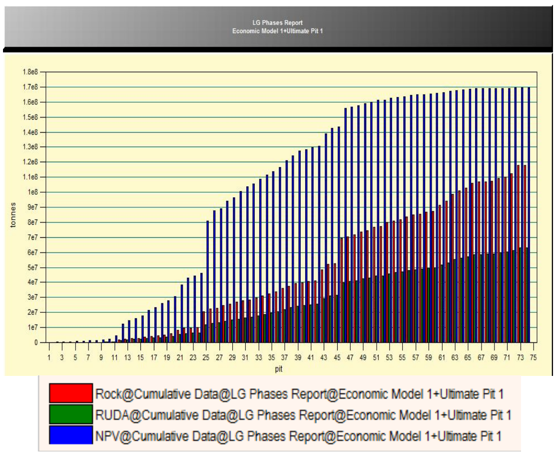


Figure 5 *NPV estimation for open pits in NPVS*

In order to facilitate the comparison of optimization results, it was necessary to select approximately the same pit contours for pushbacks and the final pit. Since the "Pit by Pit" for the Best Case of optimization gives the result of the best NPV value for an open pit with the revenue factor of 0.98 (98%), the open pit with the same revenue factor was also chosen as the final pit in NPVS. As pushbacks, the pits with revenue factors 62% (the first pushback) and 80% (the second pushback) were selected in both softwares. Table 2 and Figure 6 show the amounts of rock and ore in selected pushbacks and the final pit.

Table 2 *Amounts of rock and ore excavated in pushbacks and the final pit in Whittle and NPVS software*

Software	*Phase (Push-back)*	*Revenue factor*	*Total exca-vation*	*Oxide ore*	*Sulfide ore*	*Total ore*	*Stripping ratio*
Whittle	1	62%	33 426 102	10 782 047	9 123 921	19 905 968	0.68
NPVS			33 839 437	10 968 750	9 396 337	20 365 087	0.66
Whittle	2	80%	80 698 683	20 605 505	25 339 518	45 945 023	0.76
NPVS			80 999 662	20 823 750	25 602 075	46 425 825	0.74
Whittle	3	98%	117 459 790	26 686 638	35 720 999	62 407 636	0.88
NPVS			112 228 874	25 920 000	35 326 462	61 246 462	0.83

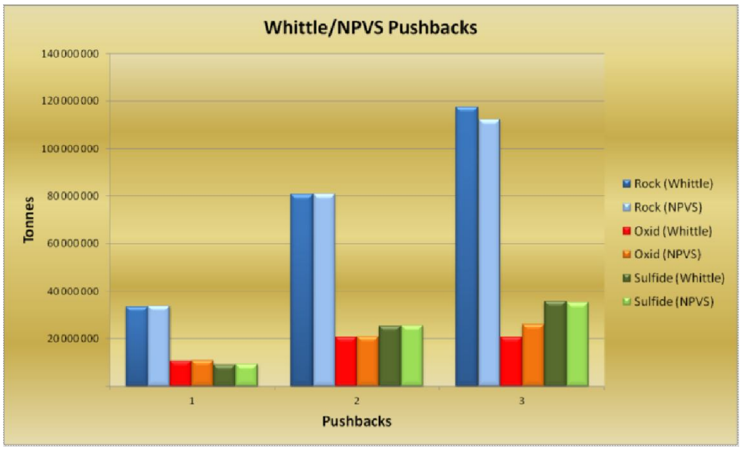
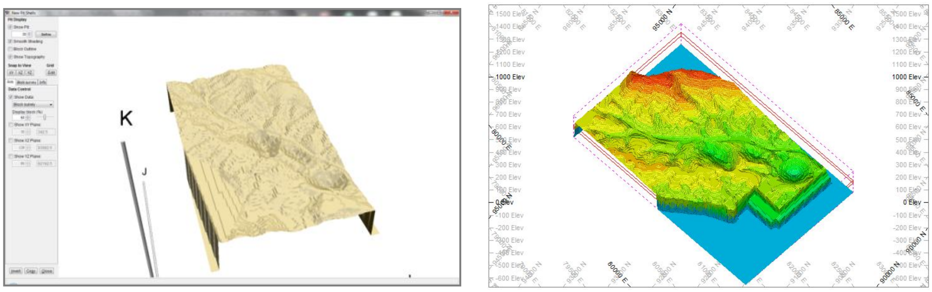


Figure 6 *Comparative review of rock and ore amounts in Whittle and NPV Scheduler pushbacks*

As it can be seen from Table 2 and Figure 6, the only noticeable difference is in total amounts of rock and oxide ore in the third phase, i.e. the final open pit. This can be explained by different approximation procedure of pit slope angle. In Whittle, pit slope angle is approximated across a number of benches, while in the NPVS this is achieved through so-called filters in the X and Y directions. In Whittle, the default value of 8 benches was adopted as a filter to approximate the pit slope angle. In NPVS, thanks to the *Check Slope* option, the accuracy of pit slope angle approximation was checked and the filter value was adopted at 17. From the above mentioned reasons, the final pit in NPVS, although with smaller amounts of total ore, also has sma-ller amounts of overburden and therefore more favorable stripping ratio. Figure 7 presents the open pit contours for the *revenue factor* of 0.98 (98%) in Whittle and NPVS.



a. b.

Figure 7 *The final open pit contour (revenue factor 98%): a –contour in Whittle; b –contour in NPVS*

Defining the Mining Schedule

Noticeable difference in the application of these two programs is in the procedure of determining the mining schedule.

Determining the mining schedule in Whittle implies the mining and ore processing limit. In this case, the program defines the schedule by achieving the first limit (either mining or processing). With the *Milawa Balanced* option, it is possible to balance the amount of overburden to be mined per years and, thus determine the appropriate mining schedule that will follow the ore processing limit as close as possible while maintaining the constant mining limit. The mining schedule, obtained in Whittle, is shown in Table 3 and Figure 8.

Determining mining schedule in NPVS allows for the "primary" limit (target) for ore processing and "secondary" limit (tracking), i.e. maintaining the total amount of rock mined per years, to define the mining schedule that follows the primary limit exactly, but also just closely maintains the total rock. The program tries to find the ideal scenario and when unable to find it, it begins to gradually relax the secondary limit until the primary objective is achieved, i.e. the "target" limit. The resulting mining schedule obtained in NPVS-in is shown in Table 4 and Figure 9.

The mining schedules shown in Tables 3 and 4 were obtained in the case of mining the final pit in three stages, i.e. two pushbacks and the final pit, and with limited mining and sulfide ore processing capacities. In both cases, a possible scenario for a mining schedule is achieved, which, if necessary, could be modified changing the selected or introducing the additional pushbacks or changing the limits.

Table 3 *Mining schedule in Whittle*

Year / Period	*Rock*	*Oxide ore*	*Input to Leach*	*Sulfide ore*	*Input to Mill*	*Total ore*	*Waste*	*Stripping ratio*	*NPV*
	t	*t*	*Cu%*	*t*	*Cu%*	*t*	*t*		*$*
1	17 000 000	3719981	0.24	1111045	0.37	4 831 026	12 168 974	2.52	4 836 966
2	17 000 000	4792264	0.31	2496350	0.45	7 288 615	9 711 385	1.33	40 597 954
3	17 000 000	4068033	0.23	5499785	0.36	9 567 818	7 432 182	0.78	41 462 231
4	17 000 000	6350167	0.21	5283643	0.29	11 633 810	5 366 190	0.46	35 248 060
5	17 000 000	1666371	0.20	5422840	0.28	7 089 211	9 910 789	1.4	8 107 899
6	17 000 000	4368596	0.20	5499436	0.23	9 868 032	7 131 968	0.72	15 347 140
7	10 053 699	1551532	0.18	5500000	0.23	7 051 532	3 002 167	0.43	8 416 079
8	5 406 091	169693	0.19	4907900	0.24	5 077 594	328 498	0.06	9 271 679
Total	**117 459 790**	**26 686 637**		**35 720 999**		**62 407 638**	**55 052 153**	**0.88**	**163 288 008**

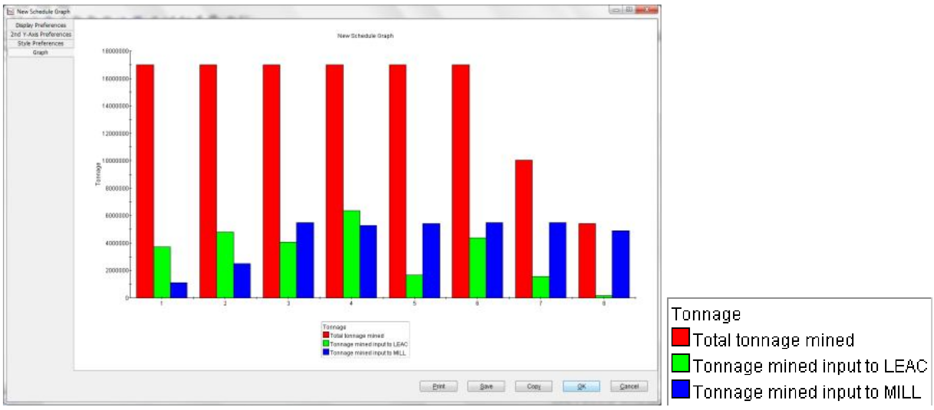


Figure 8 *Graph of mining schedule in Whittle*

Table 4 *Mining schedule in NPVS*

Year / Period	*Rock*	*Oxide ore*	*Input to Leach*	*Sulfide ore*	*Input to Mill*	*Total ore*	*Waste*	*Stripping ratio*	*NPV*
	t	*t*	*Cu%*	*t*	*Cu%*	*t*	*t*		*$*
1	17 003 250	3 020 625	0.25	1 266 300	0.43	4 286 925	12 716 325	2.97	1 375 127
2	16 967 812	4 488 750	0.30	2 503 575	0.47	6 992 325	9 975 487	1.43	37 055 864
3	16 707 262	4 995 000	0.27	5 499 900	0.37	10 494 900	6 212 362	0.59	52 671 121
4	16 500 712	6 572 813	0.22	5 498 550	0.31	12 071 362	4 429 350	0.37	40 169 189
5	13 000 500	1 282 500	0.22	5 501 250	0.29	6 783 750	6 216 750	0.92	13 289 510
6	13 688 662	2 244 375	0.21	5 499 900	0.25	7 744 275	5 944 387	0.77	11 529 474
7	13 568 175	3 155 625	0.19	5 498 550	0.24	8 654 175	4 914 000	0.57	10 330 821
8	4 792 500	160 313	0.17	4 058 438	0.23	4 218 750	573 750	0.14	5 465 836
Total	**112 228 874**	**25 920 000**		**35 326 462**		**61 246 462**	**50 982 412**	**0.83**	**171 886 941**

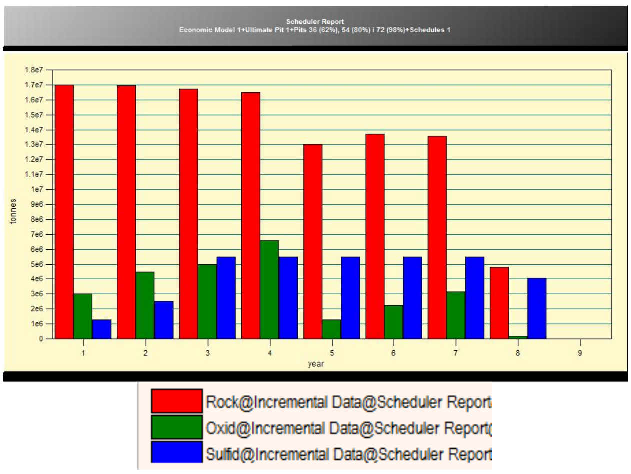
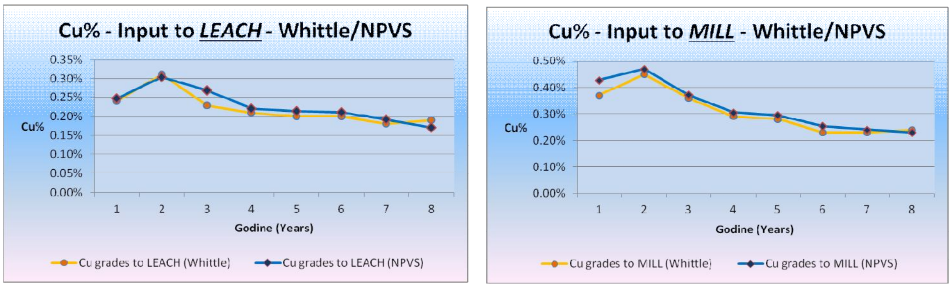


Figure 9 *Graph of mining schedule in NPVS*

The difference in approximation the pit slope angle in this software has led to some differences between the amounts of ore and waste rock which caused the software to "choose" somewhat different pit contours as the most economical ones for selected revenue factors. In addition to the differences in ore amounts for the final pit, this has led to occurrence of difference in the average grades of copper in the mining schedules, as shown in Tables 3 and 4 and Figure 10.



a. *b.*

Figure 10 *Anual ratio of the average copper grade in the input ore to LEACH (a) and MILL (b) processes for mining schedules in Whittle and NPVS*

Table 5 shows the amounts of recovered metals as the final products from Whittle and NPVS final pits. Due to larger amounts of ore and the same technological parameters of ore processing and metal extraction, slightly higher amounts of final products were obtained in the case of the final pit contours obtained in Whittle software.

Table 5 *Amounts of recovered metals from Whittle and NPVS final pit contours*

	Oxide (process LEACH)			**Sulfide (process MILL)**			**Total**		
	Cu	Au	Ag	Cu	Au	Ag	Cu	Au	Ag
	t	kg	kg	t	kg	kg	t	kg	kg
Whittle	46 337	907	11 335	81 260	1 442	15 838	**127 597**	**2 349**	**27 173**
NPVS	44 869	875	10 828	80 185	1 419	15 557	**125 054**	**2 294**	**26 385**

CONCLUSION

Due to a different procedure of setting the parameters necessary for optimization, in this case the choice of an appropriate filter or number of benches to approximate the pit slope angle, there was a difference in the ore and rock amounts that led to differences in NPV between these two cases. It might be expected that the pit, although with somewhat smaller amounts of ore, but also with a more favorable stripping ratio, resulted in higher NPV profit. Also, at least in this case, it was shown that an excess of ore in the Whittle final pit has led to reduction in the average grade of copper in the mining schedule in relation to the NPVS final pit, which has further influenced the difference in NPV. Due to relatively small differences, both softwares lead to satisfactory results in terms of the mining schedule. Therefore, one software can be used to verify the results obtained from the other software and, possibly, to improve the mining schedule.

REFERENCES

[1] Z. Vaduvesković, N. Vušović, D. Kržanović: Analysis the Possibility of Improving the Economic Indicators of Exploitation the Deposit Cementacija Kraku Bugaresku - Ore Field Cerovo, Mining and Metallurgy Engineering Bor, 1/2014; pp. 13-24

[2] K. Dagdelen, Open Pit Optimization - Strategies for Improving Economics of Mining Projects through Mine Planning, 17th International Mining Congress and Exhibition of Turkey - IMCET2001, 2001.

[3] A. Hajarian, R. Dambov, R. Karanakova Stefanovska: Long Term Production Scheduling of Sungun Copper Mine Using NPV Scheduler Software, 22nd World Mining Congress and Expo, Istanbul 2011;

[4] M L Smith: Using Milawa/4X as a Starting Solution for Mixed Integer Programming Optimization of Large Open Cut Production Schedules, Strategic Mine Planning Conference, 2001;

[5] M. E. Schlesinger, M. J. King, K. C. Sole, W. G. Davenport: Extractive Metallurgy of Copper, Fifth Edition, 2011;

[6] G. A. Kordosky: Copper Recovery Using Leach/Solvent Extraction/ Electrowinning Technology: Forty Years of Innovation, 2.2 million tones of copper annually, The Journal of The South African Institute of Mining and Metallurgy, 2002;

[7] K. Lee, D. Archibald, J. McLean, M. A. Reuter: Flotation of Mixed Copper Oxide and Sulphide Minerals with Xanthate and Hydroxamate Collectors, Mineral Engineering, 2008;

[8] Reference Manual, Four-X Strategic Planning Software for Open Pit Mines; Whittle Programming Pty Ltd, 1998;

[9] http://rtb.rs/rtb-bor-doo/rudnik-bakra-bor/rudnik-bakra-cerovo/

[10] Z. Vaduvesković, N. Vušović, D. Kržanović: Analysis the Posibility of Improving the Economic Indicators of Exploitation the Deposit Cementacija Kraku Bugaresku - Ore Field Cerovo, Mining and Metallurgy Institute Bor 1/2014, pp 13-24.

INSTITUT ZA RUDARSTVO I METALURGIJU BOR ISSN: 2334-8836
UDK: 622

UDK: 622.271:681.325(045)=861 DOI:10.5937/MMEB1402061K

Vedran Kostić[*], *Zoran Vaduvesković*[*]

UPOREDNA OPTIMIZACIJA OTKOPAVANJA LEŽIŠTA KRAKU BUGARESKU CEMENTACIJA POMOĆU SOFTVERA WHITTLE I NPV SCHEDULER

Izvod

Rad ima za cilj da prikaže postupak određivanja konačne konture kopa sa maksimalnim diskontovanim profitom, određivanje faza u otkopavanju kopa (Pushbacks) i dinamike otkopavanja za konačni kop, pomoću softverskih paketa za strateško planiranje površinske eksploatacije - Whittle i NPV Scheduler, na primeru optimizacije ležišta Cerovo Cementacija. U oba slučaja korišćeni su isti tehno - ekonomski parametri i isto početno stanje terena. Cilj ili namera autora nije da ocenjuje ili reklamira pomenute softverske pakete već da prikaže proceduru optimizacije na konkretnom primeru, uz osvrt na osnovne razlike. Upoređenje dobijenih rezultata takođe predstavlja i proveru ispravnosti rezultata optimizacije.

Ključne reči: *optimizacija, optimalna kontura kopa, faze, dinamika otkopavanja, softver, NPV*

UVOD

Ležište „Cerovo“ nalazi se u rudnom polju Mali Krivelj – Cerovo, petnaestak kilometara severozapadno od Bora.

Sl. 1. *Cerovo – Cementacija 1*

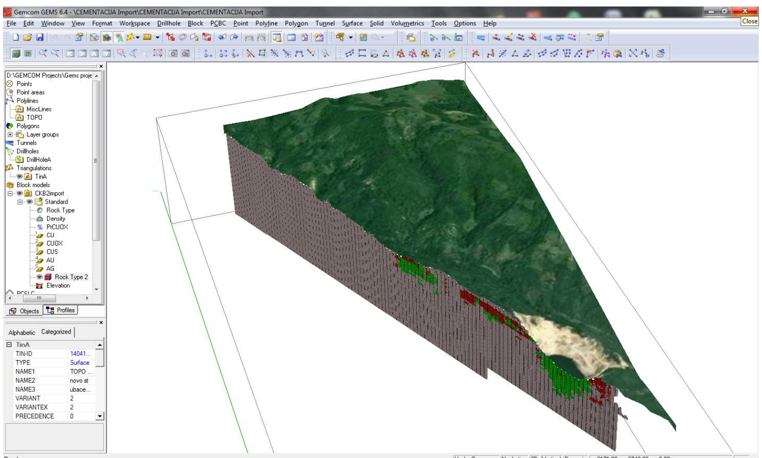
[*] *Institut za rudarstvo i metalurgiju Bor*

Na lokalitetu se nalaze rudna tela „Cerovo – Cementacija 1“, „Cerovo – Cementacija 2“, „Cerovo – Cementacija 3“, „Cerovo – Cementacija 4“, ležište „Drenova“ i „Cerovo – primarno“.

Godine 1990. započeti su radovi na otvaranju kopa Cementacija 1, i prestriping period je bio diktiran dužinom trajanja investicionih radova na objektima flotacije i hidrotransporta pulpe do flotacije u Boru, tj. infrastrukturnim objektima rudnika. Taj period je trajao nešto više od 2 godine. Ležište Kraku Bugaresku Cementacija, je cementaciona zona sekundarnog obogaćenja i glavni oksidni minerali su azurit, malahit, čak i samorodni bakar kao pojava. Od sulfidnih minerala glavni nosilac bakronosnog orudnjenja je halkopirit praćen bornitom, dok je pirit najzastupljeniji mineral u orudnjenju. U manjoj meri zastupljeni su halkozin, kovelin i azurit. [9]

Osnovni problem kod ležišta Kraku Bugaresku Cementacja je u znatnom učešću oskidnih minerala u ukupnoj rudi što smanjuje iskorišćenje bakra u flotacijskom procesu pripreme koncentrata, time i konačne efekte valorizacije ukupne proizvodnje. U procesu flotacijske koncentracije veće iskorišćenje bakra se postiže u preradi sulfidne rude nego što je to slučaj sa preradom oksidne rude. [7] Danas se u svetu za dobijanje bakra iz oksidne rude uspešno primenjuju procesi hidrometalurške prerade tehnologijom luženja i SX/EW (Solvent extraction and electrowinning, tj. solventna ekstrakcija i elektrohemijsko izdvajanje), što je pogotovu aktuelno kod formiranih gomila sa manjim sadržajem bakra poput jalovišta ili posebno formiranih “haldi” oksidne rude. [4, 5] Tehnologija luženje - SX/EW podrazumeva iskorišćenje bakra sa gomile pomoću rastvora sumporne kiseline koja se nakon perkolacije kroz gomilu prikuplja, prečišćava i u procesu solventne ekstrakcije bakarni joni prevode iz vodene u organsku fazu. Vodena faza se vraća u proces luženja dok organska faza odlazi u proces reekstrakcije, gde bakar prelazi u bakarsulfatni rastvor, iz koga se dalje dobija procesom elektrolize. Ovako dobijeni katodni bakar je čistoće 99,99% Cu. [5]

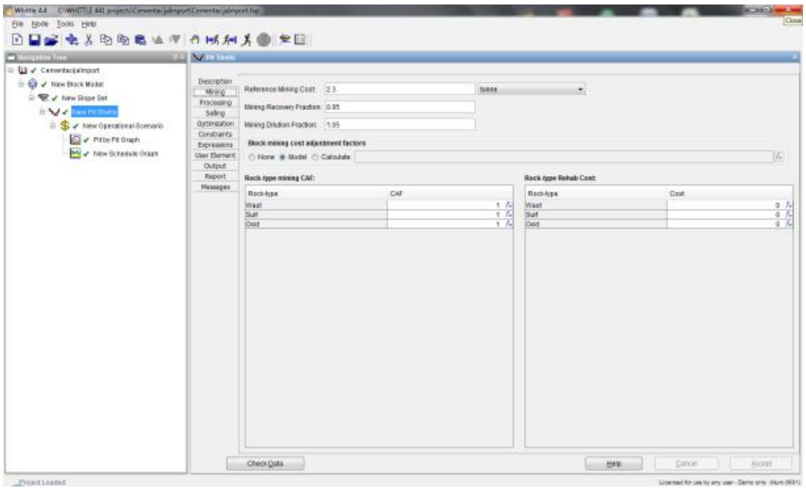
Da bi se ispitala mogućnost i efekti primene dve metode prerade rude i na ležištu Kraku Bugaresku Cementacija, bilo je potrebno prethodno preraditi blok model u softveru *GEOVIA Gems* da bi se jasno razdvojile zone sulfidne i oksidne rude i omogućila optimizacija za slučaj dve metode prerade, tj. flotiranje sulfidne (*Mill*) i luženje oksidne rude (*Leach*). Samim tim, u ležištu Cerovo Cementacija je izdvojena zona sulfidne rude sa učešćem oksidnih minerala do 10% i zona oksidne rude sa učešćem oksidnih minerala većim od 10%.



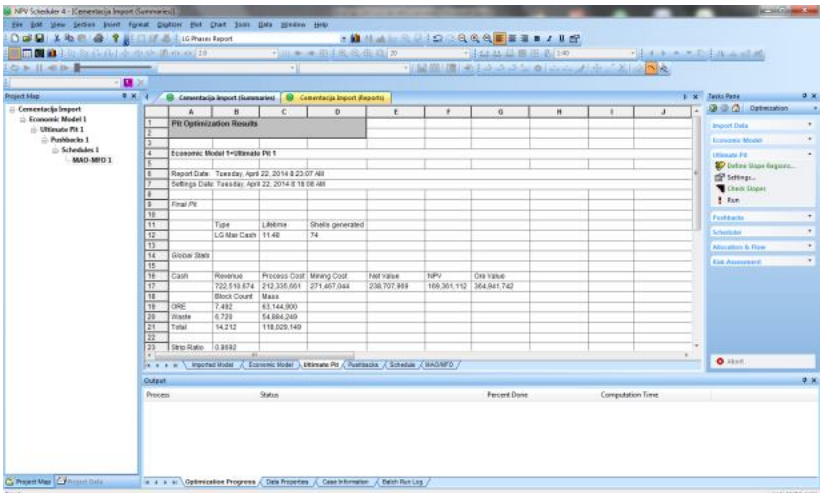
Sl. 2. *Prikaz blok modela u GEMSu sa oksidnom (crvena) i sulfidnom (zelena) rudom*

Opis softverskih paketa Whittle i NPV Scheduler

Softverski paketi *Whittle* kompanije GEOVIA i *NPV Scheduler* (NPVS) kompanije DATAMINE se koriste za strateško planiranje u površinskoj eksploataciji, kod određivanja optimalne konture površinskog kopa, izbora adekvatnih zahvata (Faze-Pushbacks) i definisanja dinamike otkopavanja u cilju ostvarivanja optimalnih tehno-ekonomskih parametara i boljih finansijskih rezulatata (slika 3).



a.



b.

Sl. 3. *"Prozori" programa Whittle (a) i NPV Scheduler (b)*

Ulazni podaci za određivanje konačne konture kopa i dinamike otkopavanja

Scenario koji je razmatran u ovom radu podrazumeva limitiranu preradu sulfidne rude u flotaciji (*Mill*) od maksimalno 2.5 mt/god u prve dve godine, sa proširenjem flotacijskog kapaciteta prerade na 5.5 mt/god u narednim godinama. Prerada oksidne rude luženjem (*Leach*) ne bi bila limitirana po godinama, već bi se prilagođavala količinama oksidne rude koje se moraju otkopati u sklopu ukupnih iskopina, kako bi se omogućilo otkopavanje količina sulfidne rude za planirani kapacitet flotacijske prerade (2.5 mil.t, odnosno 5.5 mil.t). U tabeli 1. prikazani su ulazni ekonomsko-tehnološki parametri koji su poslužili kao osnova u procesu optimizacije u oba softvera. [1]

Tabela 1. *Ulazni parametri za optimizaciju u softverima Whittle i NPVS*

Ekonomski granični sadržaj bakra u rudi	**0.15% Cu**
Cene metala	
bakar	5 000 $/t
zlato	30 000 $/kg
srebro	400 $/t
Troškovi otkopavanja	2.3 $/t
Troškovi pripreme mineralne sirovine	
flotiranje (Mill)	4 $/t
luženje (Leach)	1 $/t
Dodatni troškovi dobijanja bakra	
kod flotiranja	450 $/t
kod luženja	100 $/t
Ostali troškovi dobijanja metala	
za zlato	150 $/kg
za srebro	15 $/kg
Iskorišćenje na otkopavanju	95%
Osiromašenje na otkopavanju	5%
Iskorišćenje u procesu dobijanja metala	
bakar (flotiranje i metalurška prerada)	78.8%
bakar (luženje i SX/EW)	75%
zlato (u oba procesa)	50%
srebro (u oba procesa)	40%
Diskontna stopa	10%
Ugao boka kopa	37°

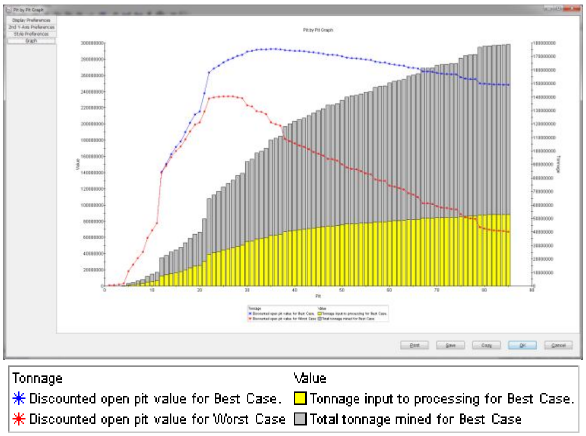
Za početno stanje uzeta je situacija terena na dan 01. 04. 2014. godine.

Izbor optimalne konture površinskog kopa i određivanje faza

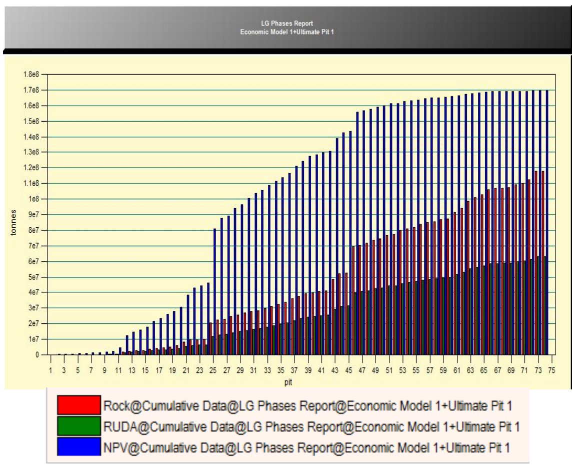
Oba softvera su bazirana na Lerch Grossman algoritmu optimizacije. Suština ovog algoritma je da, za zadate tehno-ekonomske parametre, formira najekonomičniju konturu kopa krećući se od najnižeg ekonomski prihvatljivog bloka do najvišeg bloka u modelu, pri tome poštujući definesane uglove kosina kopa. Zbog određivanja najekonomičnijeg pravca razvoja kopa, i određivanje adekvatnih faza u planiranju otkopavanja, softveri imaju mogućnost skaliranja prodajne cene metala pomoću koeficijenta (*revenue factor*) čime se dobija serija kopova (*nested pits*) od najmanjeg (za najnižu prodajnu cenu) do najvećeg (zavisno od uvećanja prodajne cene). [2, 3, 4] Kop sa koeficijentom 1.0 (100% revenue factor) predstavlja kop sa neskaliranom prodajnom metala. Za izbor optimalne konture kopa, u ovom slučaju konture kopa sa maksimalnim diskontovanim profitom ili NPV (*net present value*) potrebno je odrediti diskontnu stopu i definisati godišnju proizvodnju rude.

U softveru Whittle, NPV vrednosti se procenjuju na bazi tzv. *Best Case* i *Worst Case* scenaria. *Best Case* je scenario u kome se do konačne konture kopa stiže preko otkopavanja etaža svih određenih kontura do konačne u vidu faza (*Push-backs*). Worst Case predstavlja scenario u kome se do konačne konture kopa stiže otkopavanjem svih etaža u konačnoj konturi, tj. bez faza. Oba slučaja su, kako neekonomična (Worst Case) tako i tehnološki neostvariva u praksi (Best Case), pa je potrebno tražiti adekvatne faze i, za njih, optimalnu konačnu konturu kopa. U Whittlu se ovo označava kao *Specified Case*. [8]

Na slikama 4 i 5 prikazani su dijagrami procenjenih vrednosti za NPV u programima Whittle i NPVS



Sl. 4. *Procena NPV vrednosti "Pit by Pit graph" u softveru Whittle*

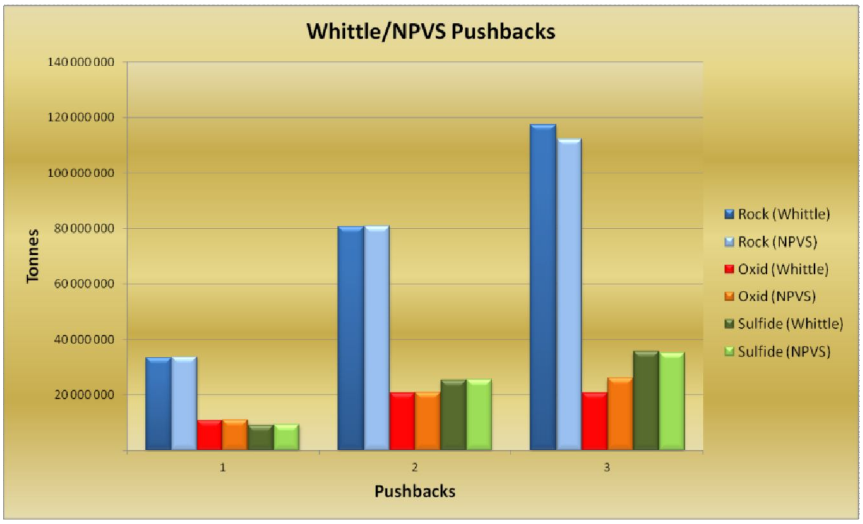


Sl. 5. *Procena NPV vrednosti za kopove u softveru NPVS*

Kako bi se omogućilo upoređivanje rezultata optimizacije bilo je potrebno odabrati približno iste konture kopova za faze i za konačnu konturu. Budući da je “Pit by Pit” optimizacija za Best Case kao razultat dala najbolju vrednost NPVa za kop sa revenue faktorom 0.98 (98%), kop sa istim revenue faktorom je izabran kao konačni kop i u NPVSu. Kao faze, u oba softvera, izabrane su konture kopova za revenue faktore 62% (prva faza) i 80% (druga faza). U tabeli 2 i na slici 6 prikazane su količine iskopina i rude u izabranim fazama.

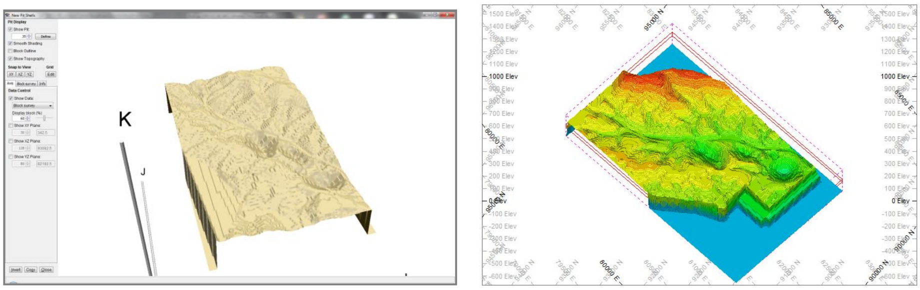
Tabela 2. *Količine rude i iskopina u fazama i konačnoj konturi u softverima Whittle i NPVS*

Softver	Faza (Push-back)	Revenue faktor	Iskopine	Oksidna ruda	Sulfidna ruda	RUDA ukupno	Koef. rask-rivke
Whittle	1	62%	33 426 102	10 782 047	9 123 921	19 905 968	0.68
NPVS			33 839 437	10 968 750	9 396 337	20 365 087	0.66
Whittle	2	80%	80 698 683	20 605 505	25 339 518	45 945 023	0.76
NPVS			80 999 662	20 823 750	25 602 075	46 425 825	0.74
Whittle	3	98%	117 459 790	26 686 638	35 720 999	62 407 636	0.88
NPVS			112 228 874	25 920 000	35 326 462	61 246 462	0.83



Sl. 6. *Uporedni prikaz količina rude i iskopina u fazama u softverima Whittle i NPV Scheduler*

Kako se to može videti iz tabele 2, i sa slike 6, jedina primetna razlika je u ukupnim količinama iskopina i oksidne rude za treću fazu, odnosno konačni kop. Ovo se može objasniti različitom procedurom aproksimacije ugla kosine boka kopa. U Whittlu se ugao aproksimira preko broja etaža, dok se u NPVSu to radi preko tzv. filtera po X i Y pravcima. U Whittlu je usvojena difoltna vrednost od 8 etaža za aproksimaciju ugla kosine kopa. U NPVSu je, zahvaljujući opciji *Slope Chek*, izvršena provera tačnosti aproksimacije ugla kosine kopa i usvojena vrednost filtera 17. Iz pomenutog razloga konačna kontura u NPVSu, iako sa manjim količinama rude, ima i manje količine jalovine a samim tim i povoljniji koeficijent raskrivke. Na slici 7 prikazane su konture za *revenue factor* 0.98 (98%) u softverima Whittle i NPVS.



a. *b.*

Sl. 7. *Konačna kontura kopa (Revenue factor 98%): a – kontura iz Whittla; b – kontura iz NPVSa*

Definisanje dinamike eksploatacije

Primetna razlika u primeni ova dva programa je kod procedure određivanja dinamike otkopavanja.

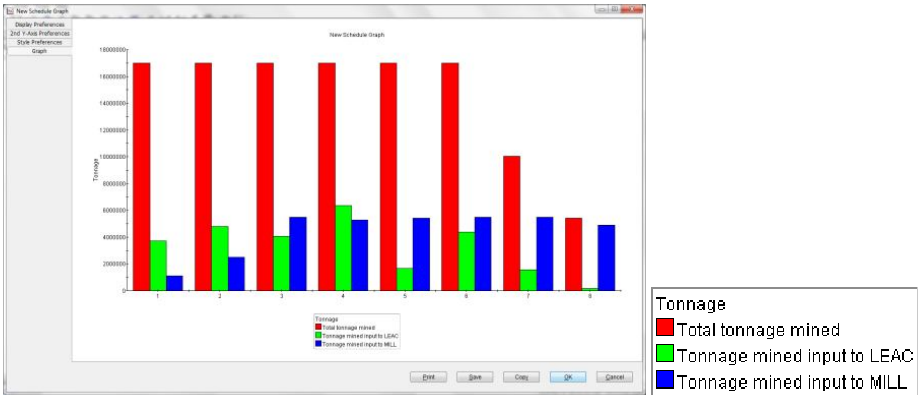
Određivanje dinamike otkopavanja u Whittle-u podrazumeva uvođenje limita na otkopavanju i u preradi rude. U ovom slučaju program dolazi do dinamike pri dostizanju prvog limita (bilo na otkopavanju ili preradi). Uz opciju *Milawa balanced* moguće je uravnotežiti količine jalovine koje se otkopavaju po godinama i time odrediti adekvatnu dinamiku otkopavanja koja najpribližnije moguće prati limit na preradi rude uz konstantan limit na otkopavanju. Dinamika dobijena u Whittlu je prikazana u tabeli 3 i na slici 8.

Određivanje dinamike otkopavanja u NPVS-u omogućuje da se uz "primarni" limit (target) na preradi rude i "sekundarni" limit (tracking), odnosno praćenje (balansiranje) ukupnih količina iskopina po godinama, odredi dinamika koja tačno prati glavni limit, ali zato samo približno prati iskopine. Program pokušava da nađe idealan scenario i u nemogućnosti da ga pronađe počinje postupno da opušta sekundarni limit (relaxing) dok ne ostvari primarni cilj, tj. "target" limit. Dobijena dinamika otkopavanja u NPVS-u je prikazana u tabeli 4 i na slici 9.

Dinamike prikazane u tabelama 3 i 4 je dobijene su za slučaj otkopavanja kopa u tri zahvata, tj. dve faze i konačni kop, i sa limitiranim kapacitetima na otkopavanju iskopina i na preradi sulfidne rude. U oba slučaja se dolazi do jedne od mogućih varijanti za dinamiku otkopavanja koja se, po potrebi, može izmeniti promenom izabranih ili uvođenjem dodatnih faza (Push-backs) ili sa izmenom limita.

Tabela 3. *Dinamika otkopavanja u softveru Whittle*

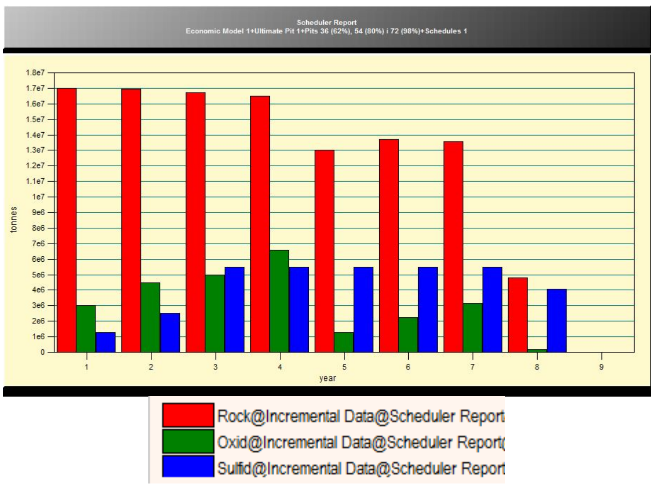
God. / Period	*Iskopine*	*Oksidna ruda*	*Input to Leach*	*Sulfidna ruda*	*Input to Mill*	*RUDA (ukupno)*	*JALOVINA*	*Koef. raskri-vke*	*NPV*
	t	*t*	*Cu%*	*t*	*Cu%*	*t*	*t*		*$*
1	17 000 000	3 719 981	0.24	1 111 045	0.37	4 831 026	12 168 974	2.52	4 836 966
2	17 000 000	4 792 264	0.31	2 496 350	0.45	7 288 615	9 711 385	1.33	40 597 954
3	17 000 000	4 068 033	0.23	5 499 785	0.36	9 567 818	7 432 182	0.78	41 462 231
4	17 000 000	6 350 167	0.21	5 283 643	0.29	11 633 810	5 366 190	0.46	35 248 060
5	17 000 000	1 666 371	0.20	5 422 840	0.28	7 089 211	9 910 789	1.4	8 107 899
6	17 000 000	4 368 596	0.20	5 499 436	0.23	9 868 032	7 131 968	0.72	15 347 140
7	10 053 699	1 551 532	0.18	5 500 000	0.23	7 051 532	3 002 167	0.43	8 416 079
8	5 406 091	169 693	0.19	4 907 900	0.24	5 077 594	328 498	0.06	9 271 679
Total	**117 459 790**	**26 686 637**		**35 720 999**		**62 407 638**	**55 052 153**	**0.88**	**163 288 008**



Sl. 8. *Grafički prikaz dinamike otkopavanja u softveru Whittle*

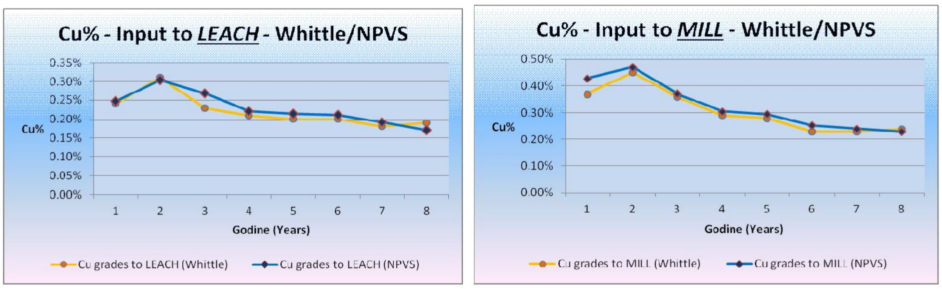
Tabela 4. *Dinamika otkopavanja u softveru NPVS*

God. / Period	*Iskopine*	*Oksidna ruda*	*Input to Leach*	*Sulfidna ruda*	*Input to Mill*	*RUDA (ukupno)*	*JALOVINA*	*Koef. raskrivke*	*NPV*
	t	*t*	*Cu%*	*t*	*Cu%*	*t*	*t*		*$*
1	17 003 250	3 020 625	0.25	1 266 300	0.43	4 286 925	12 716 325	2.97	1 375 127
2	16 967 812	4 488 750	0.30	2 503 575	0.47	6 992 325	9 975 487	1.43	37 055 864
3	16 707 262	4 995 000	0.27	5 499 900	0.37	10 494 900	6 212 362	0.59	52 671 121
4	16 500 712	6 572 813	0.22	5 498 550	0.31	12 071 362	4 429 350	0.37	40 169 189
5	13 000 500	1 282 500	0.22	5 501 250	0.29	6 783 750	6 216 750	0.92	13 289 510
6	13 688 662	2 244 375	0.21	5 499 900	0.25	7 744 275	5 944 387	0.77	11 529 474
7	13 568 175	3 155 625	0.19	5 498 550	0.24	8 654 175	4 914 000	0.57	10 330 821
8	4 792 500	160 313	0.17	4 058 438	0.23	4 218 750	573 750	0.14	5 465 836
Total	**112 228 874**	**25 920 000**		**35 326 462**		**61 246 462**	**50 982 412**	**0.83**	**171 886 941**



Sl. 9. *Grafički prikaz dinamike otkopavanja u softveru NPVS*

Razlika u aproksimaciji ugla u primenjenim softverima dovela je do određene razlike između količina rude i jalovine što je izazvalo da softveri "biraju" nešto drugačije najekonomičnije konture za odabrane *revenue* faktore. Ovo je dovelo do toga se pored razlike u količinama rude u konačnim konturama, javi i razlika u srednjem sadržaju bakra u dinamici otkopavanja, što je prikazano u tabelama 3 i 4 i na slici 10.



a. *b.*

Sl. 10. *Odnos srednjeg sadržaja bakra u ulaznoj rudi u procese LEACH (a) i MILL (b) po godinama dinamike u softverima Whittle i NPVS*

U tabeli 5 prikazane su količine dobijenog (recovered) metala kao finalnog proizvoda u konačnim konturama Whittla i NPVSa. Obzirom na veće količine rude i na iste tehnološke parametre prerade rude i dobijanja metala, dobijene su nešto veće količine finalnog proizvoda u slučaju konture dobijene u softveru Whittle.

Tabela 5. *Količine dobijenog metala u konturama Whittle i NPVS*

	Oxid (proces LEACH)			**Sulfide (proces MILL)**			**Total**		
	Cu	Au	Ag	Cu	Au	Ag	Cu	Au	Ag
	t	kg	kg	t	kg	kg	t	kg	kg
Whittle	46.337	907	11.335	81.260	1.442	15.838	**127.597**	**2.349**	**27.173**
NPVS	44.869	875	10.828	80.185	1.419	15.557	**125.054**	**2.294**	**26.385**

ZAKLJUČAK

Zbog različite procedure podešavanja parametara neophodnih za optimizaciju, u ovom slučaju izbor odgovarajućeg filtera ili broja etaža za aproksimaciju ugla kosine boka kopa, javila se određena razlika u količinama rude i iskopina koja je dovela do razlike u NPVu između ova dva slučaja. Ono što se moglo očekivati je da je kop sa, iako nešto manjim količinama rude, ali i povoljnijim koeficijentom raskrivke (Stripping Ratio) rezultovao sa većim NPV profitom. Takođe, barem u ovom slučaju, se pokazalo da je višak rude u konturi iz Whittla doveo do smanjenja srednjeg sadržaja bakra u dinamici otkopavanja u odnosu na konturu iz softvera NPVS, što je dodatno uticalo na razliku u NPVu. Obzirom na relativno male razlike, primenom oba softvera dolazi se do zadovoljavajućih rezultata u pogledu dinamike otkopavanja. Samim tim jedan softver može da posluži za proveru dobijenih rezultata iz drugog softvera i, eventualno, za poboboljšanje dinamike otkopavanja.

LITERATURA

[1] Z. Vaduvesković, N. Vušović, D. Kržanović: Analiza mogućnosti poboljšanja ekonomskih pokazatelja eksploatacije ležišta Cementacija Kraku Bugaresku - rudno polje Cerovo, Mining and Metallurgy Engineering Bor 1/2014, str. 25-36.

[2] K. Dagdelen, Open Pit Optimization - Strategies for Improving Economics of Mining Projects Through Mine Planning, 17th International Mining Congress and Exhibition of Turkey-IMCET2001, 2001.

[3] A. Hajarian, R. Dambov, R. Karanakova Stefanovska: Long term production scheduling of Sungun copper mine using NPV Scheduler software, 22nd World Mining Congress and Expo, Istanbul 2011.

[4] M. L. Smith: Using Milawa/4X as a Starting Solution for Mixed Integer Programming Optimisation of Large Open Cut Production Schedules, Strategic Mine Planning Conference 2001

[5] M. E. Schlesinger, M. J. King, K. C. Sole, W. G. Dav enport: Extractive metallurgy of copper fifth edition, 2011.

[6] G. A. Kordosky: Copper recovery using leach/solvent extraction/electrowinning technology: Forty years of innovation, 2.2 million tonnes of copper annually, The Journal of The South African Institute of Mining and Metallurgy, 2002

[7] K. Lee, D. Archibald, J. McLean, M. A. Reuter: Flotation of mixed copper oxide and sulphide minerals with xanthate and hydroxamate collectors, Mineral Engineering 2008

[8] Reference Manual, Four-X Strategic Planning Software for Open Pit Mines, Whittle Programming Pty Ltd, 1998

[9] http://rtb.rs/rtb-bor-doo/rudnik-bakra-bor/rudnik-bakra-cerovo/

[10] Z. Vaduvesković, N. Vušović, D. Kržanović: Analiza mogućnosti poboljšanja ekonomskih pokazatelja eksploatacije ležišta cementacija Kraku Bugaresku – rudno polje Cerovo, Mining and Metallurgy Institute Bor 1/2014, str. 25-36.

UDK: 622.79:681.33(045)=20
DOI:10.5937/MMEB1402081R

Radmilo Rajković, Miomir Mikić*, Daniel Kržanović**

REMEDIATION THE TAILING DUMP RTH IN TERMS OF STABILITY**

Abstract

Checking the dam stability of the flotation tailing dump RTH within RTB Bor, it was determined on some analyzed profiles that the stability coefficient has less value than the legally prescribed limits. This work presents the measures for bringing the stability coefficient of dam in prescribed limits to all profiles, as well as checking the stability upon implementation of remedial measures.

Keywords: *flotation tailing dump RTH, remediation, stability, Standard SRPS U.C5.020, computer program GeoStudio2007.*

INTRODUCTION

The flotation tailing dump RTH within RTB Bor is located southeast of the Flotation Plant Bor. To protect other surfaces from degrading, the existing excavated area of the open pit RTH at depth of 238 m after completion the operation in 1985 began to be filled with flotation tailings from the Flotation Plant Bor, Figure 1.

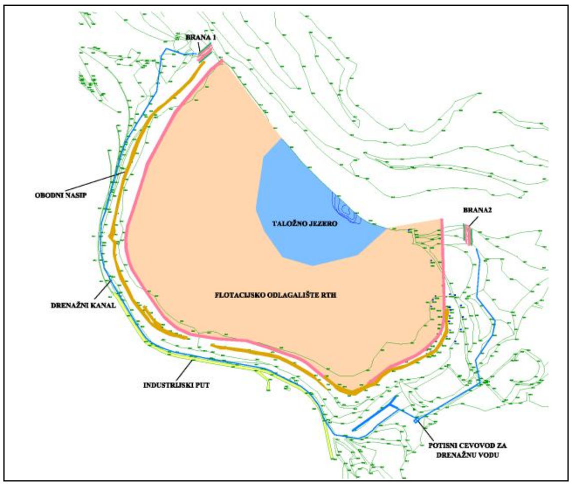


Figure 1 *Flotation Tailing Dump RTH*

* *Mining and Metallurgy Institute Bor, radmilo.rajkovic@irmbor.co.rs*

** *This work is the result of the Project TR37001 "The Impact of Mining Waste from RTB Bor on the Pollution of Surrounding Water Systems with the Proposal of Measures and Procedures for Reduction Harmful Effects on the Environment", funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia*

Flotation tailing dump is elliptical in shape with the approximate direction of the main axis east - west. Some expansion of tailing dump was made by the former valley of the Bor River in the direction of NS - SE. This valley is towards NW, i.e. to the landfill of smelter slag that is closed by dam, which was built of hydrocyclone sand. At this point, the dam relies on the high plan and represents the beginning of a semicircular dam around tailing dump.

On the west side, the flotation tailing dump RTH is separated from the flotation tailing dump Bor by peripheral dike of flotation sand. Downstream the former valley of the Bor River is dammed by an embankment, height of about 300 m and length of about 350 m from the overburden of the open pit and other waste materials (fly ash from thermal power plant, construction debris - concrete blocks, tires, etc.). A downstream flotation Dam 2 is built on such dike of cyclone sand.

On the east side, the flotation tailing dump relies on high plans of overburden of the open pit Bor.

On the SE side of the tailing dump, is a landfill of the open pit of the ore body "H". After termination the need to use the haulage road of the open pit "H", the road is dammed of hydrocyclone sand of sand tailings. This dam is the other end of the semi-circular dam formed of hydrocyclone sand of tailings.

Total length of the semi-circular dam is 1700 m with the mean dam crest elevation of 370 m above sea level.

Stability of perimeter dike of the tailing dump RTH depends on a position of sediment lake within the accumulation area; If water of sediment lake touches the inner slope of perimeter dike, on the west side of tailing dump, the stability of tailing dump is in question, especially during an earthquake above 8 degrees on the Mercalli scale. [10] Penetration of flotation sludge through the perimeter dike would cause a threat to the industrial road and railway and there would be a spillage of sludge in the Bor River, and a flood wave would endanger the village of Slatina and land and water in the coastal region of the Bor River to Timok, and then the mouth of Timok in Danube. [10]

CURRRENT STATE OF DAM

Stability calculation was done using the licensed program GeoStudio 2007, its part Slope/W, that is specialized in cases of limit equilibrium [1-3, 5-9]. The calculation was done by the method of Morgenstern - Price. Physical - mechanical parameters of the working environment are taken from [4].

The impact of groundwater on stability is modeled by piezometric water level. The calculation was made for static loads and dynamic loads for occurrence of earthquakes in seismic coefficient $K_s = 0.05$.

Stability analysis was done using the tool Tool Entry and Exit defining the area in which the sliding plane intersects the surface area and radius area of potential sliding planes, Figure 2.

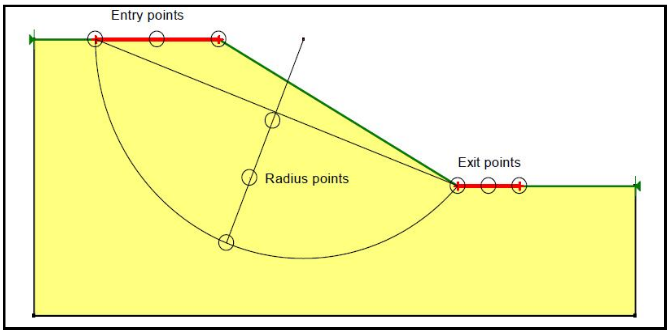


Figure 2 *Tool Entry and Exit*

Analysis the stability of flotation tailing dump RTH was done on profiles 2/1, 4*/1, 6/2, 7*/1 and 10/1. Position of analyzed profiles is shown in Figure 3. The results of calculations are shown in Table 1.

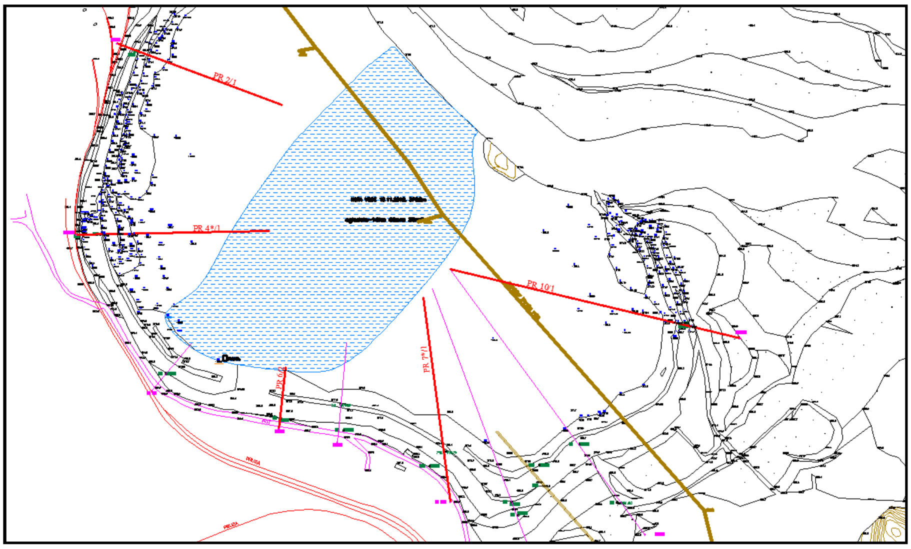


Figure 3 *Position of analyzed profiles for stability calculation*

Table 1 *Summary review of stability coefficient for analyzed profiles*

Cross section	F_s static	F_s dynamic
2/1	1.210	1.059
4*/1	2.076	1.685
6/2	1.132	1.005
7*/1	1.120	0.987
10/1	2.745	2.130

Comparing the obtained safety coefficients to the permissible minimum coefficient, prescribed by technical conditions for design of earth dams and hydrotechnical dikes - SRPS U.C5.020 [2], that for the earth dams, height over 15 m, is minimum F_s = 1.50 in the case of permanent static load, i.e. F_s = 1.00 in the case of periodical dynamic load for occurrence of earthquake, the following can be concluded:

- On profiles 2/1, 6/2 and 7*/1, the calculated values of static stability coefficients are below the prescribed limit of 1.50;
- On profiles 6/2 and 7*/1, the calculated values of dynamic stability coefficients are on the limit of 1.00.

Based on the above, the conclusion is that remediation measures have to be implemented in critical areas of dams on the flotation tailing dump RTH.

REMEDIATION MEASURES

In order to bring the dike into a stable state the following remedial measures should be taken as follows:

1. Achieving the stability of dike on tailings dump RTH by formation the beaches between the dike and water. Beach is formed by settling of larger particles immediately after hydro-cycloning. Beach width is determined by calculation the stability of dike. The existence of beach increases the safety coefficient of dam, dikes, due to lowering the level of leachate through the dike itself. By stability calculation of dike, it was found that the distance of water mirror from the inside base of a dike must not be less than 150 m.
2. In order to allow the formation of beach, it is necessary to relocate the pumping station PPS1 from present to designed location. Its relocation will reduce the water level in the accumulation lake, allowing the formation of beach with larger width, which directly leads to reduction in the level of leachate in piezometers. Increasing the beach width in the area of Dam 2 will lead to reduction in the level of leachate in the extended profile 9/1.
3. In order to control the amount of water in accumulation lake, the following is needed:
   - To reduce the flow of storm water that gravitate from catchment areas of higher plan, and which is achieved by making the protective perimeter channels on a high plan;
   - To maintain the equipment for prepumping the return process water with PPS in the working order. Due to the unplanned failures, longer delays of pump operation may be caused which will result in inability of pumping the process water due to which the water level increase in the accumulation lake. The increase in water level will come due to the introduction of additional fresh water lake in the flotation process of copper minerals. In this connection, it is necessary to plan the regular service interventions and provision of spare parts and consumables for pumps and generators.
4. Until a beach has minimum width of 150 m, it is more likely to control the leachate levels in piezometers, at least once a week and to test the stability of dams and dikes once a month. If anomalies are detected in operation of piezometers, it is required to do the stability checking for observed profiles. Considering the importance of piezometers, it is necessary to maintain all piezometers in correct and functional condition.
5. It is necessary to monitor constantly any changes on dams: occurrences of cracks, landslides and subsidences, as well as the occurrence of influx water.
6. In a part of dikes and dams where the dike height and its geometry (northwestern and western part of the tailing dump) are threatened due to the effects of wind erosion), it is necessary, as the operating conditions are created for this, it is necessary to bring the geometry of dike to the designed conditions (incline of the outer slope of 1:3 and the incline of the inner slope of 1:2.5).
7. It is necessary, as soon as possible to build the missing part of the dike (towards high plan) in length of about 40 m, with the aim of connecting the dike and plan.

8. After correction the dike geometry in order to prevent re-distortion of the dike crest, due to the effects of wind erosion, a humus layer (up to 10 cm) has to be applied in order to prevent the effect of wind and blowing of fine sand particles.
9. Monitor the water level in the accumulation so as to comply with the rule that the water level in the lake is lower by 3 m from elevation of the tailing dump dike, which provides a retention space for water reception in the event of catastrophic rainfall of 1 500 000 m^3.

CONDITION OF DAM AFTER REALIZATION THE REMEDIATION MEASURES

The results of calculations using the computer program GeoStudio 2007 [1-3, 5-9] on critical sections 2/1, 6/2 and 7*/1 after implementation of remediation measures, are shown in Figures: 4 - 9 and in Table 2.

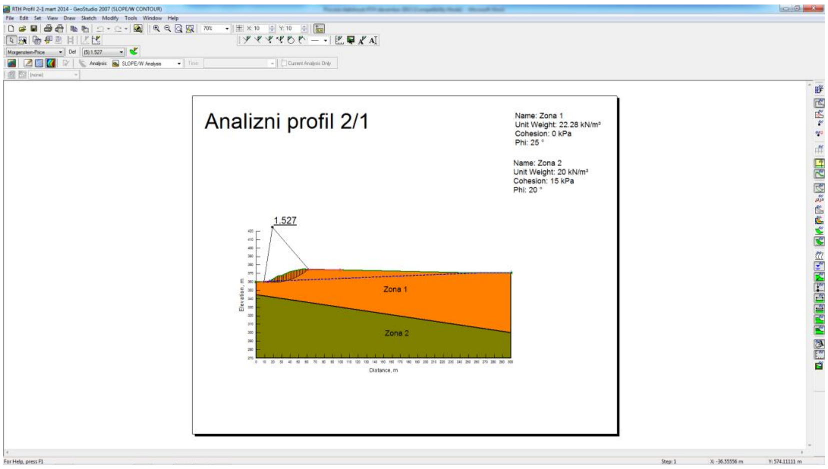


Figure 4 *Stability coefficient per profile 2/1 for static loads*

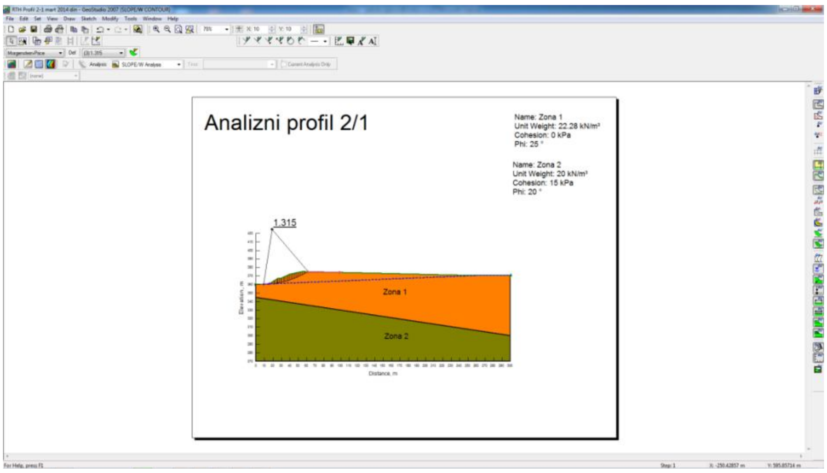


Figure 5 *Stability coefficient per profile 2/1 for dynamic loads*

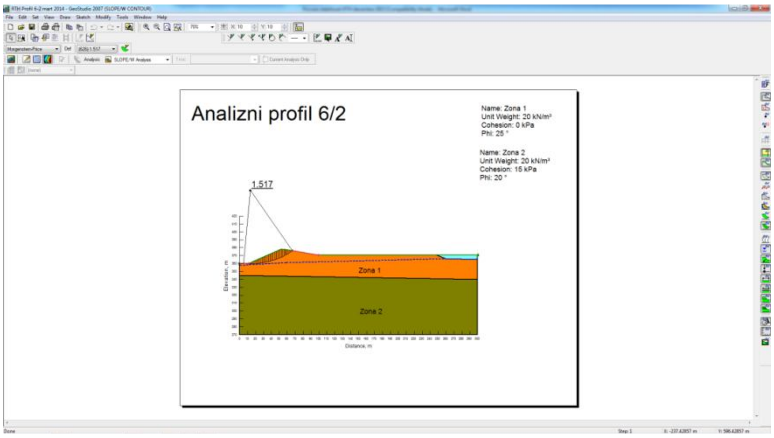


Figure 6 *Stability coefficient per profile 6/2 for static loads*

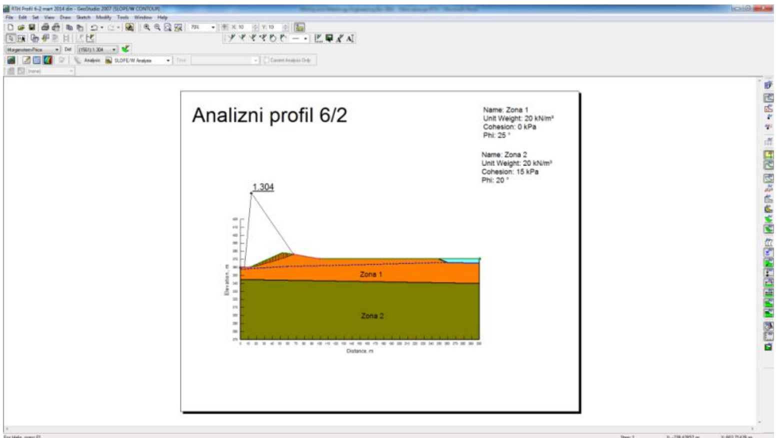


Figure 7 *Stability coefficient per profile 6/2 for dynamic loads*

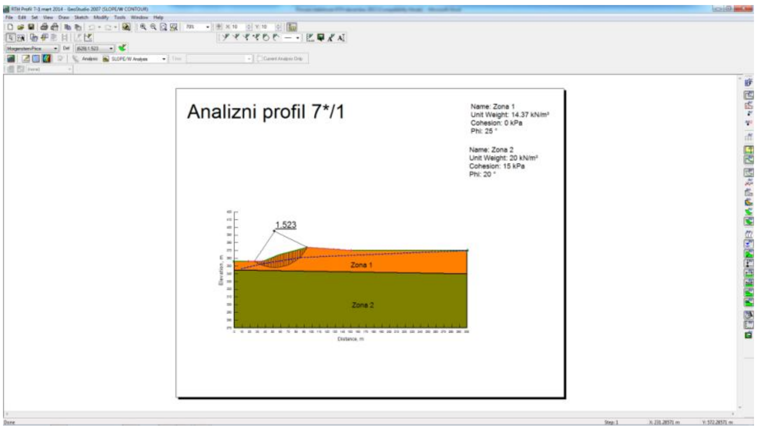


Figure 8 *Stability coefficient per profile 7*/1 for static loads*

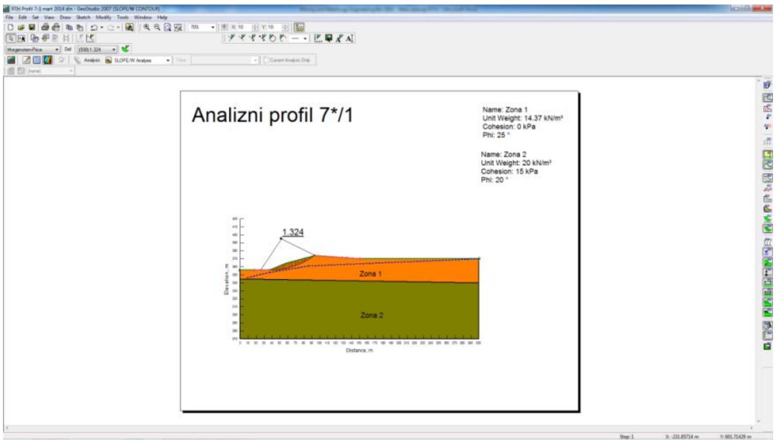


Figure 9 *Stability coefficient per profile 7*/1 for dynamic loads*

Table 2 *Summary review of stability coefficients after remedial measures*

Cross section	F_s static	F_s dynamic
2/1	1.527	1.315
6/2	1.517	1.304
7*/1	1.523	1.324

CONCLUSION

After implementation of remedial measures on the flotation tailing dump RTH in order to bring the static and dynamic coefficients of dam stability in the statutory limits, all coefficients of stability by analyzed profiles have acceptable values.

A great help in determining the distance of water mirror from the dam crest is the use of computer program GeoStudio 2007. Through this SOFTVEA performed

A variation of piezometric water level by analyzed profiles was carried out using this software until minimum required distance of water mirror was determined for which the stability coefficients are satisfactory.

Designed condition of the tailing dump dam, the use of measures to reduce the amount of accumulation water, maintenance of equipment for pre-pumping the return process water, as well as monitoring any changes on dams in order to timely response are very important for stability.

REFERENCES

[1] R. Rajković, M. Bugarin, V. Marinković: Stability Analysis of the Waste Dump "Oštreljski planir" of the Open Pit "Bor" in a Function of Water Quantity, Mining and Metallurgy Engineering Bor, 3/2013, pp. 49-64.

[2] R. Rajković, D. Kržanović, M. Mikić, Vladan Marinković: Stability of Ash and Slug Dump on Thermal Power Plant Gacko with Software Geostudio 2007; pp. 227-231; Mining 2013 Plans for Development and Improvent of Mining; Veliko Gradište, Srebrno jezero 28-31 May 2013.

[3] J. N. Stanković, S. Filipović, R. Rajković, Lj. Obradović, V. Marinković, R. Kovačević: Risk and Reliability Analysis of Slope Stability-Deterministic and Probabilistic Method; 17th International Research/Expert Conference: "Trends in the Development of

Machinery and Associated Technology"; 10-11 September 2013 Istanbul Turkey Year 17 No. 1; pp. 229-232.

[4] Report on Technical Monitoring of High Dams 1 and 2 and Peripheral Dam of the Flotation Tailing Dump of the Flotation Plant Bor"; Faculty of Mining and Geology Belgrade, 2012;

[5] M. Ignjatović, S. Ignjatović, M. Negovanović, R. Rajković, L. Djurdjevac Ignjatović, D. Ignjatović: Determination the Final Slope Angle of the Open Pit Mine During Exploitation of Oil Shale from Aleksinac Deposit Using the GeoStudio2007 – SLOPE/W Program; TTEM – Technics Technologies Education Management 2011/3; pp. 615 – 621;

[6] M. Ignjatović, R. Rajković, B. Rajković, D. Milanović, M. Popović; Stability Analysis of the Open Pit "Progorelica" by Bishop Method and Program Plan Failure Analysis; II International Symposium "Mining 2011" Mining Present State and Future Prospects and Sustainable Develop-ment; Vrnjačka banja 10 – 13 May 2011; pp. 599 – 603;

[7] M. Ignjatović, R. Rajković, M. Maksimović, D. Ignjatović: Technical Solution: Determination the Final Angles of the Newly-Designed Open Pit in the Exploitation of Shales from the Site of the Aleksinac Deposit Using the Program GeoStudio 2007 – Slope/W, Proct MSTD TR-17005 TR-1, MMI Bor No. 543, 2010;

[8] R. Rajković, D. Kržanović, R. Lekovski: Stability Analysis of Inner Waste Dump "Kutlovaca" of the Coal Open Pit Mine "Potrlica"– Pljevlja Using the GeoStudio 2007 Software; Mining Engineering 1/2010; pp. 69 – 80;

[9] R. Rajković, D. Kržanović, B. Rajković: Analysis of Stability During the Cleaning of Cassettes 1 and 2 of Settling Pond Filter of Waste Water Purification Facilities of Kolubara – Prerada Vreoci by Software Geostudio 2007; 42nd International October Conference on Mining and Metallurgy; pp. 33-40, 2010;

[10] R. Lekovski, M. Mikić, D. Kržanović; Impact of the Flotation Dumps on the Living Environment of Bor and Protective Measures; Mining and Metallurgy Engineering Bor, 2/2013, pp. 97-106.

ISSN: 2334-8836
UDK: 622

UDK: 622.79:681.33(045)=861 DOI:10.5937/MMEB1402081R

Radmilo Rajković[*], Miomir Mikić[*], Daniel Kržanović[*]

SANACIJA FLOTACIJSKOG JALOVIŠTA RTH SA ASPEKTA STABILNOSTI[**]

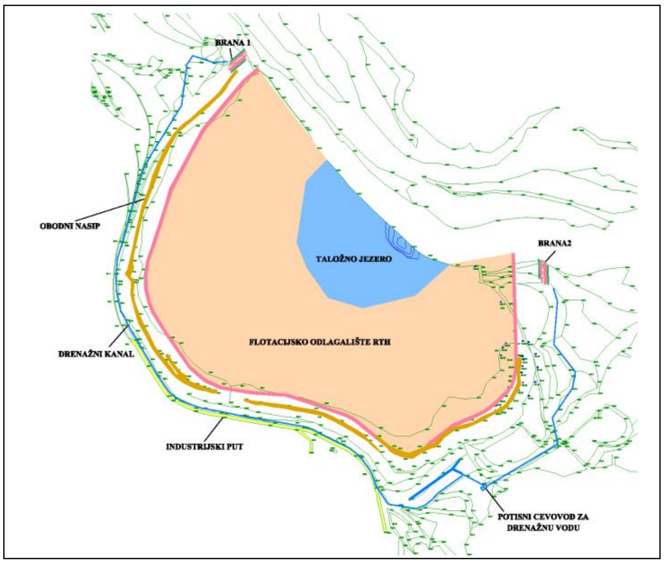
Izvod

Proverom stabilnosti brane flotacijskog jalovišta RTH u sastavu RTB Bor, utvrđeno je da na pojedinim analiznim profilima koeficijent stabilnosti ima manje vrednosti od zakonski propisanih granica. U ovom radu prikazane su mere za dovođenje koeficijenta stabilnosti brane u propisane granice na svim profilima, kao i provera stabilnosti nakom realizacije sanacionih mera.

Ključne reči: *flotacijsko jalovište RTH, sanacija, stabilnost, Standard SRPS U.C5.020, računarski program GeoStudio2007*

UVOD

Flotacijsko jalovište RTH, koje je u sklopu RTB Bor se nalazi jugoistočno od Flotacije Bor. Radi zaštite drugih površina od degradiranja, postojeći otkopni prostor površinskog kopa RTH dubine 238 m posle završetka eksploatacije 1985. godine počeo je da se zapunjava flotacijskom jalovinom iz Flotacije Bor, slika 1.



Sl. 1. *Flotacijsko jalovište RTH*

[*] *Institut za rudarstvo i metalurgiju Bor, radmilo.rajkovic@irmbor.co.rs*
[**] *Ovaj rad je proistekao iz projekta TR37001 „Uticaj rudarskog otpada iz RTB Bor na zagađenje vodotokova, sa predlogom mera i postupaka za smanjenje štetnog dejstva na životnu sredinu“, koji je finansiran sredstvima Ministarstva prosvete, nauke i tehnološkog razvoja Republike Srbije*

Flotacijsko jalovište ima oblik elipse sa približnim pravcem glavne ose istok - zapad. Izvesno proširenje jalovišta je izvršeno bivšom dolinom Borske reke u pravcu SJ – JI. Ova dolina je prema SZ tj. prema odlagalištu topioničke šljake zatvorena branom koja je izgrađena od peska hidrociklona. Na tom mestu brana se naslanja na visoki planir i predstavlja početak polukružne brane oko jalovišta.

Na zapadu flotacijsko jalovište RTH je od flotacijskog jalovišta Bor, odvojeno obodnim nasipom od flotacijskog peska. Nizvodno bivša dolina Borske reke je pregrađena nasipom visine oko 300 m i dužine oko 350 m od raskrivke sa kopa i drugog otpadnog materijala (pepela iz termoelektrane, građevinskog šuta – betonskih blokova, auto guma i drugo). Na ovakvom nasipu izgrađenja je nizvodna flotacijska brana 2 od ciklonskog peska.

Na istočnoj strani flotacijsko jalovište oslanja se na visoke planire raskrivke površinskog kopa Bor.

Sa JI strane jalovišta, nalazi se odlagalište površinskog kopa rudnog tela "H". Nakon prestanka potrebe za korišćenjem izvoznog puta površinskog kopa "H", put je pregrađen branom od hidrociklonskog peska jalovine. Ova brana predstavlja drugi kraj polukružne brane koja je formirana od hidrocikloniranog peska jalovine.

Ukupna dužina polukružne brane iznosi 1700 m sa srednjom kotom krune brane 370 mnv.

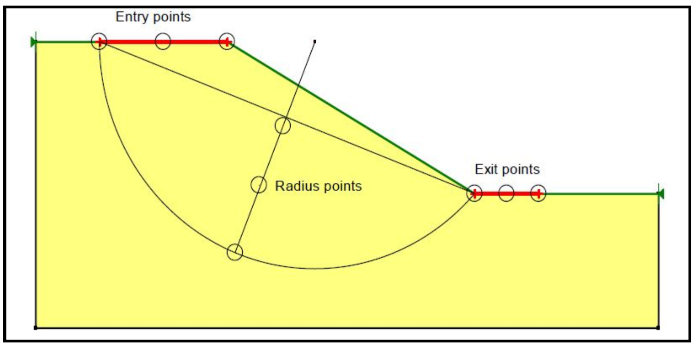
Stabilnost obodnog nasipa FJ RTH zavisi od položaja taložnog jezera unutar akumulacionog prostora. Ukoliko vode taložnog jezera dodiruju unutrašnju kosinu obodnog nasipa na zapadnoj strani jalovišta, stabilnost jalovišta je dovedena u pitanja, a naročito za vreme zemljotresa iznad 8 stepeni Merkalijeve skale. [10] Prodor flotacijskog mulja kroz obodni nasip izazvao bi ugrožavanje industrijskog puta i industrijske pruge i došlo bi do izlivanja mulja u Borsku reku, a poplavni talas bi ugrozio selo Slatinu i zemljište i vode u priobalju Borske reke do Timoka, a zatim i ušće Timoka u Dunav. [10]

POSTOJEĆE STANJE BRANE

Proračun stabilnosti je rađen licenciranim programom GeoStudio 2007, odnosno njegovim delom Slope/W, koji je specijalizovan za slučajeve granične ravnoteže [1-3, 5-9]. Proračun je rađen po metodi Morgenstern – Price. Fizičko – mehanički parametri radne sredine preuzeti su iz [4].

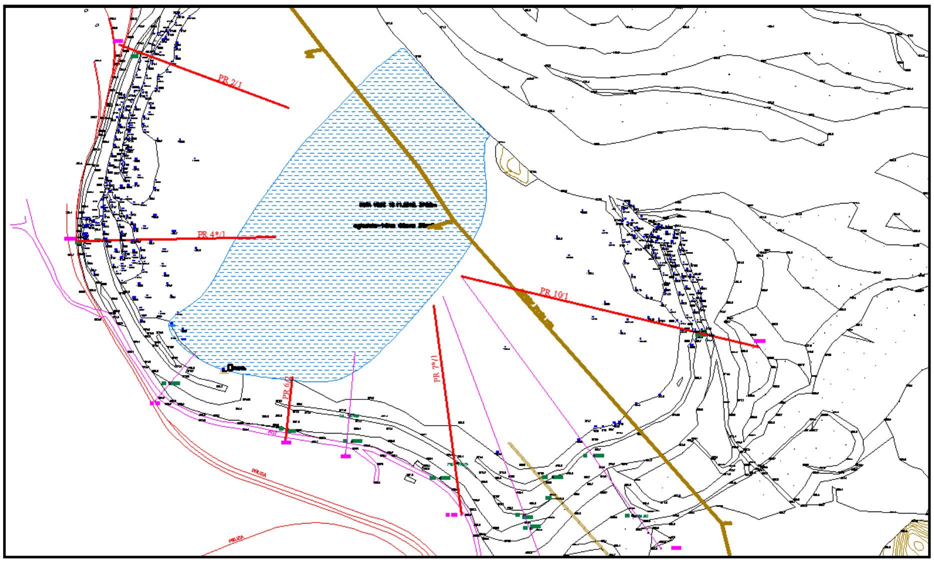
Uticaj podzemnih voda na stabilnost modeliran je piezometrijskim nivoom vode. Proračun je rađen za statička opterećenja i dinamička opterećenja za pojavu zemljotresa za koeficijent seizmike $K_s = 0,05$.

Analiza stabilnosti rađena je alatom Entry and Exit kojim se definiše oblast u kojoj klizna ravan seče površinu terena i oblast radijusa potencijalnih kliznih ravni, slika 2.



Sl. 2. *Alat Entry and Exit*

Analiza stabilnosti flotacijskog jalovišta RTH vršena je na profilima 2/1, 4*/1, 6/2, 7*/1 i 10/1. Položaj analiznih profila prikazan je na slici 3. Rezultati proračuna prikazani su u tabeli 1.



Sl. 3. *Položaj analiznih profila za proračun stabilnosti*

Tabela 1. *Zbirni pregled koeficijenta stabilnosti za analizne profile*

Profil	F_s statički	F_s dinamički
2/1	1,210	1,059
4*/1	2,076	1,685
6/2	1,132	1,005
7*/1	1,120	0,987
10/1	2,745	2,130

Upoređenjem dobijenih koeficijenata sigurnosti sa dozvoljenim minimalnim koeficijentom, propisanim tehničkim uslovima za projektovanje nasutih brana i hidrotehničkih nasipa – SRPS U.C5.020 [2], koji za nasute brane visine preko 15 m iznosi minimalno F_s = 1,50 u slučaju stalnog statičkog opterećenja, odnosno F_s = 1,00 u slučaju povremenog dinamičkog opterećenja za pojavu zemljotresa, može da se zaključi sledeće:

- Na profilima 2/1, 6/2 i 7*/1 proračunate vrednosti statičkih koeficijenata stabilnosti su ispod propisane granice od 1,50;
- Na profilima 6/2 i 7*/1 proračunate vrednosti dinamičkhi koeficijenata stabilnosti su na granici od 1,00.

Na osnovu navedenog zaključak je da se obavezno moraju sprovesti mere sanacije na kritičnim delovima brana flotacijskog jalovišta RTH.

MERE SANACIJE

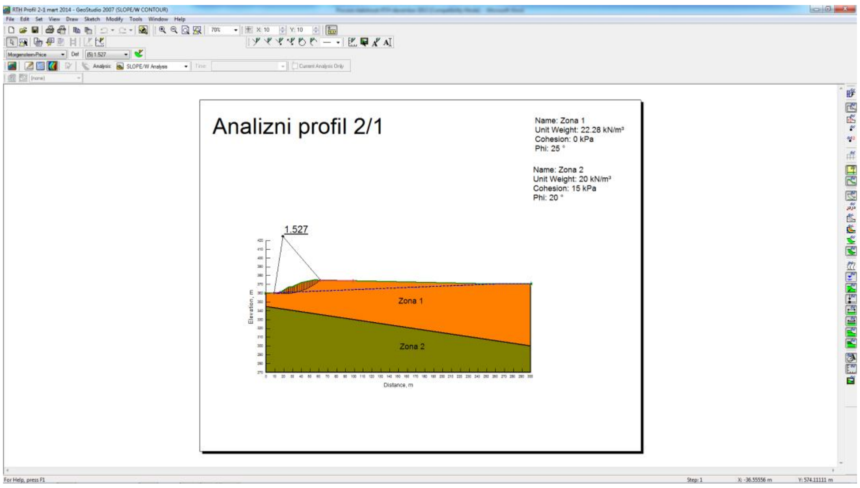
U cilju dovođenja nasipa u stabilno stanje kao mere sanacije treba se preduzeti sledeće:

1. Postizanje stabilnosti nasipa na jalovištu RTH, formiranjem plaža između nasipa i vode. Plaža nastaje istaložavanjem krupnijih čestica neposredno posle hidrocikloniranja. Širina plaže se određuje proračunom stabilnosti nasipa. Postojanjem plaže povećava se koeficijent sigurnosti brane, nasipa, usled sniženja nivoa procednih voda kroz sam nasip. Proračunom stabilnosti nasipa utvrđeno je da udaljenje vodenog ogledala od unutrašnje nožice nasipa ne sme biti manje od 150 m.
2. Da bi se omogućilo formiranje plaža, neophodno je preseliti pumpnu stanicu PPS1 sa sadašnje na projektovanu lokaciju. Njenim preseljenjem smanjiće se nivo vode u akumulacionom jezeru, što omogućava formiranje plaža veće širine što direktno dovodi do smanjenja nivoa procednih voda u pijezometrima. Povećanje širine plaže u zoni brane 2 dovešće do smanjenja nivoa procednih voda na produženom profilu 9/1.
3. U cilju kontrole količine vode u akumulacionom jezeru, potrebno je:
   - smanjiti priliv atmosferskih voda koje gravitiraju sa slivnih površina visokog planira, a koje se postiže izradom zaštitnih obodnih kanala na visokom planiru;
   - održavanje opreme za prepumpavanje povratne tehnološke vode sa PPS u funkcionalnom stanju. Usled neplaniranih kvarova, može doći do dužeg zastoja rada pumpi što će imati za posledicu, nemogućnost ispumpavanja tehnološke vode usled čega se povećava nivo vode u akumulacionom jezeru. Do porasta nivoa vode doći će usled dodatnog uvođenja sveže jezerske vode u proces flotiranja minerala bakra. S tim u vezi potrebno je planirati redovne servisne intervencije i nabavku rezervnih delova i potrošnog materijala za pumpe i agregate.
4. Dok se ne postigne plaža minimalne širine od 150 m, potrebno je češće kontrolisati nivoe procednih voda u pijezometrima, minimalno jednom nedeljno kao i vršiti proveru stabilnosti brana i nasipa jednom mesečno. Ukoliko se primete anomalije u radu pijezometara obavezno uraditi proveru stabilnosti za uočene profile. Obzirom na važnost pijezometara neophodno je održavati sve pijezometre u ispravnom i funkcionalnom stanju.
5. Potrebno je stalno praćenje eventualnih promena na branama: pojave pukotina, klizišta i sleganja, kao i pojava provirnih voda.
6. U delu nasipa i brana gde je usled dejstva erozije vetra ugrožena visina nasipa kao i njegova geometrija (severozapadni i zapadni deo jalovišta), potrebno je čim se za to stvore operativni uslovi dovesti geometriju nasipa na projektovano stanje (nagib spoljašnje kosine 1:3 i nagib unutrašnje kosine 1:2,5).
7. Neophodno je u što kraćem roku izgraditi nedostajući deo nasipa (prema visokom planiru) u dužini od oko 40 m, sa ciljem spajanja nasipa i planira.
8. Nakon korekcije geometrije nasipa u cilju sprečavanja ponovnog narušavanja krune nasipa, usled dejstva erozije vetra treba naneti sloj humusa (do 10 cm), kako bi se sprečilo dejstvo vetra i raznošenje finih čestica peska.
9. Pratiti nivo vode u akumulaciji tako da se ispoštuje pravilo da nivo

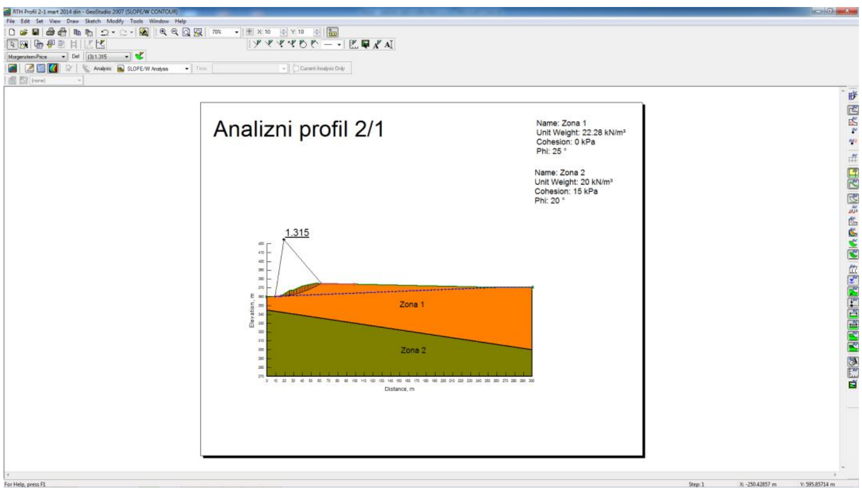
vode u jezeru bude manji za 3 m od kote nasipa jalovišta, čime se obezbeđuje retenzioni prostora za prihvat voda u slučaju katastrofalnih padavina od 1.500.000 m^3.

STANJE BRANE NAKON REALIZACIJE SANACIONIH MERA

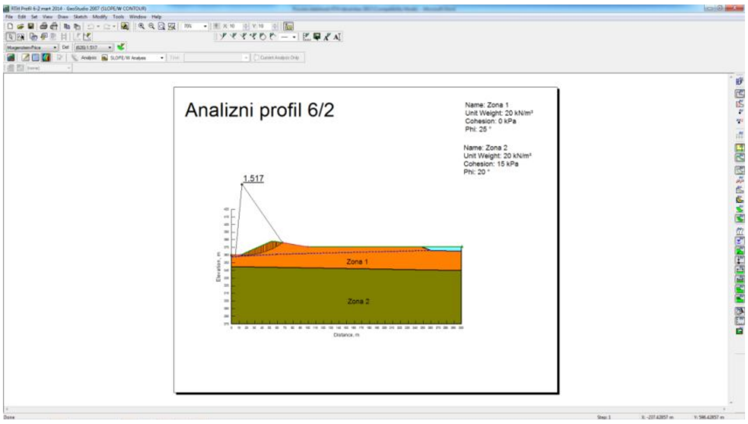
Rezultati proračuna računarskim programom GeoStudio 2007 [1-3, 5-9] na kritičnim profilima 2/1, 6/2 i 7*/1 nakon sprovođenja sanacionih mera prikazani su na slikama 4 – 9 i u tabeli 2.



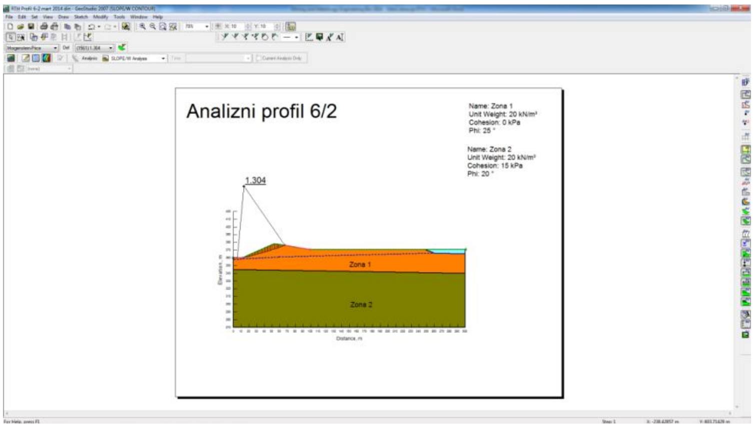
Sl. 4. *Koeficijent stabilnosti po profilu 2/1 za statička opterćenja*



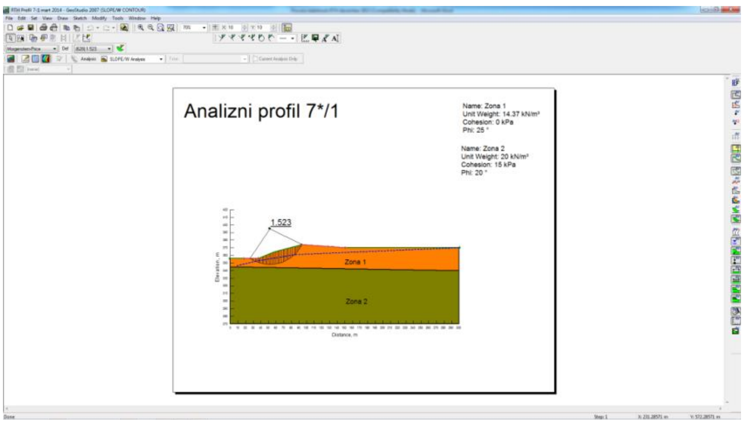
Sl. 5. *Koeficijent stabilnosti po profilu 2/1 za dinamička opterćenja*



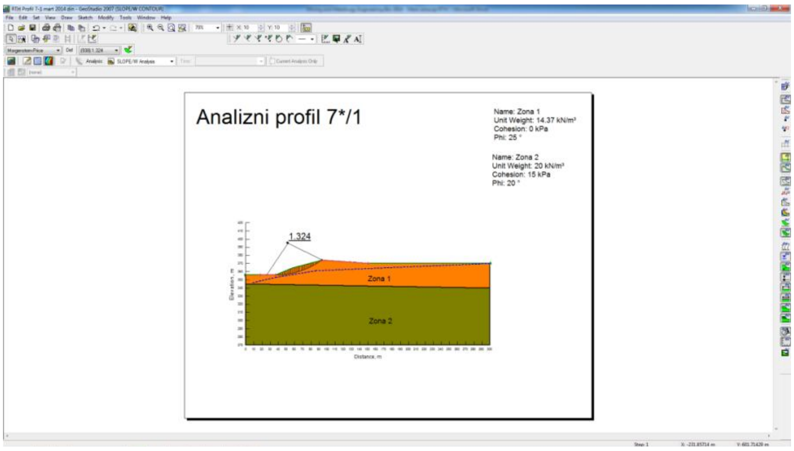
Sl. 6. *Koeficijent stabilnosti po profilu 6/2 za statička opterćenja*



Sl. 7. *Koeficijent stabilnosti po profilu 6/2 za dinamička opterćenja*



Sl. 8. *Koeficijent stabilnosti po profilu 7*/1 za statička opterćenja*



Sl. 9. *Koeficijent stabilnosti po profilu 7*/1 za dinamička opterćenja*

Tabela 2. *Zbirni pregled koeficijenta stabilnosti nakon sanacionih mera*

Profil	F_s statički	F_s dinamički
2/1	1,527	1,315
6/2	1,517	1,304
7*/1	1,523	1,324

ZAKLJUČAK

Nakon sprovođenja sanacionih mera na flotacijskom jalovištu RTH u cilju dovođenja statičkih i dinamičkih koeficijenata stabilnosti brane u zakonski propisane granice, svi koeficijenti stabilnosti po analiznim profilima imaju zadovoljavajuće vrednosti.

Velika pomoć pri određivanju udaljenosti vodenog ogledala od krune brane je upotreba računarskog programa GeoStudio 2007. Uz pomoć ovog softvea vršena je varijacija piezometrijskog nivoa vode po analiznim profilima sve dok nije utvrđena minimalna razdaljina vodenog ogledala za koju su koeficijenti stabilnosti zadovoljavajući.

Od izuzetne važnosti za stabilnost je dovođenje brane jalovišta u projektovano stanje, primena mera za smanjenje količine akumulacione vode, održavanje opreme za prepumpavanje povratne tehnološke vode, kao i praćenje eventualnih promena na branama u cilju pravovremenog reagovanja.

LITERATURA

[1] R. Rajković, M. Bugarin, V. Marinković: Analiza stabilnosti odlagališta jalovine "Oštreljski planir" površinskog kopa "Bor" u funkciji ovodnjenosti, Mining and Metallurgy Engineering Bor, 3/2013, str. 57-64.

[2] R. Rajković, D. Kržanović, M. Mikić, V. Marinković: Stability of Ash and Slug Dump on Thermal Power Plant Gacko with Software Geostudio 2007; str. 227-231; Mining 2013, Plans for development and improvent of mining; Veliko Gradište, Srebrno jezero 28-31 maj 2013.

[3] J. N. Stanković, S. Filipović, R. Rajković, Lj. Obradović, V. Marinković, R. Kovačević: Risk and Reliability Analysis of Slope Stability-Deterministic and Probabilistic Method; 17th International Research/Expert Conference: "Trends in the Development of Machinery and Associated Technology"; 10-11 September 2013, Istanbul, Turkey Year 17 No 1; str. 229-232

[4] Izveštaj o tehničkom osmatranju visokih brana 1 i 2 i obodne brane flotacijskog jalovišta pogona Flotacija Bor"; Rudarsko – geološki fakultet Beograd, 2012.

[5] M. Ignjatović, S. Ignjatović, M. Negovanović, R. Rajković, L. Đurđevac Ignjatović, D. Ignjatović: Determination of the Final Slope Angle of the Open Pit Mine During Exploitation of Oil Shale from Aleksinac Deposit During GeoStudio2007 - SLOPE/W program; TTEM - Technics Technologies Education Management 2011/3; str. 615 – 621.

[6] M. Ignjatović, R. Rajković, B. Rajković, D. Milanović, M. Popović: Stability Analysis off Open Pit „Progorelica" by Bishop Method and Program Plan Failure Analysis; II International Symposium „Mining 2011" Mining Presents State and Future Prospects and Sustainable Development; Vrnjačka banja 10 – 13 maj 2011; str. 599 – 603.

[7] M. Ignjatović, R. Rajković, M. Maksimović, D. Ignjatović: Tehničko rešenje: Određivanje završnih uglova novo projektovanog površinskog kopa pri eksploataciji uljnih škriljaca sa lokaliteta Aleksinačkog ležišta programom GeoStudio 2007 – Slope/W, Projekat MNTR TR-17005 TR-1, IRM Bor br. 543, 2010.

[8] R. Rajković, D. Kržanović, R. Lekovski: Analiza stabilnosti unutrašnjeg odlagališta jalovine „Kutlovača" površinskog kopa uglja „Potrlica" – Pljevlja softverom GeoStudio 2007, Rudarski radovi 1/2010; str. 69-74.

[9] R. Rajković, D. Kržanović, B. Rajković: Analysis of Stability During the Cleaning of Cassettes 1 and 2 of Setting Pond Filter of Waste Water Purification Facilities of Kolubara – Prerada Vreoci by Software Geostudio 2007; 42. International October Conference on Mining and Metallurgy; str. 33-40, 2010.

[10] R. Lekovski, M. Mikić, D. Kržanović; Uticaj flotacijskih jalovišta na životnu sredinu Bora i mere zaštite; Mining and Metallurgy Engineering Bor, 2/2013, str. 107-116.

MINING AND METALLURGY INSTITUTE BOR ISSN: 2334-8836
UDK: 622

UDK: 622.271:681.325:622.36(045)=20 DOI:10.5937/MMEB1402097P

Marinko Pavlović [*], Nenad Vušović [**], Miroslava Maksimović [***], Radmilo Rajković [***]

BASIC PRINCIPLES OF DEVELOPMENT AND USE A DIGITAL GEOMODEL FOR DESIGN THE OPEN PIT IN THE EXAMPLE OF QUARTZ AND SANDY CLAY DEPOSIT "BOŠNJANE" - SERBIA

Abstract

Based on the results of geological explorations carried out in the area of quartz sand and sandy clay deposit Bošnjane, a geomodel was developed using a software package Minex 5.2.3. geomodel, which was the basis for the calculation of reserves and design of the open pit in the deposit of quartz sand and sandy clay, in the specified software package.

Keywords: *geomodel, Minex 5.2.3, optimization, mine design*

INTRODUCTION

Calculation of reserves by MINEX 5.2.3 software package, starts with making three-dimensional geomodel. Interpretation of deposit and development the three-dimensional geomodel is caused by the entry of data from several files (Excel) on exploration drill holes.

Based on data obtained from exploratory works, database is formed that consists of four files: *Collars cls. Fail; Quality cls.;Lithology cls. Fail;Seam prn. Fail.*

Data from drill holes are entered into database entries in a properly way in a form of defined intervals, with the field in addition to the others *"from"* and *"to"*, i.e. defined intervals, in which the samples are analyzed.

Data from the exploratory drill holes are properly processed in the software Minex by mathematical and geostatistical methods (method of inverse distances of various degree), to determine the lawfulness of content in deposit.

Calculation of reserves is done by any method of polygons.

Block model can be refreshed in terms of entering the new data.

GEOLOGICAL STRUCTURE AND DESCRIPTION OF DEPOSIT

The deposit of quartz sand and sandy clay "Bošnjane" is situated, by sky way, about 7 km northeast of Paraćin and about 5 km south of the village of Popovac and Cement Factory "Holcim", in the village of Bošnjane.

A wider area of the deposit Bošnjane covers the eastern part of the leaf Paraćin with the signature L34-07 and the western part of the leaf Boljevac, with the signature L34-08, OGK, 1:100 000 [2].

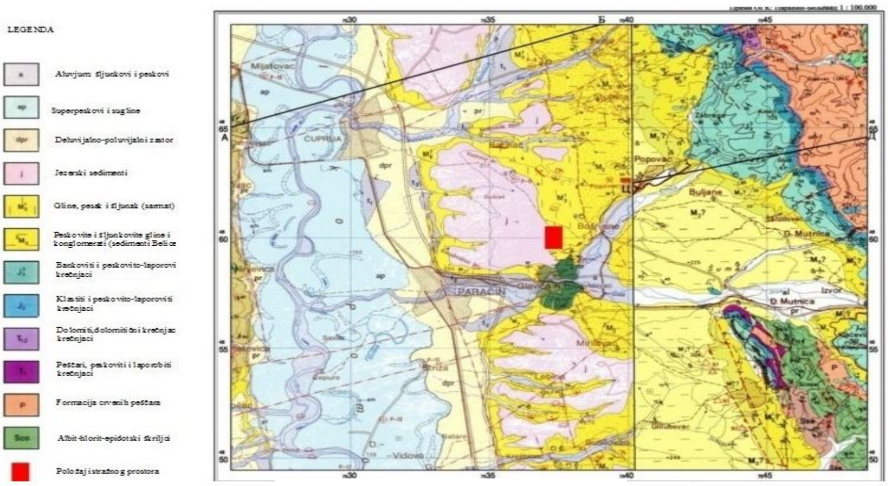
Geological structure of the quartz sand and sandy clay deposit "Bošnjane" includes

[*] *Holcim (Serbia) d.o.o. Popovac near Paraćin*
[**] *Technical Faculty Bor, University of Belgrade*
[***] *Mining and Metallurgy Institute Bor, miroslava.maksimovic@irmbor.co.rs*

the freshwater sediments of the Middle Miocene and Miocene-Pliocene. In the Middle Miocene, during Helvet, on older Miocene and often pretertial formations, the clastic sediments were deposited discordantly as well as the sediments of lake facies as the result of older Styrian phase (Figure 1).

In these freshwater sediments, according to the lithological composition, the following can be separated: Middle Miocene facies of red clay sandstones, clay marls and tuffs, then Middle Miocene of marls, and Miocene-Pliocene facies of freshwater limestones, marls, clays, sand and gravel.

GEOLOGICAL MAP
OF THE SURROUNDING AREA OF THE QUARTZ SAND AND SANDY CLAY DEPOSIT - BOSNJANJE - POPOVAC NEAR PARACIN
1:100 000



GEOLOGICAL PROFILE C-D
1:50 000

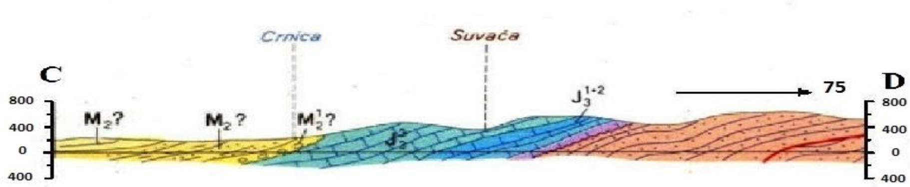


Figure 1 *Geological structure of surrounding area Bošnjane-Popovac near Paraćin*

The layers of clay and sand are horizontal to slightly inclined towards the SW. Previous explorations cover a portion of sandstone series, where it was determined that the roof of series consists of sandy clay that by the quality satisfies their use in the cement industry. The thickness of individual layers varies so there are unequal stratification. Overlying clays, due to this reason, are treated as the other useful resources. The average thickness of the overlying clay layer is about 10 m.

In the eastern and northeastern, also partly in the central part of clay deposit it has low thickness of up to 1 m, or a layer of clay is completely wedged, while in the western part of the deposit, the thickness of clay layer reaches 35 m. It has been concluded by previous explorations that, under a layer of clay, there is a series, built of: sands, sandy clays, clayey sand and gravels, gray and brown clays. In a series of sand itself, thin lentoid interlayers of sandy clay and very clayey sands appear. The thickness of these interlayers is from 10 cm to 50 cm. Thickness of contoured productive series of sands, which satisfies in terms of quality the requirements of its application in the cement industry, is about 18 m. Below this series, most often, there is a series of very clayey sands, or more rarely, sandy clay. Below this series, a series of basal Miocene sediments lies. The floor of this series consists of basal sediments of the Miocene series, built of red sandy clay, basal conglomerate and red sandstone. The lowest layers of this series lie over titonic limestone [2].

The deposit of quartz sand and sandy clay Bošnjane is of layered-lentoid form. Direction of expanding the deposit is NNW-SSE. It is seenaccording to ther direction of deposit expanding that it is approximately 600 m, and 300 m wide (direction E-W).

EXPLORATORY WORKS

Explorations in the area of the deposit Bošnjane, in order to ensure the quality reserves of quartz sand and sandy clay for use in the cement industry, were conducted into two separate time periods, i.e. from 1963 to 1965, and 2010. On the deposit of quartz sand and sandy clay Bošnjane, eight exploratory wells were drilled and total of 24 drill holes,i.e. in total 2,406 m of drilling. During the exploration of quartz sand and sandy clay deposit Bošnjane, the same methodology was more and less applied: the deposit was explored by vertical sections. The deposit of quartz sand and sandy clay Bošnjane was explored making 8 exploration wells and exploratory drilling from the surface (24 vertical drill holes). Common geological works followed (specifically included) the exploration drilling such as they were preceded by the project, performed at the same time (geological monitoring and directing of exploratory drilling, mapping and sampling) and resumed after them (making reports and studies) [2].

Geological works

Geological works in exploration the quartz sand and sandy clay deposit Bošnjane, related mainly to the surface geological mapping, monitoring, routing and geological mapping of exploratory wells and exploratory drill holes, their sampling and interpretation of the obtained results, and preparation of geological maps and development of cross-sections (profile) of deposit, countouring of deposit, calculation the reserves of mineral raw materials, etc. Geological work could include also the design of all exploratory works, preparation of reports and studies, and synthesis of data from which were made the geological profiles (sections) and geological maps. Samples were taken from exploratory drill holes, which were analyzed in the laboratories: Holcim Ltd. Popovac (chemical testing, technological testing), Mining and Metallurgy Institute Bor (geomechanical testing). Hydrogeological testing was carried out by the Geological Institute of Belgrade.

Exploratory wells

In the area of the deposit of quartz sand and sandy clay Bošnjane, eight wells, depth up to 20 m, were done. Two wells on the east, in the lowest part of the field were used for determining the hydrogeological characteristics of the field, while 6 wells (BI, B-II, B-III, B-IV, B-V and B-VI), in a square network of 100 × 100 m, ewere used for exploration the site in depth. Total length of wells is 123.4 m. Wells were discovered quartz sands of satisfactory quality, with SiO_2 content higher than 68%, which was the basic condition of its application in the cement industry.

Exploratory deep drilling

In the area of the depositof quartz sand and sandy clay Bošnjane, the exploratory drilling was done during 2010. Total of 24 drill holes were drilled with total drilling length of 862.6 m. Quartz sand of satisfactory quality for its use in the cement industry was drilled with 17 drill holes), while 7 were negative, so that the results of sampling these wells are excluded from calculations.

DEVELOPMENT OF GEOMODEL AND DESIGN OF OPEN PITS WERE DONE BY THE SOFTWARE PACKAGE MINEX 5.2.3.

Calculation of reserves by MINEX 5.2.3 software package, starts with development a three-dimensional geomodel [9]. Interpretation of deposit and development of three-dimensional geomodel is caused by the entry of data from several files (Excel) on exploratory drill holes [2]. The files contain for each drill hole: the name of drill hole, data on elevation, coordinates, data on lithological members in geological columns of drill holes (which are relevant to the assessment of position of layers in separated geological environments), as well as data on the results of chemical analyses of individual samples SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, Na_2O, SO_3 and loss on ignition.

Before starting a development of 3D model of deposit of quartz sand and sandy clay Bošnjane, it was necessary to create a database from which to access the development of model. All necessary data were obtained in the exploration process (exploratory drill holes and wells), as well as performed laboratory analyses (spatial position of each exploratory work is represented by X, Y, Z coordinates, the final depth of each exploratory work, lithological members were determined in the process of mapping the core drilling and quality data obtained by laboratory analyses). The database is comprised of 4 basic files:

- Collars cls. Fail – contains all data on spatial position of drillh holes;
- Quality cls. Fail – contains all data related to the quality;
- Lithology cls. Fail – contains all data on lithology;
- Seam prn. Fail - contains all data about the position of layers of sandy clay and quartz sand in every exploratory work. [12]

Within the contour of deposit, two different lithological members are clearly separated: a layer of clay and a layer of quartz sand. Due to this reason, each of these layers is modeled as a separate layer, which has a separate code letter. For each drill hole, a description of isolated rock types, i.e. geological column of drill hole, is given and then data were entered on characteristics of each separateed lithological type, necessary for further processing the block model of the deposit. In addition to the above-mentioned data, data were also entered on the fiedl topography. Data on topography were obtained from the Investor (Holcim Serbia doo Popovac). Figure 2 presents a graphical three-dimensional display of entered data from the database of software package MINEX 5.2.3. [8]

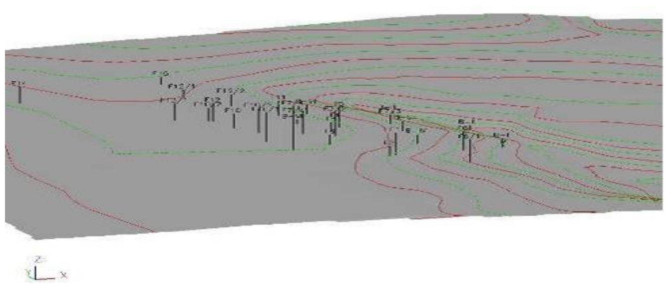


Figure 2 *3D view of topography and drill hole relationship (software package MINEX 5.2.3)*

All layers are modeled using the general method of modeling. In the process of interpolation of the missing data layers are used from minimum of 3 and a maximum of four neighboring drill holes, and radiusof exploration is limited to 250 m. While the weighting values used the general formula for weighting. After creating these layers, it was approached to their mutual spatial correlation and creating 3D models of deposit (Figure 3).

For each vertical section (profile) and horizontal section (floor), the reference surfaces and space were defined that, infront and back, covers a certain area. This type of interpretation eliminated the possibility of existence the "empty" spaces within the block model of deposit. The appearance of modeled layers by the software package MINEX 5.2.3 is shown in Figures 3 and 4. [11]

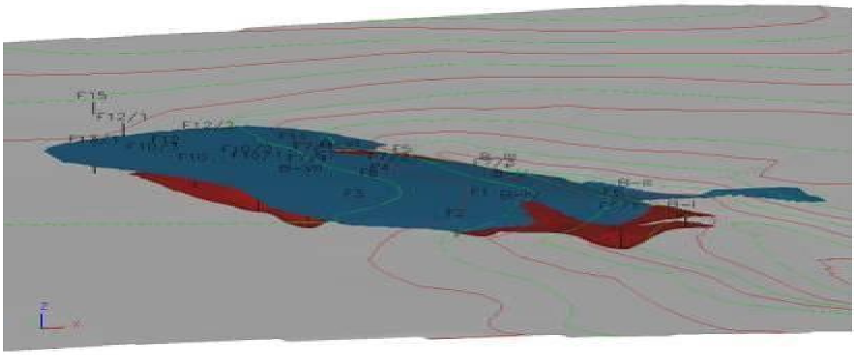


Figure 3 *3D view of layers with topography (software package MINEX 5.2.3)*

a) Gray shows topography; b)Red shows a layer of quartz sand (P1);
c) Blue shows a layer of sandy clay (G).

Figure 4 *2D view a part of cross-section through the deposit of quartz sand and sandy clay Bošnjane (software package MINEX 5.2.3)*

a) Gray shows topography; b) Red shows a layer of quartz sand (P1);
c) Blue shows a layer of sandy clay (G).

Any other data necessary for calculation of reserves, the program takes from the previously created database as well as created geological model of layers [7]. On such created model of the deposit it was possible to calculate the geological reserves both for each layer separately and deposit as a whole. [13]

SPATIAL LIMITATION OF OPEN PIT AND WASTE DUMP WITH GEOMETRY AND STABILITY ANALYSES

Construction of the open pit was done on the basis of certified balance reserves. Selection the optimal final pit contour was made using the licensed program Minex 5.2.3, which is used for optimization and analysis of open pits. [5] Optimization was done using the Pit Optimiser tool, which is based on the Lerches and Grossman algorithm, i.e.. procedure for determining the optimal open pit like the one with the highest value for the corresponding set of costs and factors of return. [6] The input parameters for optimization the deposit "Bošnjane" are:

1. Topography;
2. Geomodel of the deposit;
3. Volume mass of sand, clay and waste rosk;
4. Utilization of the excavation and preparation;
5. Unit value of a tone of sand and clay;
6. Medium and minimum SiO_2 content in the deposit;
7. Final slope angle of open pit;
8. Minimum final width of level plane;
9. Direct costs of mining the waste rock, sand and clay.

Angle of final pit slope is determined by the licensed software GEOSTUDIO 2007 or its tool Slope/W, which is specialized for methods of limit equilibrium. The default maximum open pit depth is determined based on the spatial position of sand and clay, as well as topography. The general angle of the final pit slope directly depends on the angle of slope of leveles and final width of level planes. It is assumed on the basis of the deposit geomodel that for a representative profile the ratio of clay and sand thickness is 1:1.5. [3]

According to these conditions, the assumed angle of the final pit slope is 24.3°. Minimum width of the final level plane enough for works on recultivation, is adopted at 4 m. Direct costs of mining the waste, sand and clay cover the costs of legislative normative material, human labor and current maintenance of all phases of work (mining, loading at the pit and dumps of sand and clay, transport, extra works at the opemn pit and dump, drainage) plus the costs of PPE equipment, NTO, administration and contingency costs. The results of optimization are shown in Figures 5 and 6.

Kop	Jalovina, t	Pesak, t	Glina, t	Iskopina, t	Kr	P/G	Vek rada	Jalovina, t/god	Pesak, t/god	Glina, t/god	Trošak, $	Dobit, $	NPV, $	Fp	DV, $
1	101 234	1 669 060	1 432 276	3 202 570	0.03	1.17	27.8	3 639	60 000	51 488	14 929 840	23 889 106	8 959 266	0.07056	632 156
2	101 506	1 698 708	1 433 281	3 233 495	0.03	1.19	28.3	3 585	60 000	50 625	15 076 926	24 171 159	9 094 233	0.06731	612 160
3	106 605	1 928 144	1 616 129	3 650 878	0.03	1.19	32.1	3 317	60 000	50 291	17 039 713	27 373 309	10 333 595	0.04675	483 134
4	110 279	2 091 034	1 788 937	3 990 250	0.03	1.17	34.9	3 164	60 000	51 332	18 633 835	29 897 053	11 263 218	0.03609	406 541
5	112 639	2 175 656	1 921 739	4 210 034	0.03	1.13	36.3	3 106	60 000	52 998	19 663 857	31 458 697	11 794 841	0.03155	372 181
6	113 895	2 239 338	2 023 966	4 377 199	0.03	1.11	37.3	3 052	60 000	54 229	20 448 244	32 647 227	12 198 983	0.02852	347 899
7	115 290	2 286 677	2 124 660	4 526 627	0.03	1.08	38.1	3 025	60 000	55 749	21 147 774	33 674 578	12 526 804	0.02645	331 369
8	115 970	2 328 106	2 209 098	4 653 174	0.03	1.05	38.8	2 989	60 000	56 933	21 741 314	34 552 213	12 810 900	0.02477	317 300
9	116 208	2 356 294	2 277 707	4 750 209	0.03	1.03	39.3	2 959	60 000	57 999	22 196 568	35 214 323	13 017 754	0.02368	308 305
10	116 437	2 386 328	2 328 084	4 830 849	0.02	1.03	39.8	2 928	60 000	58 536	22 575 603	35 787 465	13 211 862	0.02258	298 324
11	116 622	2 400 562	2 371 651	4 888 835	0.02	1.01	40.0	2 915	60 000	59 277	22 847 272	36 173 759	13 326 487	0.02208	294 185
12	116 779	2 412 022	2 407 887	4 936 688	0.02	1.00	40.2	2 905	60 000	59 897	23 071 424	36 491 523	13 420 099	0.02168	290 907
13	116 937	2 426 961	2 434 492	4 978 390	0.02	1.00	40.4	2 891	60 000	60 186	23 267 294	36 785 616	13 518 322	0.02117	286 164
14	117 067	2 435 000	2 468 174	5 020 241	0.02	0.99	40.6	2 885	60 000	60 817	23 463 117	37 056 637	13 593 520	0.02090	284 105
15	117 187	2 449 641	2 501 996	5 068 824	0.02	0.98	40.8	2 870	60 000	61 282	23 691 113	37 389 978	13 698 865	0.02042	279 725
16	117 293	2 459 135	2 544 273	5 120 701	0.02	0.97	41.0	2 862	60 000	62 077	23 933 903	37 724 603	13 790 700	0.02011	277 385
17	117 419	2 465 821	2 564 192	5 147 432	0.02	0.96	41.1	2 857	60 000	62 394	24 059 075	37 902 878	13 843 803	0.01990	275 511
18	117 549	2 468 537	2 591 316	5 177 402	0.02	0.95	41.1	2 857	60 000	62 984	24 198 885	38 086 124	13 887 239	0.01982	275 186
19	117 671	2 473 105	2 620 084	5 210 860	0.02	0.94	41.2	2 855	60 000	63 566	24 355 190	38 296 195	13 941 005	0.01967	274 254
20	117 745	2 475 508	2 652 137	5 245 390	0.02	0.93	41.3	2 854	60 000	64 281	24 516 336	38 505 226	13 988 890	0.01960	274 148
21	117 871	2 478 815	2 691 898	5 288 584	0.02	0.92	41.3	2 853	60 000	65 158	24 717 887	38 767 563	14 049 676	0.01949	273 896
22	117 959	2 479 794	2 726 014	5 323 767	0.02	0.91	41.3	2 854	60 000	65 957	24 881 888	38 975 340	14 093 452	0.01946	274 323
23	118 044	2 480 049	2 753 750	5 351 843	0.02	0.90	41.3	2 856	60 000	66 622	25 012 670	39 139 223	14 126 552	0.01946	274 856
24	118 044	2 480 467	2 753 750	5 352 261	0.02	0.90	41.3	2 855	60 000	66 610	25 014 668	39 143 117	14 128 449	0.01944	274 710
25	118 044	2 781 094	2 753 750	5 652 888	0.02	1.01	46.4	2 547	60 000	59 410	26 451 064	41 943 758	15 492 694	0.01206	186 858
OPT	116 528	2 213 236	2 172 835	4 502 599	0.03	1.02	36.9	3 159	60 000	58 905	21 024 894	33 270 925	12 246 031	0.02973	364 026

Figure 5 *Analytical presentation of optimizxation results*

The obtained contours which are the optimization result have no levels. As a guide for construction the open pit, which comprises the balance reserves, the contour 8 was selected, whose discounted value is at the end of the service period, which includes only the direct costs of excavation. This contour has 2,328,106 t of sand and 2,209,098 t of clay. The ratio of sand/clay is 1.05 and the overburden coefficient is 0.03 [4].

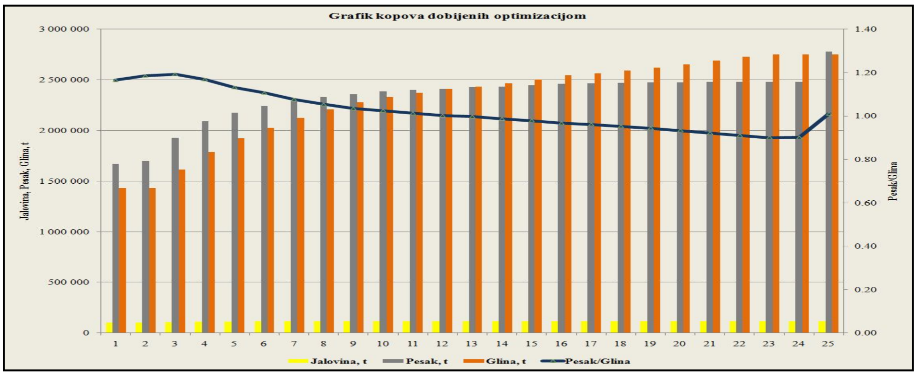


Figure 6 *Graphical presentation of optimization results*

By designed web of the final open pit, total excavation of 2,507,633 t of sand 1,941,416 t of clay was predicted. The ratio of sand/clay is 1.29, and the coefficient of overburden is 0.03. The final view of the open pit is shown in Figure 7.

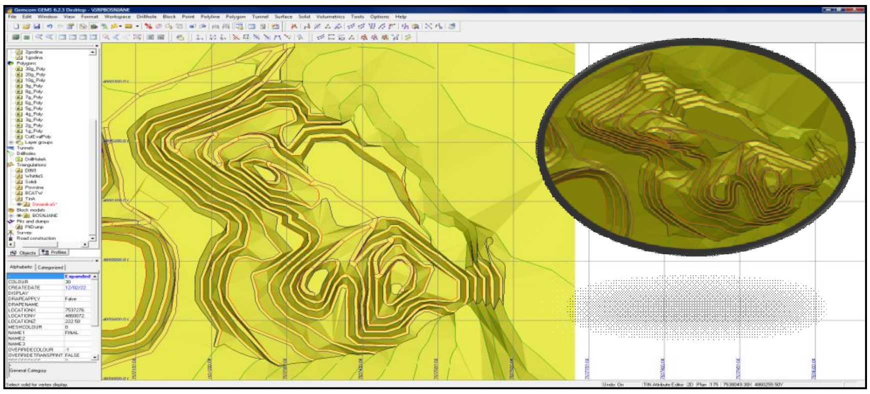


Figure 7 *View of the final open pit outline*

Construction of the clay and waste dump

A dump of the surface humus waste will be located on the northwest side of the open pit. This dump will be removed after works on recultivation, as it will be used as a borrow pit of humus in recultivation after the completitionb of operation. Waste dump has 3 levels, height 5 m. The lowest level od dump is E250/245 m, and the highest E260/255 m. View of waste dump is shown in Figure 8.

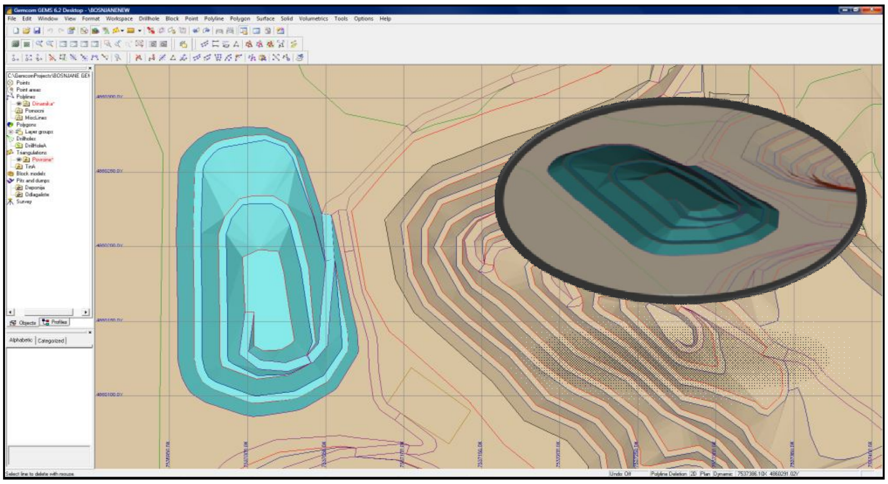


Figure 8 *Final view of waste dump*

Temporary clay dump is located on the west side of the open pit. This dump will be removed after the completion of operation as it will be used later in technological process of cement production. The required capacity of clay dump is determined by the amount of clay that is mined and not go directly into the technological process.

Clay dump has 3 levels, height 5 m. The lowest level od dump is E250/245 m, and the highest E260/255 m. Mutual position of the open pit, waste dump and clay dump is shown in Figure 10.

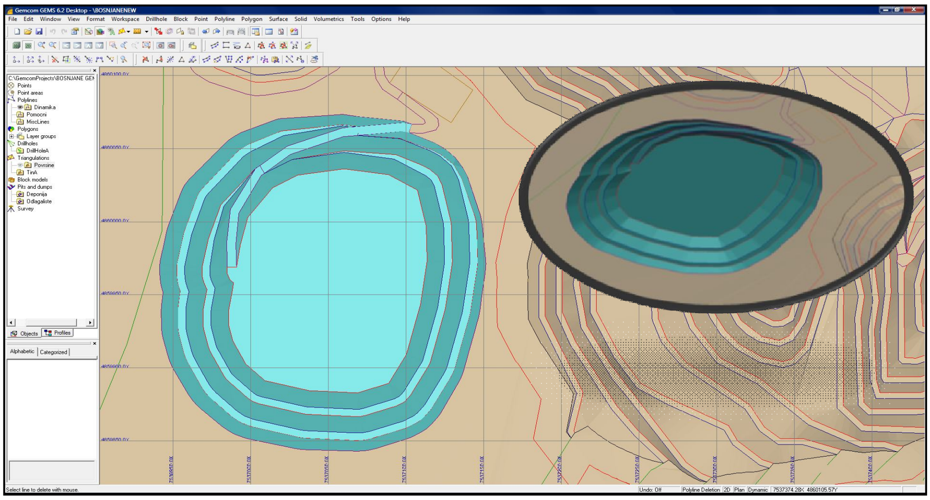


Figure 9 *Final view of clay dump*

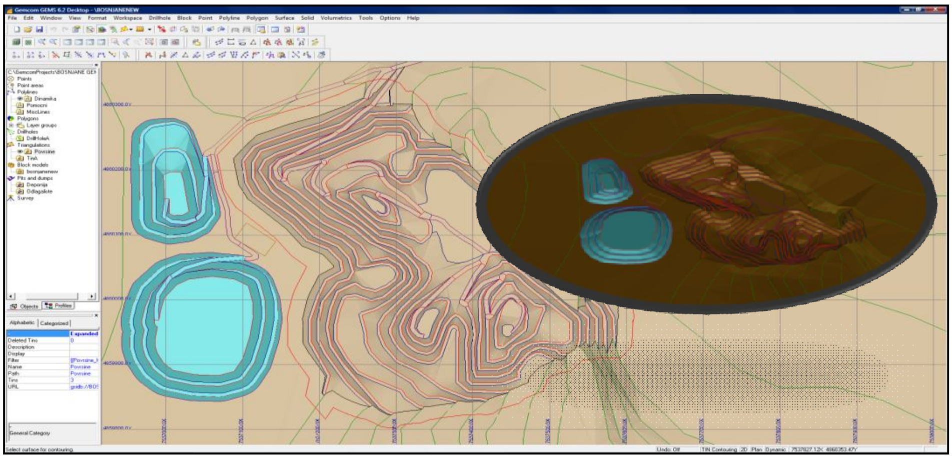


Figure 10 *Mutual position of the open pit, waste dump and clay dump*

CONCLUSION

Calculation of reserves, optimization of deposit as well as other mining designs are performed with the help of various software packages. One of the software packages used in geology, for development a geo-model, which calculates reserves and further mine design, is the program Minex 5.2.3, made in Australia in the company Surpac Minex Group Pty Ltd, which is applied in the Mining and Metallurgy Institute Bor. Development of a geomodel is done on the basis of data on the geological structure of deposits and results of geological explorations.

Optimization is done by explored and tested technical and economic parameters. An important factor in the use of the program Minex 5.2.3 is the ability to change and comparing several variants of input parameters, especially when it comes to the calculation of reserves and optimization. Using the computer technique and the appropriate software program packages, the time of preparation the project documentation and different calculations is shortened, compared to the conventional design. Using this program, the design is significantly improved in terms of time and quality due to the accurate analysis in order to select the best solutions. The application of this and similar programs has become a necessity and standard in geology and mining.

Determining the optimal open pit contour is a necessary step in design of surface mining, which is characterized by complexity and analysis of a large number of possible solutions that meet technical - technological given conditions, but mutually differ according to the economic effect. Determining the optimal open pit outline and its economic effect effect is important for balancing the reserves of mineral resources and geologic-economic evaluation of deposits of mineral resources. It is therefore necessary that the different solutions undergo the techno-economic analysis of individual variants and adopt a solution that would be optimal for the given conditions.

REFERENCES

[1] Minex manual, Surpac Minex Group Pty Ltd, 2007;

[2] Maksimović M., Marinković V., Elaborate on Mine Reserves of Quartz Sand and Sandy Clay as Raw Material for Cement Insutry in the Deposit Bošnjane - Popovac near Paraćin, 30.09.2011, MMI Bor, 2011;

[3] Rajković R. et all., Feasibility Study on Mining the Quartz Sand Bošnjane, Book 1 Text, MMI Bor, 2012;

[4] Main Mining Desing on Mining the Quartz Sand Bošnjane, Book 1, basic Concept, Department Minex and Gemcom, MMI Bor, 2012;

[5] R. Rajković, D. Kržanović, M. Mikić, V. Marinković: Construction of Ash and Slag Dump on the Thermal Power Plant Gacko With Software Gemcom 6.2 and Minex 5.2; Mining 2013 Plans For Development and Improvent Of Mining; Veliko Gradište, Srebrno Jezero, 2013., pp. 177-182;

[6] M. Ignjatović, R. Rajković, S. Ignjatović, L. Đurđevac Ignjatović, L. Kričak, R. Pantović: Determination of Optimal Contours of Open Pit Mine During Oil Shale Exploitation by Minex 5.2.3. Program; Journal of Process Management - New Technologies International, Vol 1, No.2, 2013;

[7] R. Rajković, D. Kržanović, V. Marinković: Determination of Balance Reserves in The Calcite Deposit "Kaona" and Determination of Optimum Open Pit Mine Contour Using Minex 5.2.3 Program; Mining Engineering 3/2011; pp. 19-24;

[8] R. Rajković, V. Marinković, R. Lekovski: Digital 3D Terrain Model; Mining Engineering 3/2011; pp. 33-40;

[9] D. Kržanović, R. Rajković, V. Marinković: Optimal Contour Selection of Open Pit in the Northwestern Part of Coal Deposit Potrlica – Pljevlja Using Software Package Minex 5.2.3; 3. International Symposium Energy Mining 2010;

[10] V. Marinković, R. Rajković, D. Kržanović, G. Pačkovski, D. Mitić: 2D and 3D Models, Similarity and Diferences, Copper 34 (1/2009) 2009;

[11] V. Marinković, M. Maksimović, R. Rajković; Fault Modelling Of Seams Using The Computer Programme Minex; 40th International October Conference On Mining And Metallurgy IOCMM 2008; Sokobanja, Serbia, 05 – 08 October 2008;

[12] V. Marinković, R. Rajković, M. Mikić; Calculation of Geological Reserves of the Coal Deposit by the Use of Computer Program Minex; First International Symposium Mining Energetic 07; Vrnjačka Banja, Serbia, 21 -24. November 2007.

ISSN: 2334-8836
UDK: 622

UDK: 622.271:681.325:622.36(045)=861 DOI:10.5937/MMEB1402097P

Marinko Pavlović [*], *Nenad Vušović* [**], *Miroslava Maksimović* [***], *Radmilo Rajković* [***]

OSNOVNI PRINCIPI IZRADE I KORIŠĆENJA DIGITALNOG GEOMODELA KOD PROJEKTOVANJA POVRŠINSKOG KOPA NA PRIMERU LEŽIŠTA KVARCNOG PESKA I PESKOVITE GLINE „BOŠNJANE“,SRBIJA

Izvod

Na osnovu rezultata izvršenih geoloških istraživanja na prostoru ležišta kvarcnog peska i peskovite gline Bošnjane, urađen je programskim paketom Minex 5.2.3. geomodel, koji je bio osnova za proračun rezervi i projektovanje površinskog kopa na ležištu kvarcnog peska i peskovite gline, u navedenom programskom paketu.

Ključne reči: *geomodel, Minex 5.2.3, optimizacuja i projektovanje kopa*

UVOD

Proračun rezervi programskim paketom MINEX 5.2.3, započinje izradom trodimenzionalnog geomodela. Interpretacija ležišta i izrada trodimenzionalnog geomodela uslovljena je unosom podataka iz nekoliko datoteka (Excel) o istražnim bušotinama.

Na osnovu podataka dobijenih iz istražnih radova formira se baza podataka koja se sastoji iz četri datoteke: *Collars cls. Fail; Quality cls.; Lithology cls. Fail; Seam prn. Fail.*

Podaci iz bušotina se u bazu unose na odgovarajući način u formi definisanih intervala, sa poljima pored ostalih „*from*“ i „*to*“, tj. definisanim intervalima u kojima su probe analizirane

Podaci iz istražnih bušotina se na odgovarajući način u softweru Minex obrađuju, matematičkim i geostatističkim metodama (metodama inverznih distanci različitog stepena), kako bi se utvrdila zakonomernost sadržaja u ležištu.

Proračun rezervi se vrši nekom od metoda poligona.

Blok model se može osvežiti u smislu unošenja novih podataka.

GEOLOŠKA GRAĐA I OPIS LEŽIŠTA

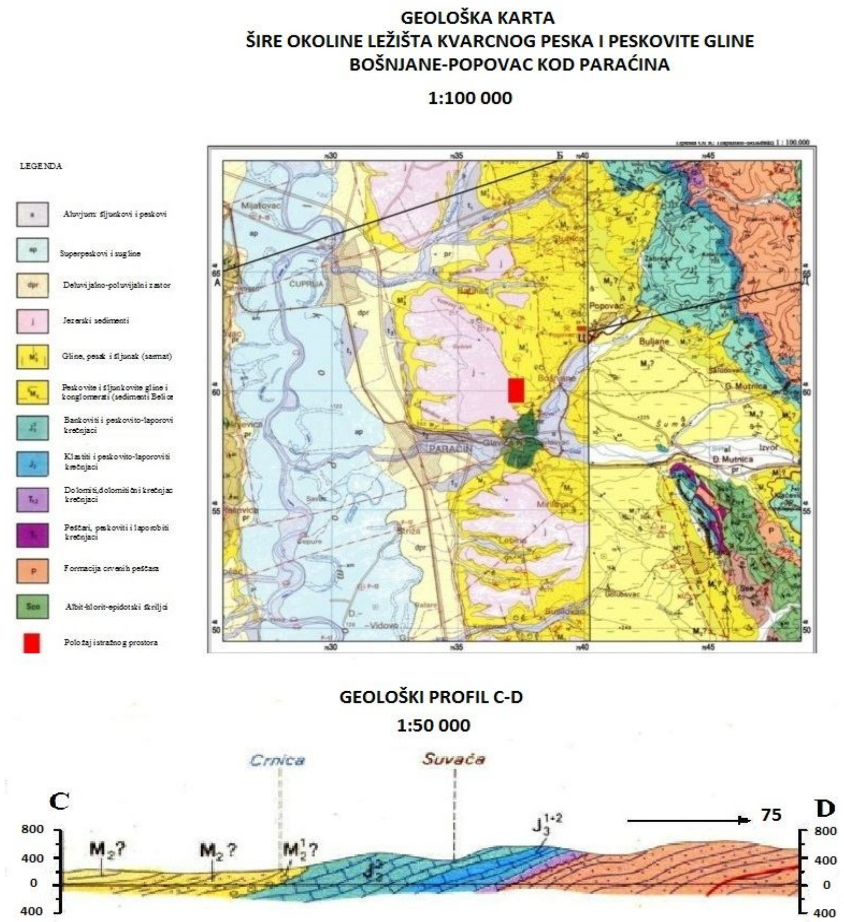
Ležište kvarcnog peska i peskovite gline „Bošnjane“, nalazi se, vazdušnom linijom, na oko 7 km severoistočno od Paraćina i na oko 5 km južno od mesta Popovac i fabrike cementa „HOLCIM“, u ataru sela Bošnjane.

Šira okolina ležišta Bošnjane obuhvata istočni deo lista Paraćin sa signaturom L34-07 i zapadni deo lista Boljevac, sa signaturom L34-08, OGK, razmere 1:100.000. [2]

U geološkoj građi ležišta kvarcnog peska i peskovite gline Bošnjane učestvuju slatko-

[*] *Holcim (Srbija) d.o.o. Popovac kod Paraćina*
[**] *Tehnički fakultet u Boru Univerzitet u Beogradu*
[***] *Institut za rudarstvo i metalurgiju Bor, miroslava.maksimovic@irmbor.co.rs*

vodni sedimenti srednjeg miocena i miocen-pliocena. U srednjem miocenu su tokom helveta, diskordantno, na starijim miocenskim, a često i pretercijarnim formacijama kao posledica starije štajerske faze, taloženi klastični sedimenti, zatim i sedimenti jezerskih facija. (slika 1) U ovim slatkovodnim sedimentima se, prema litološkom sastavu mogu izdvojiti: *srednje-miocenska facija crvenih glinovitih peščara, glinovitih laporaca i tufa, zatim srednje miocenska facija laporaca, i miocensko-pliocenska facija slatkovodnih krečnjaka, laporaca, glina, peskova i šljunkova.*



Sl. 1. *Geološka građa šire okoline ležišta Bošnjane-Popovac kod Paraćina*

Slojevi gline i peska su horizontalni do blago nagnuti u pravcu JZ. Dosadašnjim istraživanjima obuhvaćen je jedan deo peščarske serije, pri čemu je utvrđeno da povlatu serije čine peskovite gline koje po kvalitetu zadovoljavaju njihovu upotrebu u cementnoj industriji. Debljina pojedinih slojeva varira tako da imamo neujednačenu slojevitost. Povlatne gline, iz tog razloga se, tretiraju kao druga korisna sirovina. Prosečna debljina sloja povlatnih glina je oko 10 m. U istočnom i severoistočnom, delom i u centralnom delu ležišta glina ili ima malu debljinu, do 1 m, ili sloj gline potpuno isklinjava, dok u zapadnom delu ležišta, debljina sloja gline dostiže i 35 m. Dosadašnjim istraživanjima konstantovano je da se, ispod sloja gline nalazi se serija izgrađena od: peskova, peskovitih glina, zaglinjenih peskova i šljunka, sivih i mrkih glina. U samoj seriji peska se pojavljuju tanki sočivasti proslojci peskovite gline i jako zaglinjenih peskova. Debljina ovih proslojaka je od 10 cm do 50 cm.

Debljina okonturene produktivne serije peskova, koja zadovoljava u pogledu kvaliteta, zahteve njegove primene u cementnoj industriji iznosi oko 18 m. Ispod ove serije, najčešće se, nalazi serija jako zaglinjenih peskova, ili ređe, peskovite gline. Ispod ove serije leži serija bazalnih sedimenata miocena. Podinu ove serije čine bazalni sedimenti miocenske serije, izgra-đeni su od crvenih peskovitih glina, bazalnih konglomerata i crvenih peščara. Najniži slojevi ove serije leže preko titonskih krečnjaka. [2]

ISTRAŽNI RADOVI

Istraživanja u području ležišta Bošnjane, sa ciljem da se obezbede kvalitetne rezerve kvarcnog peska i peskovite gline za primenu u cementnoj industriji, vršena su u dva vremenski razdvojena perioda, odnosno od 1963. do 1965., i 2010. godine. Na ležištu kvarcnog peska i peskovite gline Bošnjane, urađeno je 8 istražnih bunara i izbušene su ukupno 24 istražne bušotine, odnosno ukupno 2.406 m bušenja. Tokom istraživanja ležišta kvarcnog peska i peskovite gline Bošnjane, primenjivana je manje-više ista metodika: ležište je istraženo po verticalnim presecima. Ležište kvarcnog peska i peskovite gline Bošnjane istraženo je izradom 8 istražnih bunara i istražnim bušenjem sa površine terena (24 vertikalne bušotine). Uobičajeni geološki radovi pratili su (preciznije obuhvatali) istražno bušenje, tako što su im predhodili (projekat), izvođeni istovremeno (geološko praćenje i usmeravanje istražnog bušenja, kartiranje i oprobavanje) i nastavljani posle njih (izrada izveštaja i elaborata). [2]

Geološki radovi

Geološki radovi pri istraživanju ležišta kvarcnog peska i peskovite gline Bošnjane, odnose se uglavnom na geološko kartiranje površine terena, praćenje, usmeravanje i geološko kartiranje istražnih bunara i istražnih bušotina, njihovo oprobavanje i interpretaciju dobijenih rezultata, te izradu geoloških karata i izradu preseka (profila) ležišta, okonturivanje ležišta, proračun rezervi mineralne sirovine itd. U geološke radove treba ubrojiti i projektovanje svih istražnih radova, izradu izveštaja i elaborata, te sintezu podataka na osnovu kojih su urađeni geološki profili (preseci) i geološke karte. Iz istražnih bušotina uzete su probe, koje su analizirane u laboratorijama: Holcima d.o.o. Popovac (hemijska ispitivanja, tehnološka ispitivanja), Instituta za rudarstvo i metalurgiju Bor (geomehanička ispitivanja). Hidrogeološka ispitivanja je izveo Geološki Institut Beograd.

Istražni bunari

Na prostoru ležišta kvarcnog peska i peskovite gline Bošnjane, urađeno je 8 bunara dubine do 20 metara. Sa dva bunara, na istočnom, najnižem delu terena, utvrđene su hidrogeološke karakteristike terena, dok je sa 6 bunara (B-I, B-II, B-III, B-IV B-V B-VI), u kvadratnoj mreži 100×100 m, istraženo nalazište po dubini. Ukupna dužina izrađenih bunara iznosi 123,4m. Bunarima su otkriveni kvarcni peskovi zadovoljavajućeg kvaliteta, sa sadržajem SiO_2 većim od 68%, što je bio osnovni uslov njegove primene u cementnoj industriji.

Istražno dubinsko bušenje

Na području ležišta kvarcnog peska i peskovite gline Bošnjane istražno bušenje rađeno je u toku 2010. godine. Ukupno su izbušene 24 bušotine, ukupne dužine bušenja od 862,6 m. Kvarcni pesak zadovoljavajućeg kvaliteta za njegovu primenu u cementnoj industriji, nabušen je sa 17 bušotina,), dok su 7 negativne, tako da su rezultati oprobavanja tih bušotina isključeni iz proračuna.

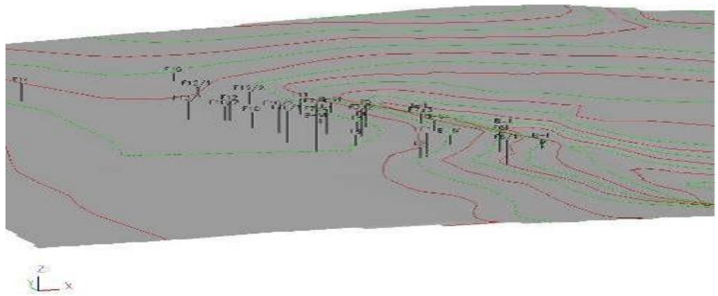
IZRADA GEOMODELA I PROJEKTOVANJE POVRŠINSKIH KOPOVA PROGRAMSKIM PAKETOM MINEX 5.2.3.

Proračun rezervi programskim paketom MINEX 5.2.3, započinje izradom trodimenzionalnog geomodela [9]. Interpretacija ležišta i izrada trodimenzionalnog geomodela uslovljena je unosom podataka iz nekoliko datoteka (Excel) o istražnim bušotinama. [2] Datoteke sadrže za svaku bušotinu: ime bušotine, podatke o koti, koordinatama, podatke o litološkim članovima u geološkim stubovima bušotina (koji su relevantni za procenu pozicije slojeva u izdvojenim geološkim sredinama), kao i podatke o rezultatima hemijskih analiza pojedinačnih proba SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, Na_2O, SO_3 i gubitak žarenjem.

Pre početka izrade *3D* modela ležišta kvarcnog peska i peskovite gline Bošnjane, bilo je potrebno formirati bazu podataka na osnovu kojih bi se pristupilo izradi modela. Do svih potrebnih podataka se došlo u procesu istraživanja (istražne bušotine, istražni bunari), kao i izvršenih laboratorijskih analiza (prostorni položaj svakog istražnog rada predstavljen X, Y, Z koordinatom, konačna dubina svakog istražnog rada, litološki članovi određeni u procesu kartiranja jezgra bušotine i podaci o kvalitetu dobijeni laboratorijskim analizama). Baza podataka se sastoji iz 4 osnovna fajla:

- *Collars cls. Fail - sadrži sve podatke o prostornom položaju bušotina;*
- *Quality cls. Fail - sadrži sve podatke vezane za kvalitet;*
- *Lithology cls. Fail - sadrži sve podatke o litologiji;*
- *Seam prn. Fail - sadrži podatke o položaju slojeva peskovite gline i kvarcnog peska, u svakom istražnom radu.* [12]

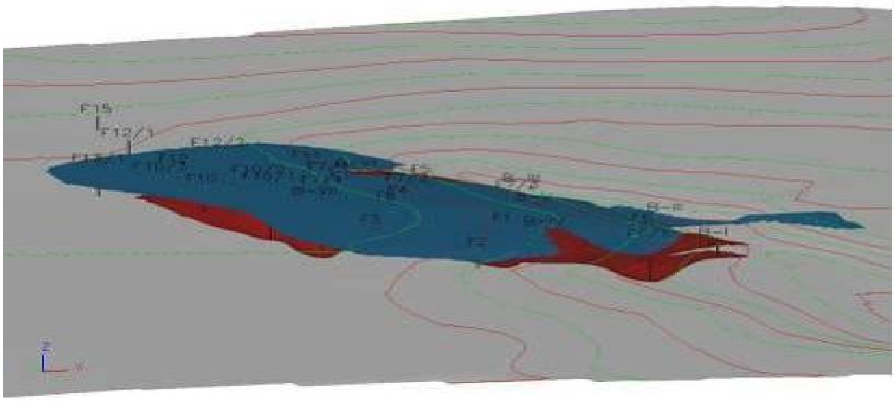
Ležište kvarcnog peska i peskovite gline Bošnjane je slojevito-sočivastog oblika. Pravac pružanja ležišta je SSZ-JJI. Po pružanju ležište se može pratiti oko 600 m, dok je široko oko 300 m (pravac I-Z). U okviru konture ležišta jasno se izdvajaju dva litološki različita člana, sloj gline i sloj kvarcnog peska. Iz tog razloga svaki od ovih slojeva modelovan je kao zaseban sloj, koji nosi posebnu slovnu oznaku. Za svaku bušotinu dat je opis izdvojenih tipova stena, odnosno geološki stub bušotine, a zatim su uneti podaci o karakteristikama svakog izdvojenog litološkog tipa, neophodni za dalju obradu blok-modela ležišta. Osim napred navedenih podataka, uneti su i podaci o topografiji terena. Podaci o topografiji preuzeti su od Investitora (HOLCIM Srbija d.o.o. Popovac). Na slici 2. dat je grafički, trodimenzionalni prikaz unetih podataka, iz baze programskog paketa MINEX 5.2.3.[8]



Sl. 2. *3D prikaz odnosa topografije i bušotina (programskim paketom MINEX 5.2.3)*

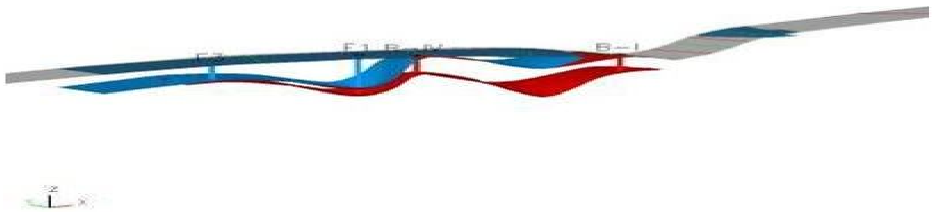
Svi slojevi su modelovani primenom opšteg metoda modelovanja. U procesu interpolacije nedostajućih slojeva korišćeni su podaci iz minimum 3, a maksimum 4 susedne bušotine, a radijus pretrage je ograničen na 250 m. Dok je za ponderisanje vrednosti korišćena opšta formula za ponderisanje. Nakon kreiranja ovih slojeva, pristupilo se njihovoj međusobnoj prostornoj korelaciji i izradi *3D* modela ležišta (slika 3).

Za svaki vertikalni presek (profil) i horizontalni presek (etažu), definisane su referentne površine i prostor, koji ispred i iza, zahvata određeni prostor. Ovakvim načinom interpretacije eliminisana je mogućnost postojanja "praznih" prostora unutar blok-modela ležišta. Izgled modeliranih slojeva programskim paketom MINEX 5.2.3 je prikazan slikama 3 i 4. [11]



Sl. 3. *3D prikaz slojeva sa topografijom (programskim paketom MINEX 5.2.3)*

a) Sivom bojom je prikazana topografija; b) Crvenom bojom je prikazan sloj kvarcnog peska (P1); c) Plavom bojom je prikazan sloj peskovite gline (G).



Sl. 4. *2D prikaz dela poprečnog preseka kroz ležište kvarcnog peska i peskovite gline Bošnjane (programskim paketom MINEX 5.2.3)*

a) Sivom bojom je prikazana topografija; b) Crvenom bojom je prikazan sloj kvarcnog peska (P1); c) Plavom bojom je prikazan sloj peskovite gline (G).

Sve ostale podatke potrebne za proračun rezervi, program preuzima iz predhodno kreiranih baza podataka, kao i izrađenog geološkog modela slojeva [7]. Na tako kreiranom modelu ležišta bilo je moguće proračunati geološke rezerve, kako za svaki sloj ponaosob, tako i za ležište u celosti. [13]

PROSTORNO OGRANIČENJE POVRŠINSKOG KOPA I ODLAGALIŠTA SA GEOMETRIJOM I ANALIZAMA STABILNOSTI

Konstrukcija površinskog kopa izvršena je na bazi overenih bilansnih rezervi. Izbor optimalne završne konture kopa izvršen je pomoću licenciranog programa Minex 5.2.3„ koji služi za optimizaciju i analizu površinskih kopova. [5] Optimizacija je izvršena alatom Pit Optimiser, koji se bazira na Lerches and Grossman algoritmu, tj. postupku za određivanje optimalnog kopa kao onog sa najvećom vrednošću za odgovarajući set troškova i faktora povraćaja. [6] Ulazni parametri za optimizaciju ležišta „Bošnjane“ su:

1. topografija,
2. geomodel ležišta,
3. zapreminska masa peska, gline i jalovine,
4. iskorišćenje na otkopavanju i pripremi,
5. jedinična vrednost tone peska i gline,
6. srednji i minimalni sadržaj S_iO_2 u ležištu,
7. ugao završne kosine kopa,
8. mimimalna završna širina etažne ravni,
9. direktni troškovi otkopavanja jalovine, peska i gline.

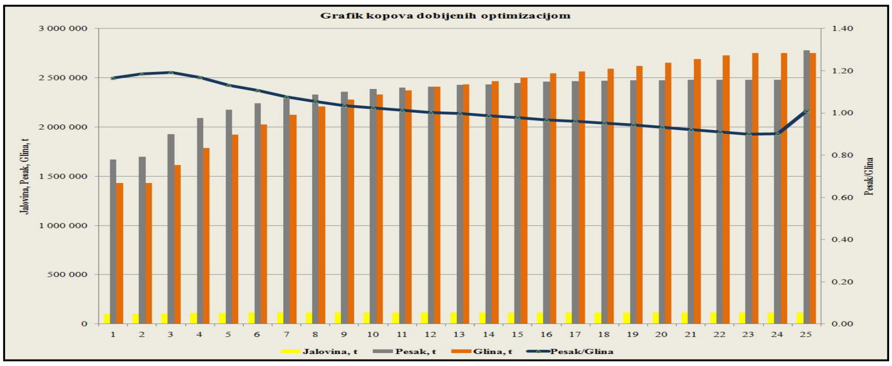
Ugao završne kosine kopa određen je licenciranim softverom GeoStudio 2007, odnosno njegovim alatom Slope/W koji je specijalizovan za metode granične ravnoteže. Pretpostavljena maksimalna dubina kopa određena je na osnovu prostornog položaja peska i gline, kao i topografije terena. Generalni ugao završne kosine kopa direktno zavisi od ugla kosine etaža i završne širine etažnih ravni. Pretpostavljeno je na osnovu geomodela ležišta da je za reprezentativni profil odnos moćnosti gline i peska 1:1,5. [3]

Prema ovim uslovima pretpostavljeni ugao završne kosine kopa iznosi 24,3°. Minimalna završna širina etažne ravni dovoljna za radove na rekultivaciji, usvojena je na 4 m. Direktni troškovi otkopavanja jalovine, peska i gline obuhvataju troškove normativnog materijala, ljudskog rada, i tekućeg održavanja za sve faze rada (kopanje, utovar na kopu i deponijama peska i gline, transport, pomoćni radovi na kopu i odlagalištu, odvodnjavanje) uvećane za troškove HTZ opreme, NTO, administracije i nepredviđene troškove. Rezultati optimizacije prikazani su na slikama 5 i 6.

Kop	Jalovina, t	Pesak, t	Glina, t	Iskopina, t	Kr	P/G	Vek rada	Jalovina, t/god	Pesak, t/god	Glina, t/god	Trošak, $	Dobit, $	NPV, $	Fp	DV, $
1	101 234	1 669 060	1 432 276	3 202 570	0.03	1.17	27.8	3 639	60 000	51 488	14 929 840	23 889 106	8 959 266	0.07056	632 156
2	101 506	1 698 708	1 433 281	3 233 495	0.03	1.19	28.3	3 585	60 000	50 625	15 076 926	24 171 159	9 094 233	0.06731	612 160
3	106 605	1 928 144	1 616 129	3 650 878	0.03	1.19	32.1	3 317	60 000	50 291	17 039 713	27 373 309	10 333 595	0.04675	483 134
4	110 279	2 091 034	1 788 937	3 990 250	0.03	1.17	34.9	3 164	60 000	51 332	18 633 835	29 897 053	11 263 218	0.03609	406 541
5	112 639	2 175 656	1 921 739	4 210 034	0.03	1.13	36.3	3 106	60 000	52 998	19 663 857	31 458 697	11 794 841	0.03155	372 181
6	113 895	2 239 338	2 023 966	4 377 199	0.03	1.11	37.3	3 052	60 000	54 229	20 448 244	32 647 227	12 198 983	0.02852	347 899
7	115 290	2 286 677	2 124 660	4 526 627	0.03	1.08	38.1	3 025	60 000	55 749	21 147 774	33 674 578	12 526 804	0.02645	331 369
8	115 970	2 328 106	2 209 098	4 653 174	0.03	1.05	38.8	2 989	60 000	56 933	21 741 314	34 552 213	12 810 900	0.02477	317 300
9	116 208	2 356 294	2 277 707	4 750 209	0.03	1.03	39.3	2 959	60 000	57 999	22 196 568	35 214 323	13 017 754	0.02368	308 305
10	116 437	2 386 328	2 328 084	4 830 849	0.02	1.03	39.8	2 928	60 000	58 536	22 575 603	35 787 465	13 211 862	0.02258	298 324
11	116 622	2 400 562	2 371 651	4 888 835	0.02	1.01	40.0	2 915	60 000	59 277	22 847 272	36 173 759	13 326 487	0.02208	294 185
12	116 779	2 412 022	2 407 887	4 936 688	0.02	1.00	40.2	2 905	60 000	59 897	23 071 424	36 491 523	13 420 099	0.02168	290 907
13	116 937	2 426 961	2 434 492	4 978 390	0.02	1.00	40.4	2 891	60 000	60 186	23 267 294	36 785 616	13 518 322	0.02117	286 164
14	117 067	2 435 000	2 468 174	5 020 241	0.02	0.99	40.6	2 885	60 000	60 817	23 463 117	37 056 637	13 593 520	0.02090	284 105
15	117 187	2 449 641	2 501 996	5 068 824	0.02	0.98	40.8	2 870	60 000	61 282	23 691 113	37 389 978	13 698 865	0.02042	279 725
16	117 293	2 459 135	2 544 273	5 120 701	0.02	0.97	41.0	2 862	60 000	62 077	23 933 903	37 724 603	13 790 700	0.02011	277 385
17	117 419	2 465 821	2 564 192	5 147 432	0.02	0.96	41.1	2 857	60 000	62 394	24 059 075	37 902 878	13 843 803	0.01990	275 511
18	117 549	2 468 537	2 591 316	5 177 402	0.02	0.95	41.1	2 857	60 000	62 984	24 198 885	38 086 124	13 887 239	0.01982	275 186
19	117 671	2 473 105	2 620 084	5 210 860	0.02	0.94	41.2	2 855	60 000	63 566	24 355 190	38 296 195	13 941 005	0.01967	274 254
20	117 745	2 475 508	2 652 137	5 245 390	0.02	0.93	41.3	2 854	60 000	64 281	24 516 336	38 505 226	13 988 890	0.01960	274 148
21	117 871	2 478 815	2 691 898	5 288 584	0.02	0.92	41.3	2 853	60 000	65 158	24 717 887	38 767 563	14 049 676	0.01949	273 896
22	117 959	2 479 794	2 726 014	5 323 767	0.02	0.91	41.3	2 854	60 000	65 957	24 881 888	38 975 340	14 093 452	0.01946	274 323
23	118 044	2 480 049	2 753 750	5 351 843	0.02	0.90	41.3	2 856	60 000	66 622	25 012 670	39 139 223	14 126 552	0.01946	274 856
24	118 044	2 480 467	2 753 750	5 352 261	0.02	0.90	41.3	2 855	60 000	66 610	25 014 668	39 143 117	14 128 449	0.01944	274 710
25	118 044	2 781 094	2 753 750	5 652 888	0.02	1.01	46.4	2 547	60 000	59 410	26 451 064	41 943 758	15 492 694	0.01206	186 858
OPT	116 528	2 213 236	2 172 835	4 502 599	0.03	1.02	36.9	3 159	60 000	58 905	21 024 894	33 270 925	12 246 031	0.02973	364 026

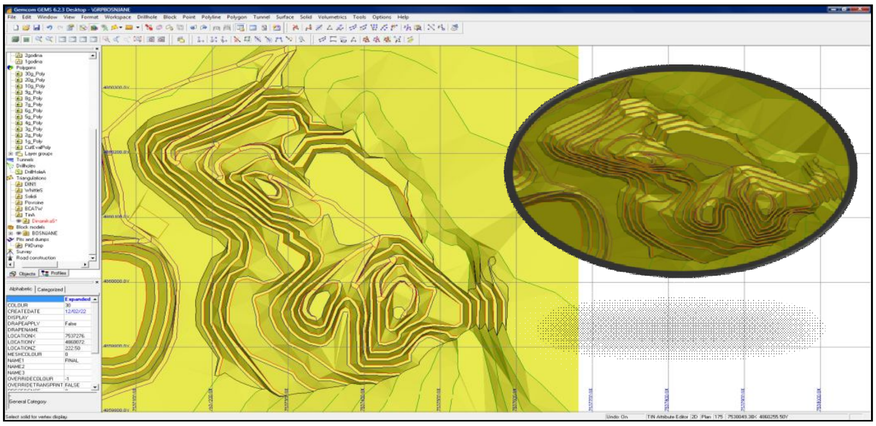
Sl. 5. *Analitički prikaz rezultata optimizacije*

Dobijene konture koje su rezultat optimizacije, nemaju etaže. Kao vodilja za konstrukciju kopa koji obuhvata bilansne rezerve izabrana je kontura 8, čija diskontovana vrednost na kraju perioda eksploatacije, koja obuhvata samo direktne troškove otkopavanja,. Ova kontura ima 2.328.106 t peska i 2.209.098 t gline. Odnos pesak/glina iznosi 1,05 a koeficijent raskrivke 0,03[4].



Sl. 6. *Grafički prikaz rezultata optimizacije*

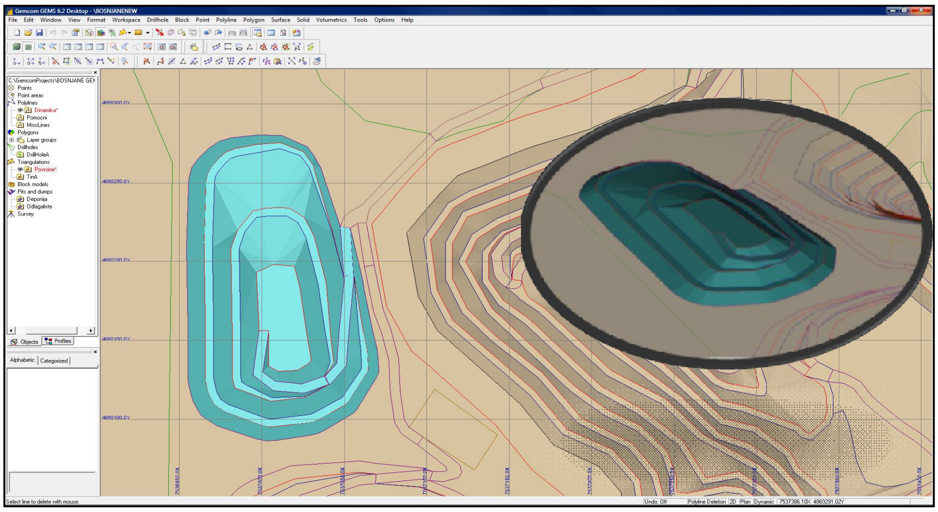
Projektovanim zahvatom završnog kopa ukupno je predviđeno otkopavanje 2.507.633 t peska i 1.941.416 t gline. Odnos pesak/glina iznosi 1,29, a koeficijent raskrivke 0,03. Izgled završnog kopa prikazan je na slici 7.



Sl. 7. *Izgled završne konture kopa*

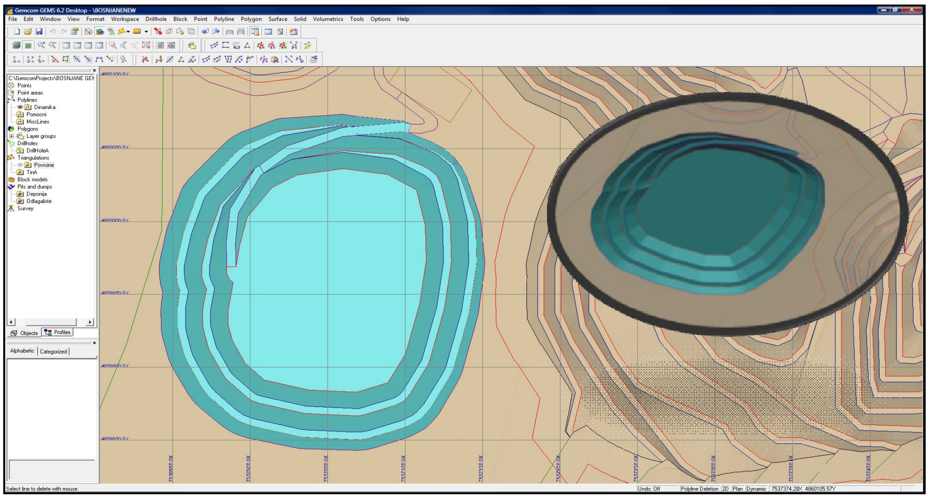
Konstrukcija deponije gline i odlagališta jalovine

Odlagalište površinske humusne jalovine biće locirano sa severozapadne strane kopa. Ovo jalovište će biti uklonjeno nakon radova na rekultivaciji, jer će se iskoristiti kao pozajmište humusa pri rekultivaciji po završetku eksploatacije. Odlagalište jalovine ima 3 etaže visine 5 m. Najniža etaža odlagališta je E250/245 m, a najviša E260/255 m. Izgled odlagališta jalovine prikazan je na slici 8.

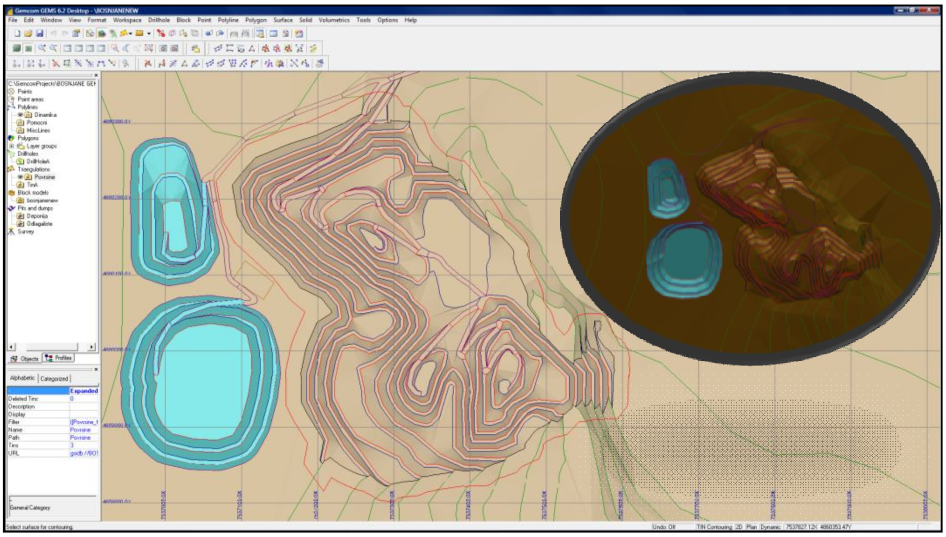


Sl. 8. *Konačni izgled odlagališta jalovine*

Privremena deponija gline locirana sa zapadne strane kopa. Ova deponija će biti uklonjena nakon završetka eksploatacije, jer će se odložena glina naknadno upotrebiti za tehnološki proces dobijanja cementa. Potrebni kapacitet deponije gline je uslovljen količinom gline koja se otkopava a ne ide odmah u tehnološki proces. Deponija gline ima 3 etaže visine 5 m. Najniža etaža deponije je E250/245 m, a najviša E260/255 m. Izgled deponije gline prikazan je na slici 9. Međusobni položaj kopa, odlagališta jalovine i deponije gline prikazan je na slici 10.



Sl. 9. *Konačni izgled deponije gline*



Sl. 10. *Međusobni položaj kopa, odlagališta jalovine i deponije gline*

ZAKLJUČAK

Proračun rezervi, optimizacija ležišta, kao i druga rudarska projektovanja, obavljaju uz pomoć različitih programskih paketa. Jedan od programskih paketa koji se koriste u geologiji, za izradu geomodela na kome se vrši proračun rezervi i dalja rudarska projektovanja, je program Minex 5.2.3, proizveden u Australiji u firmi Surpac Minex Group Pty Ltd, koji se primenjuje u Institutu za rudarstvo i metalurgiju Bor. Izrada geomodela vrši se na osnovu podataka o geološkoj građi ležišta i rezultata geoloških istraživanja. Optimizacija se vrši prema istraženim i ispitanim tehničkim i ekonomskim parametrima. Važan činilac upotrebe programa Minex 5.2.3 je mogućnost promene i upoređivanja više varijanti ulaznih parametara, pogotovu kada se radi o proračunu rezervi i optimizaciji. Primenom računarske tehnike i odgovarajućih programskih paketa skraćuje se vreme izrade projektne dokumentacije i različitih proračuna, u odnosu na klasično projektovanje. Upotrebom ovog programa projektovanje je znatno poboljšano sa aspekta vremena i kvaliteta usled mogućnosti brze analize u cilju odabira najboljih rešenja. Primena ovog i sličnih programa postala je neminovnost i standard, u geologiji i rudarstvu. Određivanje optimalne konture površinskog kopa je neophodan korak pri projektovanju u površinskoj eksploataciji, koji se karakteriše složenošću i analizom velikog broja mogućih rešenja koja odgovaraju tehničko - tehnološkim zadatim uslovima, ali se međusobno razlikuju prema ekonomskom efektu. Određivanje optimalne konture kopa, i njen ekononski efekat, je značajno za bilansiranje rezervi mineralne sirovine, i geološko-ekonomsku ocenu ležišta mineralne sirovine. Zato je potrebno da se različita rešenja podvrgnu tehno - ekonomskoj analizi pojedinih varijanti i usvoji rešenje koje će biti optimalno za date uslove.

LITERATURA

[1] Minex manual, Surpac Minex Group Pty Ltd, 2007 god

[2] Maksimović M., Marinković V., Elaborat o rezervama kvarcnog peska i peskovite gline kao sirovine za cementnu industriju, u ležištu Bošnjane-Popovac kod Paraćina, 30.09.2011, IRM Bor, 2011

[3] Rajković R. i saradnici „Studija izvodljivosti eksploatacije kvarcnog peska Bošnjane", knjiga 1 tekst, IRM Bor, 2012

[4] Glavni rudarski projekat eksploatacije kvarcnog peska Bošnjane, knjiga 1 Osnovna koncepcija, Odeljenje Minex i Gemcom, IRM Bor, 2012

[5] R. Rajković, D. Kržanović, M. Mikić, V. Marinković: Construction of ash and slag dump on the thermal power plant Gacko with software Gemcom 6.2 and Minex 5.2; Mining 2013 Plans for development and improvent of mining; Veliko Gradište, Srebrno jezero 28-31 may 2013, pp. 177-182;

[6] M. Ignjatović, R. Rajković, S. Ignjatović, L. Đurđevac Ignjatović, L. Kričak, R. Pantović: Determination of optimal contours of open pit mine during oil shale exploitation by Minex 5.2.3. program; Journal of Process Management - New Technologies International, Vol 1, No 2, 2013, pp. 1-9;

[7] R. Rajković, D. Kržanović, V. Marinković: Određivanje bilansnih ležišta kalcita „Kaona" i optimalne konture površinskog kopa programom Minex 5.2.3, Rudarski radovi 3/2011, str. 13-18;

[8] R. Rajković, V. Marinković, R. Lekovski: Digitalni 3D model terena, Rudarski radovi 3/2011, str. 25-32;

[9] D. Kržanović, R. Rajković, V. Marinković: Optimal contour selection of open pit in the northwestern part of coal deposit Potrlica – Pljevlja using software package Minex 5.2.3; 3. International symposium Energy Mining 2010, pp. 216-220;

[10] V. Marinković, R. Rajković, D. Kržanović, G. Pačkovski, D. Mitić: 2D i 3D modeli, sličnosti i razlike, Bakar 34 1/2009;

[11] V. Marinković, M. Maksimović, R. Rajković; Fault modelling of seams using the computer programme Minex; 40th International October Conference on Mining and Metallurgy IOCMM 2008, Sokobanja, Serbia, 05-08 October 2008, pp. 145-152;

[12] V. Marinković, R. Rajković, M. Mikić; Calculation of Geological Reserves of the Coal Deposit by the Use of Computer Program Minex; First International Symposium Mining Energetic 07, Vrnjačka Banja, Serbia, 21 - 24. November 2007, pp. 207-211;

MINING AND METALLURGY INSTITUTE BOR ISSN: 2334-8836
UDK: 622

UDK: 669.215/.22/.872/.65(045)=20 DOI:10.5937/MMEB1402117K

Ana Kostov[*], *Aleksandra Milosavljević*[*], *Radiša Todorović*[*], *Lidija Gomidželović*[*]

LEAD-FREE ALLOYS FOR ECOLOGICAL SOLDERS MANUFACTURING[**]

Abstract

Although the European Union's directive about environment protection as WEEE and RoHS have been carried out in 2003, led solders are still in used in Serbia. In the aim to respect the European and world directives and laws, it is necessary to reduce a quantity of toxic element and to establish lead and cadmium free solders in production. In this paper it was presented lead-free alloys, which are used for ecological solders manufacturing and various applications.
Keywords: *ecological solders, lead-free alloys, silver, gold, tin, indium.*

INTRODUCTION

On July 1, 2006 the European Union Waste Electrical and Electronic Equipment Directive (WEEE) and Restriction of Hazardous Substances Directive (RoHS) came into effect prohibiting the intentional addition of lead to most consumer electronics produced in the EU [1]. California is recently adopted a RoHS law [2] and China has a version as well. Manufacturers in the U.S. are received tax benefits by reducing the use of lead-based solder. With the Europeans WEEE Directive now mandating a phase out of lead in electronic soldering and Japan's efforts to do the same even sooner, lead-free is rapidly taking on momentum around the world.

Namely, the available evidence indicates that measures on the collection, treatment, recycling and disposal of waste electrical and electronic equipment (WEEE) as set out in Directive 2002/96/EC of 27 January 2003 of the European Parliament and of the Council on waste electrical and electronic equipment [1] are necessary to reduce the waste management problem linked to the heavy metals concerned and the flame retardants concerned. In spite of those measures, however, significant parts of WEEE will continue to be found in the current disposal routes. Even if WEEE were collected separately and submitted to recycling processes, its content of mercury, cadmium, lead and

* *Mining and Metallurgy Institute Bor, Zeleni bulevar 35, Bor, Serbia, e-mail: ana.kostov@irmbor.co.rs, aleksandra.milosavljevic@irmbor.co.rs, khurgan@ptt.rs, lgomidzelovic@yahoo.com*
** *The research presented in this paper has been done in the frame of the projects: "Development of ecological knowledge-based advanced materials and technologies for multifunctional application" No 34005 and "Modern multi-component metal systems and nanostructured materials with different functional properties" No 172037 financed by Ministry of Education, Science and Technological Development of the Republic of Serbia; as well as the project MIS ETC Code 1409, title "Promoting new ecologic filler alloys for soldering, based on the non-ferrous ore of the Romanian-Serbian cross-border area" within the Romania – Republic of Serbia IPA Cross-Border Cooperation Programme.*

chromium (VI) would be likely to pose risks to health or the environment.

Taking into account technical and economic feasibility, the most effective way of ensuring the significant reduction of risks to health and the environment relating to those substances which can achieve the chosen level of protection in the Community is the substitution of those substances in electrical and electronic equipment by safe or safer materials. Restricting the use of these hazardous substances is likely to enhance the possibilities and economic profitability of recycling of WEEE and decrease the negative health impact on workers in recycling plants.

Although the European Union's directive about environment protection as WEEE and RoHS have been carried out in 2003, led solders are still in used in Serbia. In the aim to respect the European and world directives and laws, it is necessary to reduce a quantity of toxic element and to establish lead and cadmium free solders in production.

In this paper it was presented lead-free alloys, which are used for ecological solders manufacturing and their various applications, which are optimal replacement materials for toxic ones. Those solders must have similar characteristics as standard solders and respect economical payable.

SOLDERING

Soldering is a process in which two or more metal items are joined together, by melting and flowing of a filler metal into the joint, the filler metal having a relatively low melting point. Soft soldering is characterized by the melting point of the filler metal, which is below 400°C [3]. The filler metal used in the process is called solder.

Soldering is distinguished from brazing by use of a lower melting-temperature filler metal; it is distinguished from welding by the base metals not being melted during the joining process. In a soldering process, heat is applied to the parts to be joined, causing the solder to melt and be drawn into the joint by capillary action and to bond to the materials to be joined by wetting action. After the metal cools, the resulting joints are not as strong as the base metal, but have adequate strength, electrical conductivity, and watertightness for many uses.

One of the most frequent applications of soldering is assembling electronic components to printed circuit boards. Another common application is making permanent but reversible connections between copper pipes in plumbing systems. Joints in sheet metal objects such as food cans, roof flashing, rain gutters and automobile radiators have also historically been soldered, and occasionally still are. Jewellery components are assembled and repaired by soldering. Small mechanical parts are often soldered as well. Soldering is also used to join lead came and copper foil in stained glass work. Soldering can also be used to affect a semi-permanent patch for a leak in a container cooking vessel.

Some examples of solder types and their applications are tin-lead (general purpose), tin-zinc for joining aluminium, and lead-silver for strength at higher than room temperature, cadmium-silver for strength at high temperatures, zinc-aluminium for aluminium and corrosion resistance, and tin-silver and tin-bismuth for electronics.

A solder is a fusible metal alloy with a melting point or melting range of 90 to 450°C, used in a process called soldering where it is melted to join metallic surfaces. It is especially useful in electronics and plumbing. Alloys that melt between 180 and 190°C are the most commonly used.

SOLDER ALLOYS

Tin-lead solders are commercially available with tin concentrations between 5% and 70% by weight. The greater the tin concentration, the greater the solder's tensile and shear strengths. At the retail level, the two most common alloys are 60/40 Sn/Pb and 63/37 Sn/Pb used principally in electrical work. The 63/37 ratio is notable in that it is a eutectic mixture, which means: it has the lowest melting point (183°C) of all the tin/lead alloys; and the melting point is truly a point - not a range.

At a eutectic composition, the liquid solder solidifies as a eutectic, which consists of fine grains of nearly pure lead and nearly pure tin phases, but in no way is it an intermetallic, since there are no tin-lead intermetallics, as can be seen from a tin-lead equilibrium diagram.

In plumbing, a higher proportion of lead was used. This had the advantage of making the alloy solidify more slowly, so that it could be wiped over the joint to ensure water tightness. Although lead water pipes were displaced by copper when the significance of lead poisoning began to be fully appreciated, lead solder was still used until the 1980's because it was thought that the amount of lead that could leach into water from the solder was negligible. Since even small amounts of lead have been found detrimental to health [4], lead in plumbing solder was replaced by copper or antimony, with silver often added, and the proportion of tin was increased.

Pure lead solder is known to go into solution causing big problems. Lead tin solder, however, is very stable and does not go into solution, even in land fill sites.

Hard solder, as used for brazing, is generally a copper-zinc or copper-silver alloy, and melts at higher temperatures.

In silversmithing or jewellery making, special hard solders are used that will pass assay. They contain a high proportion of the metal being soldered and lead is not used in these alloys. These solders also come in a variety of hardness, known as 'enamelling', 'hard', 'medium' and 'easy'.

Enamelling solder has a high melting point, close to that of the material itself, to prevent the joint desoldering during firing in the enamelling process. The remaining solder types are used in decreasing order of hardness during the process of making an item, to prevent a previously soldered seam or joint desoldering while soldering a new joint. Easy solder is also often used for repair work for the same reason. Flux or rouge is also used to prevent joints desoldering.

Silver solder is also used in manufacturing, when there is a need to join metal parts that cannot be welded. The alloys used for these purposes contain a high proportion of silver (up to 40%), and may also contain toxic cadmium.

Solder often comes pre-mixed with, or is used with, flux, a reducing agent designed to help remove impurities (specifically oxidized metals) from the points of contact to improve the electrical connection. For convenience, solder is often manufactured as a hollow tube and filled with flux. Most cold solder is soft enough to be rolled and packaged as a coil, making for a convenient and compact solder/flux package. The two principal types of flux are acid flux, used for metal mending, and rosin flux, used in electronics, where the corrosiveness of the vapours that arise when acid flux is heated could damage components. Due to concerns over atmospheric pollution and hazardous waste disposal, the electronics industry has been gradually shifting from rosin flux to water-soluble flux, which can be removed with deionised water and detergent, instead of hydrocarbon solvents.

LEAD-FREE SOLDER ALLOYS

Lead-free solders in commercial use may contain tin, copper, silver, bismuth, indium, zinc, antimony, and traces of other metals. Most lead-free replacements for conventional Sn60/Pb40 and Sn63/Pb37 solder have melting points from 5-20°C higher, though solders with much lower melting points are available.

Drop-in replacements for silkscreen with solder paste soldering operations are available. Minor modification to the solder pots (e.g. titanium liners and/or impellers) used in wave-soldering operations may be desired to reduce maintenance costs associated with the increased tin-scavenging effects of high tin solders. The properties of lead-free solders are not as thoroughly known and may therefore be considered less reliable in select applications, e.g. high reliability aerospace and life-critical medical. "Tin whiskers" were a problem with early electronic solders, and lead was initially added to the alloy in part to eliminate them. These problems are now considered negli-gible in modern alloys for most applications

However, solder containing lead is still used in high reliability military, aerospace-satellite and life-critical medical applications.

Different elements serve different roles in the solder alloy:

Silver provides mechanical strength, but has worse ductility than lead. In absence of lead, it improves resistance to fatigue from thermal cycles.

Copper lowers the melting point, improves resistance to thermal cycle fatigue, and improves wetting properties of the molten solder. It also slows down the rate of dissolution of copper from the board and part leads in the liquid solder.

Bismuth significantly lowers the melting point and improves wetability. In presence of sufficient lead and tin, bismuth forms crystals of Sn16Pb32Bi52 with melting point of only 95°C, which diffuses along the grain boundaries and may cause a joint failure at relatively low temperatures. A high-power part pre-tinned with an alloy of lead can therefore desolder under load when soldered with a bismuth-containing solder.

Indium lowers the melting point and improves ductility. In presence of lead it forms a ternary compound that undergoes phase change at 114°C.

Zinc lowers the melting point and is low-cost. However it is highly susceptible to corrosion and oxidation in air, therefore zinc-containing alloys are unsuitable for some purposes, e.g. wave soldering, and zinc-containing solder pastes have shorter shelf life than zinc-free.

Antimony is added to increase strength without affecting wetability.

The most attractive world lead-free alloys are so-called SAC alloys (Sn-Ag-Cu) [5]. This alloy is recommended for used by NEMI (National electronic Manufacturing Initiative) as possible replacement for lead-tin solder. SAC alloys possess relatively high temperature of melting (over $200^{o}C$) according to Sn63Pb37 (183°C), and because of that the attractive solution is adding of indium as the forth component in alloy (SIAC alloys).

Some of the alloys based on indium such as In-Sn, is mainly used in the process of cold soldering. The only faults of these alloys are high price of cost, but ductility, good lubricate and fatigue resistance are the qualities necessary for a good solders.

Likewise, the alloy which possesses some application in electronics is Sn-In-Ag alloy. The most popular is Indalloy 227 (Sn77,2In20Ag2,8), as well as Sn(71,5-91,9)In(4,8-25,9)Ag(2,6-3,3), with or without added forth element, according to investigations of Indium Corporation of America and Delphi Delco Electronic Systems.

So, the best solution is used the best properties of the both alloys Sn-In-Ag and Sn-Ag-Cu and made a new Sn-In-Ag-Cu alloy. In that case, indium content in alloy should not be high, in the aim to avoid partial melting of alloy, which is not good for practical application. The second reason is economical. High content of indium make higher price of solder. According to the above mention, the best results are reaching by the used solders with the follow content: 50-90% Sn, 10-30% In, till 10% Ag and till 2,5% Cu [6].

Besides alloys based on indium, it could be used solder alloys based on gold. This kind of alloys is especially used in multi-integrated electrical circuits with dense packages. Electronic industry is at the moment the biggest user of gold and its alloys Almost 90% of used gold and alloys based on gold are used as solders for electrical contacts at normal pressures and in vacuum.

These significant applications in electronics, gold is owing to its possibility to form low-temperature eutectic with the others elements which possess some kind of conductivity, such as In, Ga, Si, etc. [7].

Also, the phase diagrams of Au-In-Me types may play a significant role in understanding of development of microstructures at bound surface between solder materials based on indium and gold, and the base, as well as in predicting of properties and cohesion point that lead to design of potential bound surface.

Au-In-Sb-Ga and Au-In-Sb alloys (figures 1 and 2) belong to the group of possible solder materials with gold and indium.

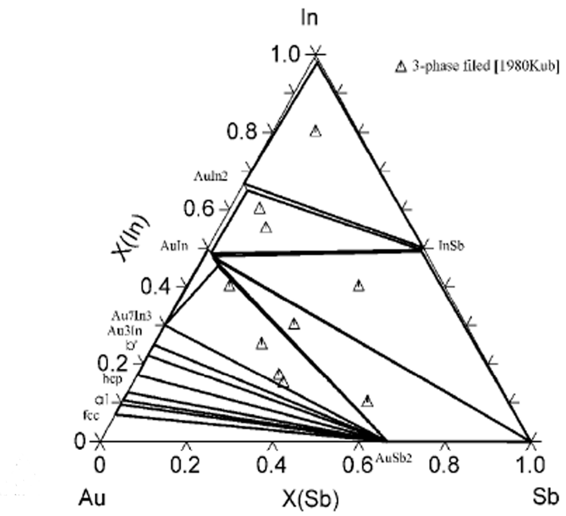


Fig. 1. *Isothermal cross-section of ternary system Au-In-Sb at 227 °C*

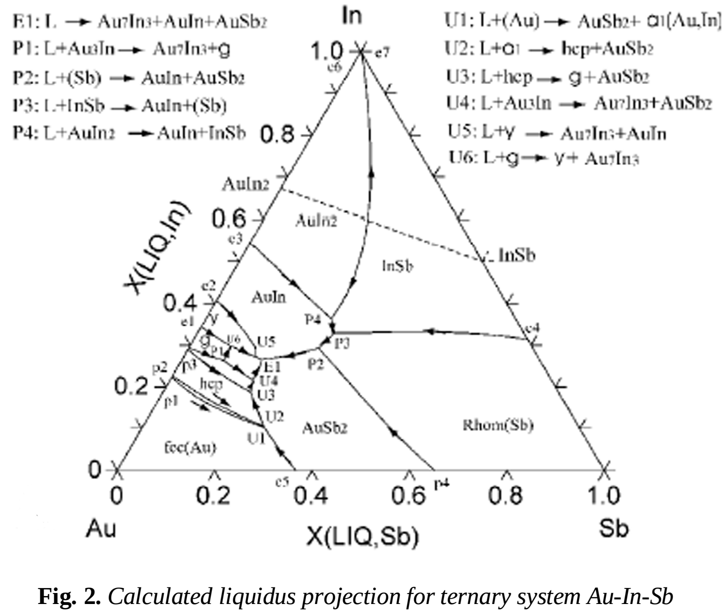


Fig. 2. *Calculated liquidus projection for ternary system Au-In-Sb*

CONCLUSIONS

The shown lead-free alloys for production of ecological solders are results of the investigation within project in the programme of researching in the field of technology developing – materials and chemical technologies during the first year of researching.

These alloys are possible to replacement toxic cadmium and lead in traditional solders. The ecological and energy efficient effects are achieved by the used of the shown alloys, as well as the better economical results, due to solder materials from abroad are replacement with the home-made products.

REFERENCES

[1] Official Journal of the European Union, Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment, p. 24.

[2] Information on http://www.dtsc.ca.gov/HazardousWaste/EWaste

[3] A. Rahn, The Basics of Soldering, John Wiley & Sons, (1993).

[4] PMID 2294437 (P, S, G, E, B), The Long-Term Effects of Exposure to Low Doses of Lead in Childhood, N. Engl. J. Med., 322 (2) (1990) 83.

[5] H. S. Liu, C. I. Liu, C. Wang, Z. P. Jin and K. Ishida, J. Electron. Mater., 32 (2003) 81.

[6] A. Milosavljevic, Thermodynamic Investigation and Structural Characterization of Alloys in Ag-In-Sn Ternary System, Master Thesis, University of Belgrade, Technical Faculty Bor, Serbia, (2006).

[7] L. Gomidzelovic, Comparative Thermodynamic Analysis and Phase Equilibrium Investigation in Au-In-Sb Ternary System, Master Thesis, University of Belgrade, Technical Faculty Bor, Serbia, (2007).

UDK: 622.24.05(045)=20 DOI:10.5937/MMEB1402123S

Ljubinko Savić[*], Nebojša Vidanović[**], Rade Tokalić[**]

STUDYING THE EFFECTS OF BOREHOLE LENGTH ON THE IMPACT DRILLING SPEED IN DIFFERENT ROCKS

Abstract

The performed tests in this work include a wide range of rock masses of the Kopaonik massive of different strength (f = 2.3 - 16). Drilling was done with drill hammers VK-24 and RK-21 at optimum sharpening angle with different drill rod lengths (0.8, 1.2, 1.6, 2.4 and 3.2). Compressed air pressure is 0.60 MPa and diameter of drilling chisel d = 32 mm. The obtained results and analysis indicate that it is possible to determine the interdependence between the borehole length and drilling speed. The results of these tests are shown in Tables 1, 2, 3 and 4 and diagrams 1, 2, 3 and 4.

Keywords: *drill hammer, drill chisel, drilling speed, rock massive, borehole length*

INTRODUCTION

Drilling speed is also the function of drilling length because the energy losses are increased by the increase of borehole length during transmission over more and longer drill rod. The increase of drill rod length causes the increase of its mass, which makes the process of turning more difficult, and, as a direct consequence, the piston moves back slowly, what extends the time of one cycle, and therefore has an impact on the number of strikes. All of this has an impact on the extent of rock mass destruction at the borehole head, and thus on drilling speed, expressed in some value of units.

The relation between the borehole length and drilling speed is not so simple and depends on many factors but it is possible to establish a way in which these relations move using the experimental forms. For example, according to the research, in the former Soviet Union, carried out by the Institute Vugi it is possible to use the empirical form:

$$V = Vo \cdot (1.06 - 0.04 \cdot \ell)$$

Where:

- V - speed that is required if the borehole length is ℓ,
- Vo - speed developed at 1.5 m. This speed is often taken as the initial drilling speed.

The current research in this field shows that it is the most reliably to perform the experimental research on the basis of the results, for each operating environment and operation mode, to determine correlations between changes in speed in relation to the change in borehole length and change of hammer drill. It can be seen from the above mentioned what is the impact of borehole length on drilling speed.

CONDITIONS OF CARRIED OUT TESTS

The tests were carried out in different areas of the rock massif Kopaonik. The rocks and minerals of different strength

[*] *University of Pristina, Faculty of Technical Science, K. Mitrovica, ljsavic@open.telekom.rs*
[**] *University of Belgrade, Faculty of Mining and Geology, vidanovic@rgf.ac.rs, tokalic@rgf.ac.rs*

(f =2.3-16) were tested. Drilling of boreholes was performed by drill hammers VK-24 and RK-21 with diameter of drill bit blade d = 32 mm and the air pressure 0.6 MPa. The standard drill rods (SANDVIK COROMANT), length (0.8, 1.2, 1.6, 2.4, and 3.2) were adopted for testing.

ANALYSIS OF THE OBTAINED RESULTS

Based on the results for each drill hammer and every working environment, the dependences between the drilling speed and borehole length are calculated. Based on the results from the working environments, the integral dependences are given for each parameter and corresponding drill hammer. The used data for this calculation and their graphical and analytical interpretations are presented in Tables 1 and 2 and diagrams 1 and 2.

Drilling speed depending on drill chisel length for weak rocks (f<5)

Table 1.

Chisel length *l (m)*	Drilling speed per working environments for drill hammer *RK-21* *V (cm/min)*								
	12	**10**	**11**	**13**	**1**	**4**	**2**	**6**	**9**
0.80	53.80	36.80	48.40	51.00	40.80	50.80	42.80	47.20	31.80
1.20	52.80	36.40	47.20	49.80	40.00	49.60	42.00	46.40	30.80
1.60	52.50	35.20	46.80	49.30	39.60	49.20	41.40	45.60	30.40
2.40	50.60	34.00	45.20	47.60	38.40	47.60	39.80	44.00	29.60
3.20	49.00	32.60	43.80	45.40	36.80	45.90	38.60	42.60	28.40

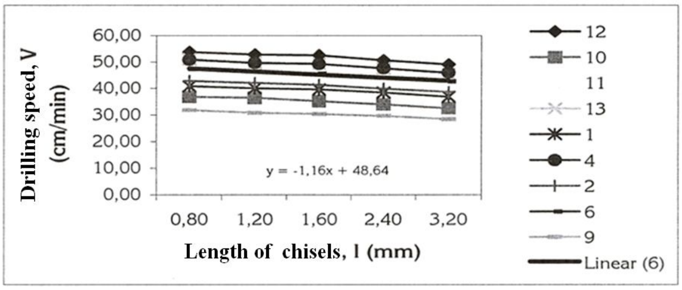


Figure 1 a *Diagram of dependence between drilling speed and drill chisel length in drilling by drill hammer RK-21, the air pressure p=0.60 MPa and drill chisel diameter d=32 mm. Drilling speed depending on drill chisel length for weak rocks (f<5).*

Drilling speed depending on drill chisel length for hard rocks (f>5)

Continuation of Table 1

Chisel length *l (m)*	Drilling speed per working environments for drill hammer *RK-21* *V (cm/min)*							
	7	**5**	**3**	**16**	**15**	**17**	**14**	**8**
0.80	36.80	39.20	32.00	38.80	33.70	24.20	27.00	21.00
1.20	36.40	38.40	31.40	38.00	33.00	24.80	26.50	20.80
1.60	35.30	37.80	30.60	37.50	32.70	23.50	26.30	20.30
2.40	33.90	36.60	29.80	36.40	31.40	22.70	25.40	19.40
3.20	32.80	35.80	28.60	35.20	30.50	21.50	24.20	18.60

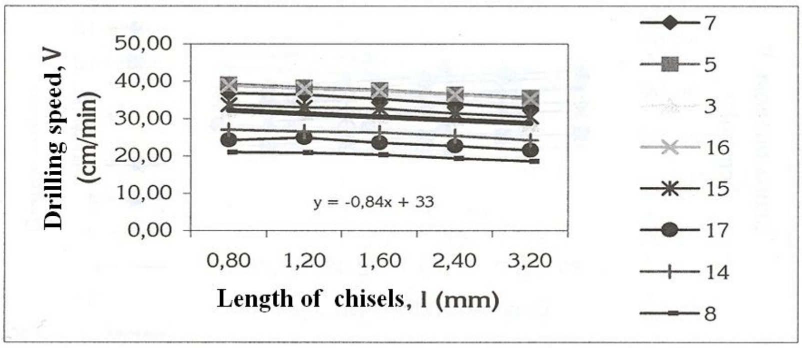


Figure 1 b *Diagram of dependence between drilling speed and drill chisel length in drilling by drill hammer RK -21, the air pressure of p=0.60 MPa and drill chisel diameter d=32 mm. Drilling speed depending on drill chisel length for hard rocks (f>5)*

Drilling speed depending on drill chisel length for weak rocks (f<5)

Table 2

Chisel length ***l (m)***	**Drilling speed per working environments for drill hammer** ***VK-24*** ***V (cm/min)***								
	12	**10**	**11**	**13**	**1**	**4**	**2**	**6**	**9**
0.80	67.80	42.60	55.80	65.00	52.00	65.40	55.20	60.60	37.20
1.20	66.80	41.40	54.60	64.20	50.80	64.00	54.60	59.80	36.60
1.60	65.40	40.80	53.80	62.40	50.20	62.80	53.40	58.40	35.80
2.40	63.20	39.60	52.20	60.80	48.80	60.20	51.80	56.00	34.60
3.20	61.40	37.80	50.60	58.60	47.20	58.20	50.00	54.60	33.20

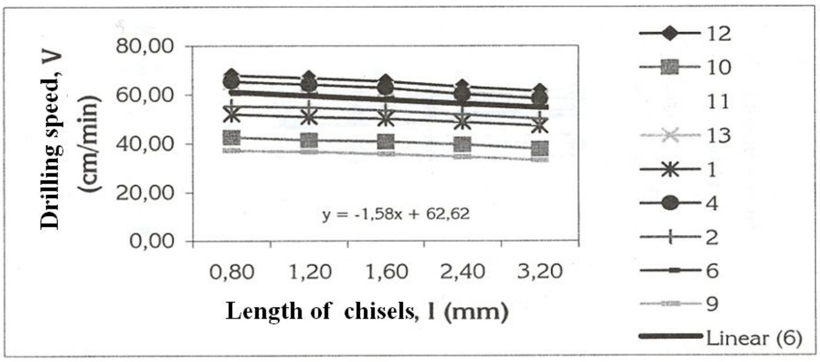


Figure 2 a *Diagram of dependence between drilling speed and drill chisel length in drilling by drill hammer VK -24, the air pressure p=0.60 Mpa and drill chisel diameter d=32 mm. Drilling speed depending on drill chisel length for weak rocks (f<5)*

Drilling speed depending on drill chisel length for hard rocks (f>5)

Continuation of Table 2

Chisel length *l (m)*	Drilling speed in working environments for drill hammers *VK-24* *V (cm/min)*							
	7	5	3	16	15	17	14	8
0.80	47.10	46.60	37.90	43.20	37.60	28.80	33.60	23.80
1.20	46.80	45.80	37.50	42.80	37.00	28.40	33.00	23.00
1.60	45.60	45.10	36.80	42.30	36.80	28.00	32.50	22.50
2.40	44.20	43.80	35.20	40.60	35.60	27.20	31.20	21.40
3.20	42.80	42.20	33.80	39.00	34.40	26.00	30.00	20.40

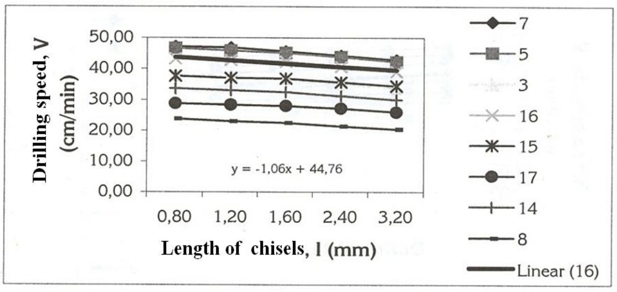


Figure 2 b *Diagram of dependence between drilling speed and drill chisel length in drilling by drill hammer VK -24, the air pressure p=0.60 MPa and drill chisel diameter d=32 mm. Drilling speed depending on drill chisel length for hard rocks (f>5)*

CONCLUSION

With increasing borehole length, the need for longer length of drilling chisels increases, which also implies higher weight. All of these increase the resistance to the drilling chisel rotation, makes difficult cleaning the borehole and increase the energy transfer losses from piston to the drill crown blade. These resistances and losses directly impact the drilling speed showing a tendency to decrease after increasing the drilling length. Based on the obtained results, it can be concluded that dispersal of data, in an integrated setting of all tested environments is high what is the reason of a large range of mechanical properties of tested environments, and changing their changeable behavior when it comes to the resistance on drilling.

The obtained results and their analysis indicate that it is possible to determine the interdependences between the above mentioned parameters.

REFERENCES

[1] Lj. Savić, The Effect of the Most Important Parameters of Chisel in Impact Drilling on the Speed of Borehole Development for Conditions in the Mines Zuta Prla, RGF Belgrade, 1990;

[2] P. Jovanović, Development the Mining Workings, RGF Belgrade, 1990;

[3] Lj. Savić, The Effect of Technological Parameters on the Speed of Rotary Impact Drilling in Hard Rocks, RGF Belgrade, 2003;

[4] P. Jovanović, Mechanical Procedures of Rock Destruction During Mining Operations RGF Belgrade, 1980;

[5] Brochures of Drilling Rig Manufacturers;

[6] M. A. Kobiliska, General Mining Operations, Gradjevinska knjiga

INSTITUT ZA RUDARSTVO I METALURGIJU BOR ISSN: 2334-8836
UDK: 622

UDK: 622.24.05(045)=861 DOI:10.5937/MMEB1402123S

Ljubinko Savić, Nebojša Vidanović**, Rade Tokalić***

PROUČAVANJE UTICAJA DUŽINE BUŠOTINE NA BRZINU UDARNOG BUŠENJA U RAZLIČITIM STENAMA

Izvod

Ispitivanja koja su izvršena u okviru ovog rada obuhvataju široku lepezu stenskih masa Kopaoničkog masivva različite čvrstoće (f=2,3 – 16). Bušenje je vršeno sa bušaćim čekićima VK-24 i RK-21, sa optimalnim uglom oštrenja sa različitim dužinama bušaće šipke (0.8, 1.2, 1.6, 2.4 i 3.2). Pritisak sabijskog vazduha 0,60 MPa, prečnik bušećeg dleta d=32 mm. Dobijeni rezultati i njihova analiza ukazuju da je moguće utvrditi međusobne zavisnosti između dužine bušotine i brzine bušenja. Dobijeni rezultati ovih istraživanja prikazani su u tabelama1, 2, 3 i 4 i diijagrama 1, 2, 3 i 4.

Ključne reči: *bušaći čekić, bušeće dleto, brzina bušenja, stenska sredina, dužina bušotine*

UVOD

Brzina bušenja funkcija je i dužine bušotine, jer sa povećanjem dužine bušotine povećavaju se gubici energije prilikom prenosa kroz sve dužu i dužu bušaću šipku. Isto tako sa povećanjem dužine šipke bušećeg dleta povećava se i njena masa, što otežava proces zaokretanja, a kao direktna posledica javlja se sporije kretanje klipa unazad, što produžava vreme jednog ciklusa, pa samim tim ima uticaja i na broj udara. Sve ovo zajedno ima svog uticaja na obim razaranja stenske mase na čelu bušotine, pa samim tim i na brzinu bušenja izraženu kroz neku od vrednosnih jedninica.

Zavisnost između dužine bušotine i brzine bušenja nije tako jednostavno i zavisi od mnogih činilaca ali je pomoću eksperimentalnih obrazaca moguće ustanoviti relaciju u kojima se ovi odnosi kreću. Tako na primer, prema istraživanjima u bivšem Sovjetskom Savezu izvršeni od strane Instituta Vugi kod ovih proučavanja moguće je korisititi empirijski obrazac:

$$V = V_o\,(1{,}06 - 0{,}04 \cdot \ell)$$

gde su:

V - brzina koja se traži ako je dužina bušotine, ℓ,

Vo - brzina koja se postiže od 1,5 m. Ova brzina se često uzima i kao početna brzina bušenja.

Aktuelna istraživanja u ovoj oblasti pokazuju da je najpouzdanije izvršiti ogledna istraživanja i na osnovu rezultata, za svaku radnu sredinu i režim rada ustanoviti korelacione odnose između promene brzine u odnosu na promenu dužine bušotine i na promenu bušaćeg čekića. Iz napred izloženog se vidi od kolikog je uticaja dužina bušotine na brzinu bušenja.

USLOVI POD KOJIMA SU IZVRŠENA ISTRAŽIVANJA

Istraživanja su obavljena u različitim stenskim sredinama Kopaoničkog masiva. Ispitivane su stene i rude različite čvrstoće

* *Univerzitet u Prištini, Fakultet tehničkih nauka, K. Mitrovica, ljsavic@open.telekom.rs*
** *Univerzitet u Beogradu, Rudarsko-geološki fakultet, vidanovic@rgf.ac.rs, tokalic@rgf.ac.rs*

(f=2.3-16). Bušenje minskih bušotina vršeno je bušaćim čekićima VK-24 i RK-21, sa prečnikom sečiva bušaće krune d=32 mm, sa pritiskom vazduha 0,6 MPpa.

Za istraživanje usvojene su standardne bušaće šipke (SANDVIK COROMANT) DUŽINE (0.8, 1.2, 1.6, 2.4 i 3.2).

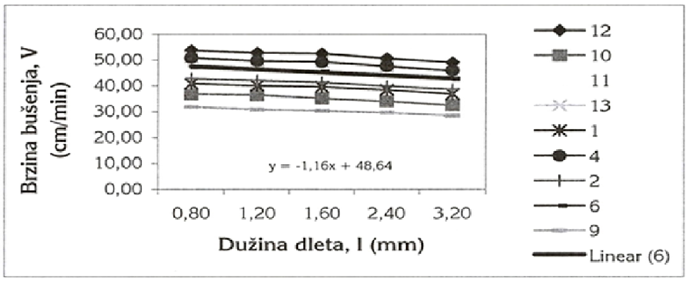
ANALIZA DOBIJENIH REZULTATA

Na osnovu dobijenih rezultata za svaki bušeći čekić i svaku radnu sredinu proračunate zavisnosti odnosa između brzine bušenja i dužine bušotine. Na osnovu pojedinačnih rezultata po radnim sredinama, za svaki parametar i odgovarajući bušaći čekić, date su integralne zavisnosti. Podaci koji su poslužili za ovaj proračun i njihove grafičke i analitičke interpretacije prikazane su u tabelama 1 i 2 i na dijagramima 1 i 2.

Brzina bušenja u zavisnosti od dužine bušaćeg dleta za slabe stene (f<5)

Tabela 1.

Dužina dleta *l (m)*	**Brzina bušenja po radnim sredinama za bušaći čekić *RK-21* *V (cm/min)***								
	12	**10**	**11**	**13**	**1**	**4**	**2**	**6**	**9**
0,80	53,80	36,80	48,40	51,00	40,80	50,80	42,80	47,20	31,80
1,20	52,80	36,40	47,20	49,80	40,00	49,60	42,00	46,40	30,80
1,60	52,50	35,20	46,80	49,30	39,60	49,20	41,40	45,60	30,40
2,40	50,60	34,00	45,20	47,60	38,40	47,60	39,80	44,00	29,60
3,20	49,00	32,60	43,80	45,40	36,80	45,90	38,60	42,60	28,40

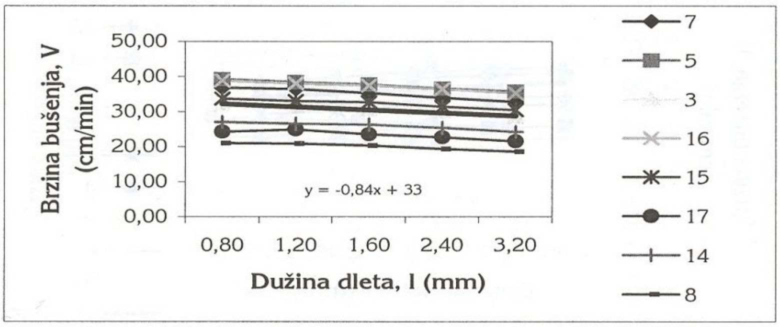


Sl. 1 a. *Dijagram zavisnosti brzine bušenja od dužine bušaćeg dleta kod bušenja bušaćim čekićem RK-21, pritisak vazduha od p=0,60 MPa i prečnikom bušaćeg dleta d=32 mm Brzina bušenja u zavisnosti od dužine bušaćeg dleta za slabe stene (f<5)*

Brzina bušenja u zavisnosti od dužine bušaćeg dleta za čvrste stene (f>5)

Nastavak tabele 1

Dužina dleta *l (m)*	**Brzina bušenja po radnim sredinama za bušaći čekić *RK-21* *V (cm/min)***							
	7	**5**	**3**	**16**	**15**	**17**	**14**	**8**
0,80	36,80	39,20	32,00	38,80	33,70	24,20	27,00	21,00
1,20	36,40	38,40	31,40	38,00	33,00	24,80	26,50	20,80
1,60	35,30	37,80	30,60	37,50	32,70	23,50	26,30	20,30
2,40	33,90	36,60	29,80	36,40	31,40	22,70	25,40	19,40
3,20	32,80	35,80	28,60	35,20	30,50	21,50	24,20	18,60

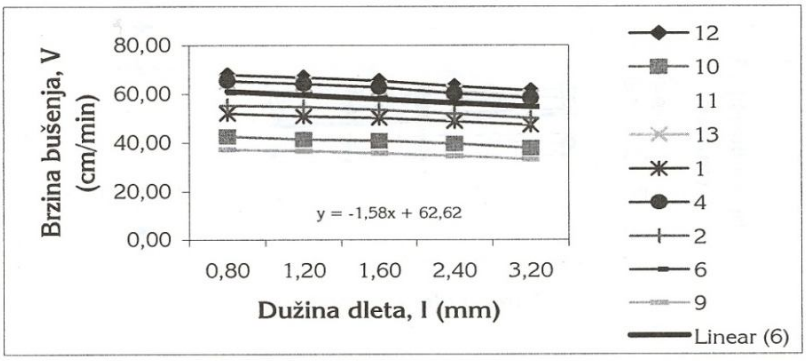


Sl. 1 b. *Dijagram zavisnosti brzine bušenja od dužine bušaćeg dleta kod bušenja bušaćim čekićem RK-21, pritisak vazduha od p=0,60 MPa i prečnikom bušaćeg dleta d=32 mm*
Brzina bušenja u zavisnosti od dužine bušaćeg dleta za čvrste stene (f>5)

Brzina bušenja u zavisnosti od dužine bušaćeg dleta za slabe stene (f<5)

Tabela 2.

Dužina dleta *l (m)*	**Brzina bušenja po radnim sredinama za bušaći čekić *VK-24*** ***V (cm/min)***								
	12	**10**	**11**	**13**	**1**	**4**	**2**	**6**	**9**
0,80	67,80	42,60	55,80	65,00	52,00	65,40	55,20	60,60	37,20
1,20	66,80	41,40	54,60	64,20	50,80	64,00	54,60	59,80	36,60
1,60	65,40	40,80	53,80	62,40	50,20	62,80	53,40	58,40	35,80
2,40	63,20	39,60	52,20	60,80	48,80	60,20	51,80	56,00	34,60
3,20	61,40	37,80	50,60	58,60	47,20	58,20	50,00	54,60	33,20

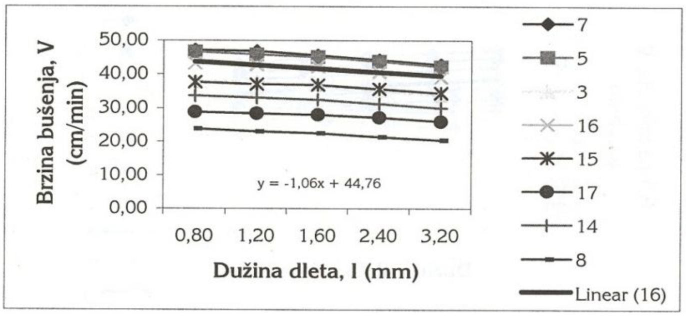


Sl. 2 a. *Dijagram zavisnosti brzine bušenja od dužine bušaćeg dleta kod bušenja bušaćim čekićem VK-24, pritisak vazduha od p=0,60 MPa i prečnikom bušaćeg dleta d=32 mm*
Brzina bušenja u zavisnosti od dužine bušaćeg dleta za slabe stene (f<5)

Brzina bušenja u zavisnosti od dužine bušaćeg dleta za čvrste stene (f>5)

Nastavak tabele 2

Dužina dleta *l (m)*	**Brzina bušenja po radnim sredinama za bušaći čekić** ***VK-24*** ***V (cm/min)***							
	7	**5**	**3**	**16**	**15**	**17**	**14**	**8**
0,80	47,10	46,60	37,90	43,20	37,60	28,80	33,60	23,80
1,20	46,80	45,80	37,50	42,80	37,00	28,40	33,00	23,00
1,60	45,60	45,10	36,80	42,30	36,80	28,00	32,50	22,50
2,40	44,20	43,80	35,20	40,60	35,60	27,20	31,20	21,40
3,20	42,80	42,20	33,80	39,00	34,40	26,00	30,00	20,40



Sl. 2 b. *Dijagram zavisnosti brzine bušenja od dužine bušaćeg dleta kod bušenja bušaćim čekićem VK-24, pritisak vazduha od p=0,60 MPa i prečnikom bušaćeg dleta d=32 mm*
Brzina bušenja u zavisnosti od dužine bušaćeg dleta za čvrste stene (f>5)

ZAKLJUČAK

Sa povećanjem dužine bušotine povećava se i potreba za većom dužinom bušećeg dleta, što za sobom povlači i veću njegovu težinu. Sve ovo povećava otpor prema obrtanju bušaćeg dleta, otežava čišćenje bušotine i uvećava gubitke prenosa energije od klipa do sečiva bušaće krune. Ovi otpori i gubici direktno utiču na brzinu bušenja, koja se povećanjem dužine bušenja pokazuje tendenciju pada. Na osnovu dobijenih rezultata moguće je zakljuciti da je osipanje podataka, kod integralnog postavljanja svih ispitivanih sredina, veliko što je razlog veliki raspon mehaničkih karakteristika ispitivanih sredina, i njihovo promenljivo ponašanje, kada je u pitanju otpor prema bušenju.

Dobijeni rezultat i njihova analiza ukazuju da je moguće utvrditi međusobne zavisnosti između napred navedenih parametara.

LITERATURA

[1] Lj. Savić, Uticaj najvažnijih parametara dleta kod udarnog bušenja na brzinu izrade minske bušotine za uslove rudnika Žuta Prla, RGF Beograd, 1990.

[2] P. Jovanović, Izrada jamskih prostorija, RGF Beograd, 1990.

[3] Lj. Savić, Uticaj tehnoloških parametara na brzinu udarno zaokretnog bušenja u čvrstim stenama, RGF Beograd, 2003.

[4] P. Jovanović, Mehanički postupci razaranja stena pri izvođenju rudarskih radova RGF, 1980.

[5] Prospekti proizvođača opreme za bušenje

[6] M. A. Kobiliška, Opšti rudarski radovi, Građevinska knjiga

MINING AND METALLURGY INSTITUTE BOR ISSN: 2334-8836
UDK: 622

UDK: 622.36/.765(045)=20 DOI:10.5937/MMEB1402131R

Dragan S. Radulović[*], Slavica R. Mihajlović[*], Živko T. Sekulić[*], Dušica R. Vučinić[**]

DEFINITION THE TECHNOLOGY METHOD OF APATITE FLOTATION CONCENTRATION FROM THE PHOSPHATE DEPOSIT ”LISINA“[***]

Abstract

This paper presents the importance of phosphate in the world, and the problems that arise in the process of preparing the low-grade phosphate ore for obtaining the phosphate concentrate using the flotation concentration. The apatite concentrates are obtained using the selective flotation from the silicate and oxide minerals while defining the process of selective flotation of apatite from carbonate deposits is the major problem worldwide.

The experimental part of this paper presents the results of laboratory flotation tests of phosphate ore from the surface part of the location "Panjevica" of the deposit "Liina". The results have enabled definition of the flotation process in continuous conditions of work.

***Keywords**: apatite, calcite, selective flotation concentration, defining the technological method*

INTRODUCTION

Increase the use of phosphate as mineral, and also products derived from phosphate in the economies of all countries of the world, classifies this mineral in strategic raw materials. Phosphates are mostly used in the chemical industry for production of fertilizers around 85%, then 5% is used as feed additive, and the other 10% of consumption of phosphorus in the chemical industry for other purposes [1]. The artificial phosphate (mineral) fertilizers are produced in chemical industry based on the ore or phosphate concentrate, the use of which is on the basis for achieving the yield and production of sufficient quantities of food to provide nutrition rapidly growing world population. The importance of phosphorus for living world is reflected in the fact that participates in the structure of nucleic acids, phospholipids, in the plants used to participate in transformation of sugars, proteins and other compounds [1, 2].

By regional geological explorations, the phosphorites in metamorphic Serbian-Macedonian mass were discovered in 1959 in the territory of Bosilegrad (southeastern of Serbia). In the period from 1959 to 1966, detailed geological explorations of phosphorite

[*] *Institute for Technology of Nuclear and Other Mineral Raw Materials, Franchet d'Esperey 86, 11000 Belgrade, Serbia, e-mail address: d.radulovic@itnms.ac.rs*

[**] *University of Belgrade, Faculty of Mining And Geology, Djušina 7, 11000 Belgrade, Serbia*

[***] *This paper is the result of research on the project TR 34013 "Development of Technological Processes for Obtaining the Ecological Materials Based on Non-metallic Minerals" and the Project TR 31003 "Development of Technologies and Products Based on Mineral Raw Materials and Waste Biomass for Protection ff Natural Resources for Safe Food Production", funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia for the period 2011-2014.*

deposit were carried out in order to establish the ore reserves, and technological studies were carried out in parallel with this work [1-3]. The last evaluation of reserves is at 100 million tones with average P_2O_5 content of 9.26%. As the U.S. have given for the highest production of phosphates and fertilizers (25-40% of world production) to those imposed quality standards and that eventually became generally accepted. For the production of fertilizer in the United States, are using different qualities of concentrate, whereby the quality of the determined content of tricalcium phosphate $Ca_3\ (PO_4)_2$ (TCP), or BPL (Bone Phosphate of Lime). In the U.S. there are three classes of quality concentrate of 74-70% TCP, TCP from 70-66%, and less than 66% of TCP. In addition, the quality of concentrate is defined over P_2O_5 content of which is considered that it should be more than 30% (corresponding to the content of about 66% TCP). Production of fertilizer quality ore and concentrate, in addition to the content of P_2O_5, is defined by the content of other components, as well as their relationship: R_2O_3 max 2,5-4,0%; Cl_2 max 0.13%; MgO max 0.25%; CaO: P_2O_5 max 1.8; P_2O_5: F min 8:1 [4].

Methods of preparation which provide phosphate rock market quality, are differ significantly in the phases of process, depending on the P_2O_5 content in the ore, ore type, content of gangue, etc. Simple methods of preparation, such as washing, slurry and classification are applied for high-grade ore. However, due to the long-term exploitation of phosphate, which is more than a hundred and fifty years, the reserve of the high-grade deposits are largely reduced [2, 4, 5]. A significant share is exploitation of a low-grade phosphate ore, which as such cannot be used without the use of sophisticated methods of preparation. In the process of preparing the low-grade ore is necessary to increase the content of P_2O_5 and achieve the most favorable ratio CaO: P_2O_5, so in the flotation concentration is usually applied for this ore, and other forms of concentration [2, 4]. Today, more than two-thirds of the world phos phates concentrate market quality obtained by the method of pre flotation in which the oxide and silicate minerals are present as minerals of tailings. Preparation of phosphate ore of sedimentary origin from the high content of carbonate is a worldwide problem and the appropriate technology at the industrial scale does not exist [6]. Since most of the world reserves of phosphate (about 80% or more) are in the form of carbonate sedimentary ore, the goal of a large number of studies in the laboratory and pilot-plant conditions, is to determine the separation of carbonate phosphate flotation process. Poorly soluble salt type minerals, such as apatite ($Ca_5(PO_4)_3$) (F, OH), fluorite (CaF_2), calcite ($CaCO_3$), scheelite ($CaWO_4$), magnesite ($MgCO_3$), barite ($BaSO_4$), are natural hydrophilic [2, 7, 8]. These minerals can be successfully separated from the oxide and silicate minerals by flotation process. However, based on the results from literature, it can be said that it is difficult to determine the conditions of mutual separation of salt-type minerals (e.g. apatite from calcite) of flotation process. As the reasons are similar physicochemical properties of these minerals, a partial solubility in water, the adsorption characteristics, or a similar affinity to the flotation reagents [2, 9]. Especially is a large influence of chemical composition of the pulp and the ionic strength of solution, since it leads to the partial dissolution of minerals and salts of the type of playing a large number of reactions in solution. Development of these reactions in solution (pulp) may be affected by preparation method of mineral raw materials prior to flotation (grinding, grading, conditioning ...). Therefore, the surface properties of minerals from the group of apatite and associated minerals in the ore, and because of that the efficiency of the process of flotation, are significantly influenced by a complex interaction of the system before and during flotation. Accordingly, the selective flotation of phosphate is much easier to reach the ore in which silicates are present, then from the carbonate ore tailings.

The active anionic and cationic active collectors are used for minerals of salt type. The fatty acids and their salts (soaps) from the group of anionic active oxidrill collector are commonly used for this group of minerals. Successful flotation of minerals from this group with the said collectors is achieved according to the literature data, without activating [2, 4, 7, 10-14]. As deprimators of minerals from this group are used sodium silicate, or quebracho tannin (containing 70% of tannic acid), aluminum sulfate, citric acid, dextrin, starch, alkali cellulose sulphate. If it is necessary, the salts of heavy metals, calcium and magnesium ions can be used as activators

EXPERIMENTAL WORK

Preparation of Sample

The sample of ore weight 2,000 kg comes from the surface part of the deposit, "Lisina" - Panjevica location. The written scheme of sample preparation of the apatite ore "Lisina" for separation the sample for laboratory and subsequent semi-industrial tests of ore is shown in Figure 1.

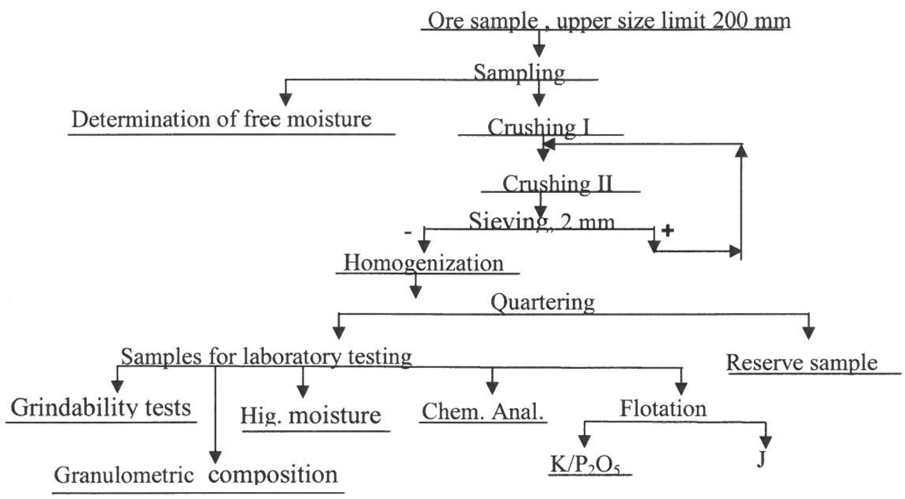


Figure 1 *The written scheme of sample preparation for phosphate ore for technological testing*

Methods and Reagents

Characterization of ore samples was carried out using the methods of chemical analysis and qualitative microscopic mineralogical analysis. HCl, NaOH and Na_2CO_3 (soda ash) were used as the reagents for regulating the pH. Na-oleate of analytical grade was applied as a collector. Tannin and Na_2SiO_3 (water glass) were used for calcite deprimating. Laboratory experiments of hydroxyapatite flotation of ore were carried out using the classical method of foam flotation in a laboratory flotation machine "Denver" D-12, with a cell volume V = 2.8 l. The floated sample these experiments, is previously prepared by wet milling process (S: L = 1: 0.43) up to 85% of fines -0.074 mm. The method and determined mode of reagents are given in a form of section of technological scheme in the part: Results and Discussion.

RESULTS AND DISCUSSION

Basic Characteristics of the Ore Phosphate Sample - Lisina

Chemical analysis: The results of chemical analysis of phosphate ore samples are given in Table 1.

Table 1 *Chemical composition of raw phosphate ore samples "Lisina" locality "Panjevica"*

Component	P_2O_5	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	S	G. Ž.	U
Content, %	16.33	34.48	2.40	7.74	0.30	30.40	0.30	0.25	2.45	0.65	4.35	6.00 ppm

Mineralogical analysis: Qualitative microscopic mineralogical analysis showed that in a sample of ore, in addition to hydroxyapatite, are present: quartz, sericite, calcite, biotite with chlorite, fine grained epidote, tourmaline, opaque minerals-organic matter, dolomite, limonite and hematite.

Laboratory Experiments of Flotation

These tests have confirmed the preferred reagent regime and gave an insight into the impact of increased of solid phase in the process of conditioning and flotation from 25 to 35% and therefore the possible changes in technological scheme. The method and regime of reagents, at which the optimal results were obtained by the flotation, is present as written in technological scheme in Figure 2.

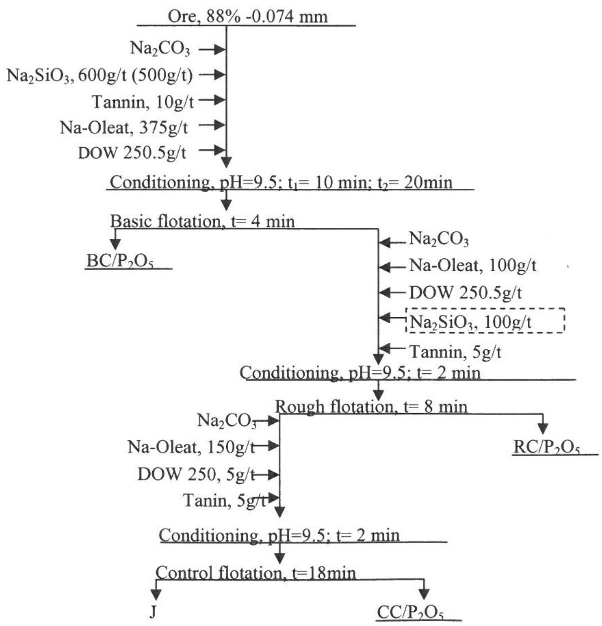


Figure 2 *Schematic presentation the method and reagent regime applied in the experiments of conditioning and flotation*

Scheme for carrying out the experiments 1 and 2 is different, because that in the experiment 1 during of the conditioning prior to basic flotation, is 10 minutes, and in experiment 2 that time was 20 minutes. Also, in experiment 1 the total amount of deprimate Na_2SiO_3 than 600 g /t is added to the conditioning before flotation, and in the experiment 2 in two portions of conditioning before flotation 500g/t and conditioning prior to coarse flotation was 100g /t.

After completion of all experiments, the products were dried, weighed, and samples were given to the chemical analysis. The results of chemical analysis are shown in Table 2 in the form of balance sheet.

Table 2 *Balance sheets of flotation tests*

Products		M,%	P_2O_5, %	Fe_2O_3, %	I P_2O_5,%	I Fe_2O_3,%
Test 1	**BC**	29.09	35.500	0.695	61.77	9.35
	RC	18.15	27.450	0.971	29.80	8.15
	BC + RC	47.24	32.407	0.801	91.57	17.51
	CC	10.51	11.300	2.283	7.10	11.10
	BC+ RC+ CC	57.75	28.57	1.07	98.67	27.61
	Tailings	42.25	0.525	3.651	1.33	71.39
	Input	100.00	16.719	2.16	1671.9	216.11
Test 2	**OK**	30.75	33.200	0.737	61.94	10.38
	GK	17.59	28.020	0.956	29.90	7.70
	OK + GK	48.34	31.315	0.817	91.84	18.08
	KK	10.18	10.440	2.355	6.44	10.98
	OK + GK+ KK	58.52	27.68	1.08	98.28	29.06
	Tailings	41.48	0.683	3.734	1.72	70.94
	Input	100.00	16.485	2.18	100.00	100.00

Based on the results shown in Table 2, it can be concluded as follows:

- Applying the flotation method, given in Figure 2, the best results are obtained both in terms of P_2O_5 and in terms of mineral content in tailings. The P_2O_5 content in the base concentrate (BC) in the experiment 1 is 35.50%, while in the experiment 2 BC is 33.20%. Total concentrate (BC+RC) in the experiment 1, P_2O_5 content is 32,407% and in the experiment 2 is 31,315 P_2O_5), thereby is the use of P_2O_5 in aggregate concentrates in both experiments over 91.50%.
- The content of Fe_2O_3 in both pooled concentrate was low; in the experiment 1 BC+RC is 0.801% Fe_2O_3, and in experiment 2 BC+RC is 0.818% Fe_2O_3.
- Regarding the control concentrate CC their quality is lower in terms of P_2O_5 content than feed grade (CC in the experiment 1, is 11.30% P_2O_5, and in the experiment 2 is 10.44% P_2O_5). Utilization of P_2O_5 in the BC experiments 1, is 7.10%, while the content of Fe_2O_3 2.283%. Utilization of P_2O_5 in the BC experiments 2 is 6.44%, while the content of Fe_2O_3 2.355%. Based on the obtained results it can be seen that the

content of Fe_2O_3 in the control concentrates of both experiments is higher than the content of incoming raw material which is 2.16%.

- P_2O_5 content in tailings is also very low, 0.525% in the experiment 1, and 0.683 in the experiment 2, so on the basis that the loss of P_2O_5 in the tailings very low 1.33 and 1.72%.
- In comparison of these two experiments, it is shown that the achieved better quality of primary concentrates is in the experiment 1, 35.50% P_2O_5, when there is less time for the basic conditioning phase of flotation (10 min. in the experiment1 and in the experiment 2, 20 minutes, compared to the experiment 2 when the quality of the concentrate is 33.20% P_2O_5. From this, it can be concluded that the extended time of conditioning can lead to desorption of oleate from the surface of apatite and since the concentrate of the basic 2 BC mass is greater than about 1.7 to 1%, that the conditioning time with prolonged activation occurs and the surfaces tailings content of concentrate. Due to the use of P_2O_5 in these two concentrates is almost the same, and the amounts of 61.77% and 61.94%, and the quality are different.

Based on the laboratory tests, and the obtained results (Table 2), it is defined by technological scheme of semi-industrial process and shown in Figure 3.

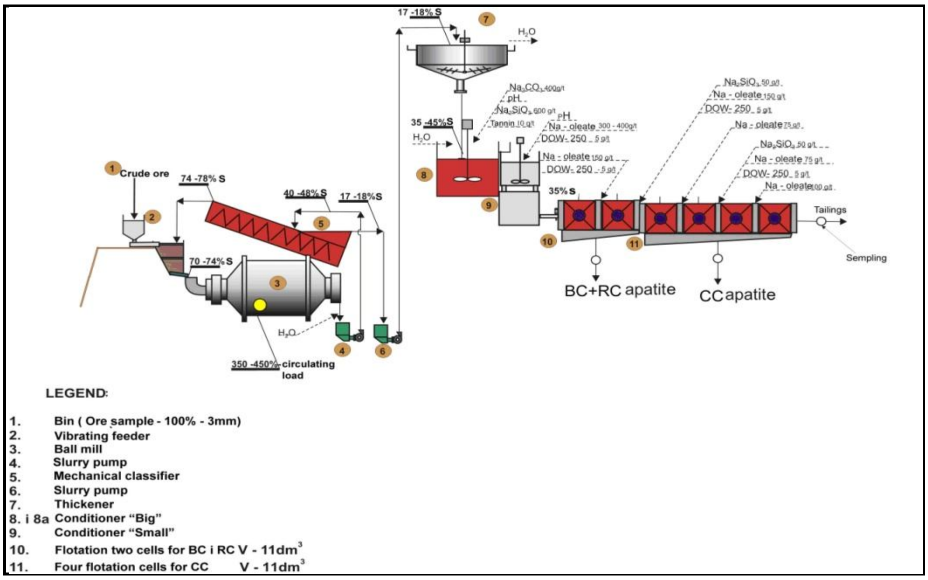


Figure 3 *Defined technological flotation scheme of apatite from phosphate ore "Lisina" in semi-industrial conditions of operation*

CONCLUSION

Phosphate is a strategic raw material in the international framework necessary for production of fertilizers and consequently food. Due to the long-term exploitation, the high-grade phosphate deposits were exhausted, and the deposits with lower P_2O_5

content of concentrates obtained by flotation. As the salt minerals (primarily calcite $CaCO_3$ and magnesite $MgCO_3$) are often found in mineral paragenesis with apatite, the method of its selective flotation from these ores is very complicated and sometimes impossible.

Based on the results presented in this paper, it can be concluded that the experiments of flotation were resulted into obtaining the concentrates of a good quality. Namely, the content of P_2O_5 in the basic experiment 1 the concentrate, is 35.50%, a P_2O_5 content summaries in the experiment 2 was 33.20%. The content of P_2O_5 in the block 1 is concentrate of the experiment, while 32.407% of the experiment 2 was 31.315%. Utilization of P_2O_5 in the group concentrates both experiments is over then 91.5%. Also, in both experiments were successfully depressed iron minerals. The content of Fe_2O_3 in each batch of concentrate is about 0.8%, which is far less than 1.5% as prescribed by the chemical industry. Slightly worse results of the experiment 2, in terms of quality concentrates, can be attributed to the prolonged period of conditioning that occurs due to desorption from the surface of collector apatite and activation of surface minerals and their tailings to concentrate. The results of the experiments were used as the basis for defining the technological process of phosphate in the semi-industrial conditions.

REFERENCES

[1] D. S. Radulović, D. Vučinić, M. Stojanović, B. Ivošević, D. Todorović, V. Jovanović, Z. Bartulović: “Improvement the Technological Method of Apatite Flotation from Phosphorous Ore "Lisina" Increasing the Content of Solid Phase from 25 to 35% in Laboratory and Semi-industrial Conditions", Technical-Technological Solution M84, 2013 (in Serbian);

[2] D. S. Radulović: “The Effect of Apatite and Calcite Ions in their Surface Properties", PhD Thesis, Faculty of Mining and Geology, University of Belgrade, 2011 (in Serbian);

[3] S. Milošević, D. Radulović, B. Ivošević, V. Antanasković, D. Vidanović, V. Djošić, Feasibility Study: “Exploitation of Phosphorous Ore from the Deposit "Lisina" near Bosilegrad and Production of Phosphorous Concentrate (K/P2O5) of Market Quality” Book 2: “Primary Processing of Phosphorous Ore "Lisina" - Production of Phosphate Concentrate (K/P2O5) of Market Quality”, Technological-Mechanical Part:, Archives of ITNMS, Belgrade, 2008 (in Serbian);

[4] J. Pavlica, D. Draškić: “Mineral Processing of Non-metallic Mineral Resources”, Faculty of Geology and Mining, Belgrade 1997;

[5] A. Z. M. Abouzeid, Int. J. Miner. Process. 85 (2008) 59–84;

[6] M. Prasad, A. K. Maajmudar, T. C. Rao, SME Min. Metall. Process. 17 (1), (2000) 49–55;

[7] N. Ćalić: “Theoretical Basis of Mineral Processing”, Belgrade, 1990;

[8] H. Sis, S. Chander, Minerals Engineering 16 (2003) 577–585;

[9] P. Somasundaran, B. Markovic, Interfacial Properties of Calcium Phosphates. In: Amjad, Z. (Ed.), Calcium Phosphates in Biological and Industrial Systems. Kluwer Academic Publishers, Dordrecht, 1998, pp. 185-201;

[10] A. M. Gaudin,: “Flotation”, McGraw Hill Book Co, 1957;

[11] Đ. Lešić, S. Marković: “Mineral Processing”, Belgrade, 1968 (inSerbian);

[12] H. S. Hana, and P. Somasundaran: ”Flotation of Salt-Type Minerals”, in M. C. Fuerstenau (Ed.), Flotation, A. M. Gaudin Memorial Vol.1, AIME, New York, NY, (1976), pp. 197-271;

[13] R. P. King, (Ed): "Principles of Flotation", "Semisoluble Salt Flotation", M. C. Fuerstenau, Institute of Mining and Metallurgy, Johanesburg, 1982;
[14] S. Milošević: "Flotation Concentration", Belgrade, 1994.
[15] M. Petrov, Lj. Andrić, Ž. Sekulić, V. Jovanović: Modeling the Mill Operation According to Density of Mill Batch and Specific Capacity, Mining and Metallurgy Engineering Bor, 1/2014, pp. 121-128.

INSTITUT ZA RUDARSTVO I METALURGIJU BOR ISSN: 2334-8836
UDK: 622

UDK: 622.36/.765(045)=861 DOI:10.5937/MMEB1402131R

Dragan S. Radulović, Slavica R. Mihajlović*, Živko T. Sekulić*, Dušica R. Vučinić***

DEFINISANJE TEHNOLOŠKOG POSTUPKA FLOTACIJSKE KONCENTRACIJE APATITA IZ RUDE FOSFATA „LISINA“***

Izvod

U radu je prikazan značaj fosfata u svetu, kao i problemi koji se javljaju u postupku pripreme siromašnijih ruda fosfata iz kojih se koncentrat fosfata dobija postupkom flotacijske koncentracije. Selektivnim flotiranjem aptita iz silikatnih i oksidnih ruda se dobijaju koncentrati apatita, dok definisanje postupka selektivnog flotiranja apatita iz karbonatnih ležišta predstavlja veliki problem u svetskim razmerama.

U eksperimentalnom delu ovoga rada su prikazani rezultati laboratorijskih opita flotiranja rude fosfata iz ležišta „Lisina“- sa površinskog dela -lokalitet „Panjevica“. Dobijeni rezultati su omogućili definisanje postupka flotiranja u kontinualnim uslovima rada.

Ključne reči: *apatit, kalciti, selektivna flotacijska koncentracija, definisanje tehnološkog postupka*

UVOD

Porast upotrebe fosfata kao minerala, a takodje i proizvoda dobijenih od fosfata, u privredama svih zemalja sveta, svrstava ovaj mineral u strateške sirovine. Fosfati se u najvećoj meri koriste u hemijskoj industriji za proizvodnju veštačkih djubriva oko 85 %, zatim oko 5% se koristi kao dodatak stočnoj hrani, ostalih 10 % potrošnje fosfora je u hemijskoj industrij za druge namene [1]. U hemijskoj industriji se na bazi rude ili koncentrata fosfata proizvode veštačka (mineralna) fosfatna djubriva, čija upotreba predstavlja osnov za postizanje prinosa i proizvodnju dovoljnih količina hrane koje omogućavaju prehranu ubrzano rastućeg svetskog stanovništva. Značaj fosfora za živi svet ogleda se u tome što učestvuje u gradji nukleinskih kiselina, fosfolipida, u biljkama služi da učestvuje u procesima transformacije šećera, belančevina i drugih jedinjenja [1, 2].

Regionalnim geološkim istraživanjem, na teritoriji Bosilegrada (jugoistočna Srbija) otkriveni su, tokom 1959. godine, fosforiti u metamorfitima Srpsko-makedonske mase. U period 1959-1966. god. izvršena su detaljna geološka istraživanja fosforitskog ležišta u cilju utvrđivanja rudnih rezervi, a paralelno

* *Institut za tehnologiju nuklearnih i drugih mineralnih sirovina, Franše d'Eperea 86, 11000 Beograd, Srbija, e-mail address: d.radulovic@itnms.ac.rs*

** *Univerzitet u Beogradu, Rudarsko geološki fakultet, Djušina 7, 11000 Beograd, Srbija*

*** *Ovaj rad je nastao kao rezultat istraživanja na Projektu TR 34013: „Osvajanje tehnoloških postupaka dobijanja ekoloških materijala na bazi nemetaličnih mineralnih sirovina“ i Projektu TR 31003: „Razvoj tehnologija i proizvoda na bazi mineralnih sirovina i otpadne biomase u cilju zaštite resursa za proizvodnju bezbedne hrane“, koje finansira Ministarstvo prosvete, nauke i tehnološkog razvoja Republike Srbije za period 2011-2014.*

sa ovim radovima obavljena su tehnološka ispitivanja. [1-3]. Poslednja procena rezervi je na oko 100 miliona tona sa srednjim sadržajem P_2O_5 od 9,26%. Kako su SAD-e decenijama davale najveću proizvodnju fosfata i mineralnih djubriva (od 25-40% svetske proizvodnje) to su one i nametnule standarde kvaliteta koji su vremenom postali opšte prihvaćeni. Za proizvodnju đubriva u SAD-u, se koriste različiti kvaliteti koncentrata, pri čemu je kvalitet određen sadržajem trikalcijum-fosfata $Ca_3(PO_4)_2$, (TCP), odnosno BPL (bone phosphate of lime). U SAD-u postoje tri klase kvaliteta koncentrata od 74-70% TCP, od 70-66% TCP, i manje od 66% TCP. Pored toga kvaliteta koncentrata se definiše i preko sadržaja P_2O_5 za koji se smatra da treba da bude preko 30% (odgovara sadržaju od oko 66% TCP). Za proizvodnju veštačkog đubriva kvalitet ruda i koncentrata, pored sadržaja P_2O_5, definisan je i sadržajem drugih komponenata, kao i njihovim odnosom: R_2O_3 max 2,5-4,0%; Cl_2 max 0,13%; MgO max 0,25%; $CaO:P_2O_5$ max 1,8; P_2O_5:F min 8:1 [4].

Postupci pripreme kojima se dobijaju fosfati tržišnog kvaliteta bitno se razlikuju u fazama izvođenja procesa u zavisnosti od sadržaja P_2O_5 u rudi, tipa rude, sadržaja minerala jalovine itd. Jednostavni postupci pripreme kao što su pranje, razmuljivanje i klasiranje primenjuju se kod bogatijih ruda. Međutim, zbog dugotrajne eksploatacije fosfata, koja traje više od sto pedeset godina, rezerve bogatih ležišta su u velikoj meri smanjene [2, 4, 5]. Značajan udeo u eksploataciji imaju siromašne rude fosfata, koje se kao takve ne mogu koristiti bez primene složenijih postupaka pripreme. U procesu pripreme siromašnijih ruda potrebno je povećati sadržaj P_2O_5 i postići što povoljniji odnos $CaO:P_2O_5$, pa se kod ovih ruda najčešće primenjuje postupak flotacijske koncentracije, ali i drugi vidovi koncentracije [2, 4]. Danas se više od dve trećine svetskih koncentrata fosfata tržišnog kvaliteta dobija postupkom flotiranja rude u kojoj su kao minerali jalovine prisutni oksidni i silikatni minerali.

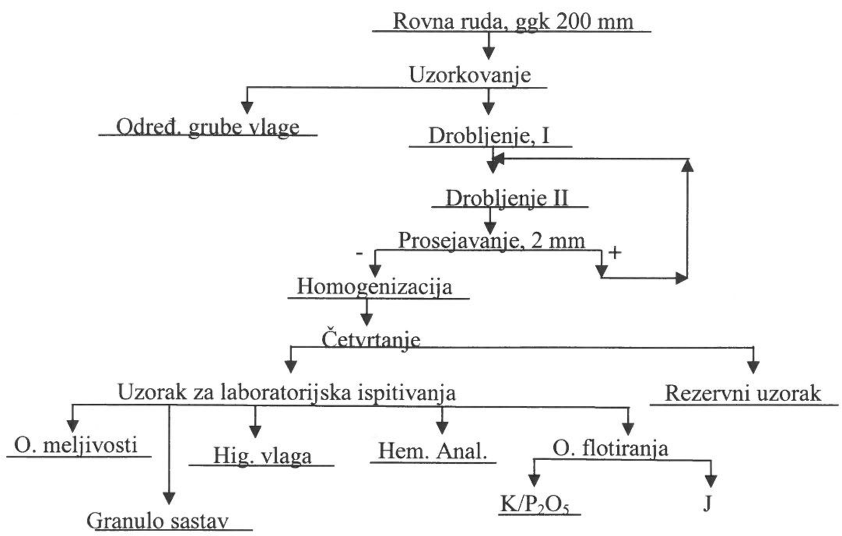
Priprema fosfatnih ruda sedimentnog porekla sa visokim sadržajem karbonata je svetski problem i adekvatna tehnologija na industrijskom nivou trenutno ne postoji [6]. Budući da je veći deo svetskih rezervi fosfata (oko 80% ili više), u obliku karbonatno sedimentnih ruda, cilj velikog broja istraživanja na laboratorijskom nivou i u pilot-postrojenjima je utvrđivanje uslova odvajanja karbonata od fosfata postupkom flotiranja. Slabo rastvorni minerali tipa soli, kao što su apatit $(Ca_5(PO_4)_3)$ (F, OH), fluorit (CaF_2), kalcit ($CaCO_3$), šelit ($CaWO_4$), magnezit ($MgCO_3$), i barit ($BaSO_4$), su prirodno hidrofilni [2, 7, 8]. Ovi minerali se mogu uspešno odvojiti od oksidnih i silikatnih minerala postupkom flotiranja. Međutim, na osnovu rezultata iz literature može se reći da je teško utvrditi uslove međusobnog razdvajanja minerala tipa soli (npr. apatita od kalcita) postupkom flotiranja. Kao uzroci navode se slične fizičkohemijske osobine ovih minerala, delimična rastvorljivost u vodi, adsorpcione osobine, odnosno sličan afinitet prema flotacijskim reagensima [2, 9]. Naročito je veliki uticaj hemijskog sastava pulpe i jonske jačine rastvora, s obzirom da dolazi do delimičnog rastvaranja minerala tipa soli i odigravanja velikog broja reakcija u rastvoru. Na odigravanje ovih reakcija u rastvoru (pulpi) može da utiče i način pripreme mineralne sirovine pre flotiranja (mlevenje, klasiranje, kondicioniranje...). Stoga na površinske osobine minerala iz grupe apatita i pratećih minerala u rudi, a samim tim i efikasnost postupka flotiranja, bitno utiču i veoma složene međusobne interakcije u sistemu pre i pri flotiranju. Shodno tome selektivno flotiranje fosfata se mnogo lakše postiže iz ruda u kojima su prisutni silikati, nego iz ruda sa karbonatnom jalovinom.

Za minerale tipa soli se koriste kako anjonski aktivni tako i katjonski aktivni kolektori. Najčešće se za ovu grupu minerala koriste masne kiseline i njihove soli (sapuni) iz grupe anjonski aktivnih okshidrilnih kolektora. Uspešno flotiranje minerala iz ove grupe sa navedenim kolektorima se prema literaturnim podacima ostvaruje bez aktiviranja [2, 4, 7, 10-14]. Kao deprimatori ove grupe minerala koriste se natrijum-silikat, tanin ili kvebračo (sadrži 70% taninske kiseline), aluminijum-sulfat, limunska kiselina, dekstrin, štirak, sulfatnocelulozna lužina, itd. Ukoliko je potrebno kao aktivatori se mogu primeniti soli teških metala, joni kalcijuma i magnezijuma.

EKSPERIMENTALNI RAD

Priprema uzorka

Uzorak rovne rude mase 2.000 kg, potiče iz površinskog dela ležišta "Lisina" - lokalitet Panjevica. Pisana šema pripreme uzorka rude apatita "Lisina" po kojoj je izdvojen uzorak za laboratorijska i za kasnija poluindustrijska ispitivanja na rudi prikazan je na slici 1.



Sl. 1. *Pisana šema pripreme uzorka rovne rude fosfata za tehnološka ispitivanja.*

Metode i reagensi

Karakterizacija uzorka rude izvršena je metodama hemijske analize i kvalitativne mikroskopske mineraloške analize. Kao reagensi za regulisanje pH sredine korišćeni su HCl, NaOH i Na_2CO_3. Kao kolektor primenjivan je Na-oleat analitičke čistoće. Za deprimiranje kalcita korišćeni su tanin i Na_2SiO_3 (vodeno staklo).

Laboratorijski opiti flotiranja hidroksiapatita iz rude su izvođeni klasičnim postupkom penaste flotacije, u laboratorijskoj flotacijskoj mašini "Denver" D-12, sa ćelijom zapremine V= 2,8 l. Uzorak koji je flotiran u ovim opitima, prethodno je pripremljene procesom mokrog mlevenja (Č:T=1: 0,43) do finoće 85% -0,074 mm.

Postupak i utvrdjeni režim reagenasa je dat u obliku tehnološke šeme u poglavlju rezultati i diskusija.

REZULTATI I DISKUSIJA

Osnovne karakteristike uzorka rovne rude fosfata - Lisina

Hemijska analiza: Rezultati hemijske analize uzorka rovne rude fosfata dati su u tabeli 1.

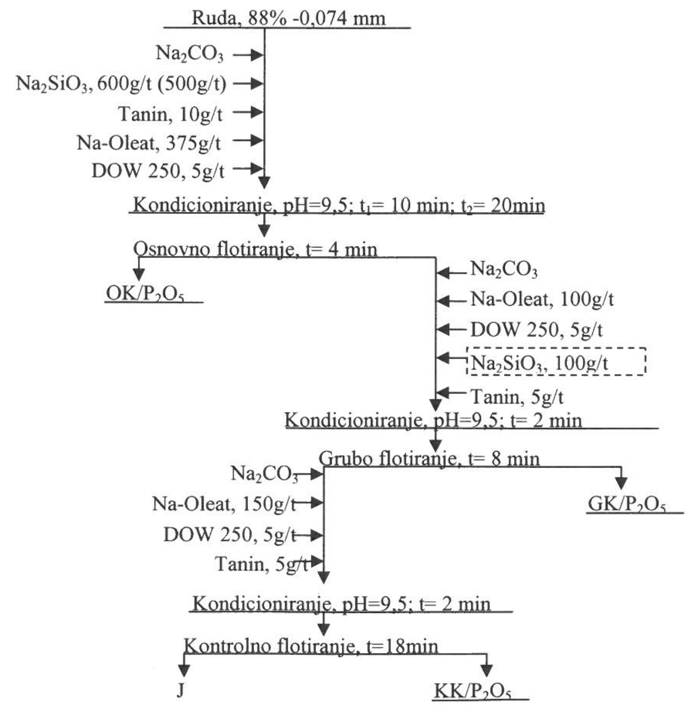
Tabela 1. *Hemijski sastav rovnog uzorka rude fosfata „Lisina“, lokalitet „Panjevica“*

Komponenta	P_2O_5	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	S	G. Ž.	U
Sadržaj, %	16,33	34,48	2,40	7,74	0,30	30,40	0,30	0,25	2,45	0,65	4,35	6,00 ppm

Mineraloška analiza: Kvalitativnom mikroskopskom mineraloškom analizom utvrđeno je da su u uzorku rude pored hidroksiapatita prisutni: kvarc, sericit, kalcit, biotit sa hloritom, sitnozrni epidot, turmalin, neprovidni minerali - organska materija, dolomit, limonit i hematit.

Laboratorijski opiti flotiranja

Ovim ispitivanjima, utvrdjen je reagentni režim i sagledavan je uticaj povećanog sadržaja čvrste faze u postupku kondicioniranja i flotiranja sa 25 na 35% i samim tim moguće izmene u tehnološkoj šemi. Postupak i režim reagenasa po kojima su dobijeni optimalni rezultati flotiranja prikazan je u obliku pisane tehnološke šeme na slici 2.



Sl. 2. *Šematski prikaz postupka i režima reagenasa primenjena u opitima kondicioniranja i flotiranja*

Šema za izvodjenje opita 1 i 2 se razlikuje u tome da je kod opita 1 vreme kondicioniranja pre osnovnog flotiranja 10 minuta, a u opitu 2 to vreme je iznosilo 20 minuta. Takodje, kod opita 1 ukupna količina deprimatora Na_2SiO_3 od 600 g/t je dodata u kondicioniranje pre osnovnog flotiranja, a kod opita 2 u dve porcije u kondicioniranje pre osnovnog flotiranja 500g/t i u kondicioniranje pre grubog flotiranja 100g/t.

Posle završetka opita flotiranja svi proizvodi su sušeni, izmereni i uzorci su dati na hemijsku analizu. Dobijeni rezultati hemijske analize su prikazani u tabeli 2 u obliku skupnog bilansa.

Tabela 2. *Bilansi opita flotiranja*

	Proizvodi	M,%	P_2O_5, %	Fe_2O_3, %	I P_2O_5,%	I Fe_2O_3,%
Opit 1	OK	29,09	35,500	0,695	61,77	9,35
	GK	18,15	27,450	0,971	29,80	8,15
	OK + GK	47,24	32,407	0,801	91,57	17,51
	KK	10,51	11,300	2,283	7,10	11,10
	OK+ GK+ KK	57,75	28,57	1,07	98,67	27,61
	Jalovina	42,25	0,525	3,651	1,33	71,39
	Ulaz	100,00	16,719	2,16	1671,9	216,11
Opit 2	OK	30,75	33,200	0,737	61,94	10,38
	GK	17,59	28,020	0,956	29,90	7,70
	OK + GK	48,34	31,315	0,817	91,84	18,08
	KK	10,18	10,440	2,355	6,44	10,98
	OK + GK+ KK	58,52	27,68	1,08	98,28	29,06
	Jalovina	41,48	0,683	3,734	1,72	70,94
	Ulaz	100,00	16,485	2,18	100,00	100,00

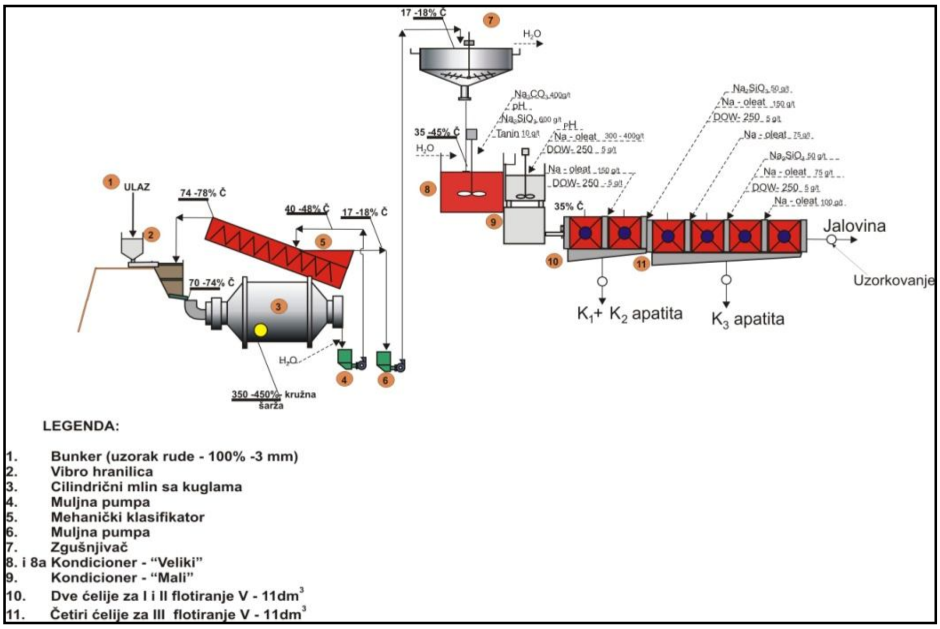
Na osnovu rezultata prikazanih u tabeli 2, može se konstatovati sledeće:

- Primenom postupka flotiranja datog na slici 2, dobijeni su najbolji rezul-tati kako u pogledu sadržaja P_2O_5, tako i u pogledu sadržaja minerala jalovine. Naime sadržaj P_2O_5 u osnovnom koncentratu (OK) opita 1 je 35,50%, dok je u OK opita 2 33,20%. U skup-nom koncentratu (OK+ GK) opita 1 sadržaj P_2O_5 je 32,407%, a u opitu 2 je 31,315 P_2O_5), pri tome je iskorišćenje P_2O_5 u skupnom koncentratu u oba opita preko 91,50%.
- Sadržaj Fe_2O_3 u oba skupna koncen-trata je nizak i u opitu 1 OK+GK je 0,801% Fe_2O_3, a u opitu 2 OK+GK je 0,818% Fe_2O_3.
- Što se tiče kontrolnih koncentrata KK njihov kvalitet je slabiji u pogledu sadržaja P_2O_5 nego u ulaznoj sirovini (KK u opitu 1 je 11,30% P_2O_5, a u opitu 2 je 10,44% P_2O_5). Iskorišćenje P_2O_5 u KK opita 1 je 7,10%, dok je sadržaj Fe_2O_3 2,283%. Iskorišćenje P_2O_5 u KK opita 2 je 6,44 %, dok je sadržaj Fe_2O_3 2,355%. Na osnovu dobijenih rezultata uočava se da je

sadržaj Fe_2O_3 u kontrolnim koncentratima oba opita veći od sadržaja u ulaznoj sirovini koji iznosi 2,16%.

- sadržaj P_2O_5 u jalovini je takođe veoma nizak, 0,525% u opitu 1 i 0,683 u opitu 2, tako da je na osnovu toga i gubitak P_2O_5 u jalovini veoma nizak 1,33 i 1,72%.
- kada se uporede ova dva opita vidi se da je postignut bolji kvalitet osnovnog koncentrata u opitu 1 35,50% P_2O_5 kada imamo kraće vreme kondicioniranja za fazu osnovnog flotiranja (10 min. u opitu 1; 20 min. u opitu 2) u odnosu na opit 2 kada je kvalitet koncentrata 33,20% P_2O_5. Iz ovoga možemo izvući zaključak da produženo vreme kondicioniranja može dovesti do desorpcije oleata sa površine apatita i pošto je osnovni koncentrat opita 2 maseno veći od OK opita 1 za oko 1,7%, da sa produženim vremenom kondicioniranja dolazi do aktiviranja površina minerala jalovine i njihovog flotiranja u koncentrat., Zbog toga je iskorišćenje P_2O_5 kod ova dva koncentrata skoro isto i iznosi 61,77% i 61,94% a kvalitet je različit.

Na osnovu izvedenenih laboratorijskih ispitivanja, i dobijenih rezultata (tabela 2) definisana je tehnološka šema poluindustrijskog procesa i prikazana je na slici 3.



Sl. 3. *Definisana tehnološka šema flotiranja apatita iz rude fosfata „Lisina" u poluindustrijskim uslovima rada*

ZAKLJUČAK

Fosfati su strateška sirovina u svetskim okvirima neophodna za proizvodnju mineralnih đubriva a samim tim i hrane. Zbog dugotrajne eksploatacije bogata ležišta fosfata su iscrpljena, a iz ležišta sa nižim sadržajem P_2O_5 koncentrati se dobijaju postupkom flotiranja. Kako se minerali tipa soli (pre svih kalcit $CaCO_3$ i magnezit $MgCO_3$) veoma često nalaze u mineralnoj paragenezi sa apatitom to je postupak njegovog slektivnog flotiranja iz ovakvih ruda veoma komlikovan a nekada i nemoguć.

Na osnovu rezultata prikazanih u ovom radu može se zaključiti da su u opitima flotiranja dobijeni koncentrati dobrog kvaliteta. Naime, sadržaj P_2O_5 u osnovnom koncentratu opita 1 je 35,50%, a sardžaj P_2O_5 opita 2 je 33,20%. Sadržaj P_2O_5 u skupnom koncentratu opita 1 je 32,407% dok je u opitu 2 31,315%. Iskorišćenje P_2O_5 u skupnim koncentratima oba opita je preko 91,5%. Takodje u oba opita su uspešno deprimirani minerali gvoždja. Naime sadržaj Fe_2O_3 u oba skupna koncentrata je oko 0,8% što je daleko manje od 1,5% koliko propisuje hemijska industrija. Nešto lošiji rezultati opita 2 u pogledu kvaliteta koncentrata mogu se pripisati produženom vremenu kondicioniranja zbog koga dolazi do desorpcije kolektora sa površine apatita kao i aktiviranja površina minerala jalovine i njihovog flotiranja u koncentrat. Rezultati opita flotiranja su poslužili kao osnova za definisanje tehnološkog postupka flotiranja fosfata u poluindustrijskim uslovima rada.

LITERATURA

[1] D. S. Radulović, D. Vučinić, M. Stojanović, B. Ivošević, D. Todorović, V. Jovanović, Z. Bartulović: "Unapredjenje tehnološkog postupka flotiranja apatita iz fosforitne rude „Lisina", povećanjem sadržaja čvrste faze sa 25 na 35%, u laboratorijskim i poluindustrijskim uslovima", Tehničko-tehnološko rešenje M84, 2013.

[2] D. S. Radulović: "Uticaj jona apatita i kalcita na njihove površinske osobine", doktorska disertacija, Rudarsko-geološki fakultet, Univerzitet u Beogradu, 2011.

[3] S. Milošević, D. Radulović, B. Ivošević, V. Antanasković, D. Vidanović, V. Đošić, Studija izvodljivosti: "Eksploatacija fosforitne rude iz ležišta "Lisina" kod Bosilegrada i proizvodnja koncentrata fosfata (K/P_2O_5) tržišnog kvaliteta" Knjiga 2: "Primarna prerada fosforitne rude "Lisina" – proizvodnja koncentrata fosfata (K/P_2O_5) tržišnog kvaliteta", Tehnolološko-mašinski deo: Arhiva ITNMS-a, Beograd, 2008.

[4] J. Pavlica, D. Draškić: "Priprema nemetaličnih mineralnih sirovina", Rudarsko-geološki fakultet, Beograd, 1997.

[5] A. Z. M. Abouzeid, Int. J. Miner. Process. 85 (2008) 59–84.

[6] M. Prasad, A.K. Maajmudar, T.C. Rao, SME Min. Metall. Process. 17 (1), (2000), pp. 49–55.

[7] N. Ćalić: "Teorijski osnovi pripreme mineralnih sirovina", Beograd, 1990.

[8] H. Sis, S. Chander, Minerals Engineering 16 (2003), pp. 577–585.

[9] P. Somasundaran, B. Markovic, Interfacial properties of calcium phosphates. In: Amjad, Z. (Ed.), Calcium Phosphates in Biological and Industrial Systems. Kluwer Academic Publishers, Dordrecht, 1998, pp. 185–201.

[10] A. M. Gaudin,: "Flotation", McGraw Hill Book Co, 1957.

[11] Đ. Lešić, S. Marković: "Priprema mineralnih sirovina", Beograd, 1968.

[12] H. S. Hana, and P. Somasundaran, "Flotation of Salt-Type Minerals", in M. C. Fuerstenau (Ed.), Flotation, A. M. Gaudin Memorial Vol. 1, AIME, New York, NY, (1976), pp. 197-271.

[13] R. P. King, (Ed): “Principles of Flotation”, “Semisoluble salt flotation”, M. C. Fuerstenau, Institute of Mining and Metallurgy, Johanesburg, 1982.

[14] S. Milošević: “Flotacijska koncentracija “, Beograd, 1994.

[15] M. Petrov, Lj. Andrić, Ž. Sekulić, V. Jovanović:Modelovanje rada mlina prema gustini šarže mlina i specifičnom kapacitetu, Mining and Metallurgy Engineering Bor, 1/2014, str. 129-136

INSTRUCTIONS FOR THE AUTHORS

Journal **MINING AND METALLURGY ENGINEERING BOR** is published four times per a year and publishes the scientific, technical and review paper works. Only original works, not previously published and not simultaneously submitted for publication elsewhere, are accepted for publication in the journal. The papers should be submitted in both, Serbian and English language. The papers are anonymously reviewed by the reviewers after that the editors decided to publish. The submitted work for publication should be prepared according to the instructions below as to be included in the procedure of reviewing. Inadequate prepared manuscripts will be returned to the author for finishing.

Volume and Font size. The work needs to be written on A4 paper (210x297 mm), margins (left, right, upper and bottom) with each 25 mm, in the Microsoft Word later version, font Times New Roman, size 12, with 1.5 line spacing, justified to the left and right margins. It is recommended that the entire manuscript cannot be less than 5 pages and not exceed 10 pages.

Title of Work should be written in capital letters, bold, in Serbian and English. Under the title, the names of authors and institutions where they work are written under the title. The author of work, responsible for correspondence with the editorial staff, must provide his/her e-mail address for contact in a footnote.

Abstract is at the beginning of work and should be up to 200 words, include the aim of the work, the applied methods, the main results and conclusions. The font size is 10, italic.

Key words are listed below abstract. They should be minimum 3 and maximum of 6. The font size is 10, italic.

Basic text. The papers should be written concisely, in understandable style and logical order that, as a rule, including the introductory section with a definition of the aim or problem, a description of the methodology, presentation of the results as well as a discussion of the results with conclusions and implications.

Main titles should be done with the font size 12, bold, all capital letters and aligned with the left margin.

Subtitles are written with the font size 12, bold, aligned to the left margin, large and small letters.

Figure and Tables. Each figure and table must be understandable without reading the text, i.e., must have a serial number, title and legend (explanation of marks, codes, abbreviations, etc.). The text is stated below the figure and above the table. Serial numbers of figures and tables are given in Arabic numbers.

References in the text are referred to in angle brackets, exp. [1, 3]. References are enclosed at the end in the following way:

[1] Willis B. A., Mineral Procesing Technology, Oxford, Pergamon Press, 1979, pg. 35. (for the chapter in a book)

[2] Ernst H., Research Policy, 30 (2001) 143–157. (for the article in a journal)

[3] www: http://www.vanguard.edu/psychology/apa.pdf (for web document)

Specifying the unpublished works is not desirable and, if it is necessary, as much as possible data on the source should be listed.

Acknowledgement is given where appropriate, at the end of the work and should include the name of institution that funded the given results in the work, with the name and number of project, or if the work is derived from the master theses or doctoral dissertation, it should give the name of thesis / dissertation, place, year and faculty where it was defended. Font size is 10, italic.

The paper works are primarily sent by e-mail or in other electronic form.

Editorial address : Journal MINING AND METALLURGY ENGINEERING BOR
Mining and Metallurgy Institute
35 Zeleni bulevar, 19210 Bor
E-mail: nti@irmbor.co.rs; milenko.ljubojev@irmbor.co.rs
Telephone: +381 (0) 30/435-164; +381 (0) 30/454-110

We are thankful for all authors on cooperation

UPUTSTVO AUTORIMA

Časopis MINING AND METALLURGY ENGINEERING BOR izlazi četiri puta godišnje i objavljuje naučne, stručne i pregledne radove. Za objavljivanje u časopisu prihvataju se isključivo originalni radovi koji nisu prethodno objavljivani i nisu istovremeno podneti za objavljivanje negde drugde. Radovi se dostavljaju i na srpskom i na engleskom jeziku. Radovi se anonimno recenziraju od strane recenzenta posle čega uredništvo donosi odluku o objavljivanju. Rad priložen za objavljivanje treba da bude pripremljen prema dole navedenom uputstvu da bi bio uključen u proceduru recenziranja. Neodgovarajuće pripremljeni rukopisi biće vraćeni autoru na doradu.

Obim i font. Rad treba da je napisan na papiru A4 formata (210x297 mm), margine (leva, desna, gornja i donja) sa po 25 mm, u Microsoft Wordu novije verzije, fontom Times New Roman, veličine 12, sa razmakom 1,5 reda, obostrano poravnat prema levoj i desnoj margini. Preporučuje se da celokupni rukopis ne bude manji od 5 strana i ne veći od 10 strana.

Naslov rada treba da je ispisan velikim slovima, bold. Ispod naslova rada pišu se imena autora i institucija u kojoj rade. Autor rada zadužen za korespodenciju sa uredništvom mora da navede svoju e-mail adresu za kontakt u fusnoti.

Izvod se nalazi na početku rada i treba biti dužine do 200 reči, da sadrži cilj rada, primenjene metode, glavne rezultate i zaključke. Veličina fonta je 10, italic.

Ključne reči se navode ispod izvoda. Treba da ih bude minimalno 3, a maksimalno 6. Veličina fonta je 10, italic.

Osnovni tekst. Radove treba pisati jezgrovito, razumljivim stilom i logičkim redom koji, po pravilu, uključuje uvodni deo s određenjem cilja ili problema rada, opis metodologije, prikaz dobijenih rezultata, kao i diskusiju rezultata sa zaključcima i implikacijama.

Glavni naslovi trebaju biti urađeni sa veličinom fonta 12, bold, sve velika slova i poravnati sa levom marginom.

Podnaslovi se pišu sa veličinom fonta 12, bold, poravnato prema levoj margini, velikim i malim slovima.

Slike i tabele. Svaka ilustracija i tabela moraju biti razumljive i bez čitanja teksta, odnosno, moraju imati redni broj, naslov i legendu (objašnjenje oznaka, šifara, skraćenica i sl.). Tekst se navodi ispod slike, a iznad tabele. Redni brojevi slika i tabela se daju arapskim brojevima.

Reference u tekstu se navode u ugličastim zagradama, na pr. [1,3]. Reference se prilažu na kraju rada na sledeći način:

[1] B.A. Willis, Mineral Procesing Technology, Oxford, Perganom Press, 1979, str. 35. *(za poglavlje u knjizi)*

[2] H. Ernst, *Research Policy*, 30 (2001) 143–157. *(za članak u časopisu)*

[3] www: http://www.vanguard.edu/psychology/apa.pdf *(za web dokument)*

Navođenje neobjavljenih radova nije poželjno, a ukoliko je neophodno treba navesti što potpunije podatke o izvoru.

Zahvalnost se daje po potrebi, na kraju rada, a treba da sadrži ime institucije koja je finansirala rezultate koji se daju u radu, sa nazivom i brojem projekta; ili ukoliko rad potiče iz magistarske teze ili doktorske disertacije, treba dati naziv teze/disertacije, mesto, godinu i fakultet na kojem je odbranjena. Veličina fonta 10, italic.

Radovi se šalju prevashodno elektronskom poštom ili u drugom elektronskom obliku.

Adresa uredništva je: Časopis MINING AND METALLURGY ENGINEERING BOR
Institut za rudarstvo i metalurgiju
Zeleni bulevar 35, 19210 Bor
E-mail: nti@irmbor.co.rs ; milenko.ljubojev@irmbor.co.rs
Telefon: 030/435-164; 030/454-110

Svim autorima se zahvaljujemo na saradnji.

CIP - Каталогизација у публикацији
Народна библиотека Србије, Београд

622

MINING and Metallurgy Engineering Bor / editor-in-chief Milenko Ljubojev. - 2013, no. 2- . - Bor : Mining and Metallurgy Institute Bor, 2013- (Bor : Grafomedtrade). - 24 cm

Tromesečno. - Je nastavak: Rudarski radovi = ISSN 1451-0162
ISSN 2334-8836 = Mining and Metallurgy Engineering Bor
COBISS.SR-ID 201387788