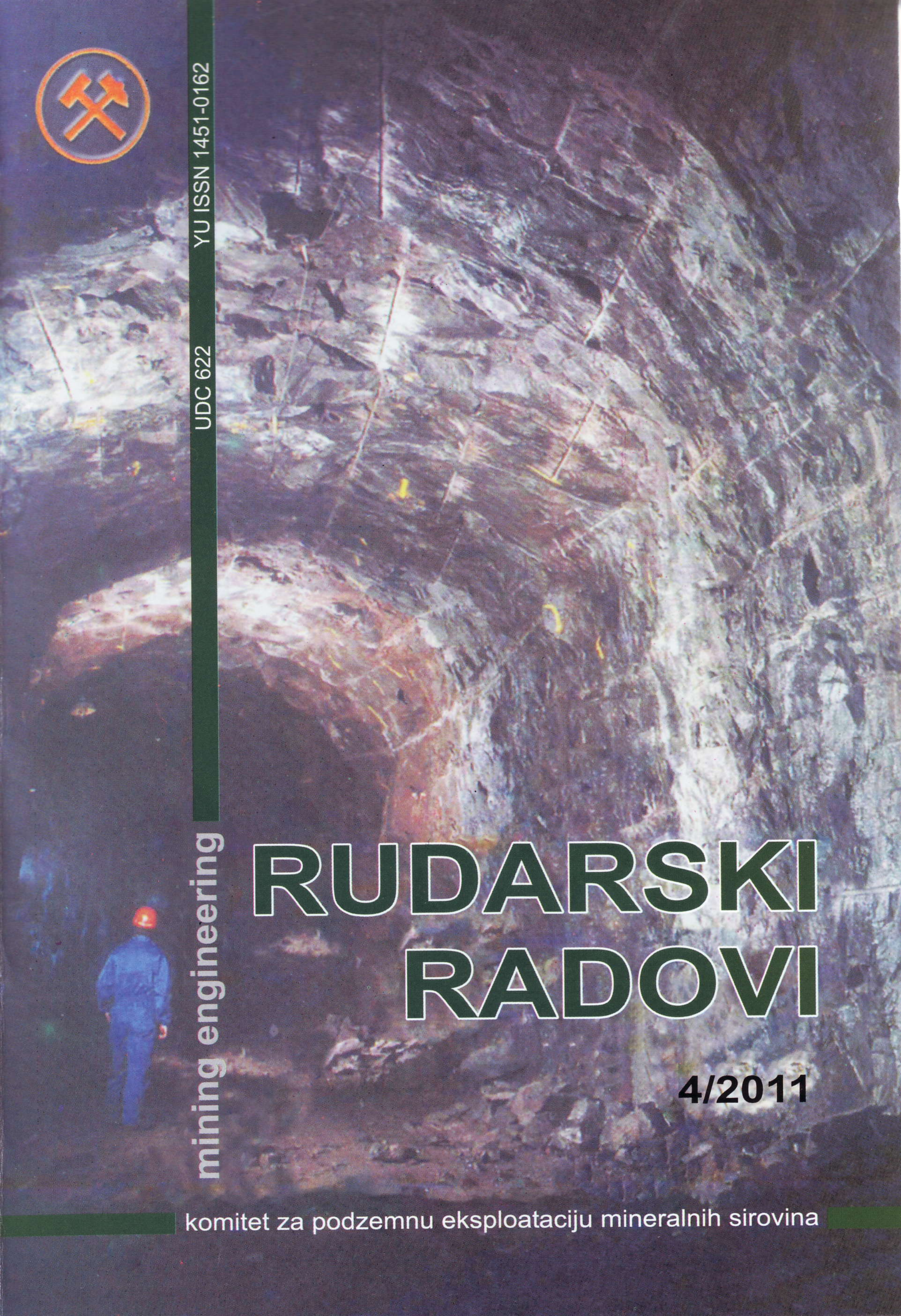

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UDK: 622.79:340.137:504.43(045)=861

Mile Bugarin, Zoran Stevanović*, Vojka Gardić*, Vladan Marinković**

PREGLED DOSADAŠNJIH GEOLOŠKIH ISTRAŽIVANJA STAROG FLOTACIJSKOG JALOVIŠTA I EU REGULATIVA IZ OBLASTI ZAŠTITE VODA**

Izvod

U radu su prikazana dosadašna geološka istraživanja starog flotacijskog jalovišta u cilju sagledavanja uticaja na kvalitet površinskih i podzemnih voda. Takođe, prikazan je pregled EU zakonodavstva iz oblasti zaštite voda. Cilj rada je bio da se sagleda problematika starog flotacijskog jalovišta i upoređivanje trenutnog stanja sa zahtevima zakonodavstva EU iz oblasti zaštite voda.

***Ključne reči:** flotacijsko jalovište, EU direktive, zaštita voda*

UVOD

Izvori zagađenja površinskih i podzemnih voda u rudarskim oblastima često su stara ili postojeća flotacijska jalovišta. Osnovni proces koji se dešava svakodnevno u jalovištima i koji predstavlja osnovni izvor zagađenja vodenih tokova je luženje komponenata iz flotacijske jalovine putem kiša. Na ovaj način nastaju vode koje, ukoliko nisu pod kontrolom, što je u Srbiji najčešći slučaj, prodoru i zagađuju podzemne i površinske tokove. Međutim, uticaj flotacijskog jalovišta ne odnosi se samo na vodene tokove. Flotacijska jalovišta takođe imaju negativan uticaj i na zagađenje zemljišta. Uticaj jalovišta na okolno zemljište može se videti kroz sledeće procese: degradiranje područja gde postoje flotacijske jalovine, distribucijom sitnih frakcija jalovine u obliku prašine i degradacija šire oblasti. Takođe, se iz prethodno navedenih činjenica može uočiti i uticaj flotacijskih jalovišta na zagađenje vazduha [1, 2]. U ovom radu dat je pregled savremenih istraživanja o starom borskom flotacijskom jalovištu, sa ciljem utvrđivanja njegovog uticaja na površinske i podzemne vode, kao i sagledavanje naših obaveza prema evropskom zakonodavstvu u pogledu zaštite voda.

* *Institut za rudarstvo i metalurgiju Bor*

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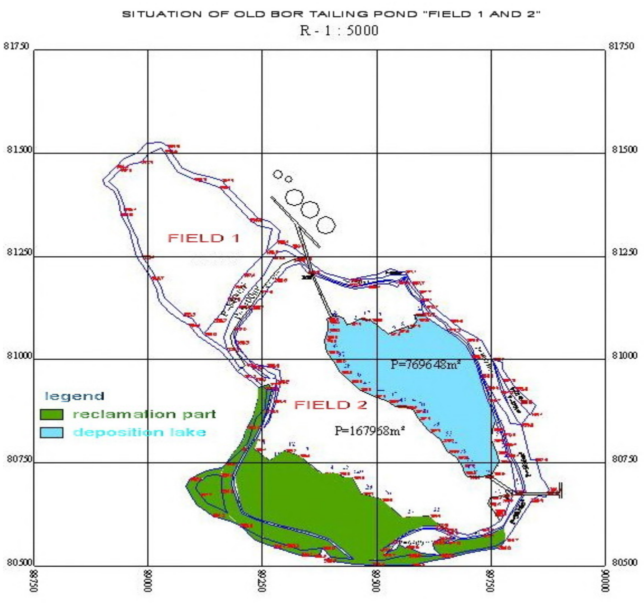
ISTORIJAT FORMIRANJA I PRETHODNA GEOLOŠKA ISTRAŽIVANJA FLOTACIJSKOG JALOVIŠTA

U neposrednoj blizini RTB Bor i njegovih proizvodnih pogona u dolini Borske reke, već duži niz godina vršeno je odlaganje flotacijske jalovine u vidu mulja, prašine i peska u varijetetima od žutosive do tamnosive i crne boje u zavisnosti od ulaznih sirovina i upotrebe različitih agenasa u postojećim proizvodnim procesima.

Deponovanje flotacijske jalovine vršeno je na klasičan način, formiranjem inicijalne brane na nizvodnom delu reke od krupnijih čestica peska i površinske raskrivke i odlaganjem flotacijske jalovine po čitavoj uzvodnoj dolini Borske reke.

Na osnovu podataka iz prethodnog perioda (tehničke dokumentacije i postojeće literature), deponovanje flotacijske jalovine započeli su Francuzi u severnom delu Borskog potoka u neposrednoj blizini postojeće železničke stanice, počev od 1934 god. pa sve do 1941 god., kada su Nemci nastavili sa deponovanjem flotacijske jalovine u nižim južnim delovima Borskog potoka. Odmah posle II svetskog rata, po izvršenoj obnovi i rekonstrukciji rudnika, nastavljeno je sa deponovanjem flotacijske jalovine, tako da je danas čitavo korito Borske reke ispunjeno flotacijskom jalovinom, a teren grubo izravnan, iznivelisan na približnoj koti 356 u središnjem delu Polja I i srednjoj koti 369 u flotacijskom jalovištu Polja II. Naime, južno od flotacijskog Polja I, upravno na Borsku reku, približno između objekata flotacije i nešto severnije od Klanice (slika 1), oformljena je brana od flotacijskog peska.



Sl. 1. *Prikaz starog flotacijskog jalovišta* [4]

Druga brana smeštena je nizvodno, a između njih je deponovana flotacijska jalovina, tako da su najgrublje čestice peska odvajane i taložene na obalama Borske reke i branama, dok se u središnji deo taložila finija flotacijska jalovina. Deponovanje jalovine vršeno je sve do 1987. god. a konačne visine brana su sledeće [3]:

- uzvodna brana kod objekata flotacije, završena je na koti 372,
- nizvodna brana završena je na koti 373 sa srednjom kotom jalovišta 369.

Prosečna dubina jalovišta iznosi oko 30 m.

Masa jalovine u jalovištu po poljima iznosi:

- Polje I 3 922,146 t
- Polje II 22,846,122 t

Ukupno 26,768,268 t

Na osnovu izvršenih geoloških bušenja iz 1963 i 1987 god., srednji sadržaj bakra, u staroj flotacijskoj jalovini, iznosi oko 0,3 %, dok se za zlato i srebro pretpostavljeni srednji sadržaji kreću oko 0,3 do 0,6 g/t za zlato i 2,5 g/t za srebro. Srednji sadržaj sumpora u jalovištu iznosi oko 10,5 %.

Hemijko ispitivanje uzoraka starog flotacijskog jalovišta urađeno je u Laboratoriji za HTK Instituta za rudarstvo i metalurgiju u Boru. Rezultati hemijskog ispitivanja prikazani su u tabeli1.

Tabela 1. *Rezultati hemijske analize uzoraka starog flotacijskog jalovišta*

Komponenta	Koncentracija %
Cu_{tot}	0.20
Cu_{ox}	0.0975
Fe	8.69
Zn	0.003
As	0.014
S	10.58
Au	0.35
Ag	3.0
SiO_2	53.34
Al_2O_3	8.52

Iz prikazanih podataka se vidi da stara flotacijska jalovina, po sadržaju korisnih komponenti, može predstavljati potencijalnu sekundarnu sirovinu za dobijanje, prvenstveno bakra, a eventualno i zlata [4]. Takođe, jako je bitno napomenuti da je uočen visoki sadržaj bakra u obliku oksida, sumpora i komponenti koje mogu imati negativni uticaj na životnu sredinu (As, Zn i drugi.). Visoki sadržaj bakra u obliku oksida u jalovini (skoro 50% u odnosu na ukupni sadržaj bakra) je činjenica koja nam ukazuje na mogućnost povećanja rastvaranja komponenti iz jalovišta, pogotovu ako se u obzir uzmu i efekti padanja kiselih kiša (sa pH vrednošću ispod 4). Rastvaranje oksidnog bakar direktno utiče na formiranje voda sa sadržajem bakarnog jona u koncentraciji i do deset puta većoj od zakonom propisanih. Odvod vode iz jalovišta nije kontrolisan proces. Vode idu direktno u Borsku reku i nastavljaju dalje u Timok i Dunav. Na ovaj način zagađuju vodu u rekama i plodno zemljište u priobalnim dolinama kroz koje reke protiču.

PREGLED ZAKONODAVSTVA EU IZ OBLASTI ZAŠTITE VODA

Zakonodavstvo Evropske unije (EU) ima nekoliko oblika pravnih instrumenata i svaki od njih se odnose na različite institucije i imaju različitu pravnu snagu. Sva važeća dokumenta EU mogu se podelite u sledeće grupe: **zakoni, direktive, odluke, preporuke i mišljenja**.

Da bi ispunili svoje obaveze po zakonima EU, a koji se odnose na zaštitu voda koje su pod direktnim uticajem flotacijskih jalovišta, neophodno je da se upoznamo sa uslovima u sledećim direktivama EU.

Directive 76/464/EEC – "framework Directive" odnosi se na ispuštanje opasnih materija - otpadnih efluenata i otpadne vode iz rudarskih i metalurških procesa koji sadrži teške metale i njihova jedinjenja, kao i druge opasne supstance po ljudsko zdravlje i životnu sredinu [5].

Tri najvažnije specifične takozvane ćerke direktive - 83/513/EEC (1)– koja se odnosi na granične vrednosti i ciljeve kvaliteta za ispuštanje kadmijuma;

Directive 84/156 / EEZ (2)- koja se odnosi na granične vrednosti i ciljeve kvaliteta za ispuštanje žive po sektorima;

Directive 86/280/EEC (3)- koja se odnosi na granične vrednosti i ciljeve kvaliteta za ispuštanje određenih opasnih supstanci, uključenih u **Listu I Aneksa Direktive 76/464/EEC (88/347/EEC)** [6-8].

Okvirna direktiva o vodama: instrument za dobro upravljanje vodama u EU - Direktiva 2000/60/EC (WFD)- Direktiva uvodi ključne elemenate za postizanje efikasnog upravljanja vodama na nivou Evropske unije, koherentan i efikasan pravni i institucionalni okvir, politika određivanja cene vode, učešće javnosti i integrisanog upravljanja vodnim resursima. Ključni cilj WFD direktive je da se poboljša ekološki status površinskih i podzemnih vodnih tela. Ekološki ciljevi WFD direktive za reke takođe se primenjuju za ispuštanje otpadnih voda iz postrojenja za prečišćavanje otopadnih voda. [9, 10].

ZAKLJUČAK

Flotacijska jalovišta predstavljaju jedan od izvora zagađenja površinskih i podzemnih voda, što predstavlja značajan ekološki problem u Srbiji. Problem je nastao kao posledica slabe ekološke politike i njene primene.

Iz iznetih podataka može se videti da staro flotacijsko jalovište ima visok sadržaj pojedinih korisnih komponenti i zbog te činjenice može da predstavlja potencijalnu sekundarna sirovina za dobijanje, pre svega bakra, a možda i zlata, što bi umanjilo negativan uticaj jalovine na životnu sredinu.

Takođe, sprovođenje mera zaštite od zagađenja predstavljaju javni interes i potrebne su u cilju zaštite zdravlja ljudi, kulturnih i materijalnih dobara.

Za punu implementaciju usvojenog nacionalnog zakonodavstva, potrebni su i svi podzakonski akti. Neophodno je uskladiti nacionalno zakonodavstvo sa zakonodavstvom Evropske unije, čime se obezbeđuje visok nivo kvaliteta životne sredine.

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Mile Bugarin, Zoran Stevanović*, Vojka Gardić*, Vladan Marinković**

REVIEW OF THE GEOLOGICAL RESEARCH OF OLD BOR FLOTATION TAILINGS AND OVERVIEW OF EU LEGISLATION IN THE FIELD OF WATER PROTECTION**

Abstract

The paper shows previous studies of geological investigations the Old Flotation tailing dump in order to assess its impact on the quality of surface and ground water. Also, an overview of the EU legislation in the field of water protection is shown. The aim of this paper is to consider the problem of the Old Flotation tailing dump and comparison the current condition with requirements of the EU legislation in the field of water protection.

Key words: *flotation tailings, EU directive, water protection*

INTRODUCTION

Sources of surface and ground water pollution in the mining regions are often the old and existing flotation tailing dumps, due to leaching the flotation material through the rain, penetration of contaminated water and its drainage into the streams. The influence of flotation tailings on the soil pollution is observed in the following ways: degraded areas of the flotation tailing dumps, distribution of small fraction of tailings in the form of dust and degradation of wider areas. Also, the air pollution is generated by the same way [1, 2]. This paper presents an overview of contemporary research on the Old Bor Flotation tailing dump with the aim of determining its effect on surface and groundwater, as well as recognition of our obligations under the European Legislation in terms of water protection.

HISTORY OF FORMATION AND PREVIOUS GEOLOGICAL INVESTIGATIONS OF THE FLOTATION TAILING DUMP

In the immediate vicinity of RTB Bor and its production facilities in the Bor River valley, the flotation tailings are disposed for many years in the form of slime, dust and sand in the varieties of yellow-gray to dark gray and black depending on

* *Mining and Metallurgy Institute Bor*

** *This work was supported by the Ministry of Education and Science of the Republic of Serbia, and within the project „The Impact of Mining Wastes from RTB Bor on the Pollution of Surrounding Water Systems with the Proposal of Measures and Procedures for Reduction Harmful Effects on the Environment“, a program of technological development (TR - 37001).*

raw materials and use the various agents in the existing production processes.

Disposal of flotation was performed by classical way, so that the downstream part of the river formed the initial barrier of coarse sand particles and surface mining overburden and disposal of flotation tailings throughout the upstream valley of the Bor River.

Based on data from the previous period (technical documentation and existing literature), disposal of tailings began by French in the north part of the Bor Stream in the near vicinity of railway station, from 1934 until 1941, when the Germans continued with disposal of tailings in the lower southern parts of the Bor Stream. Immediately after the World War II, after reconstruction of the mine, disposal of tailings continued with a deposit of tailing, so that today the entire bed of the Bor River is filled with the flotation tailings, and the terrain was roughly flattened, at approximate level of 356 m in the central part of the Field I and middle level of 369 m in the flotation tailing Field II. Specifically, in the south of the flotation Field I, perpendicular to the Bor River, approximately between the flotation facilities and just north of Slaughterhouse (Figure 1), a dam was formed of flotation sand.

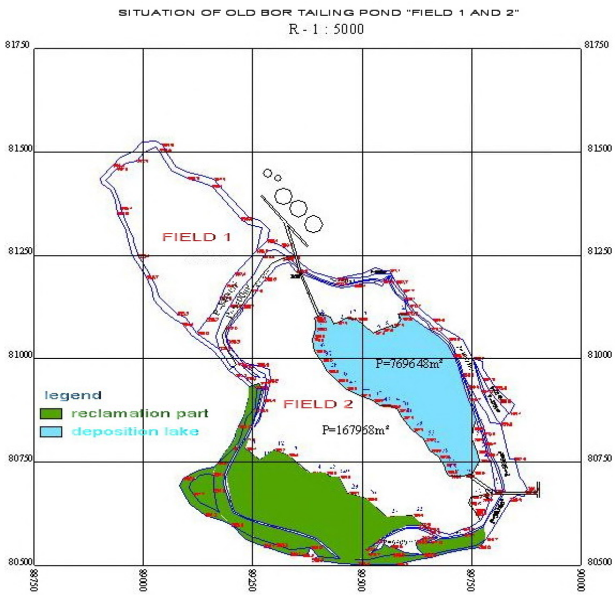

Fig. 1. *View of the old Bor Flotation Tailing Dump* [4]

The second dam is situated downstream, and the flotation tailings was deposited between the dams, such as the coarsest particles of sand were separated and deposited on the banks of the Bor River, until the middle part was filled with finer flotation tailings. Disposal of tailings was done until 1987, and the final heights of dams are the following [3]:

- upstream dam near the flotation facilities, was completed at level 372 m,
- downstream dam was completed at level 373 m with an average elevation of tailing dump of 369 m.

Average depth of tailing dump is about 30 m.

Mass of tailings in a tailing dump per fields is:

- Field I	3,922,146 t
- Field II	22,846,122 t
Total	**26,768,268 t**

Based on realized geological drillings in 1963 and 1987, medium copper content in the old flotation tailings is about 0.3%, while the supposed medium contents for gold and silver are about 0.3 to 0.6 g/t for gold and 2.5 g/t for silver. Mean content of sulphur in tailing dump is about 10.50%.

Chemical testing the samples of the old flotation tailing dump was carried out in the Laboratory for chemical – technical control of the Mining and Metallurgy Institute in Bor. The results of chemical analyzing are shown in Table 1.

Table 1. *The chemical composition of samples of old flotation tail*

Component	Content %
Cu_{tot}	0.20
Cu_{ox}	0.0975
Fe	8.69
Zn	0.003
As	0.014
S	10.58
Au	0.35
Ag	3.0
SiO_2	53.34
Al_2O_3	8.52

The presented data showed that the old flotation tailings, according to content of useful components, may pose a potential secondary raw material for obtaining, primarily copper and possibly gold [4].

Also, it is important to note that high content of copper oxide, sulphur and other environmentally very harmful elements (As, Zn, etc.) was observed. High copper content in the form of oxide (almost 50% of total copper content) in tailings also suggested the increased possibility of solubility the tailings due to the effects of acid rain (with pH value below 4). Dissolution of oxide copper has direct effect on formation the water with high content of copper ion in concentration up to ten times higher than legally prescribed. Water drainage from tailing dump is uncontrolled process. The water goes directly into the Bor River and continues further into Timok and Danube, thus polluting water in the rivers and fertile coastal land in the valleys through which the rivers flow.

REVIEW OF THE EU LEGISLATION IN THE AREA OF WATER PROTECTION

Legislation of the European Union (EU) has several forms of legal instruments and each of them relating to the different institutions and has different legal force. All legal documents related to the EU could be divided into the following groups: **regulations, directives, decisions, recommendations and opinions**.

To fulfil the obligations under the EU law, and concerning the protection of water around flotation tailing dump, it is necessary to become familiar with the requirements in the following EU directives.

Directive 76/464/EEC – "framework Directive" on discharge of dangerous substances - the waste effluents and wastewater from mining and metallurgical processes containing heavy metals and their compounds, as well as other dangerous substances for the human health and the environment are subject to the general provisions and principles of Directive 76/464/EEC [5].

The Three Most Important Specific Daughter Directives of our field of consideration are as follows - **83/513/EEC Cadmium Daughter Directive to DSD** - on limit values and quality objectives for cadmium discharges (Daughter to 2006/11/EC), **84/156/EEC Mercury Daughter Directive to DSD** - on limit values and quality objectives for mercury discharges by sectors other than the chlor-alkali electrolysis industry, **86/280/EEC List I Daughter Directive to DSD -** on limit values and quality objectives for discharges of certain dangerous subances included in List I of the Annex to Directive 76/464/EEC (88/347/EEC) [6-8].

The Water Framework Directive: An Instrument for Good Water Governance

in the EU - Directive 2000/60/EC (WFD) - This Directive introduces key elements to achieve effective water governance at the European Union level, a coherent and effective legal and institutional framework, water-pricing policies, public participation and an integrated water resources management system. The WFD's key objective is to improve the ecological status of surface and groundwater bodies. The WFD's ecological objectives for rivers are also applied for water discharge from the wastewater treatment plants [9, 10].

CONCLUSION

Flotation tailings are the source of surface and ground water pollution, which represents a significant ecological problem in Serbia, and was created as a result of weak an ecological policy and its implementation.

From the presented data can be seen that the old flotation tailings has high content of some useful components, and because of that fact may pose a potential secondary raw material for obtaining, primarily copper and possibly gold, which would solve the problem of impact of tailings on the environment.

Also, the needs and public interest are to implement protection measures against pollution, to protect human health, cultural and material goods, for the full implementation of adopted national legislation making it is necessary and all by-laws. It is necessary to harmonize national legislation with EU legislation, thus ensuring a high level of environmental quality.

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UDK: 621.361(045)=861

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KVALITET GLINA U LEŽIŠTU DUŠANOVAC (KOD NEGOTINA)**

Izvod

Ležište glina [3,5] *Dušanovac, nalazi se u severoistočnom delu Republike Srbije, u ataru sela Dušanovac, oko 9 km severozapadno od Negotina. Osnovni cilj dvogodišnjeg geološkog istraživanja bio je da se pojave glina na području „Dušanovac" kod Negotina istraživanjem dovedu do faze okonturivanja ležišta, kojim će se dobiti svi podaci za overu rezervi glina kao mineralne sirovine. Geološkim istraživanjima vršenim u periodu 2008/10 godine* [3,5]*, definisane su geološke karakteristike ležišta, kvalitet glina* [4,3,6,7]*, ocena potencijalnosti istražnog prostora* [3]*, kao i proračun geoloških rezervi ležišta mineralne sirovine* [3].

U navedenom periodu urađena su 4 istražna raskopa i izbušeno je 12 istražnih geoloških bušotina. Geološkim plitkim vertikalnim bušotinama izbušeno je ukupno 717,00 metara [3].

Ovaj rad prikazuje kvalitet glina u ležištu Dušanovac, rezultati tehnoloških ispitivanja i mogućnosti pripreme ove sirovine a što je značajno za samu mogućnost primene. Prema boji gline u ležištu Dušanovac su podeljene na četiri tipa: braon glina [3,4,6,7]*; žuta glina (javlja u celom ležištu, leži ispod braon gline, prosečne debljine je oko 13,0 m., masna je, jako plastična i slabo peskovita); braon-siva glina i siva glina.*

Primena ovih glina [3,5] *(žuta glina) pri rekultivaciji Flotacijskog jalovišta Veliki Krivelj* [8] *(a i drugih jalovišta nastalih radom RTB-a) doprinela bi konačnom rešenju eliminiacije ekološke katastrofe ovog jalovišta.*

Ključne reči: *kvalitet glina, mogućnost primene, ležište, mineralna sirovina.*

UVOD

Ležište glina Dušanovac, nalazi se na oko 9 km od Negotina [3,5], u ataru sela Dušanovac (slika 1). U morfološkom pogledu područje pripada niziji, koja je smeštena između Dupljanske reke (leve pritoke Jaseničke reke) i Dunava. Ležište se nalazi na nadmorskoj visini oko 90 metara (dok je grad Negotin na nadmorskoj visini od oko 45 m). Vodeni tokovi pripadaju slivu Dunava (u neposrednoj blizini ležišta, nalazi se hidroelektrana

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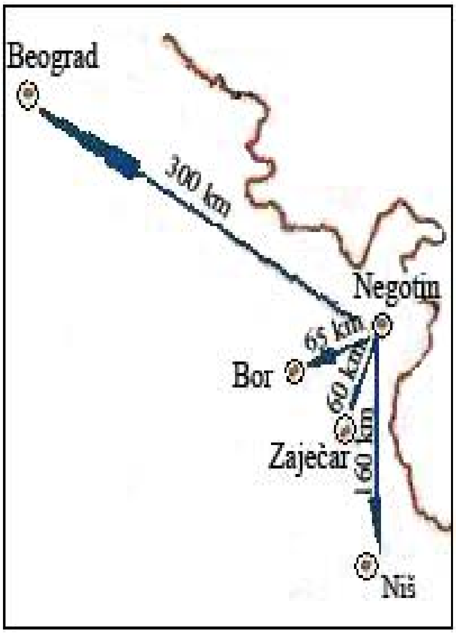
** Institut za rudarstvo i metalurgiju Bor*

*** Rad je proizašao iz projekta broj 33021 „Istraživanje i praćenje promena naponsko deformacionog stanja u stenskom masivu „in situ" oko podzemnih prostorija sa izradom tunela sa posebnim osvrtom na tunel Kriveljske reke i Jame Bor", koji je finansiran sredstvima Ministarstva za prosvetu i nauku Republike Srbije*

Đerdap), odnosno Crnomorskom slivu. Hidrografska mreža je gusta i dobro razvijena.

Ležište glina Dušanovac prostorno se nalazi u sedimentima donjeg pliocena (peskovi, gline i peščari). Istražni prostor Dušanovac je detaljno istraživan 2008/2010 godine, istražnim raskopima i plitkim istražnim geološkim bušotinama. Ovim radovima istražen je istražni prostor, okontureno je ležište, sagledan je kvalitet glina kao mineralne sirovine (što direktno ukazuje na mogućnost primene) i obračunate su ukupne rezerve u ležištu glina. Ukupne rezerve glina u ovom ležištu iznose 69.041.871 tona (rezerve A+B kategorije).



Sl. 1. *Pregledna karta udaljenosti ležišta glina "Dušanovac" kod Negotina od drugih gradova u Srbiji*

ISTORIJAT GEOLOŠKIH ISTRAŽIVANJA ŠIRE OKOLINE LEŽIŠTA GLINA DUŠANOVAC

Značajnije podatke o geološkoj građi i tektonskim odnosima šire okoline istražnog prostora [5] Dušanovac (sada već okonturenog ležišta), nalazimo u radovima Toule F., Zlatarskog G., Žujovića J. (1889, 1893), Radovanovića S. i Pavlovića P. (1891), koji daju prve detaljne podatke o neogenu i kvartaru Krajine, i koji predstavljaju osnovu za dalja proučavanja neogena i kvartara ove oblasti.

Proučavanjem kvartarnih tvorevina u dunavskom Ključu i Negotinskoj Krajini bavio se Cvijić J. (1903, 1908, 1921), detaljnim geološkim istraživanjima stratigrafskih i tektonskih odnosa Mirgoci G. (1905), Radovanović S. (1907, 1916) i Bončev St. (1923). Detaljne podatke o stratigrafskoj i tektonskoj problematici pretercijalnih formacija ove oblasti dao je Petrović K. (1928, 1937), koji kaže da istočno od đerdapske navlake leži nova strukturna jedinica, mokranjska navlaka, čije se čelo nalazi na liniji Crnomasnica-Mokranje.

Poseban doprinos proučavanju geološke građe ovih prostora dao je Petković V. (1930 i dalje), koji je izneo postavke koje su aktuelne i danas. U okviru svojih studija neogenih naslaga veliku pažnju poklanjao je Stevanović P., koji je na osnovu fosilnog materijala prvi (1940) odredio hronostratigrafsko mesto najmlađih sedimenata, smatrajući da su šljunkovi Brze Palanke levantijske starosti. U više svojih radova, od 1950. godine, Stevanović P. raspravlja o: tortonu, sarmatu, meotu i pontu, sa stanovišta biostratigrafije, paleogeografije, facija i tektonike.

Geološka istraživanja na istražnom prostoru Dušanovac, vršena su primenom geoloških metoda [5], u okviru izrade Osnovne geološke karte (OKG), a prikazana Tumačem OKG za list Negotin 1:100.000. Nemetalične mineralne sirovine sa ovog područja, koriste se kao tehnički građevinski kamen i opekarska glina, iako detaljna geološka istraživanja na ovom prostoru nisu vršena. Prema literaturnim podacima, vršena su poludetaljna geofizička istraživanja (primenom gravimetrijskih metoda), tokom 1969. godine (Zavod za geološka i geofizička istraživanja Beograd). Podatke o obimu i gustini ovih istraživanja nemamo.

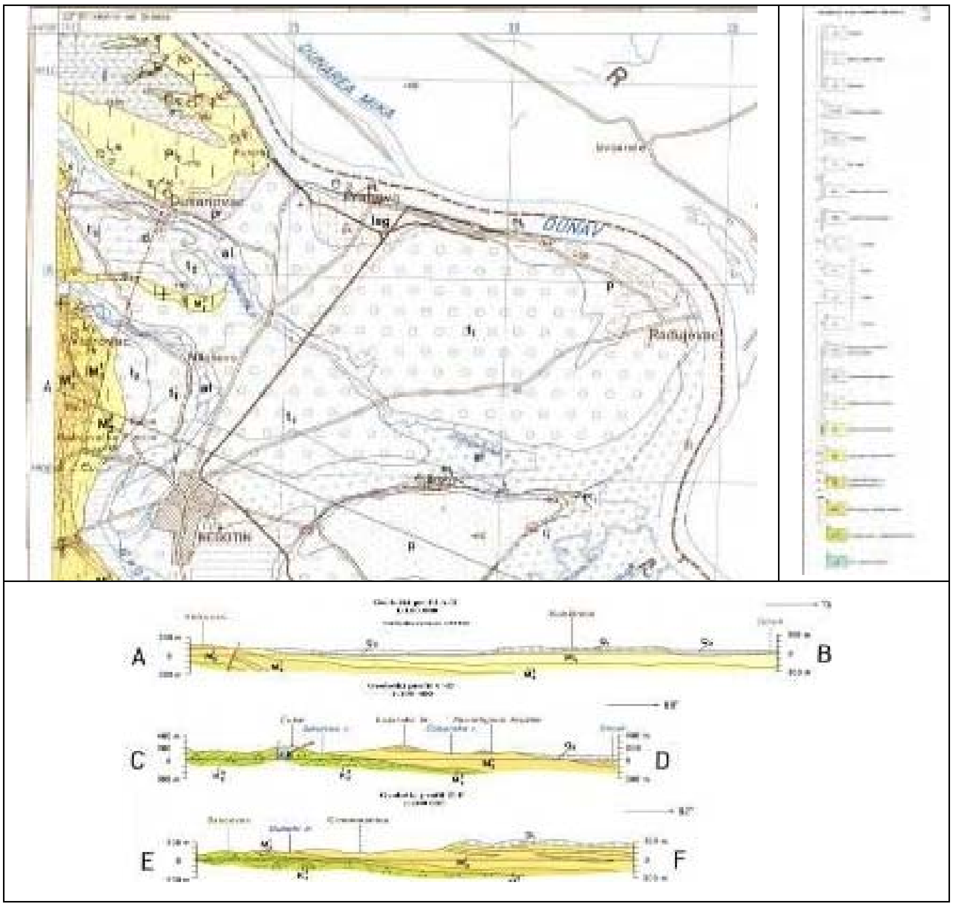
GEOLOŠKE KARAKTERISTIKE ŠIRE OKOLINE LEŽIŠTA GLINA DUŠANOVAC

Teren šire okoline ležišta glina Dušanovac, nalazi se na listu Negotin OGK [5], razmere 1:100.000 (slika 2). Najstariji sedimenti u ovoj oblasti su titon-valendijski krečnjaci kod Mokranja i Rajca, koji leže preko senona. Predstavljaju alohtone tvorevine, donete sa zapada na čelu mokranjske navlake. Senonski sedimenti razvijeni su u flišnoj faciji. Senonske sedimente čine peščari, glinci i konglomerati. Podina im nije utvrđena, dok povlatu čine miocenski slojevi. U superpozicionom pogledu razlikuju se tri dela:

- ►donji, sa smenom peščara i glinaca, i slabo izraženim tragovima laminacije;
- ►srednji, u kome je zapažena alternacija peščara, konglomerata i glinaca; i
- ►gornji, sa sekvencama peščar-glinac, veoma bogat laminacijom i drugim teksturnim oblicima. Senonski flišni basen imao je najverovatnije pravac sever-jug, dok je paleotransport materijala dolazio sa jugoistoka, iz oblasti mezijske platforme. Sedimenti generalno padaju u pravcu zapad-jugozapad.

Neogene naslage [5] imaju veliko rasprostranjenje. Na osnovu bogatih fosilnih ostataka mekušaca i mikrofaune, neogeni kompleks je rasčlanjen na torton, sarmat, meot i pont. Najstariji kvartarni sedimenti predstavljeni su jezerskim šljunkovima i peskovima, sa *Elephas medridionalis.* Leže u obliku izolovanih erozionih krpa, diskordantno preko sarmata i senona. Ove tvorevine predstavljaju produkte jedne jezerske faze, za vreme donjeg pleistocena. Mlađe kvartarne tvorevine predstavljene su rečno-jezerskim sedimentima.

Dunav je u starije sedimente usekao četiri terase, koje su izgrađene od šljunkova, suglina i supeskova. Terasni šljunkovi izgrađuju donje delove profila, dok sugline i supeskovi, ponekad lesolikog habitusa leže iznad šljunkova. Ovakav granulometrijski odnos ukazuje na stvaranje facija u uslovima različitih dinamičkih faza Dunava, kod svakog pojedinačnog ciklusa.



Sl. 2. *Geološka građa šire okoline istražnog prostora, list Negotin (sa karakterističnim profilima)*

Aluvijalni nanosi [5] su takođe heterogenog sastava. Facije korita predstavljene su šljunkovima i peskovima, koji izgrađuju sve profile aluvijalnih ravnica. Facije povodnja su ređe, i predstavljene su šljunkovitim suglinama, koje leže preko facije korita. Rasprostranjeni su i živi peskovi, koji leže preko tzv. gradske terase. Proluvijalni genetski tip stvara se povremenim tokovima Studene reke i potoka Plandište.

To su mali plavinski konusi, izgrađeni od šljunkova, koji preovlađuju u korenim delovima, dok gline i peskovi redovno leže u njihovim perifernim delovima. Ima i nešto deluvijalnog materijala, predstavljenog šljunkovitim suglinama, kojih ima više u zoni spiranja, dok suglinovitog i supeskovitog materijala ima znatno više u perifernim delovima zone akumulacije.

GEOLOŠKE KARAKTERISTIKE LEŽIŠTA GLINA DUŠANOVAC

Geološku građu ležišta [3,5] čine peskovi, gline i peščari ponta (Pl_1), kao i znatno manje zastupljen proluvijum holocena (prQ_2) izgrađen od: šljunkova, peskova i suglina.

Najstariji kvartarni sedimenti [5] predstavljeni su rečno-jezerskim šljunkovima, peskovima i suglinama. Po svojim karakteristikama odgovaraju aluvijalnim šljunkovima i peskovima. Šljunkovi su srednje do krupnozrni, heterogenog sastava, različite zaobljenosti i slabe sortiranosti, i javljaju se najčešće u vidu sočiva uloženih u peskove. U sastav šljunkova ulaze, peščari, krečnjaci, mikrokonglomerati, kvarc, rožnaci, gnajs-graniti i dr.

Preko šljunkova leže žuti peskovi, peskovite sugline i supeskovi lesolikog habitusa. U njima je zapažena horizontalna slojevitost, tragovi prorastanja barskom vegetacijom, pa je logično da ovi deponati predstavljaju produkt vodene sredine.

Sedimenti donjeg pliocena [5] (ponta) su debljine oko 300 m (slika 3.). Podinu ove serije čine peskovi i peskovite gline iznad kojih kontinualno leži tanji sloj laporaca predpostavljene debljine oko 20 – 30 m. Iznad laporaca je taložen sloj peskovitih glina sa postepenim prelazom ka opekarskim glinama koje leže na samoj površini terena, a predpostavljene su debljine od oko 80 m.

Sl. 3. *Otvorena etaža sa koje se povremeno eksploatiše glina*

Sedimenti kvartara [5] su predstavljeni: proluvijalnim šljunkovima, peskovima i suglinama, na mestima gde su se javljali tokovi bujičarskog karaktera, kao i deluvijalnim suglinama i supeskovima. Kod deluvijalnih tvorevina, bliže zoni spiranja preovlađuju supeskovi sa šljunkovitim detritusom, dok se dalje, u zoni akumulacije, materijal usitnjuje i postaje znatno glinovitiji.

METODE GEOLOŠKOG ISTRAŽIVANJA LEŽIŠTA GLINA DUŠANOVAC

Geološka istraživanja istražnog prostora [5], na lokalitetu Dušanovac, kod Negotina, vršena su u period 2008/10 godine. Izvršeno je:

- ►Rekognosciranje terena i reambu lacija geološke karte;
- ►Definisane su geološke karakteristike (strukturni sklop, uslovi zaleganja, kontura i oblik) ležišta,
- ►Kvalitet glina (mogućnosti pripreme i primene glina).
- ►Izvršena je ocena potencijalnosti istražnog prostora, kao i proračun geoloških rezervi ležišta gline kao mineralne sirovine.

Od istražnih radova urađena su 4 raskopa i i izbušeno je 12 plitkih vertikalnih istražno geoloških bušotina. Geološkim plitkim vertikalnim bušotinama izbušeno je ukupno 717,00 metara. U jugoistočnom delu istražnog prostora izbušeno je 5 istražnih bušotina, po mreži 400×200 m, a 2 istražne bušotine u severnom obodnom delu istražnog prostora. Izbušeno je 7 bušotina (407,5 m bušenja) u 2008/2009. godini i 7 bušotina (309,5m) 2009/2010. godini.

Sve istražne radove [3,5] pratilo je kontinuirano kartiranje i oprobavanje (materijala iz raskopa i jezgra bušotina). Isti material (probe) kontinuirano je laboratorijslki ispitivan. Prilikom proračuna rudnih rezervi [3], kao glavna korisna komponenta tretirana je Al_2O_3, a kao prateće štetne komponente Fe_2O_3, SiO_2, CaO i TiO_2.

REZULTATI GEOLOŠKOG ISTRAŽIVANJA LEŽIŠTA GLINA DUŠANOVAC

Rekognosciranjem terena i reambulacijom geološke karte [3] (deo lista Negotin 1 razmere 1:25 000), potvrđeno je da su prisutne uglavnom neogene tvorevine i u manjoj meri kvartarne tvorevine. **Pont (Pl_1)** je predstavljen peskovima, glinama i peščarima. Ovi sedimenti pripadaju polubrakičnim („kaspibrakičnim“) facijama. Smatra se da slojevi ponta leže konkordantno preko meota, sa postepenim facijalnim prelazom. Naslage ponta imaju znatno razviće oko sela Dušanovac. Vidljiva debljina Pontijskih naslaga iznosi oko 150 m, dok je ukupna debljina, idući prema istoku svakako veća.

Teren na kome je vršeno geološko istraživanje raskopima i istražnim bušotinama predstavlja blago zatalasanu rečnu dolinu (slika 4). Prostorno, ležište se nalazi u sedimentima donjeg pliocena (pont). Ležište ima oblik izduženog sočiva, sa pružanjem severozapad-jugoistok [3]. Po pružanju se može pratiti više od 2,5 km, dok je prosečne širine oko 320 m. Istražnim radovima obuhvaćen je severni i zapadni deo ležišta, površine od oko 0,4 km^2.

Sl. 4. *Teren u domenu ležišta glina Dušanovac (levo) i pogled sa ležišta na hidroelektranu Đerdap 2 (desno)*

Istraživanje ležišta glina [3,5] raskopima (ukupno 4 raskopa dimenzija 2×2,5×1 m) i istražnim geološkim bušotinama. Po vertikalnom profilu u svim raskopima je od površine terena pa do dubine od 0,6-0,7 m uočena crnica, a ispod toga žuto smeđa peskovita glina sa pojavom karbonata. Iz svakog raskopa uzeta je po jedna proba za hemijska ispitivanja.

Intervali oprobavanja [3] jezgra iz istražnih bušotina bili su 1 ili 2 m. Ukupno je uzeto 370 pojedinačnih proba, od kojih je formirana 41 kompozitna proba. Kompozitne probe formirane su posebno za žutu klasu glina, posebno za sivu klasu kvaliteta glina.

Proučavanjem stubova bušotina[3] uočeno je da makroskopski, prema boji gline ležište možemo raščlaniti na četiri sloja:

- ►Braon glina leži neposredno ispod humusnog pokrivača koji je prosečne debljine oko 0,7 m. Glina je slabo do jače peskovita, prosečna debljina ovog sloja iznosi oko 1,5 m.
- ►Žuta glina leži ispod braon gline, prosečne debljine je oko 13,0 m. Ova glina je masna, jako plastična i slabo peskovita, opažene su mestimične pojave FeO kao i prevlake MnO. Sloj žute gline se javlja u celom ležištu;
- ►Braon-siva glina je prostorno pozicionirana ispod žute, a iznad sive gline. Sloj braon-sive gline predstavlja zonu mešanja žute i sive gline jako je peskovita, a prosečna debljina ovog sloja je oko 6,0 m.
- ►Siva glina je prosečne debljine od oko 35,5 m nalazi se ispod braon-sive gline. Jako je peskovita, ne retko se u okviru ovog sloja uočavaju tanki proslojci jače zaglinjenog peska. U ovom sloju se takođe javljaju i fosilni ostatci predstavljeni ljušturicama školjaka. Sloj sive gline sa porastom dubine postepeno prelazi u jako zaglinjeni pesak. Sve bušotine su nabušile sloj sive gline.

Od laboratorijskih ispitivanja na uzetim probama vršena su fizičko-mehanička ispitivanja [4], ispitivanje granulometrijskog sastava [6,7], laboratorijska tehnološka ispitivanja i hemijska ispitivanja. Tehnološka ispitivanja u poluindustrijskom i industrijskom obimu, nisu vršena.

KVALITET GLINA U LEŽIŠTU DUŠANOVAC

Pod kvalitetom mineralne sirovine podrazumeva se sadržaj korisnih komponenti i mogućnost upotrebe mineralne sirovine [5]. Pouzdanost određivanja kvaliteta sirovine u ležištu zavisi od metoda oprobavanja, mase proba, skraćivanja proba na licu mesta, pripreme i obrade u laboratoriji, kao i od tačnosti metoda analize.

Sadržaj korisnih i štetnih komponenti [3], u ležištu glina Dušanovac, određeni su hemijskim analizama pojedinačnih proba uzetih iz bušotina, izbušenih sa površine terena. Pojedinačne probe analizirane su na Al_2O_3, TiO_2, SiO_2, Fe_2O_3, CaO, gubitak žarenjem (GŽ) i H_2O^- (tabela 1). Kompozitna proba dobijena je sjedinjavanjem materijala deset ili pet uzastopnih, pojedinačnih proba (desetometarski interval). Kompoziti proba analizirani su na: SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, S ukupni, SO_3, TiO_2, K_2O, Na_2O, Cr_2O_3, gubitak žarenjem, MnO, FeO, CO_3, Mn, Fe, Cu i pH.

Tabela 5.2: *Hemijski (srednji) sadržaji glina u ležištu Dušanovac iz pojedinačnih proba po klasama kvaliteta, proračunati programskim paketom MINEX 5.2.1.*

Klasa	Srednji sadržaj (%)						
	Al_2O_3	TiO_2	SiO_2	Fe_2O_3	CaO	G.ž.	H_2O^-
GB (žuto braon glina)	16,7	0,85	57,2	6,28	2,7	9,99	18,9
GI (žuta glina)	16,5	0,86	57,5	6,01	4,16	9,59	20,5
GII (siva glina)	16,7	0,87	56,5	5,94	3,64	9,51	20,4
Celo ležište	16,6	0,87	56,8	5,97	3,78	9,54	20,4

Fizičko-mehanička ispitivanja [4] vršena su na uzorcima gline, peskovite gline i jako zaglinjenog peska. Ispitivanja fizičko-mehaničkih karakteristika uzoraka glina uzetih oprobavanjem jezgra istražnih bušotina vršena su po važećim standardima za svaku vrstu ispitivanja za potrebe rudarstva ili prema preporukama međunarodnog društva za mehaniku stena (ISRM).

Od fizičkih osobina na uzorcima glina [4], određeni su sledeći parametri: vlažnost - W [%], specifična težina ili zapreminska težina čvrstih čestica - γ_s [kN/m^3], zapreminska težina - γ_z [kN/m^3], poroznost - n [%], brzina prostiranja longitudinalnih talasa - V_L [m/s], kondenzacija glina i granice plastičnosti. Određeni su mehanički parametri [4]: parametri otpornosti pri direktnom smicanju, i jednoosna čvrstoća na pritisak. Dakle, radnu sredinu [4], u kojoj će se odvijati eksploatacija, čine gline, slabopeskovite gline, jače peskovite gline i jako zaglinjeni peskovi. Pretpostavljeni ugao etažne kosine i završni ugao kosine kopa se usvajaju na osnovu sledećih fizičko – mehaničkih karakteristika radne sredine: zapreminska težina glina d = 19,71 kN/m^3 (1,971 t/m^3); kohezija glina C = 0,380 MPa; ugao unutrašnjeg držanja glina, φ = 15,33°. Na osnovu fizičko – mehaničkih osobina glina [4] ležišta Dušanovac kod Negotina, zaključuje se da su inženjersko–geološke karakteristike relativno povoljne i da neće biti većih problema u fazi eksploatacije.

Ispitivanje granulometrijskog sastava glina iz ležišta Dušanovac kod Negotina, vršeno je na dva načina: Ispitivanjem granulometrijskog sastava svake pojedinačne probe [6,7] iz svih bušotina i ispitivanjem granulometrijskog sastava kompozitnih uzoraka [6,7]. Kompozitni uzorci su formirani prema klasama kvaliteta, za svaku pojedinačnu bušotinu. Karakteristično je da krupne klase (-0,212+0,106 mm) učestvuju sa oko 1%. Veći deo čini klasa -0,020+0,000 mm sa učešćem od 61-75%.

Tehnološka ispitivanja glina [3] iz ležišta Dušanovac u cilju iznalaženja pravca kojim treba usmeriti dalja laboratorijska istraživanja i ispitivanja, izvršena je kraća serija eksperimenata izdvajanja fine frakcije metodom sedimentacije i dekantacije. Imajući u vidu zastupljenost minerala gline u veoma finim frakcijama, ispod 20 mikrona, u eksperimentima se težilo ka iznalaženju mogućnosti za povećanje udela (masenih učešća) istih, odnosno povećanja sadržaja Al_2O_3, a time i dobijanja visokog kvaliteta prirodne gline, koja kao takva može naći široku primenu u svim granama industrije.

ZAKLJUČNA RAZMATRANJA O PRIMENI GLINA U LEŽIŠTU DUŠANOVAC

Gline se najviše koriste [3] u industriji vatrostalnog materijala, opekarskoj industriji, industriji porcelana i fine keramike, keramičkoj industriji, industriji papira, hemijskoj, farmaceutskoj industriji, za isplaku i pri sanaciji degradiranih površina (rekultivaciji zemljišta). Na osnovu industrijske primene glina, definisani su i zahtevi za kvalitetom, a odnose se na mineralni sastav, sadržaj Al_2O_3, TiO_2, i SiO_2, sadržaj nečistoća, pH vrednost, hemijsku stabilnost, bubrenje, vatrootpornost, krupnoću čestica, belinu.

Ležište glina Dušanovac pripada sedimentnim ležištima [1,2], nastalim od materijala razlaganja i izluživanja stena, koji je kasnije mehanički prenet i pretaložen. U cilju obezbeđenja domaće sirovine [5] (što je sigurno najracionalniji pristup obezbeđenja potreba postojećih industrijskih kapaciteta), laboratorijski su ispitane gline ležišta Dušanovac. Ležište se nalazi u sedimentima donjeg pliocena (pont), ima oblik izduženog sočiva, sa pružanjem severozapad-jugoistok. Po pružanju, prati se više od 2,5 km, dok je prosečne širine oko 320 m. Istražnim radovima obuhvaćen je severni i zapadni deo ležišta, površine od oko 0,4 km^2.

Geološkim istraživanjem ležišta Dušanovac, gline su podeljene na četiri tipa:

- ►braon glina (prosečne debljine osi oko 1,5 m);
- ►žuta glina (prosečne debljine je oko 13,0 m);
- ► braon-siva glina (prosečna debljina oko 6,0 m). Predstavlja zonu mešanja žute i sive gline; i
- ►siva glina. (prosečne debljine od oko 35,5 m).

Ukupne rezerve glina u ovom ležištu iznose 69.041.871 tona [3] (rezerve A+B kategorije).

Primena žutih glina [3] pri rekultivaciji Flotacijskog jalovišta Veliki Krivelj[8] (a i drugih jalovišta nastalih radom RTB-a) doprinela bi konačnom rešenju eliminiacije ekološke katastrofe ovog jalovišta.

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CLAY QUALITY IN THE DEPOSIT DUŠANOVAC (NEAR NEGOTIN)**

Abstract

The clay deposit [3,5] Dušanovac is located in the northeastern part of Serbia, in the area of the village Dušanovac, about 9 km northwest of Negotin. The main goal of two-year geological investigation was lead the formation of clay in the area of "Dušanovac" near Negotin to a phase of deposit contouring, which will get all data for verification the reserves as clay minerals. Geological investigations, carried out during 2008/10 [3,5] have defined the geological characteristics of the deposit, quality of clay [4,3,6,7], evaluation the potentiality of prospecting area [3] as well as calculation the geological reserves of mineral resource deposit [3].

During this period, 4 prospecting trenches were done and 12 prospecting drill holes were drilles. Shallow geological vertical drill holes drilled the total of 717.00 meters [3].

This work has resulted from the Project 33021, which is funded by the Ministry of Education and Science of the Republic of Serbia (the quality of the clay deposit Dušanovac, the results of technological tests and the possibility of preparing these materials and what is important for the very possibility of application are shown). According to the color of clay in the deposit Dušanovac, the clay is divided into four types: brown clay [3,4,6,7]; yellow clay (it appears in all deposit, lying below the brown clay, average thickness is about 13.0 m, it is greasy, very plastic and slightly sandy), brown-gray clay and gray clay.

The use of these clays [3,5] (yellow clay) in the recultivation the flotation tailing dump Veliki Krivelj [8] (and other tailing dumps, formed by operation of RTB) would contribute to the final solution of environmental disaster of this tailing dump.

Key words: *clay quality, possibility of use, deposit, mineral raw material*

INTRODUCTION

The clay deposit Dušanovac is situated about 9 km from Negotin [3,5], in the area of the village Dušanovac (Figure 1). In the morphological sense, the area belongs to a depression which lies between the Dupljanska River (left tributary of the Jasenička River) and Danube. Deposit is located at altitude of about 90 m (while the town Negotin is at altitude of about 45 m). Water flows belong to the Danube River Basin (the Iron Gate Hydropower is situated near deposit), i.e the Black Sea basin. Hydrographic network is dense and well developed.

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The clay deposit Dušanovac is spatially located in the lower Pliocene sediments (sands, clays and sandstones). The exploration area Dušanovac was explored in detail in 2008/2010 by the exploratory trenches shallow geological exploration drill holes. Those works investigated the exploration area, countoured the deposit, the clay quality as the mineral resource was tested (which directly points out the possibility of use) and total reserves were calculated in the clay deposit. Total reserves of clay in this deposit amount to 69,041,871 tons (reserves of A + B category).

Fig. 1. *General map of distances the clay deposit Dušanovac near Negotin from other towns in Serbia*

HISTORY OF GEOLOGICAL INVESTIGATIONS OF WIDER SURROUNDINGS THE CLAY DEPOSIT DUŠANOVAC

More important information about the geological structure and tectonic relations of broader investigation area [5] Dušanovac (now contoured deposit), are found in the works of Toule F., Zlatarski G., J. Žujović (1889, 1893), Radovano vić S. and Pavlović P. (1891), which provide the first detailed data on the Neogene and Quaternary of Krajina, and which are the basis for further study of Neogene and Quaternary of this area.

Study the Quaternary formations in the Danube Ključ and Negotin Krajina was done by Cvijić J. (1903, 1908, 1921); detailed geological research, stratigraphic and tectonic relations was done by Mirgoci G. (1905), Radovanović S. (1907, 1916) and Bončev St. (1923). Detailed information on the stratigraphic and tectonic problems of pre-tertiary formations of this area were given by Petrović K. (1928, 1937), who stated that on the east of the Iron Gate cover is a new structural unit, the Mokranjska cover, whose head is on the line-Crnomasnica - Mokranje.

A special contribution to the study of geological structure of this region was given by V. Petković (1930 and further), who presented the settings that are current today. Within his studies of Neogene sediments, P. Stevanović paid much attention, who, based on fossil material, first (1940) determined the chronostratigraphic place of the youngest sediments, considering that the gravel of Brza Palanka are of levantian age. In several of his works, since 1950, Stevanović P. discussesd on: Thornton, Sarmatian, Meotian and Pontian and, from the point of biostratigraphy, paleogeography, facies and tectonics.

Geological explorations on the exploration area Dušanovac, were carried out using the geological methods [5], within the preparation of basic geological map (BMG) and present by the BMG interpreter for the leaf Negotin 1:100.000. Non-metallic mineral resources of this area, are used as a technical construction stone and brick clay, although detailed geological explorations in this area were not carrie out. According to literature data, semi-detailed poludetaljna geophysical investigations were carries out (using the gravimetric method), during 1969 (Department for Geological and Geophysical Studies, Belgrade). There are no data on the extent and density of these investigations.

GEOLOGICAL CHARACTERISTICS OF WIDER SURROUNDINGS OF THE CLAY DEPOSIT DUŠANOVAC

Terrain of wider surroundings of the clay deposit Dušanovac, is situated on the leaf Negotin BMG [5], scale 1:100,000 (Figure 2). The oldest sediments in this area are the Tithonian – Valanginian limestones near Mokranje and Rajac, which lie across the Senonian. They represent the allochthonous formations, taken from the west on the Mokranje cover. The Senonian sediments are developed in the flysch facies. He Senonian sediments are sandstones, shales and conglomerates. Their floor has not been established, until the Miocene strata are roof. In superposition terms, there are three parts:

- ►lower, with replacement of sandstones and shales, and poorly marked traces of lamination;
- ►intermediate, with observed alternation in sandstone, conglomerates and shales; and
- ►upper, with sequences sandstone-shales, very rich with lamination and other texture forms. The Senonian flysch basin was probably the north-south direction, while the paleotransport of material came from the southeast, in the field of Moesian platform. The sediments generally fall in the west-southwest direction.

The Neogene sediments [5] have a great extent. Based on rich fossil of molluscs and microfauna, the Neogene complex is divided into Thornton, Sarmatian, and Meothian and Pontian. The oldest Quaternary sediments are represented by lake gravels and sands with Elephas medridionalis. They lie in the form of isolated erosion patches, unconformably over the Sarmatian and Senonian. These creations are the products of a lake phase, during the Lower Pleistocene. Younger Quaternary formations are represented by the river- lake sediments.

The Danube cut into older sediments four cterraces, which are made of gravel, loam and sand dust. Terrace gravels build up lower parts of profile, while loam and sand dusts, sometimes loess habit lie above the gravel. Such grain-size ratio points the creation of facies in the conditions of various dynamic phases of the Danube, with each individual cycle.

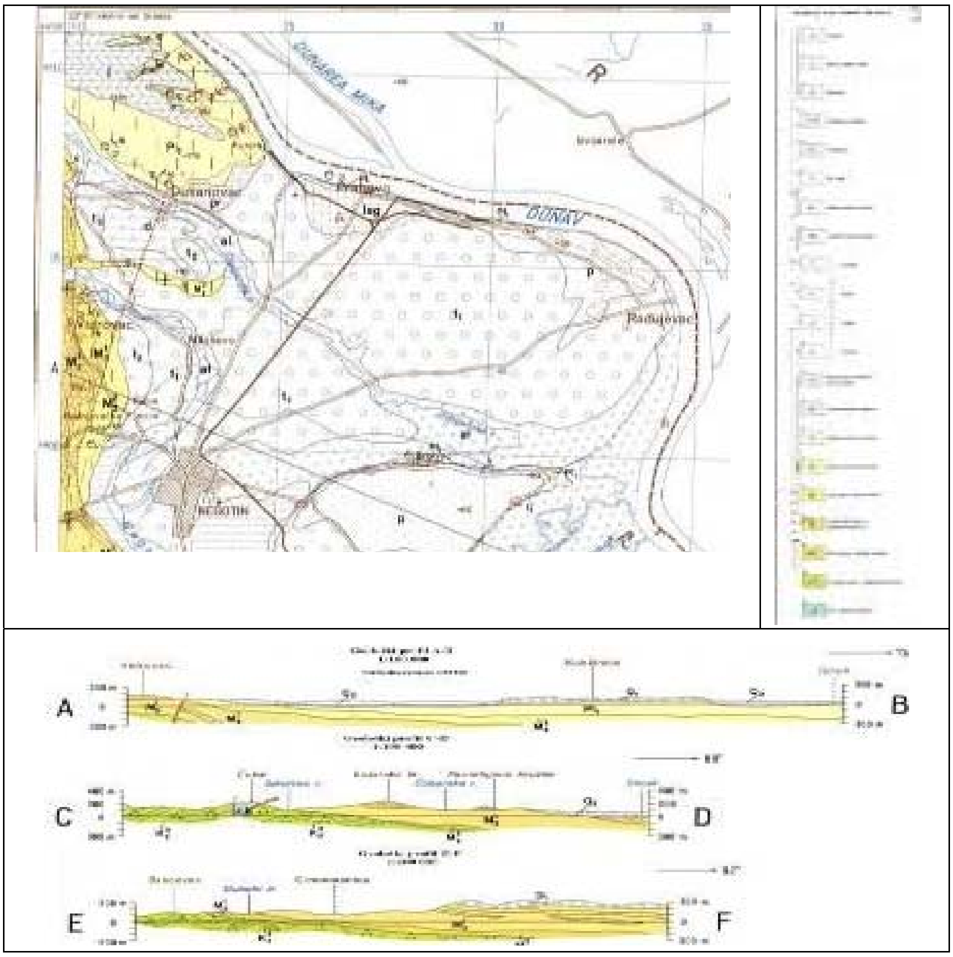

Fig. 2. *Geological structure of wider surroundings, the Negotin leaf (with characteristic profiles)*

Alluvial deposits [5] are also of heterogeneous composition. The bed facies are represented by gravels and sands, making up all the profiles of alluvial plains. The water bed facies are rare, and presented gravel loams, lying across the bed of facies. Live sands are also widespread, lying over the so-called urban terrace. Proluvial genetic type is created by periodical flows of the Studena River and Plandište stream. These are small flooding cones, made of gravel, which are prevalent in the parts of roots, while the clays and sands lie regularly in their peripheral parts. There are some deluvial material, presented by gravel loams, which are more in the zone of leaching, while loam and sand dust materials is much more in the peripheral parts of the accumulation zone.

GEOLOGICAL CHARACTERISTICS OF THE CLAY DEPOSIT DUŠANOVAC

The geological structure of deposit [3,5] consists of sand, clay and pontian sandstone (Pl_1) and significantly less frequent proluvium Holocene (prQ_2) made of: gravel, sand and loam.

The oldest Quaternary sediments [5] are presented by river-lake gravels, sands and loams. According to their characteristics, they correspond to alluvial gravels and sands. Gravels are medium to coarse-grained, the heterogeneous composition of different curvature and weak sortness, and most often occur in the form of lenses embedded in the sand. The composition of gravel consists of sandstone, limestone, micro conglomerates, quartz, cherts, gneiss-granite and others. Yellow sands, sand loams and loams of loess habiti lie over gravels. The horizontal bedding is observed in them as well as the traces of marsh vegetation growns, so it is logical that these are the product of aquatic environment

Lower Pliocene sediments [5] (Pontian) are about 300 m thick (Figure 3). This series consists of shelf sands and sandy clay, above which a thin marl layer lies with supposed thickness of about 20 - 30 m. Above the marl is deposited the layer of sandy clay, with a gradual transition to a brick clay lying on the surface of the ground, and of the supposed thickness of about 80 m.

Fig. 3. *Open bench from which the clay is occasionally exploited*

Quaternary sediments[5] are presented by: proluvial gravels, sands and loams, in places where the streams of torrent character appeared as well as in diluvial loams and sand dusts. In deluvial formations, closer to the zone of leaching, the sand dusts are dominant with gravel detritus, while further, in the accumulation zone, the material becomes much finer and clayey.

METHODS OF GEOLOGICAL EXPLORATION THE CLAY DEPOSIT DUŠANOVAC

Geological explorations the investigation area [5] on the site Dušanovac near Negotin, were carried out in the period 2008/10. The following was carried out:

- ►Field survey and reambulation of geological map;
- ► Geological characteristics (structural set, lying conditions, contour and shape) of deposit were defined;
- ► Clay quality (possibilities of preparation and use of clay);
- ► Assessment of potentiality the exploratory area was made as well as calculation of geological reserves of clay deposit as mineral resource.

The following exploratory works were done: 4 trenches and 12 shallow vertical prospecting drill holes were done. Shallow geological drill holes drilled total of 717.00 meters. In the southeastern part of the exploratory area, 5 prospecting drill holes were drilles in the network 400x200 m, and 2 prospecting drill holes in the northern peripheral part of the exploratory area. Seven drill holes were drilled (407.5 m drilling) in 2008/2009 and 7 drill holes (309.5 m) in 2009/2010.

All exploratory works[3,5] were followed by continuous mapping and sampling (material from trenches and core drilling). The same material (sample) was continuously laboratory tested. When the ore reserves [3] were calculated, Al_2O_3 was treated as the main useful component, and Fe_2O_3, SiO_2, CaO and TiO_2 as the accompanying harmful components.

RESULTS OF GEOLOGICAL EXPLORATION THE CLAY DEPOSIT DUŠANOVAC

Field survey and geological map reambulation [3] (part of the list Negotin, a scale of 1:25 000), confirmed that mainly the Neogene formations, less Quaternary formations, are present. Pont (Pl1) is represented by sands, clays and sandstones. These sediments belong semi-brackish ("caspibrackish") facies. It is believed that the Pontian layers lie over concordantly over meota, with a gradual facial transition. Pontian deposits have significantly development around the village Dušanovac. Visible thickness of layers is about 150 m, while the total thickness, going to the East, is certainly higher.

The terrain on which the geological prospecting was carried out by trenches and prospecting dreill holes is a hilly river valley (Figure 4). Spatially, the deposit is located in the sediments of the Lower Pliocene (Pontian). Deposit has a shape of elongated lenses, in the north-south [3] direction. By direction, it can be traced over 2.5 km, while the average width is about 320 m. Exploratory works covered the northern and western part of deposit, an area of about 0.4 km^2.

 

Fig. 4. *Field in the domain of clay deposit Dušanovac (left) and the view from the Hydroelectric Plant Iron Gate 2 (right)*

The clay deposit [3,5] was explored by trenches (totally 4 trenche, dimensions 2×2.5×1 m) and geological prospecting drill holes. According to the vertical profile of all trenches, the ground surface to the depth of soil from 0.6 to 0.7 m was observed, and below that the yellow brown sandy clay with the appearance of carbonate. One sample was taken frfrom each trench for chemical testing.

Sampling intervals [3] of cores from prospecting drill holes were 1 or 2 m. Total of 370 individual samples were taken, out of which 41 composite samples were formed. Composite samples were specially formed for the yellow clay class, specially for the gray class of clay quality.

Studying the pillars of drill holes [3], it was observed that macroscopically,according to the color of clay deposit, four layers can be broken down:

- ► Brown clay lies immediately below the humus cover, which has the average thickness of about 0.7 m. Clay is poor to more sandy, the average thickness of this layer is about 1.5 m;
- ► Yellow clay lies below brown clay, average thickness of about 13.0 m. This clay is greasy, very plastic and slightly sandy with occasional occurrence of FeO and MnO coating. A layer of yellow clay occurs throughout the deposit;
- ► Brown-gray clay is spatially positioned below the yellow and above the gray clay above. A layer of brown-gray clay represents a zone of mixing of yellow and gray clay and it is very sandy, and the average thickness of this layer is about 6.0 m.
- ► Gray clay is the average thickness of about 35.5 m and it is located below the brown-gray clay. It is very sandy, and thin interlayers of a strong clay sand are very rarely observed in this thin layer. The fossil remains of shells also occur in this layer. A layer of gray clay with increasing of a depth gradually becomes very clay sand. A layer of gray clay was drilled by all drill holes.

Physical-mechanical testing [4], grain-size distribution testing [6,7], laboratory technology and chemical testing were carried out from laboratory testing on taken samples. Technological tests in semi-industrial and industrial scale, were not done.

CLAY QUALITY IN THE DEPOSIT DUŠANOVAC

Quality of mineral deposits involves the content of useful components and possibility of use the mineral resources[5]. Reliability of determining the quality of raw material in deposit depends on sampling method, sample weight, sample reduction on-site, preparation and processing in the laboratory, as well as the accuracy of methods of analysis.

Content of useful and harmful components [3], in the clay deposit Dušanovac, were determined by chemical analyses of individual samples taken from the drill holes, drilled from the field surface. Individual samples were analyzed on Al_2O_3, TiO_2, SiO_2, Fe_2O_3, CaO, loss on calcination (LC) and H_2O^- (Table 1). Composite sample was obtained by material merging of ten or five consecutive, individual samples (ten meter interval). Composites of samples were analyzed on: SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, S total, SO_3, TiO_2, K_2O, Na_2O, Cr_2O_3, loss on calcination, MnO, FeO, CO_3, Mn, Fe, Cu and pH.

Table 5.2. *Chemical (average) contents of clay in the deposit Dušanovac from individual samples per quality classes, calculated using the program package MINEX 5.2.1.*

Class	Average content (%)						
	Al_2O_3	TiO_2	SiO_2	Fe_2O_3	CaO	G.ž.	H_2O^-
GB (yellow brown clay)	16.7	0.85	57.2	6.28	2.7	9.99	18.9
GI (yellow clay)	16.5	0.86	57.5	6.01	4.16	9.59	20.5
GII (gray clay)	16.7	0.87	56.5	5.94	3.64	9.51	20.4
Whole deposit	16.6	0.87	56.8	5.97	3.78	9.54	20.4

Physical-mechanical testing [4] were carried out on samples of clay, sandy clay and strongly clay sand. Testing of physical-mechanical characteristics of clay samples, taken by core sampling of prospecting drill holes, were carried out according to the current Standards for each type of testing for the needs of mining or as recommended by the International Society for Rock Mechanics (ISRM).

The following parameters were carried out from physical properties of the clay samples [4]: humidity - W [%], specific gravity or bulk density of solids - γ_s [kN/m^3], bulk density - γ_z [kN/m^3], porosity - n [%], rate of propagation of longitudinal waves - V_L [m/s], clay condensation and plasticity limits. Mechanical parameters were determined [4]: resistance parameters in direct shear, and uniaxial compressive strength. Thus, the working environment [4], in which exploitation will take place, make clay, slightly sandy clay, strong sandy clay and more heavily clay sands. Assumed angle of bench slope and final slope angle of open pit are adopted based on the following physical - mechanical characteristics of working environment: bulk density of clay d = 19.71 kN/m^3 (1.971 t/m^3); clay cohesion C = 0.380 MPa, angle of internal support of clay, φ = 15.33°. Based on the physical - mechanical properties of clay [4] of the deposit Dušanovac near Negotin, it is concluded that the engineering-geological characteristics are relatively favorable and that there will not be major problems in the exploitation phase.

Testing of grain-size distribution from the clay deposit Dušanovac near Negotin, was done by two ways: studying the grain-size distribution of each individual sample [6,7] from all drfill holes and testing the grain-size distribution of composite samples [6,7]. Composite samples were formed according to the class quality for each individual drill hole. Characteristically, the coarser classes (-0.212 +0.106 mm) account with about 1%. Most of them is the class -0.020 +0.000 mm with a participation of 61-75%.

For technological tests of clay [3] from the deposit Dušanovac for the aim of finding out a direction which should be focused to further laboratory investigations and testing, a short series of experiments was carried out for separation the fine fraction using the method of sedimentation and decantation. Having in mind the presence of clay minerals in very fine fractions, less than 20 microns, it was oursued in the experiments to find out the opportunities for increasing a proportion (mass participation) of the same or increasing Al_2O_3 content, thereby obtaining high quality natural clay, which as such can found a wide use in all branches of industry.

FINAL DISCUSSIONS ON CLAY USE IN THE DEPOSIT DUŠANOVAC

Clays are mostly used [3] in the refractory material industry, brick industry, porcelain and stoneware, ceramics industry, paper industry, chemical industry, pharmaceutical industry, for rinding and rehabilitation of degraded areas (land recultivation). Based on the industrial application of clay, the requirements for quality are defined and they are related to the mineral composition, content of Al_2O_3, TiO_2, and SiO_2, content of impurities, pH value, chemical stability, swelling, fire resistance, coarse-grain particles, whiteness.

The clay deposit Dušanovac belongs to the sedimentary deposits [1,2], formed of decomposition material and leaching of rocks, which was later transferred and re-deposited. In order to ensure the domestic raw materials [5] (which is certainly the most rational approach to supply the needs of existing industrial facilities), the clay from deposit Dušanovac was laboratory tested. Depositis in the sediments of the Lower Pliocene (Pontian), it has elongated shape of the lens, in the north-east direction. Along direction, it can be followed more than 2.5 km, while its average width is about 320 m. Exploratory works have covered the northern and western part of the deposit, an area of about 0.4 km^2.

By geological exploration the deposit Dušanovac, the clay is divided into four types:

- ► brown clay (average thickness of about 1.5 m);
- ► yellow clay (average thickness of about 13.0 m);
- ► brown-gray clay (average thickness of about 6.0 m). It represents a zone of mixing the yellow and gray clay; and
- ► gray clay (average thickness of about 35.5 m).

Total reserves of clay in this deposit amount 69,041,871 tons [3] (reserves of A+B category).

The use of yellow clay [3] in recultivation of the flotation tailing dump Veliki Krivelj [8] (and other tailing dump, formed by operation of RTB) would contribute to the final solution of elimination the environmental disaster of this tailing dump.

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FIZIČKE I MEHANIČKE OSOBINE ANKER SMEŠE PRIMENJENE NA RUDNOM TELU „T“**

Izvod

Jedan od materijala koji je korišćen za obezbeđenje stabilnosti tokom eksploatacije rudnog tela „T“ je i ankerna smeša. Bilo je neophodno proveriti fizičke i mehaničke osobine ankerne smeše zbog njenog učešća u stabilnost stenske mase. Rezultati ovih ispitivanja su prikazani u ovom radu.

Ključne reči: *ankerna smeša, rudno telo "T", fizičke i mehaničke osobine.*

UVOD

Beton je heterogena, višefazni material dobijen povezivanjem različitih vrsta agregata sa cementnom pastom. Agregat predstavlja linearnu elastičnu komponentu, a cementna pasta je visoko elastična komponenta.

Mešanejm betonskih komponenti u kontrolisanim uslovima ima za cilj da se dobije potpunija homogenizacija smeše sa pravilno povezanim agregatom i cementnom pastom.

Po zahtevu firme Polimerinžekt D.O.O. iz Bugarske, koja je izvodila radove na osiguranju stabilnosti stenske mase tokom eksploatacije rudnog tela "T" u borskoj jami, uzorci ankerne smeše su ispitivani na pritisnu čvrstoću.

Uzorke je dostavio Polimerinžekt.

REZULTATI ISPITIVANJA

Uzorci ankerne smeše su dopremljeni u laboratoriju za geomehaniku. Dimenzije uzoraka su 7,3 cm u prečniku i 7,5 cm (visina), slika 1.

Na slici 2 je predstavljen izgled uzoraka nakon ispitivanja.

* *Institut za rudarstvo i metalurgiju Bor*
** *Rad je proizašao iz projekta broj 33021 „Istraživanje i praćenje promena naponsko deformacionog stanja u stenskom masivu „in situ“ oko podzemnih prostorija sa izradom tunela sa posebnim osvrtom na tunel Kriveljske reke i Jame Bor“, koji je finansiran sredstvima Ministarstva za prosvetu i nauku Republike Srbije*

Sl. 1. *Uzorci ankerne smeše pre testiranja*

Sl. 2. *Uzorci nakon testiranja*

Ova ankerna smeša će biti korišćena u rudnom telu „T“. Korišćen je beton PC 42.5N i gotova injekciona smeša za ankere ROFIX 995.

Test pritisne čvrstoće je izvršen na betonu nakon 7 dana sazrevanja, kako je zahtevano od strane Polimerinžekt-a. Ispitivanja su sprovedena prema standardu SRPS U.M2.008: 1994. Rezultati su prikazani u tabeli 1.

Tabela 1. *Rezultati ispitivanja*

Oznaka uzorka	**Dimenzije uzorka d x h [cm]**	**Sila loma P [kN]**	**Jednoosna čvrstoća na pritisak σ_p [MPa]**	**Zapre-minska masa [kg/m^3]**	**Brzina prostiranja longitudinalnih talasa V_L [m/s]**
1.	7,3x7,5	151,0	36,09	1940,0	3440,0
2.		147,0	35,14	1913,0	3424,0
3.		131,0	31,32	1936,0	3318,0
Srednja vrednost:		143,0	34,18	1929,67	3394,0

ZAKLJUČAK

Sveža betonska masa pokazuje određene karakteristike koje utiču na druge faze procesa proizvodnje. Često se postavljaju dva pitanja:

1. Koje osobine betona su važne sa gledišta racionalnog korišćenja tehnološke opreme?

2. Koja od ovih osobina je najvažnija za obezbeđenje kvaliteta očvrsle mase?

Može se reći da su najvažnije osobine betona:

- homogenost,
- obradivost,
- segregacija,
- vreme vezivanja,
- temperatura,
- pritisna čvrstoća.

Prema dobijenim rezultatima može se reći da testirana ankerna smeša zadovoljava kriterijume za koje je namenjena u rudnom telu „T“.

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PHYSICAL AND MECHANICAL PROPERTIES OF ANCHOR MIXTURE APPLIED IN THE ORE BODY "T"**

Abstract

One of the materials, used for ensuring the stability in exploitation the ore body "T" is the anchor mixture. It was necessary to check the physical and mechanical properties of anchor mixture because of its participation in the rock mass stability. The results of these tests are present in this paper.

Key words: *anchor mixture, ore body "T", physical and mechanical properties*

INTRODUCTION

Concrete is a heterogeneous, multiphase material, obtained by binding various types of aggregates with the cement paste. Aggregate present a linear elastic component and the cement paste is high elastic component.

Mixing of concrete components in the controlled conditions is aimed to obtain more complete homogenization of mixture with properly bound aggregate and cement paste.

On the request of the company Polimerinžekt Ltd. from Bulgaria, which carried out the works on ensuring the rock mass stability in exploitation the "T" ore body in the Bor pit mine, the samples of anchor mixture were tested on a compressive strength.

Samples were delivered by Polimerinžekt Ltd.

TESTS RESULTS

Anchor mixture samples were delivered to the Laboratory for Geomechanics. Dimensions of the samples were 7.3 cm (diameter) and 7.5 cm (height), Figure 1.

Figure 2 presents the appearance of samples after testing.

* *Mining and Metallurgy Institute Bor*

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Fig. 1. *Anchor mixture samples before testing*

Fig. 2. *Samples after testing*

This anchor mixture will be used in the "T"ore body. The applied concrete was PC 42.5N and complete prepared injection mixture for anchors, ROFIX 995.

Compressive strength test was carried out on a concrete after 7 days of maturing, as it was requested by Polimerinžekt Ltd. Testing was carried out according to the Standard SRPS U.M2.008: 1994. The results are shown in Table 1.

Table 1 *Test results*

Sample designation	Sample dimensions d x h [mm]	Failure force P [kN]	Uniaxial compressive strength σ_p [MPa]	Bulk density [kg/m^3]	Rate of longitudinal waves V_L [m/s]
1.	7.3x7.5	151.0	36.09	1940.0	3440,0
2.		147.0	35.14	1913.0	3424,0
3.		131.0	31.32	1936.0	3318,0
Mean values:		143.0	34.18	1929.67	3394.0

CONCLUSION

Fresh concrete mass shows the certain characteristics which affect the other phases of production process. Two questions are often asked:

1. Which properties of concrete are important from the standpoint of rational use the technological equipment?

2. Which of these characteristics is the most important for quality assurance of harden mass?

It could be said that the most important characteristics of concrete are:

- homogeneity
- workability,
- segregation,
- binding time,
- temperature,
- compressive strength.

According to the obtained results, it could be said that tested anchor mixture satisfies the criteria for use in the "T" ore body.

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MOGUĆNOST PRIMENE DROBLJENOG AGREGATA GRANULACIJE 0/31,5 MM SA LOKALITETA "ZAGRAĐE-KOP 5", ZA PRIPREMU PRISTUPNIH PUTEVA DO NOVE TRASE KRIVELJSKOG KOLEKTORA***

Izvod

U ovom radu prikazani su rezultati laboratorijskih ispitivanja kamenog agregata dobijenog iz kopa Zagrađe-5 kao mogući materijal za izradu nasipa i tamponskih slojeva od nevezanog kamenog materijala. Ispitivanja su rađena na uzorcima drobljenog kamena, kao i osnovnog kamena od koga je agregat dobijen. Rezultati ispitivanih karakteristika materijala u potpunosti zadovoljavaju zahteve odgovarajućih propisanih standarda.

Ključne reči: *Zagrađe-kop 5, kameni agregat, osnovni kamen*

UVOD

Drobljeni agregat u granulaciji 0/31,5 mm se koristi za izradu donjih nosećih (tamponskih) slojeva od nevezanog kamenog materijala i izradu nosećih slojeva kolovoznih konstrukcija od bitumeniziranog materijala. Izbor agregata treba da zadovolji tehničko, ekonomsko kao i pitanje dostupnosti agregata na određenom podnevlju (mestu gde se izvodi konstrukcija).

Imajući to u vidu, može se zaključiti da je optimalno rešenje za izradu pristupnih puteva i saobraćajnica do nove trase Kriveljskog kolektora agregat dobijen drobljenjem krečnjaka sa lokaliteta Zagradje kop-5 kod Bora.

U ovom radu biće prikazani rezultati ispitivanja sa osvrtom na mogućnost primene ovog agregata u navedene svrhe.

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*** *Ovaj rad je proistekao iz Projekata broj TR 33021 „Istraživanje i praćenje promena naponsko deformacionog stanja u stenskom masivu „in situ“ oko podzemnih prostorija sa izradom tunela sa posebnim osvrtom na tunel Kriveljske reke i Jame Bor“ i TR 36014 “Geotehnički aspekti istraživanja i razvoja savremenih tehnologija građenja i sanacija deponija komunalnog otpada“ koji finansira Ministarstvo za prosvetu i nauku Republike Srbije*

REZULTATI LABORATORIJSKIH ISPITIVANJA

Uzorak drobljenog kamena (krečnjaka) granulacije 0/31,5 mm (slika 1.), kao i osnovnog kamena od koga je napravljen agregat (slika 2.), na kojima su izvršena laboratorijska ispitivanja, odabran je od strane stručnih lica iz Instituta za rudarstvo i metalurgiju Bor.

Sl. 1. *Pripremljeni agregat za ispitivanje*

Sl. 2. *Pripremljeni uzorci za ispitivanje od osnovnog kamena*

Mineraloško-petrološka analiza (SRPS B.B8.004)

Minerološko-petrografska analiza, makroskopska i mikroskopska su pokazale sledeće:

Makroskopski opis:

Uzeti uzorci su masivne teksture, sitnozrne strukture, beložućkaste boje.

Veoma sitne žilice ispunjene su čistim kalcitom.

Mikroskopski opis:

Stena je mikrokristalaste do kriptokristalaste strukture. Izgrađena je od kalcita, koji se javlja u vidu nepravilnih sitnozrnih do krupnozrnih kristala. Matriks je mestimično ispresecan finim žilicama koje su ispunjene mikrokristalastim kalcitom.

Rezultati laboratorijskih ispitivanja osnovnog kamena, kao i agregata prikazani su tabelama 1. i 2.

Tabela 1. *Rezultati ispitivanja osnovnog kamena*

ISPITIVANJE		U SKLADU SA	REZULTAT
Jednoosna čvrstoća na pritisak	U prirodnom stanju	SRPS B.B8.012	76,79 MPa
	U vodom zasićenom stanju		70,99 MPa
	Pad pritisne čvrstoće		7,55 %
Postojanost na mrazu (Na_2SO_4)		SRPS B.B8.010	postojan
Otpornost na habanje po Beme-u		SRPS B.B8.015	22,64 $cm^3/50cm^2$
Otpornost na habanje po Beme-u izraženo gubitkom mase		SRPS B.B8.015	8,20 %

Tabela 2. *Rezultati ispitivanja kamenog agregata*

KARAKTERISTIKA	ISPITIVANJE	U SKLADU SA	ISPITANO	REZULTAT
Fizička svojstva	Zapreminska masa u rastresitom stanju	SRPS ISO 6782	celokupan uzorak	1,708 g/cm^3
	Zapreminska masa u zbijenom stanju			1,841 g/cm^3
	Upijanje vode	SRPS ISO 6783	zrna veća od 4 mm	1,02 %
Mehanička svojstva agregata	Ispitivanje otpornosti protiv drobljenja i habanja – Los Angeles	SRPS B.B8.045	gradacija B	24,3 %
Konstruktivne karakteristike	Optimalan sadržaj vode	SRPS U.B1.038	celokupan uzorak	5,93 %
	Maksimalna zapreminska masa			2,282 g/cm^3
	Kalifornijski indeks nosivosti- CBR	SRPS U.B1.042		98,0 %
Karakteristike postojanosti	Postojanost agregata na dejstvo mraza	SRPS B.B8.044	celokupan uzorak	1,08 %
Karakteristike zrna	Sadržaj slabih zrna	SRPS B.B8.037	zrna veća od 4 mm	nema
	Sadržaj zrna nepovoljnog oblika	SRPS B.B8.048		3,2 %
Karakteristike granulometrijskog sastava	Granulometrijski sastav	SRPS B.B8.029	celokupan uzorak	povoljan
	Sadržaj čestica manjih od 0,09 mm	SRPS B.B8.036		1,90 %
	Sadržaj čestica manjih od 0,06 mm			0,75 %
	Sadržaj čestica manjih od 0,02 mm			nema
Sadržaj štetnih sasto-jaka	Sadržaj grudvi gline	SRPS B.B8.038	celokupan uzorak	nema
	Sadržaj organskih materija	SRPS B.B8.039		
Opasnost od štetnog dejstva mraza	Prema sadržaju čestica manjih od 0,02 mm	SRPS U.E9.020	celokupan uzorak	nema

ANALIZA REZULTATA ISPITIVANJA

Detaljnim laboratorijskim ispitivanjem drobljenog agregata granulacije 0/31,5 mm, kao i ispitivanjem krečnjaka iz kojeg je dobijen ispitivani agregat, utvrđeno je sledeće:

A. KAMEN

Mineraloško-petrografskom analizom utvrđeno je da kamen od kojeg je proizveden agregat 0/31,5 mm po vrsti stena mikrokristalasti do kristalasti krečnjak, koji je sa aspekta inženjerske petrografije povoljan kao tehnički građevinski kamen.

Fizičkomehanička svojstva ispitivanog kamena zadovoljavaju navedene tehničke uslove. Pojedinačne vrednosti jednoosne čvrstoće na pritisak idu i preko 80 MPa, a srednja vrednost je 76,79 MPa. Kamen ima malo upijanje vode, 0,11<0,50 % i postojan je na dejstvo mraza.

B. AGREGAT

Mineraloško petrografska analiza

Analizom je utvrđeno da se ispitivani agregat 0/31,5 mm sastoji od odlomaka krečnjaka, po vrsti stena je mikrokristalasti do kristalasti krečnjak. Sa gledišta inženjerske petrografije, njihov mineraloško-petrološki sastav zadovoljava zahteve za izradu nasipa i tampona temelja objekata.

Mehanička svojstva

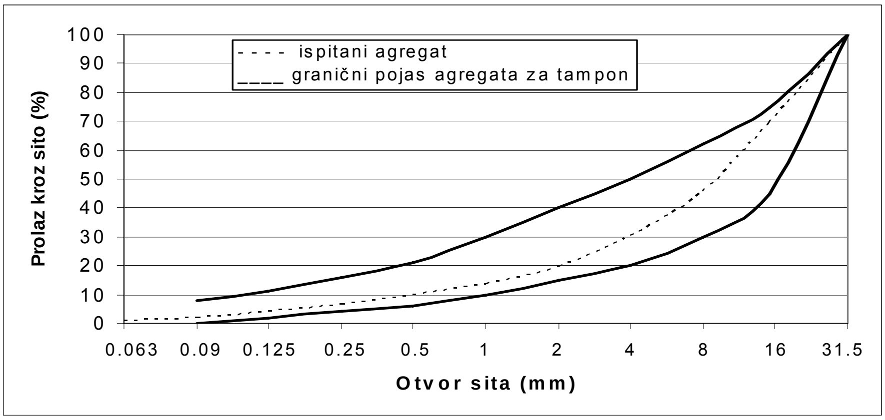
Ispitivani agregat preko otpornosti na mehaničke udare i habanje trenjem po metodi »Los Angeles«, gradacija »B« je 24,3 % zadovoljava tehničke uslove za drobljeni agregat koji se koristi za izradu nasipa i tampona temelja objekata (propisani max. je 40 %).

Karakteristike zrna

Izražene preko sadržaja slabih zrna i zrna nepovoljnog oblika su povoljne:
- Agregat ne sadrži slaba zrna
- Sadržaj zrna nepovoljnog oblika (dimenzija većih od 3:1) je 3,2 %, propisani max. je 40 %.

Karakteristike granulometrijskog sastava

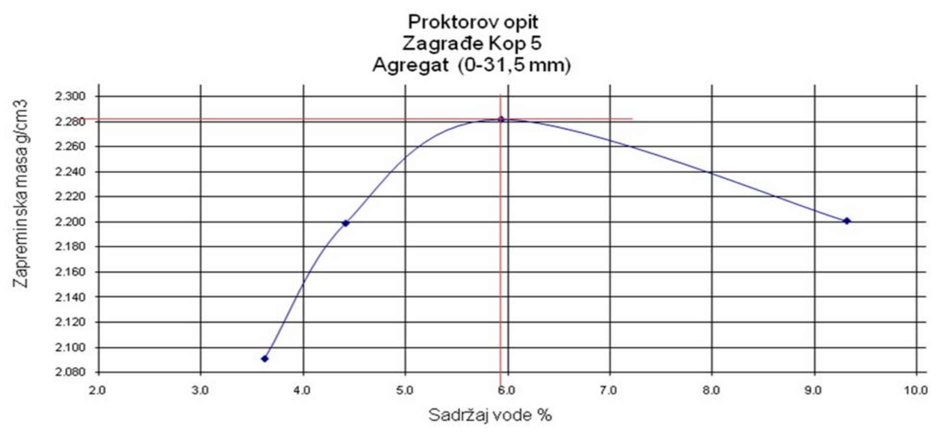
Kriva granulometrijskog sastava (slika 3.) pokazuje dobru rasporedjenost količine zrna veličine od 0 do 31,5 mm. Uz odredjeno procentualno učešće sa agregatima veće i manje granulacije može se koristiti za izradu nasipa i tampona te-melja objekata. Stepen neravnomernosti granulometrijskog sastava po Allen-Hazen-u je U = 10,47 što znači da je agregat umereno neravnomernog sastava.



Sl. 3. *Kriva granulometrijskog sastava ispitivanog kamenog agregata*

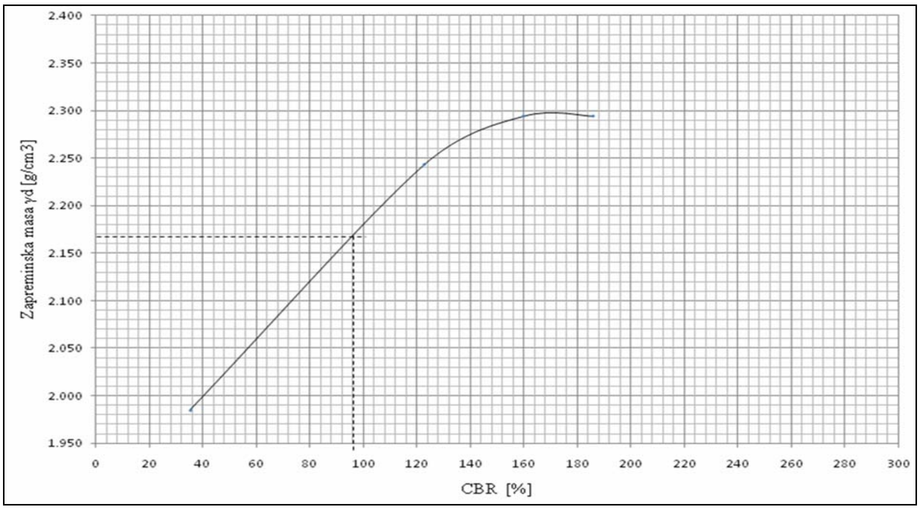
Konstruktivne karakteristike

Određivanjem odnosa vlažnosti i suve zapreminske mase tla Proktorovim testom optimalni sadržaj vode $W_{opt.}$ je 5,93 % pri kome je maksimalna zapreminska masa γ_{dmax} = 2,282 g/cm^3 (Slika 4.).



Sl. 4. *Određivanje odnosa vlažnosti i suve zapreminske mase tla*

Određivanje kalifornijskog indeksa nosivosti (slika 5.), izvedenog nakon Proktorovog testa, pokazao je da CBR (95% γ_{dmax}) iznosi 98 % (propisani min. je 80 %).



Sl. 5. *Određivanje kalifornijskog indeksa nosivosti*

Sadržaj štetnih sastojaka

Ispitivani agregat ne sadrži štetne sastojke – grudve gline ni organske materije.

Postojanost agregata prema dejstvu mraza

Prema metodologiji kristalizacijom Na_2SO_4, ispitivani agregat je postojan na mrazu.

ZAKLJUČAK

Ova ispitivanja su pokazala da drobljeni kameni agregat sa lokaliteta Zagrađe kop-5 zadovoljava sve uslove propisane standardom i može se uspešno koristiti za izradu nasipa i tamponskih slojeva saobraćajnica. Parametri kontrole kvaliteta utvrđeni u agregatu mogu biti narušeni, kako samim procesom eksploatacije, tako i zbog mogućih promena koje nastaju u samom nalazištu, pa je potrebno vršiti njihovo redovno praćenje i peroidično proveravanje.

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POSSIBILITY OF USE THE CRUSHED AFFREGATE, GRAIN-SIZE 0/31.5 MN, FROM THE SITE "ZAGRADJE-OPEN PIT5" FOR PREPARATION THE ACCESS ROADS TO THE NEW ROUTE OF THE KRIVELJ COLLECTOR***

Abstract

This paper presents the results of laboratory tests the stone aggregate, obtained from the open pit Zagradje-5 as a possible material for embankment and buffer layers of unbound stone material. Tests were conducted on samples of crushed stone as wel as the stone base from which the aggregate was obtained. The results of tested material characteristics fully meet the requirements of relevant prescribed standards.

Key words: *Zagradje-open pit 5, stone aggregate, stone base*

INTRODUCTION

Crushed aggregate in granulation 0/31.5 mm is used to make the lower supporting (buffer) layers of unbound stone material and production of load-bearing layers of road construction of bituminous material. Selection of aggregate should meet the technical, economic as well as the question of aggregate availability in the certain region (where construction is performed).

Having that in mind, it can be concluded conclude that the optimum solution for construction the access roads and roads to the new route of Krivelj collector,the obtained aggregate by crushing of limestone from the site Zagradje Open Pit-5 near Bor.

This paper presents the test results with regard to the applicability of this aggregate for the stated purposes.

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** *Faculty of Mining and Geology Belgrade*
*** *This paper is produced from the project no. 33021 “Researching and monitoring changes in stress-deformation condition of rock massif “in-situ” around undergraund facilities with development of model with special emphasis on Krivelj river tunnel and Bor pit”, and TR 36014, “Geotechnical aspects of research and development of modern technologies for construction and rehabilitation of landfill for municipal solid waste“ funded by means of the Ministry of Education and Science of the Republic of Serbia*

RESULTS OF LABORATORY TESTS

A sample of crushed stone (limestone), grain size 0/31,5 mm (Figure 1), and the stone base of which the aggregate is made (Figure 2), where laboratory tests were carried out, was selected by the experts from the Mining and Metallurgy Institute Bor.

Fig. 1. *Prepared aggregate for testing*

Fig. 2. *Prepared samples for testing of a stone base*

Mineralogical-petrologic analysis (SRPS B.B8.004)

Mineralogical-petrographic analysis, macroscopic and microscopic analyses showed the following:

Macroscopic description:

Taken samples are of massive texture, fine-grained structure, and yellowish white color. Very small veins are filled with pure calcite.

Microscopic description:

Rock is of micro crystal to crypto crystal structure. It was built of calcite, which appears in the form of irregular fine-grained to coarse-grained crystals. Matrix is locally intersected by fine veins, filled with micro crystals of calcite.

The results of laboratory tests of basic stone and aggregates are shown in Tables 1 and 2.

Table 1. *Test results of basic stone*

TEST		IN ACCORDANCE WITH	RESULT
Uniaxial compressive strength	In natural condition	SRPS B.B8.012	76.79 MPa
	In water saturated condition		70.99 MPa
	Compressive strength drop		7.55 %
Resistance to frost (Na_2SO_4)		SRPS B.B8.010	stable
Wear resistance per Beme		SRPS B.B8.015	22.64 $cm^3/50cm^2$
Wear resistance per Beme expressed by weight loss		SRPS B.B8.015	8.20 %

Table 2. Test results of stone aggregate

CHARACTERISTIC	TESTING	IN ACCORDANCE WITH	TESTED	RESULT
Physical properties	Bulk density in dispersed state	SRPS ISO 6782	overall sample	1.708 g/cm^3
	Bulk density in compacted state			1.841 g/cm^3
	Water absorption	SRPS ISO 6783	grains larger than 4 mm	1.02 %
Mechanical properties of aggregate	Resistance testing against crushing and abrasion – Los Angeles	SRPS B.B8.045	gradation B	24.3 %
Structural characteristics	Optimum water content	SRPS U.B1.038	overall sample	5.93 %
	Maximum bulk density			2.282 g/cm^3
	Californian bearing index- CBR	SRPS U.B1.042		98.0 %
Stability characteristics	Aggregate resistance to frost effects	SRPS B.B8.044	overall sample	1.08 %
Grain characteristics	Content of weak grains	SRPS B.B8.037	grains larger than 4 mm	no
	Content of unfavorable grain shape	SRPS B.B8.048		3.2 %
Grain-size distribution characteristics	Grain-size distribution	SRPS B.B8.029	overall sample	favorable
	Particle content less than 0.09 mm	SRPS B.B8.036		1.90 %
	Particle content less than 0.06 mm			0.75 %
	Particle content less than 0.02 mm			no
Contents of harmful ingredients	Content of clay lumps	SRPS B.B8.038	overall sample	no
	Content of organic matters	SRPS B.B8.039		
Risk of frost adverse effects	According to particle content less than 002 mm	SRPS U.E9.020	overall sample	no

ANALYSIS OF TEST RESULTS

Detailed laboratory testing of crushed aggregate of grain size 0/31.5 mm, as well as limestone testing from which the tested aggregate was obtained, the following was determined:

A. STONE

Mineralogical-petrographic analysis has confirmed, that the stone of which the aggregate 0/31.5 mm was produced by the type of rock, is crystalline to micro-crystalline limestone, which is a favorable from the aspect of engineering petrography as a technical construction stone.

Physical-mechanical properties of tested stone meet these technical requirements. Individual values of uniaxial compressive strength are over 80 MPa, and the mean value is 76.79 MPa. The stone has low water absorption, 0.11 <0.50%, and it is resistant to the effects of frost.

B. AGGREGATE

Mineralogical-petrographic analysis

Analysis has revealed that the tested aggregate 0/31.5 mm is composed of limestone fragments, by the type of rock, is crystalline to microcrystalline limestone. From the aspect of engineering petrography, their mineralogical-petrographic content meets the requirements for construction the embankments and foundation pads of facilities.

Mechanical properties

Tested aggregate over resistance to mechanical shocks and wear friction by the method of "Los Angeles", gradation "B", is 24.3% and it meets the technical requirements for crushed aggregate that is used for construction of embankments and foundation pads of facilities (prescribed maximum is 40%).

Grain characteristics

Grain characteristics, expressed by the content of weak grains and grains with unfavorable shape, are favorable:

- Aggregate does not contain the weak grains
- Content of grains with unfavorable shape (size larger than 3:1) is 3.2%, the prescribed maximum is 40%.

Characteristics of grain size distribution

Curve of grain-size distribution (Figure 3) shows a good distribution of grain sizes from 0 to 31.5 mm. With the certain percentage participation with aggregates of larger and smaller grain size, it can be used for construction the embankments and foundation pads of facilities. The degree of inequality the grain-size distribution by the Allen Hazen is U = 10.47, that means that the aggregate is of moderate uneven composition.

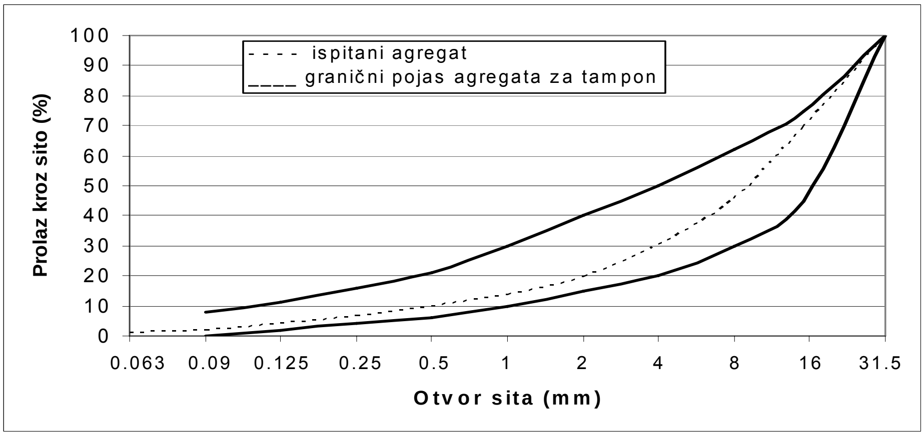

Fig. 3. *Curve of grain-size distribution of tested stone aggregate*

Structural characteristics

Determining the relationship between humidity and dry bulk density of soil using the Proctor test, the optimum water content $W_{opt.}$ is 5.93% at which maximum bulk density $\gamma_{dmax} = 2.282$ g/cm^3 (Figure 4).

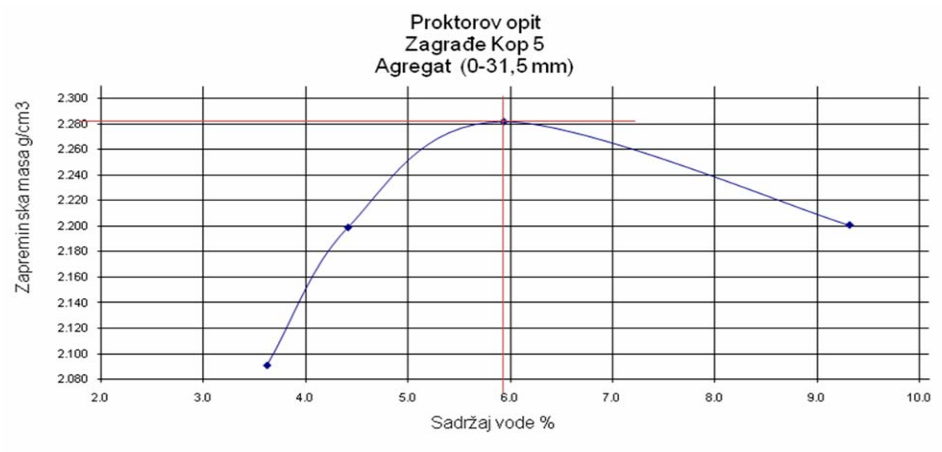

Fig. 4. *Determining the relationship between moisture content and dry bulk density of soil*

Determination of the Californian loading index (Figure 5), derived after the Proktor test, showed that the CBR (95% γ_{dmax}) is 98% (prescribed min. is 80%).

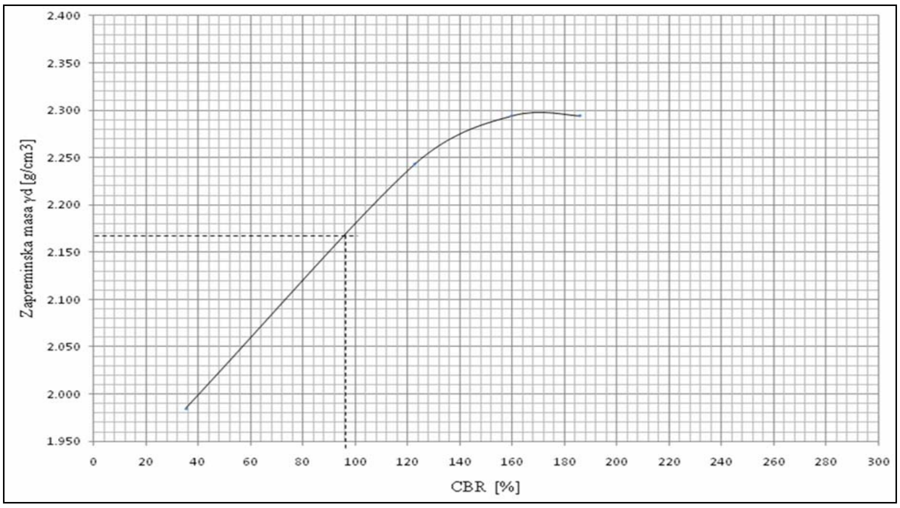

Fig. 5. *Determination of the Californian loading index*

Content of harmful ingredients

The tested aggregate contains no harmful ingredients - lumps of clay or organic matters.

Aggregate resistance to the frost effects

According to the methodology of Na_2SO_4crystallization, the tested aggregate is resistant to frost.

CONCLUSION

These studies have shown that the crushed stone aggregate from the site Zagradje Open Pit-5 meets all prescribed requirements of the standard and can be successfully used for construction of embankments and road pad layers. Determined quality control parameters in aggregate may be affected both by the actual process of exploitation and due to possible changes that occur in the site, so it is needed to perform their regular monitoring and periodical checking.

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ANALIZA UTICAJA RAZVOJA RUDNIKA VELIKI KRIVELJ NA IZGRADNJU NOVIH OBJEKATA ZA DEVIJACIJU KRIVELJSKE REKE**

Izvod

U ovom radu dat je pregled razvoja rudnika Veliki Krivelj, koji se nalazi u sastavu Rudarsko topioničarskog basena Bor, u narednom četrdesetogodišnjem periodu i izvršena analiza uticaja tog razvoja na izgradnju objekata za izmeštanje Kriveljske reke.

Na osnovu sprovedene analize utvrđeno je koji se novi objekti moraju izgraditi kako bi eksploatacija rude na rudniku Veliki Krivelj mogla da se odvija nesmetano i u skladu sa usvojenim dugoročnim planovima od strane menadžmenta Kompanije.

Ključne reči: *rudnik Veliki Krivelj, razvoj, objekti za devijaciju Kriveljske reke*

1. UVOD

Velike promene u svetskoj proizvodnji bakra nastale, pre svega, usled konstantnog povećanja cene bakra od 2004. godine, koja je u 2011. godini dostigla i prosečnu vrednost od 9 500 $, pozitivno su uticale i na proizvodnju bakra u kompaniji RTB Bor.

Na osnovu sprovedenih analiza potencijalnosti ležišta u Boru i Majdanpeku menadžment RTB-a Bor usvojio je strategiju daljeg razvoja rudničke proizvodnje, koji će se bazirati na masovnoj eksploataciji rude bakra na površinskim kopovima Veliki Krivelj i Cerovo, koji posluju u okviru DOO Rudnici bakra Bor (RBB) i kopova Južni i Severni revir, koji se nalaze u sklopu Rudnika bakra Majdanpek (RBM).

U sastavu Rudnika bakra Veliki Krivelj nalaze se dve tehnološke celine: površinski kop i flotacija.

Površinski kop Veliki Krivelj nalazi se na udaljenosti oko 4 km severoistočno od

* *Institut za rudarstvo i metalurgiju Bor*

** *Rad je proizašao iz projekta broj 33021 „Istraživanje i praćenje promena naponsko deformacionog stanja u stenskom masivu „in situ“ oko podzemnih prostorija sa izradom tunela sa posebnim osvrtom na tunel Kriveljske reke i Jame Bor“, koji je finansiran sredstvima Ministarstva za prosvetu i nauku Republike Srbije*

Bora. Pronađeno je 1969. godine, a dobilo je naziv po istoimenom selu koje se nalazi u neposrenoj blizini ležišta.

Radovi na otkopavanju otkrivke započeli su 1979. godine, a prve količine rude otkopane su 1982. godine. Danas proizvodnja koncentrata bakra iz rude sa površinskog kopa Veliki Krivelj čini oko 75% od ukupne proizvodnje RBB-a, dok je učešće rude sa površinskog kopa oko 90% ukupno otkopane rude, sa trendom daljeg povećanja.

U neposrednoj blizini površinskog kopa izgrađena su drobilična postrojenja, flotacija i drugi prateći objekti neophodni za eksploataciju i preradu, odnosno obogaćivanje rude flotacijskim postupkom. Dobijeni koncentrat bakra se prevozi i prerađuje u Topionici u Boru.

Rudnik bakra Veliki Krivelj od početka eksploatacije rude za deponovanje flotacijske jalovine koristi prostor dobijen pregrađivanjem doline Kriveljske reke.

Da bi se realizovalo novo proširenje flotacijskog jalovišta neophodno je prethodno izgraditi nove objekte za devijaciju Kriveljske reke, koji se nalaze u zoni flotacijskog jalovišta. Na ovaj način obezbedio bi se prostor za trajno deponovanje flotacijske jalovine.

2. KONCEPT RAZVOJA RUDNIKA BAKRA VELIKI KRIVELJ

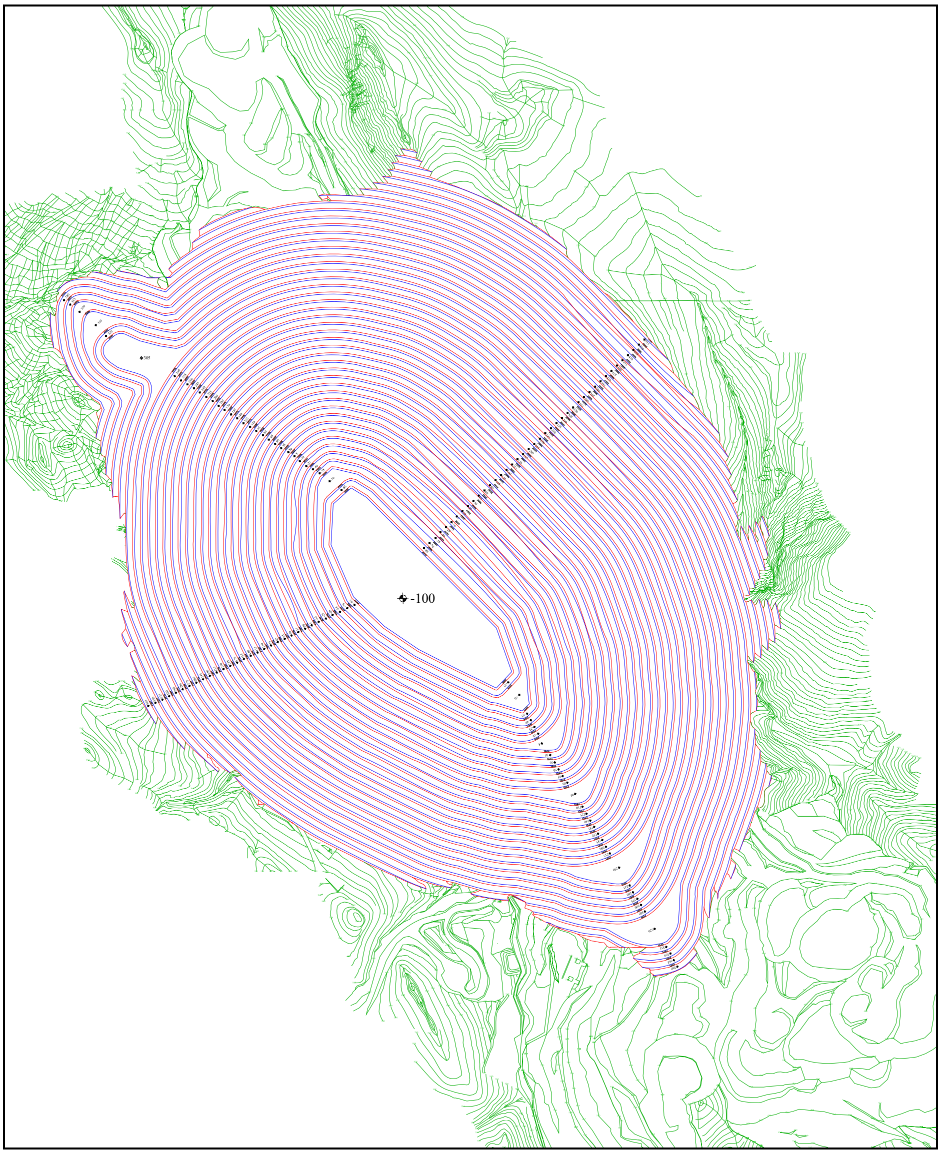
Na osnovu overenih rezervi rude bakra, usvojenog godišnjeg kapaciteta otkopavanja rude od 10,6 miliona tona i predviđene cene bakra na svetskom tržištu metala od 6 000 $ po toni katode definisana je konačna optimalna kontura površinskog kopa do k-100 u okviru koje će se odvijati buduća eksploatacija do 2050. godine, slike 1 i 2.

Koncepcijski razvoj kopa u narednom periodu eksploatacije opredeljen je na osnovu sledećih uslova:

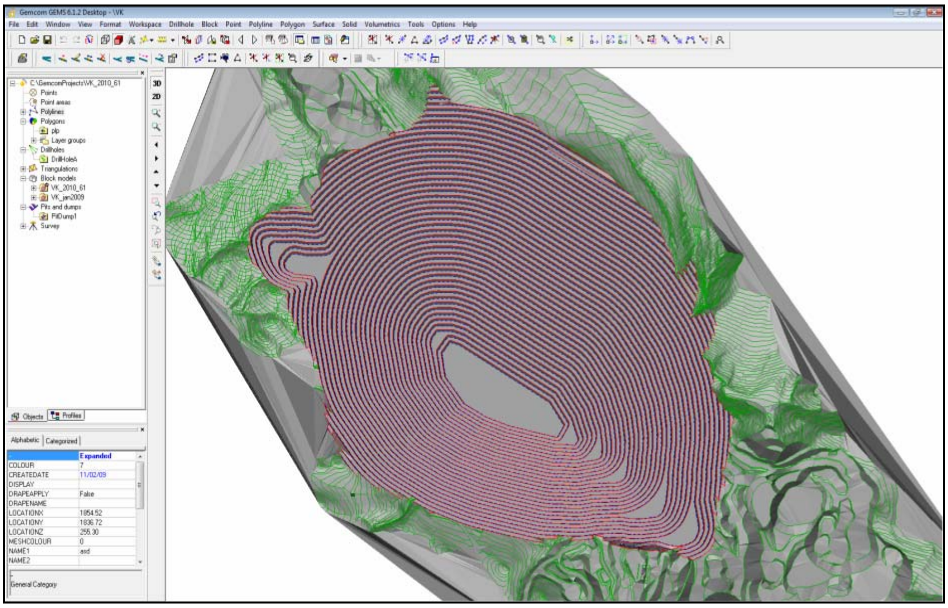
- maksimalnom iskorišćenju ležišta
- održanju kontinuiteta u otkopavanju rude, sa pripadajućim količinama otkrivke
- mogućnosti otkopavanja partija rude sa različitim sadržajima bakra i pravljenje određenog odgovarajućeg kompozita
- stvaranje mogućnosti za nesmetan rad više jedinica primenjene osnovne opreme, odnosno njihov rad na različitim lokacijama na kopu
- obezbeđenje potrebne sigurnosti, kako pri izvođenju rudarskih radova, tako i nakon završetka otkopavanja na površinskom kopu.

Osnovni eksploatacioni konačne optimalne konture površinskog kopa Veliki Krivelj su:

- ukupna količina iskopina, t 912 773 628
- količina otkrivke, t 503 115 419
- količina rude, t 409 658 209
- granični sadržaj bakra u rudi, % C_u 0,150
- prosečan sadržaj bakra u rudi, % C_u 0,324
- koeficijent otkrivke, t/t 1,228



Sl. 1. *Izgled završne konture pk Veliki Krivelj do kote k-100 m (2D prikaz)*



Sl. 2. *Izgled završne konture pk Veliki Krivelj do kote k-100 m (3D prikaz)*

Ruda bakra sa površinskog kopa Veliki Krivelj prerađuje se u pogonu flotacija Veliki Krivelj, čiji je sadašnji kapacitet 8,5 miliona tona rude.

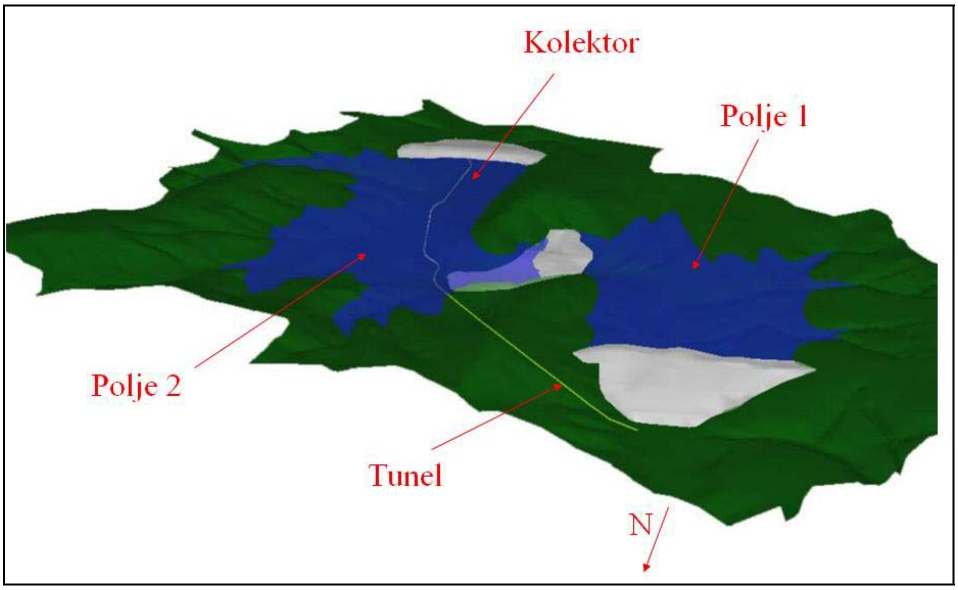
Povećanje kapaciteta pogona flotacije na 10,6 miliona tona godišnje podrazumeva sledeće procese:

- sekundarno i tercijalno drobljenje sa prosejavanjem do krupnoće od 100 % - 16 mm,
- dvostepeno mlevenje u mlinovima sa šipkama i kuglama sa jedostepenim klasiranjem u hidrociklonima do krupnoće od 55 do 60 % klase –0,074 mm,
- osnovno flotiranje rude sa domeljavanjem osnovnog i kontrolnog koncentrata do krupnoće 85 % - 0,074 mm i trostepeno prečišćavanje,
- dvodnjavanje definitivnog koncentrata bakra u procesu zgušnjavanja i filtriranja do sadržaja vlage od 10 % i
- deponovanje jalovine.

Povećanje kapaciteta otkopavanja i prerade rude sa sadašnjih 8,5 miliona tona na 10,6 miliona tona na godišnjem nivou neminovno zahteva i obezbeđenje prostora za odlaganje flotacijske jalovine. U sadašnjem trenutku na flotacijskom jalovištu Veliki Krivelj može se deponovati još oko 48,5 miliona m^3 jalovine, a vremenski je ograničeno do početka 2015. godine.

S obzirom da prostor doline Kriveljske reke predstavlja, za sada, jedinu realnu, dugoročnu lokaciju za deponovanje flotacijske jalovine iz flotacije Veliki Krivelj nameće se potreba da se maksimalno iskoriste prostorne mogućnosti koje pruža dolina Kriveljske reke.

Nakon zapunjavanja preostalog prostora flotacijskog jalovišta Veliki Krivelj tehnološki je moguće uzvodno proširenje jalovišta Veliki Krivelj u pravcu površinskog kopa Veliki Krivelj i transportnog sistema za jalovinu izgradnjom nove brane 4. Nova brana će formirati i novo akumulaciono Polje 3 uzvodno od postojeće brane 1, slika 4.



Sl. 3. *Prikaz sadašnjeg izgleda flotacijskog jalovišta Veliki Krivelj sa postojećim objektima za devijaciju Kriveljske reke u 3D formatu*

3. TEHNIČKI OPIS NOVIH OBJEKATA ZA DEVIJACIJU KRIVELJSKE REKE

Da bi realizovali planovi potencijalnog razvoja rudnika Veliki Krivelj, kojima se obuhvata naredni period do 2050. godine, potrebno je ispuniti niz preduslova, a među njima je svakako i izgradnja objekata za izmeštanje Kriveljske reke u zoni flotacijskog jalovišta Veliki Krivelj.

Za dalju eksploataciju na ovom rudniku predviđena je izgradnja sledećih kapitalnih objekata:

- tunela za devijaciju Kriveljske reke u zoni Polja 2
- tunela za devijaciju Kriveljske reke u zoni Polja 3
- veze (tunel - kolektor) između sadašnjeg tunela za Borsku reku i novog tunela za Kriveljsku reku
- kolektora za uvođenje Saraka potoka u novi tunel Kriveljske reke.

Takođe neophodno je izgraditi i sledeće hidrotehničke objekte:

- drenažni sistem za branu 4
- pumpnu stanicu drenažne vode za branu 4

- sistem za dovod pulpe i gravitacijsko napajanje hidrociklona na brani 4.

Pored izgradnje navedenih objekata neophodno je instalisati nove cevovode za vraćanje povratne vode iz jezera Polja 3 do rezervoara Kriveljske flotacije ili za uključivanje u postojeći sistem povratne vode i izvršiti izmeštanje cevovoda vode za piće Surdup – Bor.

Za izmeštanje toka Kriveljske reke u zoni Polja 2 predviđeno je da se izgradi tunel unutrašnjeg prečnika D = 3,0 m i duzine L = 2 450 m. Tunel se gradi u brdskoj masi desne obale, slika 4. Najteža deonica za izvođenje, dužine oko 300 m, nalazi se na delu tunela koji treba da se izvede ispod temelja brane 2 na oko 10 m ispod nivoa stene u koritu reke. Ova deonica će se, po potrebi, izvoditi sa prethodnom konsolidacijom terena u zoni oko predviđenog iskopa.

Izrada tunela u stenskoj masi ispod dolinskih strana, a na kotama koje se nalaze u nivou korita Kriveljske reke (andeziti, konglomerati i peščari, peščari i laporci) nije do sada predstavljala značajnije tehničke probleme, pa stoga ne bi trebalo očekivati posebne teškoće ni u izradi tunela kojim ce se izvršiti trajna devijacija Kriveljske reke na preostalom delu ove deonice. Posle izgradnje tunela na ovoj deonici, kolektor ce se plombirati.

Za izmeštanje toka Kriveljske reke u zoni Polja 3 predviđeno je da se izgradi tunel unutrašnjeg prečnika D = 3,0 m i dužine L = 1 700 m. Tunel se gradi u brdskoj masi leve obale, slika 4. Obloga tunela je debljine d = 25 cm i od armiranog betona je MB20 dvostrano armirana.

Za vezu između postojećeg tunela kojim se sprovodi Borska reka, tj. za uvođenje voda iz sliva Borske reke i voda od odvodnjavanja potkopa predviđen je armirano betonski kolektor unutrašnjeg prečnika D = 1,60 m i dužine L = 350 m.

Kolektorom Saraka potoka uvode se vode sa slivnog područja Saraka potoka u tunel Kriveljske reke. Konstrukcija kolektora je od armiranog betona MB30 dvostrano armirana. Unutrašnje površine su zaštićene antikorozionim premazima. Dimenzije kolektora su:

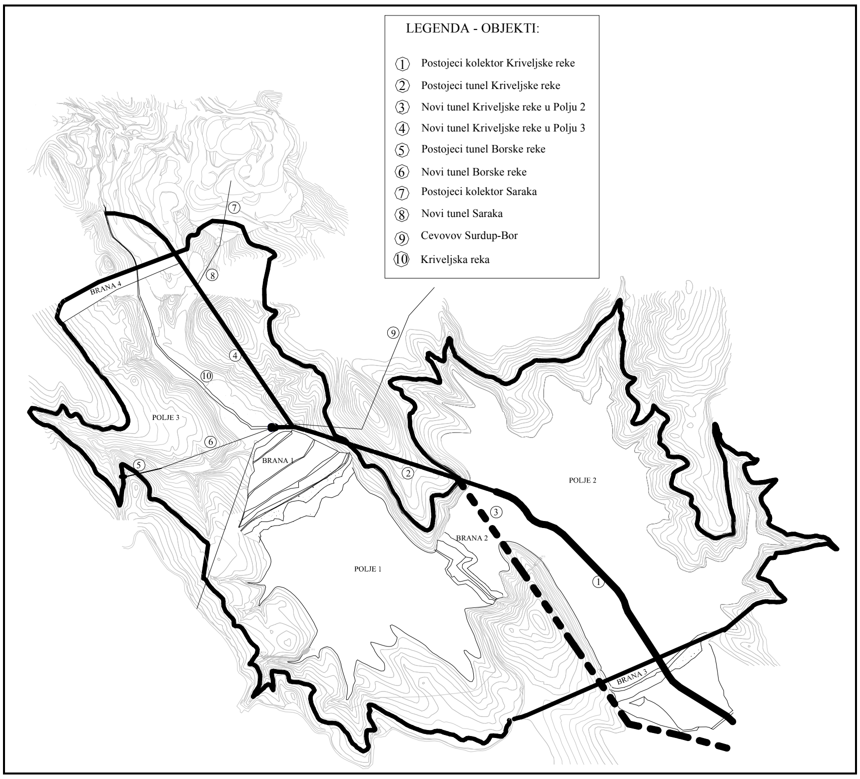
prečnik	D = 1,8 m
debljina zida	d = 45 cm.

Izgradnjom tunela za devijaciju Kriveljske reke u zoni Polja 3 doći ce do bitnog pogoršanja uslova sa stanovišta veličine zone zahvaćene plavljenjem velikim vodama Kriveljske reke. Naime, može se smatrati da će se i uzvodno od brane 4 pri nailasku poplavnog talasa formirati uspor, odnosno akumulacija dubine oko 27 m (za slučaj 10 000 godišnjih velikih voda) što bi značilo plavljenje svih površina koje su na kotama nižim od kote 320 m.

Od postojećih rudničkih objekata koji se nalaze u mogućoj zoni plavljenja su:

- površinski kop,
- transportna sistem za jalovinu i
- vodozahvat sa taložnikom i pumpnom stanicom.

Da bi se omogućilo regulisano oticanje Kriveljske reke za vreme poplava, neophodno je formirati dovoljno velik akumulacioni (retenzioni) prostor od oko 6×10^6 m^3 na pogodnoj lokaciji u dolini Kriveljske reke uzvodno od Velikog Krivelja. Taj akumulacioni prostor bi se formirao sa maksimalnom kotom vode od 371,0 m što bi iziskivalo izgradnju brane visine oko 34 m sa krunom na koti 373,0 m.



Sl. 4. *Dispozicija objekata za izmeštanje Kriveljske reke u zoni flotacijskog jalovišta Veliki Krivelj*

4. ZAKLJUČAK

Realizacija planova razvoja rudnika Veliki Krivelj, u narednom četrdesetogodišnjem periodu, podrazumeva ispunjavanje niz preduslova, a među njima se kao veoma važan ističe izgradnja kapitalnih objekata za izmeštanje Kriveljske reke u zoni flotacijskog jalovišta Veliki Krivelj i to:

- tunela za devijaciju Kriveljske reke u zoni Polja 2
- tunela za devijaciju Kriveljske reke u zoni Polja 3
- veze (tunel - kolektor) između sadašnjeg tunela za Borsku reku i novog tunela za Kriveljsku reku i
- kolektora za uvođenje Saraka potoka u novi tunel Kriveljske reke.

Takođe, da bi se izbeglo moguće formiranje poplavnog talasa uzvodno od brane 4, kao posledica izgradnje tunela kroz polje 3 flotacijskog jalovišta i ugrožavanja površinskog kopa, transportnog sistema za jalovinu i vodozahvata sa taložnikom i pumpnom stanicom, neophodno je uzvodno od sela Veliki Krivelj izgraditi retenzionu branu visine oko 34 m.

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Daniel Kržanović, Miomir Mikić*, Milenko Ljubojev **

ANALYSIS OF DEVELOPMENT EFFECTS OF THE VELIKI KRIVELJ MINE ON CONSTRUCTION THE NEW FACILITIES FOR DEVIATION THE KRIVELJ RIVER**

Abstract

This paper gives an overview of development the Veliki Krivelj Mine, located within the Mining and Smelting Basin Bor, in the next forty year period and an analysis of this development impact on construction the facilities for relocation the Krivelj River.

Based on carried out analysis, it was determined that the new facilities have to be be built as the ore mining in the Veliki Krivelj Mine could be realized smoothly and in accordance with the adopted long-term plans of the Company management.

Key words: *Veliki Krivelj Mine, development, facilities for deviation the Krivelj River*

1. INTRODUCTION

The major changes in the world copper production occurred primarily due to the constant increase in copper prices since 2004, which also reached in 2011 the average value of 9 500 $, positively affected the copper production in the company RTB Bor.

Based on the realized analyses of potentialities the deposits in Bor and Majdanpek, the management of RTB Bor has adopted a strategy of further development the mining production, which will be based on the mass exploitation of copper ore at the open pits Veliki Krivelj and Cerovo, operating within the Copper Mines Ltd. Bor (RBB) and North and South Mining District, within the Copper Mine Majdanpek (RBM).

Within the Copper Mine Veliki Krivelj, large there are two technological systems: open pit and flotation.

Open Pit Krivelj is located at a distance about 4 km northeast of Bora. It was found in 1969 and it was named after the same named village, located in the vicinity of deposit.

* *Mining and Metallurgy Institute Bor*

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Works on overburden excavation began in 1979, and the first quantity of ore were excavated in 1982.Today, production of copper concentrate from the ore of the open pit Veliki Krivelj makes about 75% of the total production of RBB, while the share of open pit ore is with about 90% of the excavated ore, with a trend of further increasing.

The crushing plants, flotation and other auxiliary facilities were built in the near vicinity of open pit, necessary for exploitation and processing, and enrichment of ore by the flotation method. The resulting copper concentrate is transported and processed in the Smelter in Bor.

Copper mine Veliki Krivelj since the beginning of ore exploitation uses the space, obtained by damming the Krivelj River valley, for disposal the flotation tailings.

In order to realize the new extension of flotation tailing dump, it is necessary to previously build the new facilities for deviation the Krivelj River, located in the zone of flotation tailings. In this way, the space will be provided for permanent disposal of flotation tailings.

2. CONCEPT OF DEVELOPMENT THE COPPER MINE VELIKI KRIVELJ

Based on the verified reserves of copper ore, the adopted annual ore mining capacity of 10.6 million tons of copper and predicted copper price on the world metal market of 6 000 $ per ton of cathode, the final optimum contour of open pit was defined to k-100, within which the future exploitation will be developed until 2050, Figures 1 and 2.

Conceptual development of open pit in the future period of exploitation is committed on the basis of the following conditions:

- maximum utilization of deposit,
- maintaining the continuity in the ore excavation, with corresponding quantities of overburden,
- possibility of mining the ore parties with different copper contents and making the certain suitable composite,
- creation the opportunities for smooth operation of several units of the applied basic equipment, and their work on different locations at the open pit,
- providing the necessary security, both in the execution of mining works, and after excavation at the open pit.

The basic exploitation parameters of the final optimum contour of the open pit Veliki Krivelj are:

- total quantity of excavation, t 912 773 628
- quantity of overburden, t 503 115 419
- quantity of ore, t 409 658 209
- limit copper content in the ore, % Cu 0.150
- average copper content in the ore, % Cu 0.324
- overburden coefficient, t/t 1.228

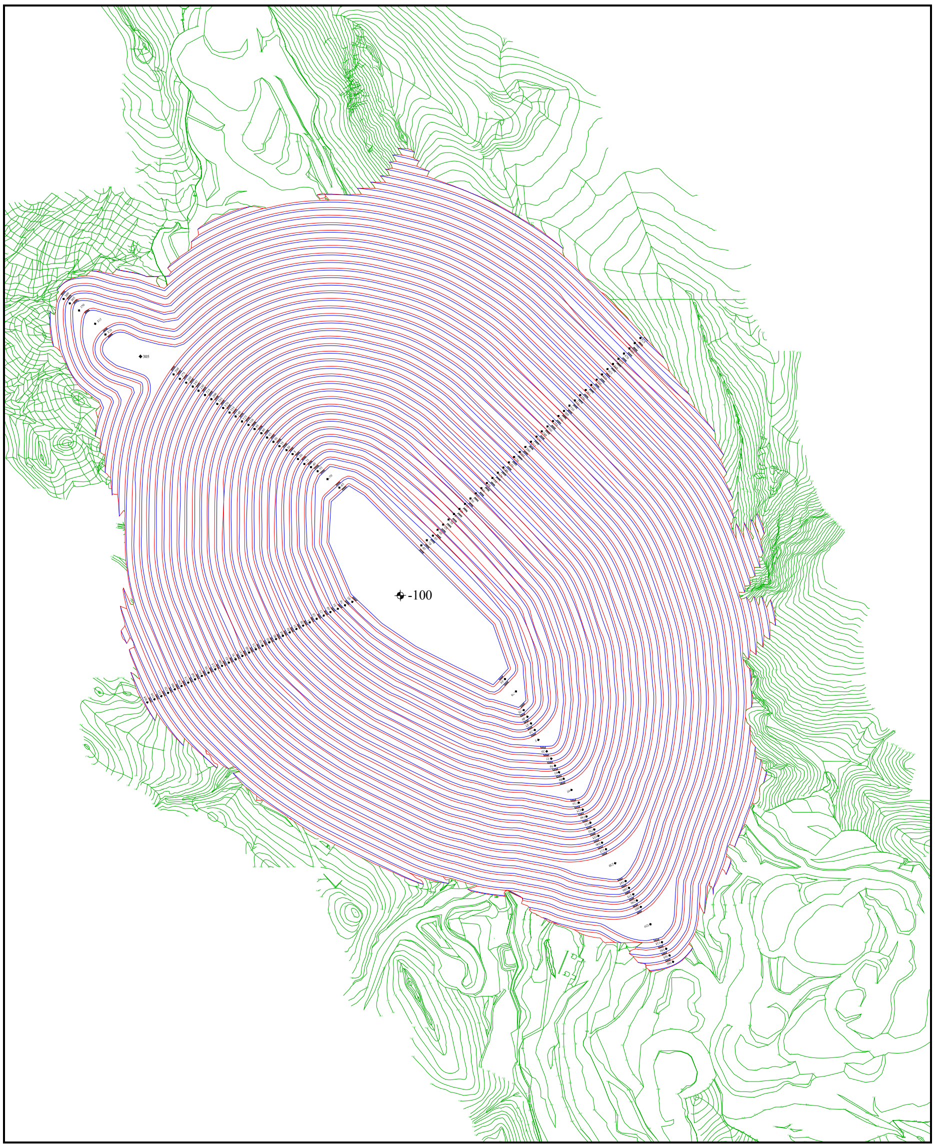

Fig. 1. *View of the final contour of the open pit Veliki Krivelj up to the elevation k-100 m (2D review)*

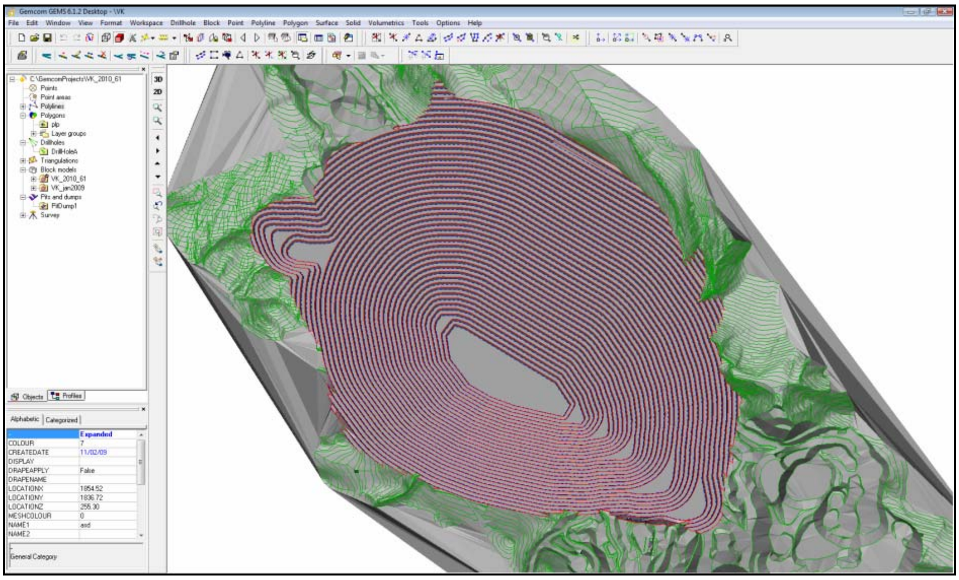

Fig. 2. *View of the final contour of the open pit Veliki Krivelj up to the elevation k-100 m (3D review)*

Copper ore from the open pit Veliki Krivelj is processed in the Flotation Plant Veliki Krivelj Great, whose current capacity is 8.5 million tons of ore.

Increasing the capacity of the Flotation Plant to 10.6 million tons per year includes the following processes:

- secondary and tertiary crushing with screening to the size range of 100% - 16 mm,
- two-stage grinding in bar and ball mills with one-stage sizing in hydrocyclones to the size-range of 55 to 60%, size class -0.074 mm,
- primary ore flotation with additional grinding of primary and control concentrate to the size range of 85% - 0.074 mm and three-stage cleaning,
- dewatering the final copper concentrate in the process of thickening and filtration to the moisture content of 10%, and
- disposal of tailings.

Increasing the capacity of ore mining and processing from the current 8.5 million tons to 10.6 million tons at yearly level inevitably requires and provides the spaces for disposal of flotation tailings. At present, about 48.5 million m^3 of tailings could be deposited at the flotation tailing dump Veliki Krivelj, and that is the time limited to the beginning of 2015.

Since the area of the Krivelj River valley is, for now, the only real, long-term disposal site for the flotation tailings from the Flotation Plant Veliki Krivelj there is a need to maximize the spatial opportunities provided by the Krivelj River valley.

After filling the remaining space of the Veliki Krivelj flotation tailing dump, it is technologically possible to expand the Veliki Krivelj tailing dump upstream in the direction of the Open Pit Veliki Krivelj and transport system for waste by construction a new Dam 4. The new dam will also form a new accumulation Field 3 upstream of the existing Dam 1, Figure 4.

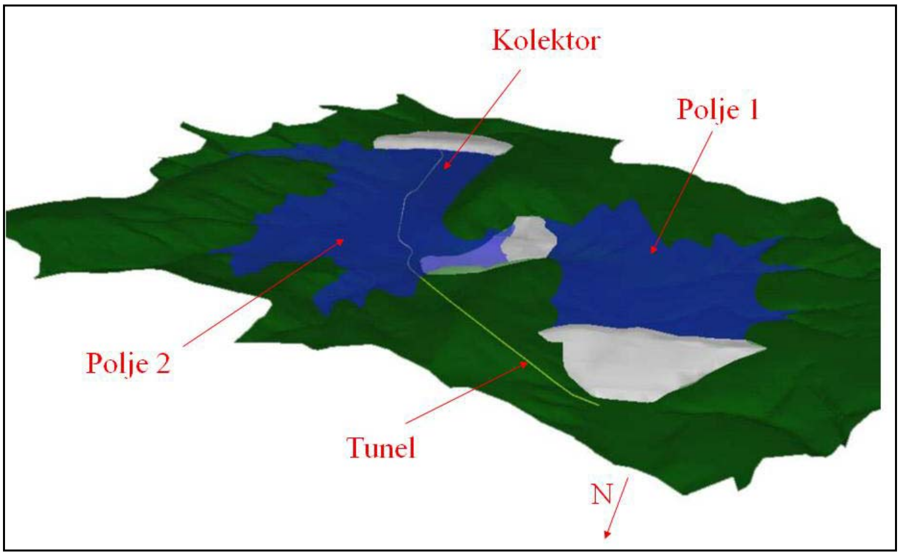

Fig. 3. *Review of the present appearance of the flotation tailing dump Veliki Krivelj with the existing facilities for deviation of the Krivelj River in 3D format*

3. TECHNICAL DESCRIPTION OF THE NEW FACILITIES FOR DEVIATION OF THE KRIVELJ RIVER

To realize the plans of potential development the Veliki Krivelj Mine, which include the following period until 2050, it is necessary to meet a number of preconditions, among them is certainly the construction of facilities for relocation the Krivelj River in the zone of flotation tailing dump Veliki Krivelj.

For further exploitation of this mine, the construction of the following capital facilities is anticipated:

- tunnel for deviation the Krivelj River in the zone of Field 2
- tunnel for deviation the Krivelj River in the zone of Field 3
- connections (tunnel - collector) between the existing tunnel for the Bor River and a new tunnel for the Krivelj River
- collector for introduction the Saraka Stream into a new tunnel of the Krivelj River.

Also, it is necessary to construct the following hydrotechnical facilities:

- drainage system for Dam 4
- pump station of drainage water for Dam 4
- system for supply of pulp and gravitational power of hydrocyclone on Dam 4.

In addition to the construction of these facilities, it is necessary to install the new pipelines for return the feedback water from the lake of Field 3 to the tanks of the Krivelj Flotation Plant or connection into the existing system of feedback water and to make the relocation of pipeline for drinking water Surdup - Bor.

For relocation the Krivelj River flow in the zone of Field 2, construction of a tunnel, inside diameter D = 3.0 m, length L = 2 450 m, is anticipated. The tunnel is built in the hilly mass of right bank, Figure 4. The most difficult section for construction, about 300 m in length, is on a tunnel part that has to be performed under the foundation of Dam 2 to about 10 m below the rock level in the river bed. This section will be, if necessary, performed with the previous consolidation of field in the zone around planned excavation.

Development of a tunnel in the rock mass under the valley sides, and at elevations contained in the level of the Krivelj River bed (andesites, conglomerates and sandstones, sandstones and marls) was not a significant technical problem, and therefore it should not be expected any special difficulties in a tunnel construction which will be made a permanent deviation of the Krivelj River in the remaining part of this section. After construction of tunnel on this section, the collector will be sealed.

For relocation the Krivelj River flow in the zone of Field 3, construction of a tunnel, inside diameter D = 3.0 m, length L = 1 700 m, is anticipated. The tunnel is built in the hilly mass of left bank, Figure 4. The tunnel lining thickness is d = 25 cm and made of reinforced concrete MB 20, two-sides reinforced.

For connection of the existing tunnel, for the Bor River, that is the introduction of water from the Bor River basin and water from drainage adit, the reinforced concrete is designed collector, internal diameter D = 1.60 m and length L = 350 m, is anticipated.

The Saraka Stream collector introduces the water from the catchment area of the Saraka Stream into the Krivelj River tunnel. Collector structure is made of reinforced concrete MB30, two-sided reinforced. Internal surfaces are protected with anti-corrosive coatings. Dimensions of collector are:

- diameter D = 1.8 m
- wall thickness d = 45 cm.

Tunnel construction for deviation the Krivelj River in the zone of Field 3 will substantially deteriorate the conditions from the point of zone size, affected by flooding with high water of the Krivelj River. Namely, it can be considered that upstream of Dam 4 in flooding wave, the flood wave will slow down, or the accumulation of about 27 m depth (in a case of 10 000 annual high water), what would mean the flooding of all areas that are at elevations below 320 m elevation.

The following existing mining facilities are situated in a possible flooding zone:

- open pit,
- transport system for waste, and
- water intake with settling pond and pump station.

To allow the regulated run of the Krivelj River during floods, it is necessary to form a large enough storage (retention) an area of approximately 6 x 10^6 m^3 at a suitable location in the Krivelj River valley upstream from Veliki Krivelj. The accumulation space would be formed with maximum water elevation of 371.0 m, what would require the construction of a dam, height of about 34, with a crown at elevation of 373.0 m.

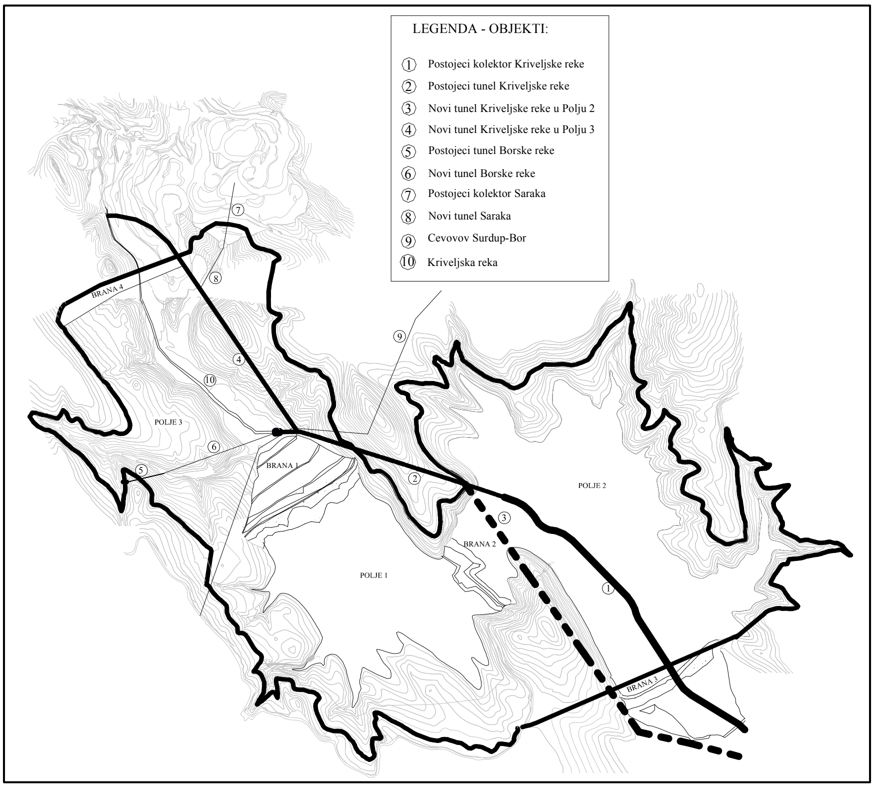

Fig. 4. *Disposition of facilities for relocation the Krivelj River in the zone of flotation tailing dump Veliki Krivelj large Krivelj*

4. CONCLUSION

Implementation the development plans of the Veliki Krivelj Mine, in the next forty year period, involves filling a number of pre-conditions, including the very important one as the construction of capital facilities for relocation the Krivelj River in the zone of flotation tailing dump Veliki Krivelj, as follows:

- tunnel for deviation the Krivelj River in the zone of Field 2
- tunnel for deviation the Krivelj River in the zone of Field 3
-
- connections (tunnel - collector) between the existing tunnel for the Bor River and a new tunnel for the Krivelj River
- collector for introduction the Saraka Stream into a new tunnel of the Krivelj River.

Also, to avoid a possible formation of flooding wave upstream of Dam 4, as the consequence of a tunnel construction through Field 3 of the flotation tailing dump and threatening the open pit, transport system for waste and water intake with settling pond and pump station, it is necessary to construct a retention dam, height of about 34 m, upstream from the village Veliki Krivelj.

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OPTIMIZACIJA PROIZVODNO – TEHNIČKIH PARAMETARA STUBNE METODE OTKOPAVANJA UGLJENIH SLOJEVA

Izvod

Problematika obrađena u ovom radu posvećena je definisanju metodologije optimizacije osnovnih prirodno-tehničkih parametara stubne metode otkopavanja slojeva mrkog i lignitskog uglja veće debljine u složenim prirodno-geološkim uslovima. Na osnovu razmatranog metodološkog pristupa izvršeno je matematičko modeliranje parametara stubnog otkopa odnosno stubne otkopne baterije.

Ključne reči: *rudnik, kopanje, ugalj*

1. UVOD

Složeni uslovi eksploatacije u ležištima uglja u Srbiji zahtevaju sistematski rad u cilju unapređenja metode i tehnologije otkopavanja (sistem otkopavanja), posebno vezano za parametre proizvodnosti, produktivnosti, sigurnosti i ekonomičnosti. Otkopavanje je osnovna faza procesa eksploatacije uglja koja najvećim delom utiče i na ostale faze procesa podređujućih svom krajnjem cilju. Metoda i tehnologija otkopavanja sve više utiču na način otvaranja ležišta, dok njegov sistem priprema zavisi u potpunosti od metode otkopavanja. Osnovni pravac sistema otkopavanja slojeva uglja podzemnim načinom usmerena je ka uvođenju i unapređenju metoda širokih čela sa kompleksnom mehanizacijom. Međutim, u pojedinim ležištima prirodno-geološki uslovi su takvi da ne omogućavaju primenu navedene metode, tako da se iznalaze druga specifična rešenja otkopavanja.

Celokupna proizvodnja rudnika sa podzemnom eksploatacijom u Srbiji obavlja se u osam rudnika sa jedanaest jama, pri čemu su im opšte karakteristike niska proizvodnja, nizak stepen mehanizovanosti i visoko učešće teškog fizičkog rada što u ukupnom bilansu daje nepovoljne finansiske efekte poslovanja. Prisutni prirodno – geološki uslovi uticali su na izbor tehnoloških rešenja otkopavanja, tako da se danas u svim jamama primenjuju stubne metode otkopavanja u različitim varijantama, kod kojih su radne faze polumehanizovane, a i proizvodni efekti različiti, uglavnom usled različitosti uslova eksploatacije. U cilju poboljšanja efekata primene stubnih otkopa u rudnicima uglja u Srbiji nameće se potreba njihove

* *JP PEU Resavica*

racionalizacije i optimizacije tehničko-ekonomskih parametara, sobzirom da će ovaj način otkopavanja biti dominantan u mnogim rudnicima. Sada ovi rudnici predstavljaju proizvodne pogone sa niskom proizvodnjom. [1]..[12]

Cilj provedenih istraživanja u okviru ove teme je da se da novi pristup stubnim metodama otkopavanja, a okvir istraživanja su rudnici sa podzemnom eksploatacijom uglja u Srbiji. Osim metoda analize i sinteze u istraživanjima su korišćene eksperimentalne metode i metode matematičkog modeliranja. [13]..[20].

2. PRIMENA STUBNIH METODA OTKOPAVANJA UGLJENIH SLOJEVA VEĆE DEBLJINE

Stubne metode otkopavanja sa tehnologijom miniranja primenjene u podzemnim rudnicima uglja u Srbiji karakterišu se sledećim:

- širokom primenom zbog mogućnosti prilagođavanja geometrije radnog fronta i taktike otkopavanja složenim uslovima eksploatacije,
- niskom proizvodnošću i produktivnošću, potrebom rada većeg broja otkopnih jedinica i dekoncentrisanost rudarskih radova,
- visokim utroškom repromaterijala u procesu pripreme i otkopavanja,
- visokim učešćem pripremnih radova.

Stubne metode otkopavanja primenjuju se za otkopavanje ugljenih slojeva u složenim prirodno-geološkim uslovima, odnosno u delovima ležišta u kojima nije racionalna primena metoda širokih čela ili kratkih mehanizovanih otkopa.[21]..[27].

Metoda se primenjuje sa tehnologijom kratkobušotinskog miniranja za debljine slojeva 2-6 m, a primenom dubokobušotinskog miniranja (DBM) i do debljine od 10m.

Osnovni princip stubne metode otkopavanja sastoji se u otkopavanju pripremljenih stubova, i to povlačenjem otkopnih uskopa na obe strane. Osnovna priprema za primenu ove metode otkopavanja sastoji se u izradi prostorija po pružanju ugljenog sloja – osnovica za otkopavanje kojima se otkopno polje deli po padu sloja na nagnute stubove dužine cca 30 m.

Osnovice za otkopavanje se izrađuju u podnom delu ugljenog sloja (a u slučaju bujave podine ostavlja se zaštitna ploča debljine 0,5-1,0 m) i u toku otkopavanja se međusobno povezuju spojnim vezama radi bolje organizacije transporta i provetravanja. Izrada otkopnih osnovica vrši se bušačko-minerskim radovima i podgrađuje najčešće čeličnom kružnom podgradom.

Dobijanje uglja se vrši u tri faze, i to:

- I faza otkopavanja – izrada otkopne pripreme (uskopa)
- II faza otkopavanja – dobivanje uglja iz bočnih krila u potkopnom i natkopnom delu i iznad otkopne pripreme,
- III faza otkopavanja – dobivanje uglja iz bočnih krila u potkopnom delu iznad raskršća otkopne osnovice i otkopne pripreme.

Otkopna priprema se izrađuje iz otkopne osnovice po podini ugljenog sloja sa dužinom 30 m. i vrši se bušačko – minerskim radovima.

Po završetku izrade otkopne pripreme započinje se sa otkopavanjem bočnih krila i natkopnog dela. Širina bočnih krila iznosi prema starom radu 3,0 m, a prema narednom stubu 2,0 m. Dobivanje uglja u ovoj fazi vrši se naizmenično miniranjem bokova i stropa sa lepezom dubokih bušotina, sa jednim ili više razdvojenih (parcijalnih) punjenja. Posle miniranja svake lepeze vrši se separatno provetravanje radilišta, postavljanje zaštitnih »vrata«, a zatim nagrtanje uglja na grabuljasti transporter i izvoz uglja iz otkopa.

Točenje uglja iz otkopa vrši se postepeno sa kontinuiranim podasipapom starog rada. Na ovaj način se uspostavi kontinuirano točenje uglja iz odminirane lepeze i zastalog dela od predhodnih lepeza.

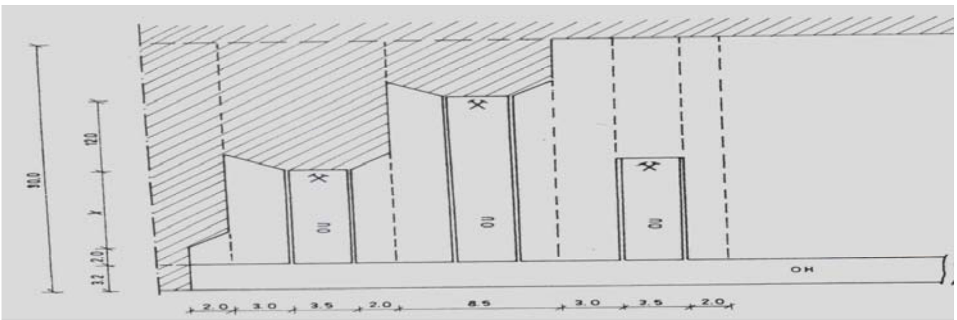
Dobivanje uglja iznad raskršća otkopne osnovice i otkopne pripreme vrši se u trećoj fazi otkopavanja koja predstavlja završnu fazu otkopavanja jedne otkopne pripreme (uskopa).

Provetravanje otkopnih priprema i otkopa vrši se separatno sa cevnim ventilatorima koji se lociraju u ograncima sveže vazdušne struje.

Transport uglja kod ove metode je mehanizovan, a uspostavlja se sa dvolančanim grabuljastim transporterima koji se sukcesivno produžavaju sa napredovanjem radilišta, odnosno skraćuju kad povlačenja otkopa.

Na jednoj otkopnoj osnovici formiraju se obično tri radilišta, pri čemu je jedno uvek u napredovanju, drugo naizmenično u napredovanju i povlačenju i treće u povlačenju.

Dispozicija radilišta na jednoj otkopnoj osnovici kod primene ove metode otkopavanja dat je na slici 1.



Sl. 1. *Dispozicija radilišta na jednoj otkopnoj osnovici*

3. METODOLOGIJA PRORAČUNA KAPACITETA STUBNIH OTKOPA

Istraživanja parametara stubnih otkopa u osnovi polaze od najvažnijeg parametra, debljine ugljenog sloja koji se otkopava, s obzirom da od ovog parametra zavise parametri kapaciteta otkopa i otkopnih učinaka, a samim time su povezani i ekonomski parametri.

U samom otkopnom polju visina proizvodnje zavisi od broja otkopnih jedinica, odnosno broja otkopnih osnovica na kojima se istovremeno vrše radovi otkopavanja.

Kod proračuna kapaciteta pošlo se od postavke da se proizvodnja dobija sa jedne otkopne osnovice u otkopnom polju, na kojoj radove izvode istovremeno tri radilišta. Ovako formirana radilišta čine jednu otkopnu bateriju.

Kapacitet otkopa stubne otkopne baterije sa tehnologijom dobijanja sa DBM sastoji se od zbirnog kapaciteta otkopa u napredovanju (I faza) i otkopa u povlačenju (sa natkopnim dobijanjem – II i III faza).

$$Q_v = q_{vn} + q_{vp}$$

gde su:

q_{vn} - kapacitet otkopa u napredovanju

q_{vp} – kapacikapacitet otkopa u povlačenju

Kapacitet otkopa u napredovanju iznosi:

$$q_{vn} = F_n \text{ x } \gamma \text{ x } n_1$$

gde je:

$F_n = 8{,}52\ m^2$ – profil otkopa u napredovanju

$\gamma = 1{,}30$ – zapreminska masa uglja

n_1 = napredovanje otkopa u smeni (m/smenu)

Veličine F_n i γ su konstantne, dok je veličina n_1 promenljiva i uglavnom zavisi od organizacije rada i primenjene mehanizacije.

Kapacitet otkopa u povlačenju se izračunava pomoću izraza:

$$q_{vp} = F_p \text{ x } \gamma \text{ x } \zeta \text{ x } n_2, \text{ (t/smenu)}$$

gde su:

F_p – poprečni profil otkopa u povlačenju (m^2)

γ – zapreminska masa uglja (1,30)

ζ – koeficijent iskorišćenja

n_2 – brzina povlačenja otkopa (m/smenu)

$$F_p = (S \text{ x } d) - F_n$$

Površina poprečnog preseka je određena širinom otkopa S (8,5 m^2), debljinom ugljenog sloja d umanjenog za profil otkopa u napredovanju (8,5 m^2)

$$F_p = 8{,}5\ d - 8{,}5$$

Koeficijent iskorišćenja usvaja se kao veličina γ = 0,70 % dobijena na osnovu statističke analize iskustvenih podataka.

Ukupno raspoloživo radno vreme u smeni je različito od rudnika do rudnika, a za potrebe izračunavanja vremena trajanja pojedinih radnih operacija usvojene su sledeće prosečne veličine:

- radno vreme u jami .... 450 min
- dolazak na radilište .... 30 min
- odmor u toku smena............ 30 min
- odlazak sa radilišta .... 30 min
- efektivno radno vreme u smeni .... 360 min

Vreme trajanja ciklusa na dobijanju uglja zavisi od vremena trajanja pojedinih radnih operacija:

$$T = t_1 + t_2 + t_3 + t_4 + t_5 + t_6, \text{ (min)}$$

gde je:

t_1 – vreme pripremnih radnji (min)

t_2 – vreme za izradu minskih bušotina (min)

t_3 – vreme punjenja i paljenja minskih bušotina (min)

t_4 – vreme za utovar i odvoz uglja

t_5 – vreme za podgrađivanje, odnosno osiguranje otkopa (min)

t_6 – vreme izvršenja pomoćnih radnih operacija (min)

Vremena t_1, t_5 i t_6 za sve debljine sloja imaju iste vrednosti, dok vremena t_2, t_3 i t_4 direktno zavise od debljine sloja koji se otkopava.

Na osnovu analize vremena izvršenja radnih operacija (t_2, t_3 i t_4) i promene debljine sloja (d= 3 – 10 m) formirana je kriva promene brzine napredovanja – povlačenja otkopa:

$$n_2 = a + \frac{b}{d} \text{ (m/smenu)},$$

gde su:

a = 0,62 i b = 1,75 koeficijenti dobijeni analizom vremena izvršenja pojedinih radnih operacija.

Sređivanjem izraza za kapacitet otkopa u povlačenju dobija se sledeći oblik:

$$q_{vp} = (8{,}5 \text{ x } d - 8{,}5) \text{ x } 0{,}91 \text{ x } \text{ x } \left(0{,}62 + \frac{1{,}75}{d}\right) \text{ (t/smenu)}$$

Izračunavanje vrednosti parametara vršeno je na računaru po izrađenom matematičkom modelu, a međusobne zavisnosti ispitivanih veličina prikazane su tabelarno i dijagramski.

1. $d = 3, ..., 10m$
2. $q_{vn} = F_n \times g \times n$,

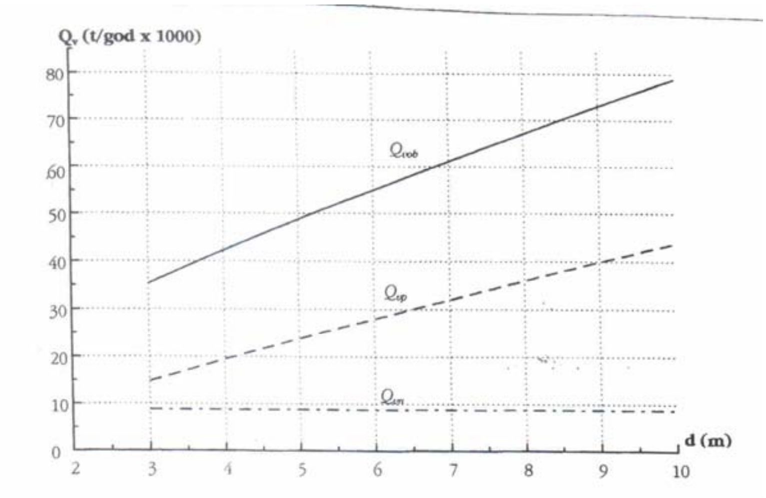
   $F_n = 8,5\ m^2$
3. $q_{vp} = (8,5 \times d - 8,5) \times 0,91 \times$

   $\times (62 + \frac{1,75}{d})$
4. $q_{vob} = (q_{vn} + q_{vp}) \times 1,5$
5. $Q_{vn} = 3 \times q_{vn} \times 264$
6. $Q_{vp} = 3 \times q_{vp} \times 264$
7. $Q_{vob} = 3 \times q_{vob} \times 264$
8. $N_{vn} = 3168$
9. $N_{vp} = 3168$
10. $N_{vob} = (N_{vn} + N_{vp}) \times 1,5 = 9504$
11. $U_{vn} = \frac{Q_{vn}}{N_{vn}}$
12. $U_{vn} = \frac{Q_{vp}}{N_{vp}}$
13. $U_{vob} = \frac{Q_{vob}}{N_{vob}}$
14. $N_1 = 3 \times 264 \times 1,5 = 1188$
15. $N_2 = 1188 \times n_2 s$

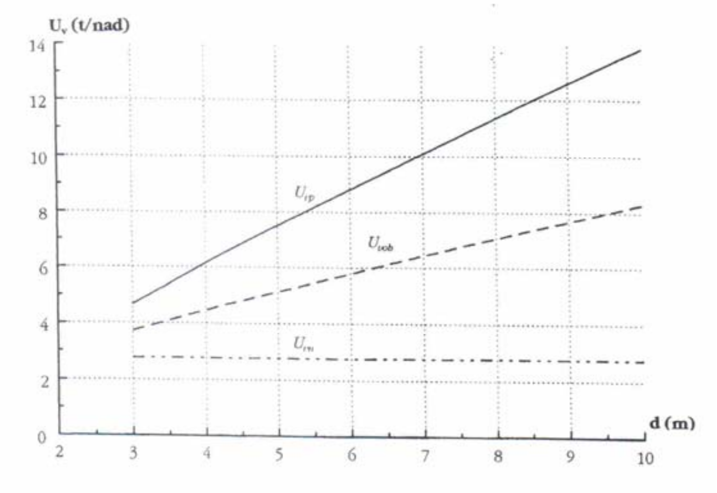
Tabela 1. *Ulazni podaci programa za proračun parammetara stubnog otkopa sa tehnologijom DBM*

Debljina sloja d (m)	Kapacitet otkopa		Napr. povl. otkopa		Nadnice		Učinak
	smenski q_{vp} (t/sm)	dnevni q_{vpd} (t/v)	smensko n_2s(m/sm)	dnevno n_2d (m/d)	u smeni	dnevno	otkopa U_p(t/nad)
1	2	3	4	5	6	7	8
3	18.62	55.86	1.20	3.60	4	12	4.65
4	24.54	73.62	1.05	3.17	4	12	6.13
5	30.01	90.03	0.97	2.91	4	12	7.50
6	35.26	105.78	0.91	2.73	4	12	8.81
7	40.38	121.14	0.87	2.61	4	12	10.09
8	45.41	134.84	0.83	2.49	4	12	11.35
9	50.40	151.20	0.81	2.43	4	12	12.60
10	55.34	166.02	0.79	2.38	4	12	13.84

Tabela 2. *Promena parametara stubnog otkopa u povlačenju u zavisnosti od debljine sloja*



Sl. 2. *Zavisnost godišnje proizvodnje stubne otkopne baterije od debljine sloja*



Sl. 3. *Zavisnost učinka kod stubne otkopne baterije od debljine sloja*

4. ZAKLJUČAK

Proračunom dobijene vrednosti parametara pokazuju da je kapacitet stubnog otkopa, odnosno stubne otkopne baterije, direktno zavisan od debljine ugljenog sloja koji se otkopava kao i vremena izvršenja radnih operacija miniranja natkopnog uglja i utovara u odvozni transporter.

U odnosu na sada primenjeni način stubnog otkopavanja, ovim istraživanjima je predviđeno dobijanje natkopa sa DBM razdvojenim parcijalnim minskim punjenjima, čime se dobija značajno uvećanje kapaciteta i povećava sigurnost zaposlenih. Dalja istraživanja neophodno je usmeriti ka uvođenju mahanizovanog utovara sa mobilnim mašinama, a što će dodatno uticati na povećanje proizvodnosti i produktivnosti stubnog otkopavanja.

S obzirom na prirodno-geološke uslove u većini ležišta uglja predisponiranih sistemu podzemne eksploatacije zaključuje se da će se stubno otkopavanje i dalje zadržati te je za poboljšanje finansijskih performansi poslovanja rudnika, neophodno nastaviti sa daljim istraživanjima u primeni predloženih rešenja.

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OPTIMIZATION OF NATURAL – TEHNICAL PARAMETERS FOR THE PILLAR METHOD OF COAL EXCAVATION

Abstract

This work is dedicated to a definition of the optimization methodology of optimization the basic natural- technical parameters for the pillar method of excavation the dark coal and lignite seams of larger thickness in complex natural – geological conditions. Mathematical modeling of pillar excavation parameters was done on the basis of discussed methodological approach.

Key words: *mine, excavation, coal*

1. INTRODUCTION

The complex exploitation conditions of coal deposits in Serbia require systematical operation to the aim of improvement the method and technology of mining (mining system), particularly regarded to the parameters of production, productivity, safety and economy. Excavation is the main phase the coal mining that mainly affects the other phases of process subordinating them to its ultimate goal. Mining methods and technologies increasingly affect the way of deposit opening, while its preparing system depends entirely on the excavation method. The main direction of excavation system of underground coal mining is aimed to introduction and improvement the methods of longwall face using the complex machinery. However, in some deposits, the natural and geological conditions are such that they do not allow the use of given method, so it is necessary to seek the other specific solution of mining methods.

The entire production of the mine with underground mining in Serbia is carried out in eight of eleven pit mines, with their general characteristics of low production, low level of mechanization and high proportion of hard physical labor in the total balance that give the adverse financial effects of business. Present natural - geological conditions have influenced the selection of mining technology solutions, so that today in all pits the pillar mining method are applied in different forms, where the working phases are de-mechanized and production effects are different, mainly due to the diversity of exploitation conditions. In order to improve the effects of use the pillar stopes in the coal mines in Serbia there is a need for their rationalization and optimization of technical - economic parameters, considering that this mining method will be a dominant in many mines.

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Now, these mines are production facilities with low production [1], [12].

The aim of realized research within this topic is to give a new approach to pillar mining methods, and within the research framework are mines with underground mining of coal in Serbia. In addition to the method of analysis and synthesis, the experimental methods and mathematical modeling methods were used in studies[13],[20].

2. THE USE OF COAL PILLAR MINING METHODS FOR SEAMS WITH LARGER THICKNESS

Pillar mining methods with the blasting technology, applied in the underground coal mines in Serbia, are characterized by the following:

- Wide use due to a possibility of adjusting the geometry of working front and exploitation tactics to the complex mining conditions,
- low production and productivity with a need to operate a number of excavation units and deconcentration of mining operations,
- high consumption of raw materials in the preparation and excavation process,
- high share of preparatory works.

Pillar mining methods are applied for mining of coal seams in complex natural-geological conditions, that is in the parts of deposit in which the rational application of longwall face method is short mechanized slopes is not used [21], [27].

The method is used with a technology short-drill blasting for thickness of seams 2 - 6m, and by use the deep-drill blasting (DDB) and to a thickness of 10 m.

The basic principle of pillar mining method consists of excavation the prepared pillars by pulling the excavation slopes on both sides. Basic preparation for implementation of this mining method consists in making room per direction of coal seam - the basis for excavation where the excavation field is shared by drop of seam on the sloping pillars approximately 30 m in length.

Bases for excavation are made in the floor area of coal seam floor area (in the case flooding floor, a protective plate, thickness from 0.5 to 1.0 m, is left) and during excavation they are mutually connected with connecting links for better organization of transport and ventilation. Preparation of excavation bases is carried out by drilling-blasting works and it is usually supported using the circular steel support.

Coal is produced in three phases, as follows:

- Phase I of excavation – preparation for excavation (exploitation sites)
- Phase II of mining – coal obtaining from the side wings in the overlying and underlying part and over the excavation preparation
- Phase III of excavation – coal obtaining from the side wings in the underlying part over the junction excavation base and excavation preparation.

Excavation preparation is made from the excavation per underlying stratum coal seam to the length of 30m and the drilling – blasting works are carried out

Upon completion of excavation preparation begins, the excavation of the side wings and over stope part starts. Width of side wings towards the old work is 3.0 m, and to the next pillar 2.0 m. Obtaining of coal at this stage is carried out alternately by blasting the sides and ceiling with a fan of deep blast holes, with one or more separated (partial) charging. After blasting of each fan, the separately ventilation of the site is done, the protective "door" are installed and then loading of coal on a face conveyor and coal transport from stope. Coal pouring from stope is carried out gradually with a continuous sub-stowing of old work. In this way, a continuous pouring of coal is established from blasted fan and retained part of previous fans.

Obtaining of coal above the junction of the base and excavation preparation is carried out in the third stage of excavation, which represents the final phase of a mining excavation preparation (exploitation sites). Ventilation of the excavation preparations is done separately with the tube fans, located in the branches of fresh air flow.

Transport of coal by this method is mechanized, and established bydouble-chain face conveyors that are successively extended with the advancement of the site, or reduced in a stope drawing.

In one excavation base, usually three sites are formed, with one still in progress, the second alternate in advancing and drawing and the third in drawing.

The layout of the site on one excavation base for the application of this method of mining is shown in Figure 1.

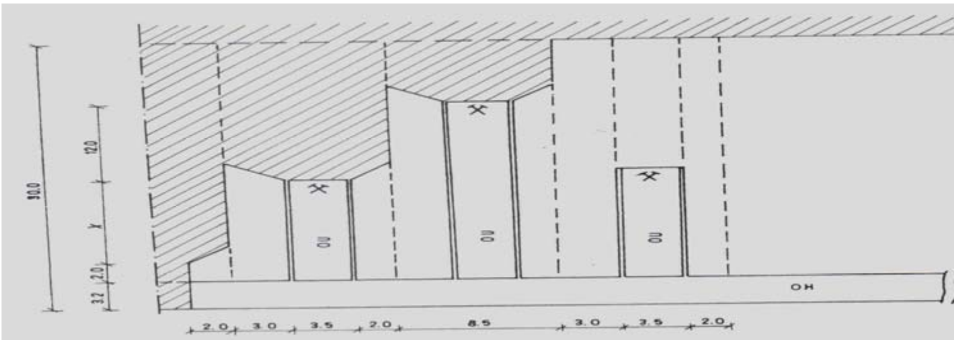

Fig. 1. *Layout of the site on one excavation base*

3. CALCULATION METHODOLOGY OF PILLAR STOPE CAPACITY

Studying the parameters of pillar stopes basically starts from the most important parameter, the thickness of coal seams which are mined, since this parameter depends on the parameters of stope capacity and stope effects, and thus the economic parameters are connected.

In the field of excavation, the height of production depends on the number of excavated units or the number of the excavated base on which the excavation works are carried out simultaneously.

In calculation the capacity, it started from the assumption that the production is obtained from one excavated base in the excavation field, which is done by simultaneous operation of three sites. Such formed excavation sites make one pillar stope.

Capacity of excavation the pillar stope with the technology of obtaining the DDB consists of the sum capacity of stope in progress (Phase I) and stope in drawing (with over stope obtaining - Phase II and III).

$$Q_v = q_{vn} + q_{vp}$$

where:

q_{vn} - stope capacity in progress,

q_{vp} – stope capacity in drawing.

Stope capacity in progress is:

$$q_{vn} = F_n \times \gamma \times n_1$$

where:

$F_n = 8.52\ m^2$ – stope profile in progress

$\gamma = 1.30$ – bulk density of coal

n_1 = stope progress in a shift (m/shift)

Values F_n and γ are constant, until value n_1 is variable and mainly depends on work organization and used mechanization.

Stope capacity in drawing is calculated by the expression:

$$q_{vp} = F_p \times \gamma \times \zeta \times n_2,\ \text{(t/shift)}$$

where:

F_p – stope cross section in drawing (m^2)

γ – bulk density of coal (1.30)

ζ – utilization coefficient

n_2 – rate of stope drawing (m/shift)

$$F_p = (S \times d) - F_n$$

Cross section area is determined by slope width S (8.5 m^2), coal seam thickness d less the stope profile in progress (8.5 m^2)

$$F_p = 8.5\ d - 8.5$$

Utilization coefficient is adopted as a value $\gamma = 0.70$ %, obtained based on statistical analysis of experienced data.

Total available working time per shift is different from mine to mine, and for the needs of calculation the duration time of individual work operations, the following average values were adopted:

- working time in a pit .... 450 min
- coming to a site .... 30 min
- break during shift .... 30 min
- departure from site .... 30 min
- effective working time per shift... 360 min

Time of coal production cycle depends on time of some working operations:

$$T = t_1 + t_2 + t_3 + t_4 + t_5 + t_6,\ \text{(min)}$$

where:

t_1 – time of preparation works (min)

t_2 – time for making the blast holes (min)

t_3 – time for charging and ignition the blast holes (min)

t_4 – time for loading and transport of coal

t_5 – time for support or stope ensuring (min)

t_6 – time for realization the ancillary working operations (min)

Times t_1, t_5 and t_6 for all seam thicknesses have the same values, until the times t_2, t_3 and t_4 are directly dependent on a seam thickness that is excavated.

Based on time analysis of working operations (t_2, t_3 and t_4) and change of seam thickness (d= 3 – 10 m), a curve of progress rate change – stope drawing, was formed.

$$n_2 = a + \frac{b}{d}\ \text{(m/shift)},$$

where:

a = 0,62 and b = 1.75, a coefficient obtained by analysis the time of realization of some working operations.

Rearranging the expression for the stope capacity in drawing, the following form is obtained:

q_{vp} = (8,5 x d – 8,5) x 0,91 x

$$x\ (0{,}62 + \frac{1{,}75}{d})\ \text{(t/shift)}$$

Calculation of parameter values was done by computer per mathematical model, and interdependences of tested values are shown in tables and diagrams.

1. d = 3, ... , 10m
2. $q_{vn} = F_n$ x g x n,
   $F_n = 8{,}5\ m^2$
3. q_{vp} = (8,5 x d – 8,5) x 0,91 x
   $$x\ (62 + \frac{1{,}75}{d})$$
4. $q_{vob} = (q_{vn} + q_{vp})$ x 1,5
5. Q_{vn} = 3 x q_{vn} x 264
6. Q_{vp} = 3 x q_{vp} x 264
7. Q_{vob} = 3 x q_{vo}b x 264
8. N_{vn} = 3168
9. N_{vp} = 3168
10. $N_{vob} = (N_{vn} + N_{vp})$ x 1,5 = 9504
11. $U_{vn} = \frac{Q_{vn}}{N_{vn}}$
12. $U_{vn} = \frac{Q_{vp}}{N_{vp}}$
13. $U_{vob} = \frac{Q_{vob}}{N_{vob}}$
14. N_1 = 3 x 264 x 1,5 = 1188
15. N_2 = 1188 x n_2 s

Table 1. *Input data of program for calculation the parameters of pillar stope with DDB technology*

Seam thickness d (m)	Stope capacity		Stope progress - drawing		Wages		Effect
	Shift q_{vp}(t/shift)	Daily q_{vpd} (t/v)	Shift n_2s(m/shift)	DAily n_2d(m/d)	In a shift	Daily	Stope U_p(t/wage)
1	2	3	4	5	6	7	8
3	18.62	55.86	1.20	3.60	4	12	4.65
4	24.54	73.62	1.05	3.17	4	12	6.13
5	30.01	90.03	0.97	2.91	4	12	7.50
6	35.26	105.78	0.91	2.73	4	12	8.81
7	40.38	121.14	0.87	2.61	4	12	10.09
8	45.41	134.84	0.83	2.49	4	12	11.35
9	50.40	151.20	0.81	2.43	4	12	12.60
10	55.34	166.02	0.79	2.38	4	12	13.84

Table 2. *Change of parameters of pillar stope in drawing depending on a seam thickness*

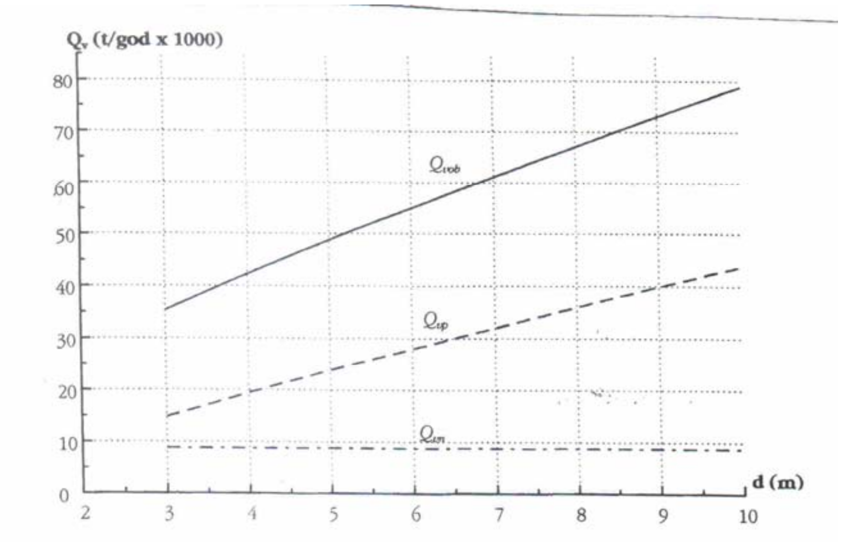

Fig. 2. *Dependence of annual production of a pillar stope on a seam thickness*

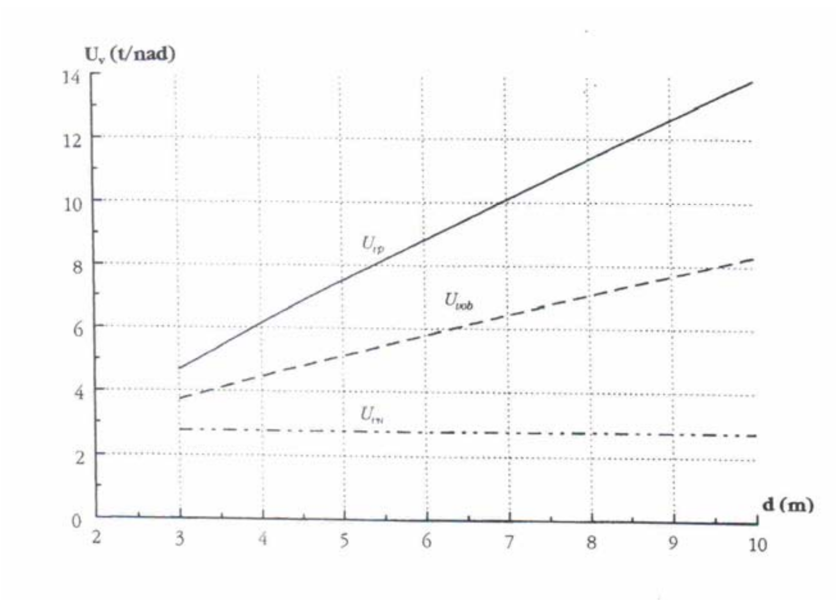

Fig. 3. *Dependence of effect of a pillar stope on a seam thickness*

4. CONCLUSION

Calculation of the obtained parameter shows that the capacity pillar stope is directly dependent on the thickness of coal seams which are mined as well as the time of performing the work operations of blasting the over stope coal and loading on a transport conveyor.

In relation to the existing used method of pillar mining, this research has provided the obtaining of over stope with DDB separated by partial blasting charging, resulting in a significant increase in capacity and increase the safety of employees. Further research has to be directed to introduction the mechanized loading with mobile machines, what will further affect the increase in production and productivity and productivity of pillar mining.

Regarding to the natural-geological conditions in the majority of coal deposits of predisposed to the underground mining system, it is concluded that the pillar mining will further exist so for improvement of financial performance of the mine, it is necessary to continue with further studies in the application of proposed solutions.

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PRIMENA SOFTVERSKIH PAKETA WHITTLE I GEMCOM ZA PRORAČUN BILANSNIH REZERVI RUDE BAKRA U LEŽIŠTU JUŽNI REVIR MAJDANPEK***

Izvod

Primena softvera za proračun rezervi u savremenoj geološkoj i rudarskoj nauci i praksi omogućuje da se u kratkom vremenskom periodu sagleda veliki broj varijanti i iznađu najbolja rešenja.

Dobijeni rezultati su zadovoljavajućeg kvaliteta i tačnosti, i u skladu sa svetskim standardima.

U radu je prikazana primena softvera Whittle i Gemcom za (kod) obračuna bilansnih rezervi ležišta Južni revir Majdanpek.

Ključne reči: *softverski paketi Whittle i Gemcom, ležište Južni revir Majdanpek, bilansne rezerve.*

1. UVOD

Bilansne rezerve čvrstih mineralnih sirovina čine delovi ležišta koji se mogu rentabilno eksploatisati postojećom tehnikom i tehnologijom.

Bilansnost rezervi utvrđuje se propisanom tehnoekonomskom analizom.

Za utvrđivanje bilansnih rezervi potrebno je prethodno usvojiti odgovarajuće kriterijume, odnosno usvojiti granične vrednosti nekih naturalnih pokazatelja, koje se odnose na kvalitet mineralne sirovine i rudarsko tehničke uslove eksploatacije.

U slučaju ležišta bakra Južni revir Majdanpek, za utvrđivanje bilansnosti rezervi od bitnog su značaja maksimalna dubina eksploatacije, maksimalno dozvoljena vrednost koeficijenta otkrivke i minimalni, tj. maksimalni srednji sadržaj korisnih komponenti u ležištu.

Nakon prethodne izrade blok modela

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ležišta, kao i utvrđenih polaznih parametara (cene eksploatacije i prerade, gubitaka, razblaženja, investicija i cena finalnih proizvoda) moguće je pristupiti optimizaciji ležišta u programskom paketu *Whittle*.

Za izbor najpovoljnije konture bilansnih rezervi izvršena je analiza više varijanti kopa u konturi graničnog sadržaja bakra 0,15%, konkretno 86 varijanti. Nakon toga konstruisan je površinski kop u softveru *Gemcom* i na osnovu njega izvršen proračun bilansnih rezervi, za šta je korišćen takođe *Gemcom,* i to njegov modul *Volumetrics*.

2. PRIMENJENE METODE PRORAČUNA REZERVI

Za proračun (rudnih) rezervi u ležištu Južni revir Majdanpek korišćena je metoda mini blokova.

Metoda mini blokova je stručno verifikovana i detaljno prikazana u odgovarajućoj stručnoj literaturi, u kojoj se izdvaja kao posebna metoda u grupi topoloških metoda proračuna rudnih rezervi.

Pri izboru metode mini blokova, kao osnovne, imalo se u vidu da je ležište bakra Južni revir Majdanpek u osnovi istraženo pravougaonom mrežom istražnih bušotina 100×50 m, a konture orudnjenja proverene su na nekoliko horizonata rudarskim istražnim radovima. Takođe, ležište ima izgled izduženog sočiva ujednačene debljine orudnjenja.

Usvojeni mini blokovi predstavljaju kocku čije su stranice 15 m zbog toga što je projektovana visina eksploatacionih etaža takođe 15 m, kao i moćnost rude u njemu.

Za procenu proračunskih blokova korišćena je metoda pravog krigovanja.

Kod velikih ležišta, kao što je slučaj sa ležištem bakra Južni revir Majdanpek, prednost proračuna rezervi korišćenjem računarske tehnike u odnosu na proračun drugim („manuelnim”) metodama ogleda se u sledećem:

- moguće je u kratkom vremenskom periodu generisati veliki broj varijanti, izvršiti njihovu analizu i iznaći najbolje rešenje,
- ovako dobijeni rezultati zadovoljavajuće su tačnosti i u stručnoj javnosti prihvaćeni kao reprezentativni,
- potencijalni kreditori i koncesionari zahtevaju da se ispoštuje opisana metodologija i da ležište bude prikazano u digitalnom obliku.

3. TEHNO EKONOMSKI PODACI ZA PROCENU VREDNOSTI LEŽIŠTA

Usvojeni polazni tehno ekonomski podaci, potrebni za procenu vrednosti ležišta, prikazani su u tabeli 1. Oni su usvojeni na bazi dugogodišnjeg proizvodnog iskustva na ovom rudniku, planskih dokumenata rudnika, postojećih studija za eksploataciju ovog ležišta i procene kretanja tržišnih cena metala u Svetu u narednom periodu.

Ukupna investiciona ulaganja za kop i flotaciju procenjena su na 50 000 000 $. Mogući kapacitet proizvodnje usvojen je prema Planu razvoja proizvodnje rude bakra u RTB-u i iznosi 8,5 miliona tona rude godišnje

Za analizu mogućnosti otkopavanja uzeto je stanje kopa geodetski snimljeno na dan 05. 02. 2011. godine.

Bazni parametri eksploatacije usvojene su na osnovu dosada stečenog iskustva u otkopavanju istog ležišta, odnosno:

- visina etaže 15 m,
- ugao kosine etaže 70°,
- ugao završne kosine kopa u rasponu od 35 - 38° i
- širina etažnih ravni u rasponu od 13,0 – 18,5 m.

Pregled ostalih tehno ekonomski parametri za optimizaciju ležišta sistematizovan je u tabeli broj 1.

Tabela 1. *Pregled polaznih tehno ekonomskih parametara za optimizaciju ležišta*

Parametar	Jednica	Vednost
Bazne cene metala		
➢ bakra	USD/t	6 500,00
➢ zlata	USD/kg	35 000,00
➢ srebra	USD/kg	650,00
Troškovi otkopavanja rude	USD/t	2,00
Troškovi otkopavanja jalovine	USD/t	2,00
Troškovi flotacijske prerade rude	USD/t	3,80
Troškovi metalurške prerade koncentrata bakra	USD/t Cu katode	750,00
Troškovi rafinacije zlata	USD/kg	150,00
Troškovi rafinacije srebra	USD/kg	15,00
Flotacijska iskorišćenja		
➢ bakra	%	82,0
➢ zlata	%	55,0
➢ srebra	%	55,0
Metalurška iskorišćenja		
➢ bakra	%	95,0
➢ zlata	%	91,0
➢ srebra	%	91,0
Godišnji kapacitet prerade rude	t/god	8 500 000
Diskontna stopa	%	10

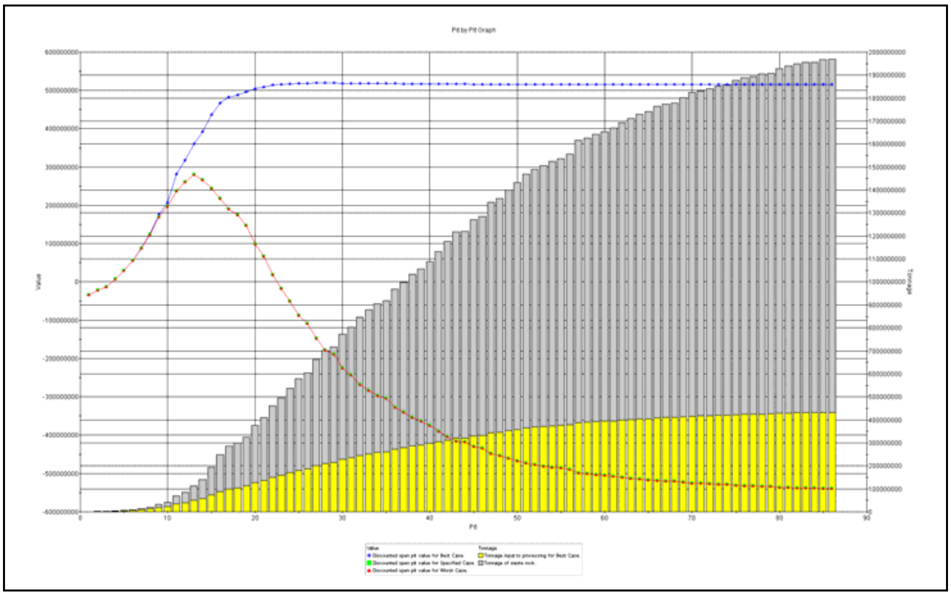
4. EKONOMSKE GRANICE OTKOPAVANJA LEŽIŠTA I PRORAČUN BILANSNIH RUDNIH REZERVI

Utvrđivanje ekonomske granice otkopavanja ležišta površinskim kopom, tj. utvrđivanje graničnog kopa za navedene polazne tehnoekonomske parametre, urađeno je programskim paketom za optimizaciju površinskih kopova *Whittle*, a na osnovu izrađenog blok modela ležišta.

Navedeni programski paket određuje granicu kopa po *Lersh-Grossman* algoritmu, a primenjen je *Cut–off* postupak. Ovim metodom se za svaki orudnjeni blok izračunava mogući profit i troškovi za slučaj njegovog otkopavanja.

Za jednu kombinaciju tehnoekonomskih parametara dobija se jedan granični kop, ali se promenom nekih od ulaznih parametara menja kontura graničnog kopa. Softwer ima mogućnosti da primenom koeficijenta cene metala menja veličinu prihoda i time generiše više mogućih kontura kopova, što je prikazano na slici 1.

Promenom cena metala tj. mogućeg prihoda, primenom faktora prihoda definisane su različite granice kopova. Sa grafika se takođe može očitati ukupna količina iskopina (rude i jalovine) koje su zahvaćene kopom, kao i količine koje je softver okarakterisao kao ruda.



Sl. 1. *Grafički prikaz količina rude i jalovine i vrednosti kopova za granični sadržaj 0,15% Cu u rudi*

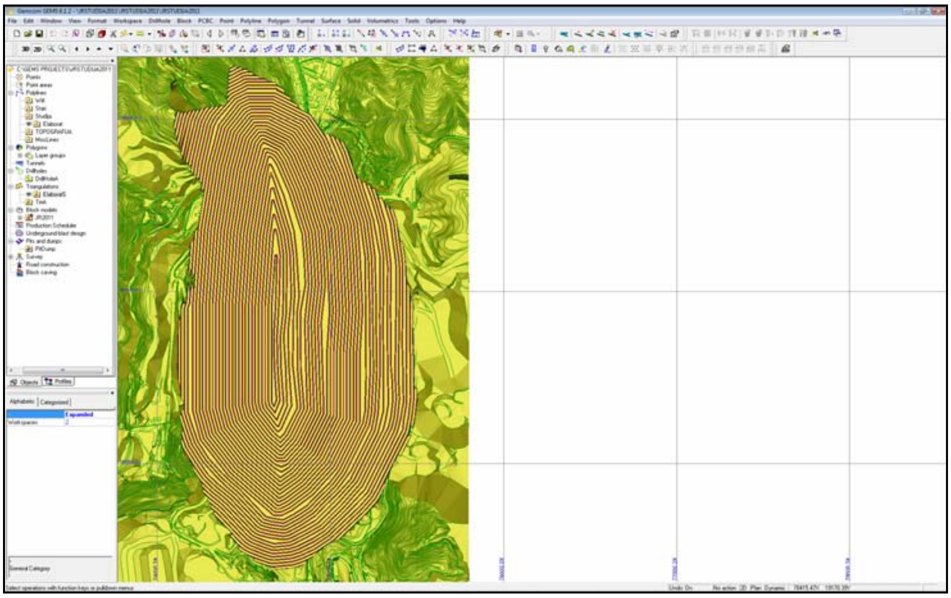
Projektovano otkopavanje na površinskom kopu Južni revir vršiće se po varijanti „*best case*“, odnosno otkopavanje po međuzahvatima tzv. *pushback*-ovima.

Granični kop za napred navedene polazne tehnoekonomske parametre je kop sa faktorom prihoda jednakim jedinici, odnosno kop broj 36. S obzirom da su kopovi od broja 34 do broja 38 pozitivni, po “*best*“ varijanti otkopavanja, sa postojećim podacima koji su uzeti u optimizaciji, za konstrukciju površinskog kopa koji obuhvata bilansne rezerve izabran je kop broj 33, koji ima faktor povraćaja 0,94. Ovaj kop izabran je sa jedne strane zbog prostornih ograničenja, a sa druge strane zbog sigurnosti, s obzirom na mogućnost da investicona ulaganja nisu u potpunosti definisana. Pretpostavljeni profit koji je dobijen u programskom paketu *Whittle* za varijantu kopa broj 33, omogućila bi dodatne investicije, a da pri tome ekonomska vrednost ležišta ostane pozitivna.

Konstruisana završna kontura kopa u programu *Gemcom* ima 41 etažu. Najviša etaža je E+590, a najniža etaža je E-10. Projektovanim zahvatom predviđeno je otkopavanje čiji su glavni parametric dati u tabeli 2. Izgled završne konture kopa prikazan je na slici 2.

Tabela 2. *Bilansne rezerve u ležištu bakra Južni revir Majdanpek u konturi graničnog sadržaja 0,15% Cu*

Materijal	Količina
Ruda (t)	246 947 462
Jalovina (t)	596 081 443
Iskopina (t)	843 028 905
Koeficijent raskrivke (t/t)	2,414
Cu (%)	0,357
Ag (g/t)	1,469
Au (g/t)	0,199



Sl. 2. *Izgled završne konture kopa*

5. ZAKLJUČAK

Bilansne rezerve ležišta Južni revir Majdanpek utvrđene su na osnovu vrednosti graničnih naturalnih pokazatelja koje se odnose na kvalitet mineralne sirovine i rudarsko tehničke uslove eksploatacije, primenom softvera *Whittle* i *Gemcom*.

Za utvrđivanje bilansnosti rezervi, u slučaju tog ležišta, od bitnog značaja su maksimalna dubina eksploatacije, maksimalno dozvoljena veličina koeficijenta otkrivke i minimalni, tj. maksimalni srednji sadržaj korisnih komponenti u ležištu.

Za izbor najpovoljnije konture bilansnih rezervi izvršena je optimizacija ležišta u softveru *Whittle* na osnovu izrađenog blok modela ležišta, pri čemu je dobijeno više varijanti kopa u konturi graničnog sadržaja bakra 0,15%, tačnije 86 varijanti kopova. Navedeni programski paket određuje granicu kopa po *Lersh-Grossman* algoritmu, a primenjen je *Cut–off* postupak. Ovim metodom se za svaki orudnjeni blok izračunava mogući profit i troškovi za slučaj njegovog otkopavanja.

Proračun bilansnih rezervi izvršen je u softveru *Gemcom*, modul *Volumetrics*.

Granični kop za napred navedene polazne tehnoekonomske parametre je kop sa faktorom prihoda jednakim jedinici, odnosno kop broj 36. S obzirom da postoji mogućnost greške kod procene investicionih ulaganja, zbog sigurnosti za konstrukciju površinskog kopa koji obuhvata bilansne rezerve izabran je kop broj 33. Pretpostavljeni profit koji je dobijen u programskom paketu *Whittle* za varijantu kopa broj 33, omogućio bi dodatne investicije, a da pri tome ekonomska vrednost ležišta ostane pozitivna.

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APPLICATION THE SOFTWARE PACKAGES WHITTLE AND GEMCOM FOR CALCULATION THE BALANCE RESERVES OF COPPER ORE IN THE SOUTH MINING DISTRICT DEPOSIT MAJDANPEK***

Abstract

Application of software for calculation the reserves in a modern geological and mining science and practice enables the short term look at a number of variants and finding out the best solutions.

The obtained results had satisfactory quality and accuracy, and according to the international standards.

This paper presents the application of software Whittle and Gemcom for a (Code) of calculation the balance reserves of the deposits South Mining District Majdanpek.

Key words: *software packages Whittle and Gemcom, deposit, South Mining District Majdanpek, balance reserves.*

1. INTRODUCTION

Balance reserves of solid mineral deposits are deposit parts that can be profitably mined by the existing techniques and technology.

Balance of reserves is determined by prescribed techno-economic analysis.

It is necessary to adopt previously the appropriate criteria for determining the balance of reserves, i.e. to adopt the limit values of some natural indicators, which relate to the quality of mineral resource and mining–technical conditions of exploitation.

In a case of the copper deposits South Mining District, maximum depth of exploitation, maximum allowed value of overburden ratio and minimum, i.e. maximum average content of useful components in deposit are very important for determining the balance of reserves.

After previous development the block model of deposit as well as determined initial parameters (costs of exploitation and processing, losses, dilution, investment and price of final products), it is possible to

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access the deposit optimization in the *Whittle* software package.

Many variations of the open pit, in a contour of limit copper content 0.15%, specifically 86 variants, were analyzed to select the best contour of balance reserves. Then, the open pit was designed in the software *Gemcom,* and based on it, a calculation of balance reserves was made, for which *Gemcom* was also used, and it is its module *Volumetrics.*

2. THE APPLIED METHODS OF RESERVE CALCULATIONS

Mini-block method was used for calculation the ore reserves in the deposit South Mining District Majdanpek.

Mini-block method is professionally verified present in a detail in the relevant technical literature, where it is isolated as a separate method in a group of topological methods for calculation the ore reserves.

In selecting the mini-block method, as the base, it was in a mind that the copper deposit South Mining District Majdanpek was basically explored by rectangular grid of exploration drill holes 100 × 50 m, and the contours of mineralization were tested in several horizons by mining prospecting works. Also, the deposit has a form of elongated lenses of uniform mineralization thickness.

The adopted mini-blocks are a cube with sides of 15 m due to the designed height of exploitation benches, also 15 m, and ore thickness in it.

Kriging method was used for evaluation the calculation blocks.

In large deposits, as it is the case with the copper deposit South Mining District Majdanpek, the advantage of reserve calculation using computer technology in relation to the calculation of other (“manual”) methods are the following:

- it is possible in a short period of time to generate a large number of variants, carry out their analysis and find the best solution,
- thus obtained results have satisfactory accuracy and they are accepted as the representative in the expert public,
- potential creditors and concessionaires require to comply with described methodology and that the deposit is displayed in a digital form.

3. TECHNO-ECONOMIC DATA FOR EVALUATION THE DEPOSIT VALUE

The adopted initial techno-economic data needed to evaluate the deposit value, are shown in Table 1. They were adopted on the basis of many years production experience in this mine, mine planning documents, existing studies for exploitation of this deposit and assess the trends in market prices of metals in the world in next period.

Total investments for open pit and flotation are estimated to 50 000 000 $. Possible production capacity was adopted according to the Plan of development the copper ore production in RTB and it is 8.5 million tons of ore annually.

The condition of open pit, geodetic recorded on 05.02.2011, was taken for analysis the possibility of mining.

The basic parameters of exploitation were adopted on the basis of gained experience in excavation the deposit, that is:

- bench height, 15 m,
- angle of bench slope, 70°,
- angle of final pit slope in the range of 35 - 38°, and
- width of bench level in the range of 13.0 to 18.5 m.

Review of other techno-economic parameters for deposit optimization is systematized in Table 1.

Table 1. *Summary of initial techno-economic parameters for deposit optimization*

Parameter	Unit	Value
Base metal prices		
➢ copper	USD/t	6 500.00
➢ gold	USD/kg	35 000.00
➢ silver	USD/kg	650.00
Costs of ore mining	USD/t	2.00
Costs of waste mining	USD/t	2.00
Costs of flotation ore processing	USD/t	3.80
Costs of metallurgical treatment of copper concentrate	USD/t Cu cathode	750.00
Gold refining costs	USD/kg	150.00
Silver refining costs	USD/kg	15.00
Flotation efficiencies		
➢ copper	%	82.0
➢ gold	%	55.0
➢ silver	%	55.0
Metallurgy recoveries		
➢ copper	%	95.0
➢ gold	%	91.0
➢ silver	%	91.0
Annual ore processing capacity	t/year	8 500 000
Discount rate	%	10

4. ECONOMIC LIMITS OF DEPOSIT EXCAVATION AND CALCULATION THE BALANCE ORE RESERVES

Determination of economic limit of deposit excavation by open pit, i.e. determination the limit open pit for mentioned starting techno-economic parameters, was carried out using the software package for optimization the open pit, *Whittle*, based on developed block model of deposit.

The mentioned software package sets the open pit limit per *Lersh-Grossman* algorithm, and the *Cut-off* procedure was applied. This method is used to calculate a potential profit for each mineralized block and costs in the event of its excavation.

For one combination of technoeconomic parameters, one limit open pit is obtained, but the contour of limit open pit is changed by changing of some input parameters. Software has the abilities to change the size of revenues using the coefficient of metal price and thus to generate a number of possible open pit contours, as shown in Figure 1.

Changing the metal prices, i.e. potential revenue, different limits of open pit were defined by applying the revenue factor. It is also read from graphic the total quantity of excavation (ore and waste) that are affected by open pit as well as the characterized quantities by software as the ore.

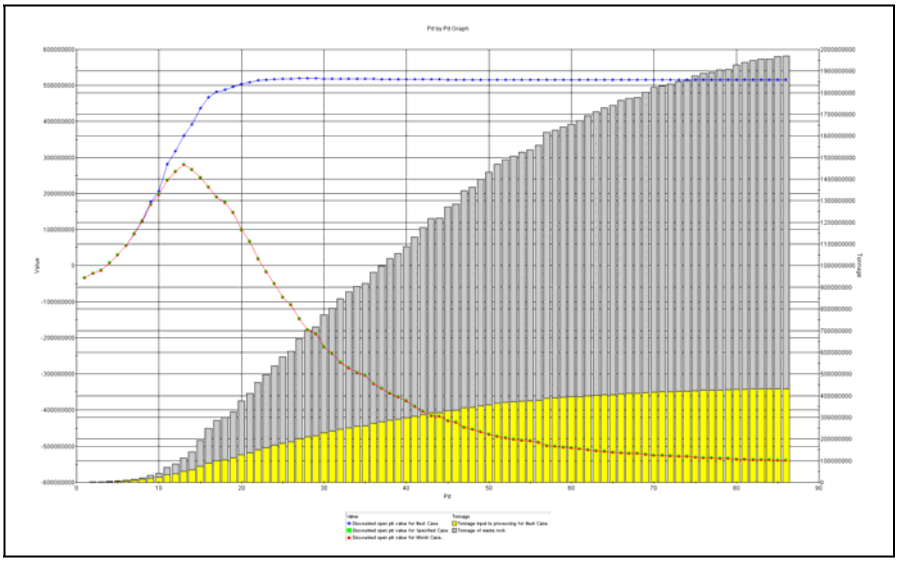

Fig. 1. *Graphical presentation the quantities of ore and waste and value of open pits for limit content of 0.15% Cu in the ore*

Designed open pit mining of the South Mining District will be realized by the *"best case"* variant or so-called *pushback* excavation.

Limit open pit for the aforementioned initial techno-economic parameters is the open pit with a factor of income equal to one, or the open pit No.36. Since the open pits from No.34 to No.38 are positive, according to the "*best*" variant of excavation, with the existing data taken into optimization, the open pit No.33, with recovery factor of 0.94, was selected for construction the open pit that includes the balance reserves.

This open pit was selected due to the spatial constraints, on one hand, and the other hand, due to the security, regarding to a possibility that the investments are not fully defined. The assumed profit, obtained in the software package *Whittle* for the variant of open pit No.33, would provide the additional investments, while the economic value of deposit remains positive.

Constructed final contour of open pit in the software package *Gemcom* has 41 benches. The highest bench is E+590, and the lowest bench is E-10. The designed pushback assumed excavation with main parameters given in Table 2. View of the final open pit contour is shown in Figure 2.

Table 2. *Balance reserves in the copper deposit South Mining District Majdanpek in a contour of limit content 0.15% Cu*

Material	Qunatity
Ore (t)	246 947 462
Waste (t)	596 081 443
Excavation (t)	843 028 905
Overburden ratio (t/t)	2.414
Cu (%)	0.357
Ag (g/t)	1.469
Au (g/t)	0.199

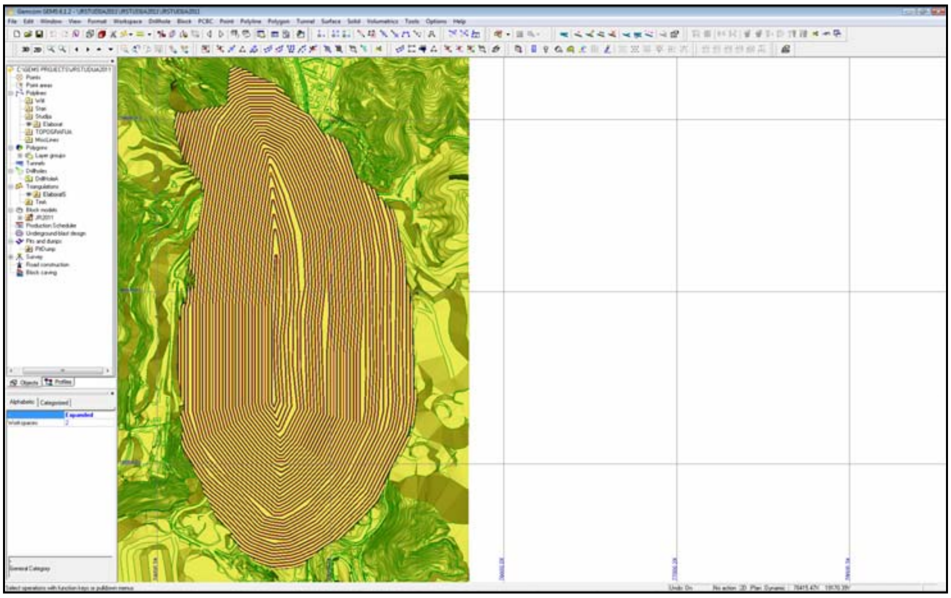

Fig. 2. *View of the final open pit contour*

5. CONCLUSION

Balance reserves of the deposit South Mining District Majdanpek were determined on the basis of limit natural indicators related to the quality of mineral resources and mining technical conditions of exploitation, using the software *Whittle* and *Gemcom.*

For selection the most suitable contour of balance reserves, the deposit optimization was made in the software *Whittle*, based on developed block model of deposit, where several variants were obtained in a contour of limit copper content 0.15%, more precisely 86 variants of open pits.

The mentioned software package sets the open pit limit per *Lersh-Grossman* algorithm, and the *Cut-off* procedure was applied. This method is used to calculate a potential profit for each mineralized block and costs in the event of its excavation.

Calculation of balance reserves was mode in the software *Gemcom*, module *Volumetrics*.

Limit open pit for the aforementioned initial techno-economic parameters is the open pit with a factor of income equal to one, or the open pit No.36. Since the open pits from No.34 to No.38 are positive, according to the "*best*" variant of excavation, with the existing data taken into optimization, the open pit No.33 was selected for construction the open pit that includes the balance reserves. The assumed profit, obtained in the software package *Whittle* for the variant of open pit No.33, would provide the additional investments, while the economic value of deposit remains positive.

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NOVO LABORATORIJSKO POSTROJENJE ZA GRANULIRANJE IZMENJENIM TEHNOLOŠKIM POSTUPKOM IZLIVANJA TOPIONIČKE ŠLJAKE[**]

Izvod

Jalovišta i šljakišta kao izvor velikih količina metala imaju sve veći ekonomski značaj. Šljaka u pogonima RTB-a prerađuje se u postrojenju koje nije projektovano za preradu šljake, već samo prilagođeno tim uslovima. Dobijeni rezultati su lošiji od očekivanih, pa se nastavljaju ispitivanja koja bi mogla da ih unaprede. Jedna od mogućnosti je proces granuliranja šljake koji daje čitav niz pravaca za ispitivanje uticaja na proces usitnjavanja i koncentracije. Za te potrebe konstruisano je laboratorijsko postrojenje uz pomoć kojeg će se dobiti veće količine granulata neophodnog za dalja ispitivanja.

Ključne reči: *topionička šljaka, granuliranje, laboratorijsko postrojenje*

1. UVOD

Proizvodnja metala bi u budućnosti mogla biti značajno manja u odnosu na sadašnju, zbog činjenice da se rezerve metala u prirodnom obliku u rovnim rudama ubrzano iz godine u godinu smanjuju. Drugi razlog, limitirane proizvodnje metala predstavljaju sve stroţiji zakoni o zaštiti životne sredine, zbog otpada koji nastaje masovnom preradom siromašnih ruda. Ogromne količine metala zarobljene u jalovištima i šljakištima, za naredni period mogu predstavljati potencijalne sirovine za dobijanje novih količina metala. Mineraloški sastav šljaka dobijen iz metalurške prerade zavisi od mnogih faktora, a jedan od značajnih je tehnologija metalurške prerade. U zavisnosti od gore napomenutog, sadržaj korisne komponente varira u granicama koje predstavljaju veći sadržaj nego prisustvo njihovo u rovnim rudama.

Šljake dobijene preradom obojenih metala su uglavnom šljake iz proizvodnje

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bakra. Glavne komponente šljaka dobijenih iz metalurgije bakra su Fe i SiO_2. Sadržaj bakra u skoro svim šljakama metalurške prerade bakra kreće se u rasponu od 0,5 do 4,0 %, što je znatno više od sadržaja bakra u rudama ležišta bakra, koja se danas eksploatišu. Šljake dobijene metalurškom preradom bakra, najčešće se različitim postupcima pripreme i koncentracije tretiraju radi ponovnog dobijanja bakra.

U poslednjih nekoliko decenija, sve veći značaj se daje preradi sekundarnih sirovina, sa ciljem ukupnog povećanja stepena iskorišćenja na korisnoj komponenti – bakru. Praksa je pokazala da se sekundarne sirovine razlikuju od primarnih sirovina, ruda, u pogledu mineraloško fizičko-hemijskih i mehaničkih karakteristika. Dosadašnja svetska istraživanja u oblasti prerade mineralnih sirovina, bazirala su se na istraživanju prerade primarnih sirovina (ruda). Samim tim svi rezultati, teorije i zaključci dobijeni istraživanjima primarnih sirovina, ne mogu se u potpunosti prihvatiti i primenjivati u procesu tretmana sekundarnih sirovina.

Topionička šljaka iz procesa metalurške prerade koncentrata se po svojim mineraloškim, fizičko – hemijskim i mehaničkim osobinama dosta razlikuje od primarnih sirovina. Ponašanje topioničke šljake u procesima drobljenja, mlevenja, flotiranja, različito je od ponašanja ruda koje su osnov za dobijanje koncentrata bogatog bakrom. Karakteristike topioničke šljake, kao što su specifična masa i tvrdoća, utiču da se sam proces prerade rude ne može bez ikakvih promena primeniti u preradi topioničke šljake.[1] Razlike koje postoje u fizičko-hemijskim i mehaničkim osobinama primarne sirovine, rude i sekundarne sirovine, topioničke šljake, nameću potrebu za temeljnim istraživanjima, radi upoznavanja ponašanja topioničke šljake u procesu prerade i mogućnost optimizacije procesa radi poboljšanja tehnoloških rezultata i smanjenja troškova prerade.

2. GRANULIRANJE ŠLJAKE

Topionička šljaka iz pogona RTB-a, prerađuje se u pogonu flotacije koji je projektovan za preradu rude a koji je samo prilagođen uslovima prerade šljake. Sa tim u vezi javlja se niz poteškoća koje se ogledaju kroz veliku potrošnju električne energije i lošije tehnološke rezultate od nekih sličnih pogona u svetu. Ranija istraživanja koja se odnose na stepen usitnjavanja, pokazala su da krupnoća granulometrijskog sastava ulaza u mlin sa šipkama može da se snizi postupkom granuliranja[2] koji je ustvari jedan jednostavan i jeftin proces, a kojim može da se izbegne tehnološki postupak trostepenog drobljenja i prosejavanja. Tokom granuliranja vodi se predaje značajna količina toplotne energije, koja može da se koristi u razne svrhe. Proces granulacije tek treba istražiti, ispitati uticaj granuliranja i način izvođenja postupka granuliranja na tehnološke pokazatelje flotacijske koncentracije. U cilju daljih ispitivanja konstruisano je laboratorijsko postrojenje za granuliranje šljake uz pomoć kojeg će se dobiti veće količine granulirane šljake neophodne za eksperimente.

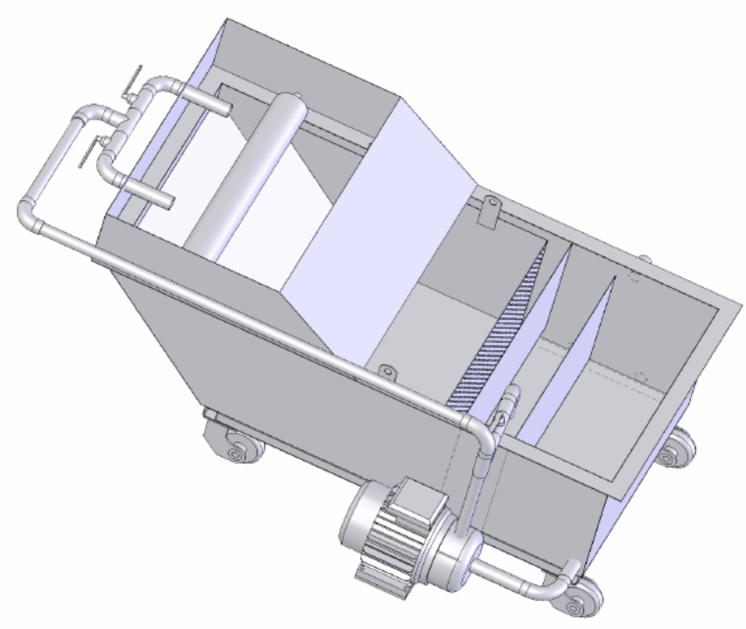
3. OPIS GRANULATORA

Konstruisani granulator je mobilan, tako da može da opslužuje više različitih laboratorijskih peći za topljenje, koje imaju različitu funkcionalnu namenu. Peći su locirane u laboratoriji za pirometalurgiju u Institutu za rudarstvo i metalurgiju Bor. Konstrukcija granulatora omogućava, da se šljaka naglo hladi mlaznicama, koje se nalaze na čeonoj prednjoj strani rezervoara, odmah iza valjka, kome je jedan deo potopljen u rashladnu vodu. Ispod valjka je prihvatni koš sa perforiranim dnom, koji prihvata nastale granule i koji se nakon izlivanja celokupne količine šljake iz peći vadi uz pomoć dizalice i nakon ceđenja, odlaže u korpu za granulisanu šljaku.

Na slikama br. 1 i 2., dati su respektivno vizuelni 3D prikaz konstruisanog granulatora topioničke šljake i jedna od laboratorijskih peći za topljenje, koje su, kako smo već naveli, locirane u laboratoriji za pirometalurgiju u Institutu za rudarstvo i metalurgiju Bor.

Laboratorijski granulator i peć su kompatibilni i funkcionišu u sprezi kada se usijana i rastopljena šljaka izliva direktno u laboratorijski granulator radi naglog hlađenja. Tada se dešava složeni proces očvršćavanja topioničke šljake kroz njenu prekristalizaciju i složenu mineralošku transformaciju do potpunog hlađenja iste i stvaranja staklaste fajalitske strukture sa ostacima bakra u nekoj mineralnoj ili slobodnoj – metalnoj-elementarnoj formi u ukupnom iznosu od oko 1%.

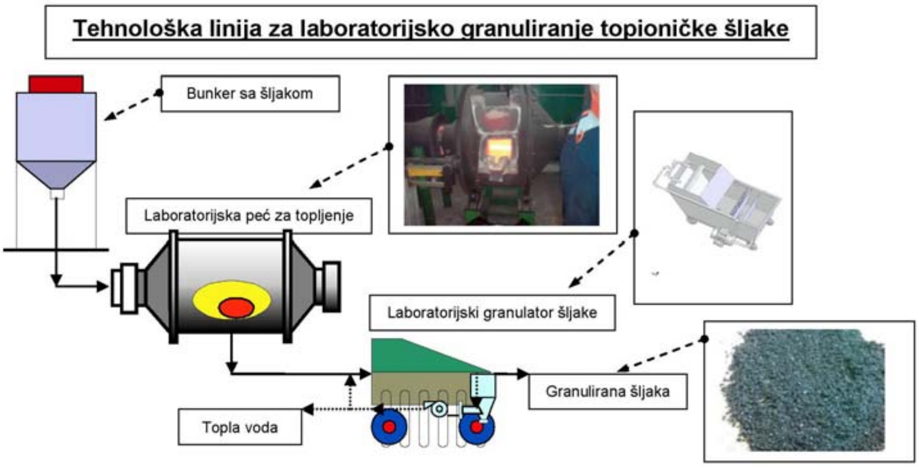
Prilikom naglog hlađenja šljake oslobađaju se i gasovi sa vodenom parom, koje prihvata hauba u kojoj se vrši kondenzacija vodene pare, a ostatak gasa sa nekondenzovanom vodenom parom odvodi u sistem za prečišćavanje otpadnih gasova, koji je tako konstruisan, da opslužuje i druge laboratorijske peći za topljenje.



Sl.1. *Vizuelni 3D prikaz konstruisanog granulatora topioničke šljake*

Sl.2. *Laboratorijska peć za topljenje*

Sam granulator slika 1., se sastoji iz rezervoara za vodu, koša, obrtnog valjka i cirkulacionog sistema za vodu. Rezervoar za vodu je napravljen od čeličnog lima debljine 1-3mm. Unutar sebe, na izlaznom kraju su dve pregrade za smirivanje preliva vode i taloženje čvrstih čestica. Omogućeno je pražnjenje razervoara pri dnu. Koš za granule je od čeličnog lima sa perforiranim dnom i sa mogućnošću vađenja iz rezervoara. Cirkulacioni sistem se sastoji iz cirkulacione pumpe, razvodnog cevovoda nazivnog prečnika NV25 i mlaznica za raspršivanje vode. Mlaznice za raspršivanje vode stvaraju horizontalni ravanski mlaz vode. Potrošnja električne energije cirkulacione pumpe je od 0,8-1,3 kW. Protok vode je do 5 m^3/h, radni pritisak u cevovodu je 6 bara. Ukupna masa granulatora je oko 200 kg. Gabaritne dimenzije granulatora dužina/širina/visina su: 1600 mm /850 mm/ /810 mm. Izgled sprege peći za topljenje i laboratorijskog granulatora dat je kroz tehnološku šemu laboratorijskog izvođenja postupka za granuliranje topioničke šljake prikazanog na slici 3.



Sl.3. *Tehnološka šema laboratorijskog postupka za granuliranje topioničke šljake*

4. POSTUPAK GRANULIRANJA ŠLJAKE

Za laboratorijski eksperiment korišćena je šljaka koja je izuzeta iz pogona drobljenja sa transportne trake, pre procesa tercijernog drobljenja. Šljaka je na deponiji bila izložena atmosferilijama, pa je sadržala određenu količinu vlage zbog čega je prethodno osušena na sobnoj temperaturi. Radi karakterizacije izuzetog uzorka urađena je hemijska analiza šljake i prikazana je u tablici 1.

Tablica 1: *Hemijski sastav polazne šljake*

Jedinjenje - hemijski element	Cu	Fe_3O_4	CaO	S	Fe	FeO	SiO_2	Al_2O_3
Sadržaj [%]	0,68	1,754	17,26	1,07	25,69	26,75	43,76	3,89

Šljaka je zatim podvrgnuta topljenju u laboratorijskoj indukcionoj peći za topljenje, snage 100 kWh, u loncu zapremine V=10 l, proizvođača ELING - Loznica. Sama granulacija izvedena je u laboratorijskim uslovima u posudi za hlađenje šljake. Prilikom eksperimenta istopljeno je 25 kg šljake, a temperatura pri kojoj je šljaka izlivena je bila t=1250 ^{o}C. Merenje temperature šljake obavljeno je potapajućim pirometrom.

Na taj način dobijen je primarni uzorak granulirane topioničke šljake na kojem je sprovedeno dalje ispitivanje granulometrijskog sastava, hemijskog sastava itd. Dakle, u laboratorijskim uslovima je potvrđena mogućnost granuliranja topioničke šljake i stvoreni su preduslovi za konstrukciju laboratorijskog uređaja za granuliranje. Taj novi laboratorijski uređaj treba da omogući, kao prvo:

- Ispitivanje uslova granulacije topioničke šljake u cilju dobijanja što finijeg granulata kroz varijaciju geometrijsko - konstruktivnih, tehnoloških i radnih parametara laboratorijskog granulatora topioničke šljake.

Kao drugo:

- Stvaranje veće količine raznih tipova granulirane šljake radi tehnoloških ispitivanja flotacijske koncentracije korisnih komponenata.

I konačno:

- Kreaciju predloga novog ili izmenjenog tehnološkog procesa flotaci-jske koncentracije korisnih komponenata energetski i tehnološki efikasnijeg.

Ujedno, ovaj novi laboratorijski uređaj predstavlja model koji će poslužiti pored navedenih ispitivanja i za konstrukciju većeg polu-industrijskog ili industrijskog granulatora topioničke šljake.

5. ZAKLJUČAK

Za potrebe unapređenja rezultata flotacijske prerade topioničke šljake konstruisan je laboratorijski uređaj za granuliranje pomoću kojeg će se jednostavnijim putem u laboratoriji dobiti veće količine granulata neophodnog za dalja tehnološka ispitivanja. Novi laboratorijski uređaj predstavlja model koji će poslužiti za konstrukciju većeg polu-industrijskog ili industrijskog granulatora topioničke šljake. Na taj način omogućeće se flotacijska prerada topioničke šljake energetski i tehnološki efikasnijim procesom.

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NEW LABORATORY PLANT FOR GRANULATION USING THE CHANGED TECHNOLOGICAL PROCESS OF SMELTER SLAG DISCHARGING**

Abstract

Tailing and slag dumps, as a source of large quantities of metals, are of increasing economic importance. Slag in the plants of RTB is processed in a plant which is not designed for slag processing, but only adapted to those conditions. The obtained results are worse than the expected ones, and testing are continued that could improve them. One possibility is the process of slag granulation, which provides a number of directions for investigation the impacts on the process of fragmentation and concentration. For this purposes, a laboratory plant was designed to obtain larger quantities of granulate, needed for further investigations.

Key words: *smelter slag, granulation, laboratory plant*

1. INTRODUCTION

Production of metals in the future could be significantly lower than the present, due to a fact that the reserves of metals in natural form in the run-of-mine ore are rapidly decreased from year to year. The other reason of limited metal production is more and stricter laws on environmental protection due to a waste waste generated in the mass processing of low grade ore. Large quantities of metal, trapped in the tailing and slag dumps, for the next period, may be the potential raw materials for new quantities of metal. Mineralogical composition of slag, obtained from metallurgical treatment, depends on many factors, and one of the important is a technology of metallurgical treatment. Depending on the above mentioned, the content of useful components varies within the limits that present higher content than their presence in their run-of-mine ore.

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The slag, obtained by treatment of non-ferrous metals, is mainly slag from copper production. The main components of slag, obtained from the copper metallurgy, are Fe and S_iO_2. Copper content, in almost all slag of copper metallurgical treatment, is in the range of 0.5 to 4.0%, what is considerably more than copper content in the ore deposits of copper, which is now exploited. The slag, obtained by metallurgical copper treatment, usually with different methods of preparation and concentration, are treated for re-obtaining of copper.

In recent decades, an increasing importance is given to the processing of secondary raw materials in order to increase a recovery degree of useful component - copper. Practice has shown that the secondary materials are different from primary raw materials, ores, in terms of mineralogical physic-chemical and mechanical characteristics. Previous world investigations in the field of processing the mineral raw materials, are based on an investigation of primary processing of raw materials (ores). Therefore, all results, theories and findings obtained by investigation the primary raw materials, cannot be fully accepted and applied in the processing of secondary raw materials.

Balance reserves of solid mineral deposits are deposit parts that can be profitably mined by the existing techniques and technology.

Balance of reserves is determined by prescribed techno-economic analysis.

It is necessary to adopt previously the appropriate criteria for determining the balance of reserves, i.e. to adopt the limit values of some natural indicators, which relate to the quality of mineral resource and mining-technical conditions of exploitation.

Smelter slag from the process of metallurgical treatment of concentrate is quite different from primary raw materials on its mineralogical, physical - chemical and mechanical properties. The behavior of smelter slag in the processes of crushing, grinding and flotation, is different from behavior of minerals that are the basis for obtaining the rich copper concentrate. Characteristics of smelter slag, as well as the specific weight and hardness, have influence to the process of ore processing that cannot be applied without any changes in processing of smelter slag (1). Differences in physical-chemical and mechanical properties of primary raw materials, ore and secondary raw materials, smelter slag, have imposed the need for basic research, in order to introduce the behavior of smelter slag in the processing and possibility of process optimization due to improve the technological results and reduce the treatment costs.

2. SLAG GRANULATION

Smelter slag from the sites of RTB, is processed in the flotation plant which is designed for ore processing, and which is only adapted to the conditions of slag processing. Regarding to this, there are a number of difficulties which are reflected through high power consumption and poorer technological results of some similar plants in the world. Previous studies regarding to a degree of fragmentation, have showed that coarseness of grain-size distribution of inlet into rod mill can be lowered by granulation process(2) which is actually a simple and inexpensive process and which can be used for avoiding the technological process of three-stage crushing and sieving. During granulation, a significant amount of thermal energy is submitted to water, which can be used for various purposes. Granulation process has yet to be studied, to examine the influence of granulation and granulation method conducting on technological parameters of flotation concentration. For the aim of further testing, the laboratory plant was designed for slag granulation which will give large quantities of granulated slag, needed for the experiments.

3. DESCRIPTION OF GRANULATOR

The constructed granulator is mobile, so it can handle a variety of laboratory smelting furnaces that have different functional purpose. Furnaces are located in the laboratory in the Mining and Metallurgy Bor. The construction of granulator allows rapidly cooling of slag by jets, which are located on the front side of tank, just behind the cylinder, with a submerged part in cooling water. A reception cage, with perforated bottom, is below a roller, which accepts the resulting granules and those, after discharge the total amount of slag from the furnace, is removed with a crane, and after filtering, stored in a cage for granulated slag.

In figures 1 and 2, respectively, are given the visual 3D reviews of constructed granulator of smelter slag and one of the laboratory smelting furnaces, which, as already stated, are located in the laboratory for pyrometallurgy in the Mining and Metallurgy Institute Bor.

Laboratory granulator and furnace are compatible and work in conjunction when heated and molten slag is discharged directly into the laboratory granulator for rapid cooling. Then, the complex process of smelter slag hardening is carried out through its precrystalization and complex mineralogical transformation to a complete cooling of the same and formation the glassy fayalite structure with the remains of copper in some mineral or free - metal-elemental form in the total amount of about 1%.

During the rapid cooling of slag, gases are released with water vapor, which accepts the hood where the condensation of water vapor is carried out, and the rest of gas with non-condensed water vapor is led into the system for waste gas treatment, which is so constructed to serve also the other laboratory smelting furnaces.

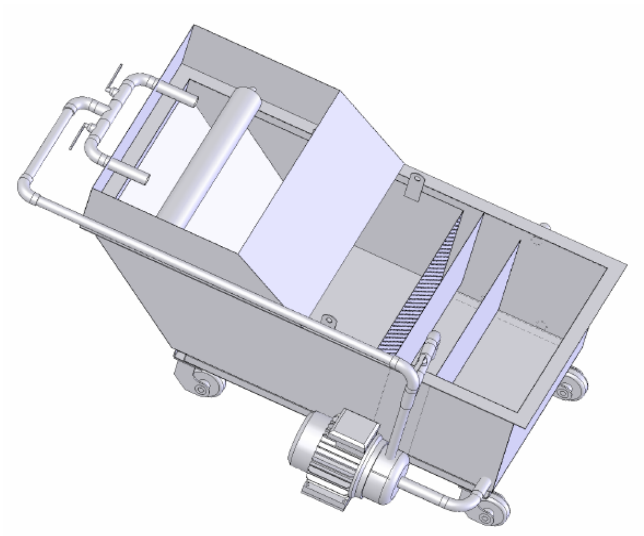

Fig. 1. *Visual 3D review of designed granulator for smelter slag*

Fig. 2. *Laboratory smelting furnace*

The granulator, Figure 1, consists of a water tank, cage, rotating drum and water circulation system. The water tank is made of steel sheet, thickness 1-3mm. Within it, at the output end, two compartments are situated for soothing the water overflow and sedimentation of solid particles.

The tank is possible to discharge on the bottom. Cage for granules is made of steel sheet with perforated bottom and possibility of removing from the tank. Circulation system consists of a circulation pump, distribution pipeline of NV25 nominal diameter and nozzles for water spraying. Nozzles for water spraying produce a horizontal plane water jet. Electricity consumption of circulation pump is from 0.8 to 1.3 kW. Water flow is up to $5m^3/h$, working pressure in the pipeline is 6 bar. The total mass of granulators is about 200 kg. Granulator dimensions of length/ /width/heightare 1600mm/850mm/810mm. Appearance of coupling of smelting furnace and laboratory granulator is provided through a technological scheme of laboratory performing the procedure for smelter slag granulation, shown in Figure 3.

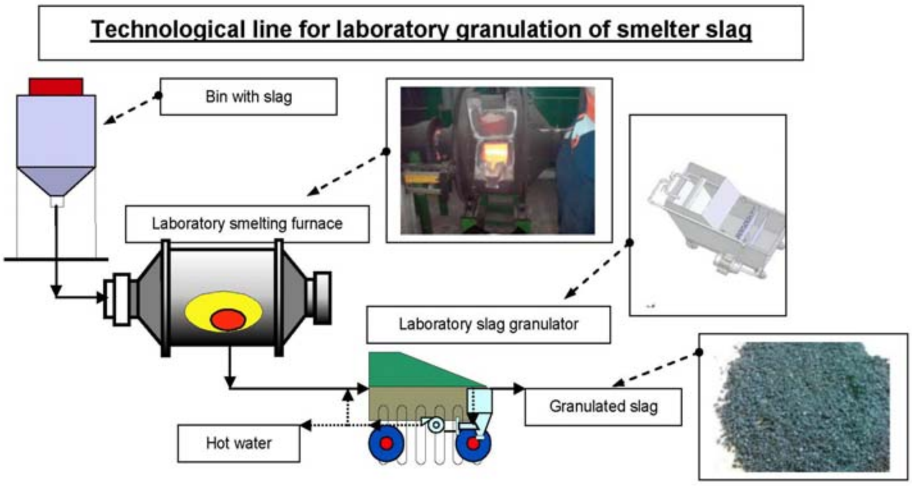

Fig. 3. *Technological scheme of laboratory process for smelter slag granulation*

4. PROCESS OF SLAG GRANULATION

For laboratory experiment, the slag was used which was taken from the crushing plant from conveyor belt, before the tertiary crushing process. Slag was exposed to the weather conditions on a dump, so it contained the certain amount of moisture why it was pre-dried at room temperature. For characterization of taken sample, the chemical analysis of slag was carried out and shown in Table 1.

Table 1: *Chemical composition of starting slag*

Compound–chemical element	Cu	Fe_3O_4	CaO	S	Fe	FeO	SiO_2	Al_2O_3
Content [%]	0.68	1.754	17.26	1.07	25.69	26.75	43.76	3.89

Slag was then subjected to smelting in a laboratory induction furnace, power of 100 kWh, in a pot, volume V = 10 l, ELING – Loznica manufacturer. The granulation was carried out in the laboratory conditions in a pot for slag cooling. During the experiment, 25 kg of slag was melted and the temperature of slag pouring was t=1250^{o}C. Temperature measurement was performed by the slag immersion pyrometer.

In this way, the primary sample of granulated slag was obtained where further investigation of grain-size distribution, chemical composition, etc. was conducted. So, in the laboratory conditions, a possibility of smelter slag granulation was confirmed and the preconditions were formed for construction of laboratory device for granulation. This new laboratory device should provide, as the first:

- Study the conditions of smelter slag granulation in order to obtain as much as possible finer granules through the variation of geometrical-structural, technological and operational parameters of laboratory granulator of smelter slag.

As the second:

- Creating the large quantities of various types of granulated slag for technological testing the flotation concentration of useful components.

And final:

- Designing the new or changed technological process of flotation concentration the useful components and energy and technology more efficient.

Also, this new laboratory device represents a model that will be used in addition to the above mentioned tests and for construction a larger semi-industrial or industrial granulator of smelter slag.

5. CONCLUSION

For the needs of improvement the results of flotation processing the smelting slag, a laboratory device was designed for granulation which will be used for obtaining larger amounts of granules, required for further technological studies, by simplest way in the laboratory. The new laboratory device is a model that will be used for construction of larger semi-industrial or industrial granulator of smelter slag. In this way, the flotation processing of smelter slag will be energy and technology more efficient.

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ANALIZA RIZIKA I HAZARDA EVIDENTIRANIH U RMU KAKANJ[**]

Izvod

Rizik i krizne situacije atributi su koji se sudbinski vežu za sam pojam rudarenja, jer je taj poziv historijski povezan sa rizikom prilikom svakodnevnog obavljanja radnih operacija i funkcionisanja rudnika u cjelini.

Važeća zakonska regulativa u BiH nije u suglasju sa primjenjenim ISO standardima, koji nemaju ustanovljene modele za upravljanje strateškim rizikom u rudarskoj djelatnosti. Zato treba nastojati da se primjenjeni modeli nađu što prije u oblasti koju je potrebno regulisati zakonskim aktima ili na neki drugi način uvesti u pravni okvir koji će biti obavezujući. Svjetska iskustva nakon uvođenja strateškog upravljanja rizikom i kriznim situacijama ukazuju na poboljšanje općih sigurnosnih uvjeta i smanjenje incidentnih događaja sa štetnim posljedicama.

U radu je istaknuto da je, u uslovima koji vladaju, moguće i potrebno pristupiti sistemskom upravljanju rizikom i hazardom u rudarstvu, bez obzira na nepostojanje ustanovljenih normi.

***Ključne riječi**: rizik, hazard, rudarstvo, upravljanje rizikom*

1. UVOD

U svom višestoljetnom postojanju, rudarenje je ostalo duboko ukorijenjeno u svim sredinama u kojima je imalo dugu tradiciju. Posebno je to izraženo u novije vrijeme, dakle zadnjih nešto više od stotinu godina, kada je došlo do intenziviranja proizvodnje uglja, što je praktično bio osnov za industrijsku revoluciju. U svim sredinama gdje se vršila rudarska djelatnost, bez obzira na lokalitet, može se slobodno reći da je rudarenje bilo osnov privrednog-gospodarskog generatora od početka XX vijeka. Bez obzira na tu privrednu značajku, rudarenje je imalo i svoje društvene uticaje na sredine u kojima je obavljano. Tu se slobodno može govoriti o "rudarskoj civilizaciji" koja se manifestovala i uvukla u sve pore života: od jezika, arhitekture, supkulture, kulture i sporta. Rudarska kultura, da bi opstala bila je prisiljena da "komunicira" s podzemnom okolinom i mjestom rada i da se

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[**] *Ovaj rad je proistekao iz magistarskog rada autora pod naslovom „Upravljanje rizikom i kriznim situacijama u tranzicionom modelu strateškog odlučivanja u rudnicma uglja u BiH" RGGF Tuzla, marta 2010. godine.*

prema njemu odnosi s strahopoštovanjem. Svako zanemarivanje ili izazivanje znakova koje priroda i jama šalju može biti kobno za život cijelog "kamarata" smjene. Za nepoštivanje ili olako shvaćanje tih implicitnih i nepisanih pravila vrlo se često plaćala najviša cijena. To je uslovilo razvitak svojevrsnog strahopoštovanja prema jami i rudniku natpisom "SRETNO" koji stoji iznad svih ulaza u jamu. Tim univerzalnim pozdravom se pozdravljaju svi rudari u svijetu.[1]

2. TRETIRANJE RIZIKA I HAZARDA

Na prostorima sadašnje Bosne i Hercegovine kao i bližeg okruženja, dakle prostora bivše Jugoslavije, problem rizika i hazarda, vezanih za rudarsku djelatnost, nije posebno izučavan niti je tretiran kao takav. Sve se svodilo da se u okvirima postojeće zakonske legislative i regulative kao i tehničkih propisa ukaže na pojedine opasnosti i krizne situacije koje su mogle da se dogode. Kao rezultat toga, tehnički propisi su mijenjani i pooštravane su mjere koje je trebalo preduzimati kako ne bi došlo do realizacije incidentnih, odnosno kriznih situacija sa fatalnim posljedicama bilo za ljude ili materijalna sredstva. Mora se konstatovati da su propisane mjere često bile posljedica realiziranog kriznog događaja koji se desio. A takvih je nažalost, na ovim prostorima bilo jako puno.

Međutim, u svijetu, u drugačijem društvenom ambijentu ili svojinskim odnosima, uvidjelo se da treba predviđati krizne situacije, njihovo predupređivanje, eliminaciju kao i kvantificiranje svih elemenata koji ulaze u ukupnu analizu.

Gledano istorijski, metode i tehnike ocjene nivoa rizika tehničkih sistema razvijaju se relativno kasno u odnosu na ostale oblasti inženjerske struke.

U novije vrijeme, u vremenu opće globalizacije svih vidova tržišta i gospodarstva u širem smislu te riječi, isto tako, ideje i praksa upravljanja rizikom se globaliziraju. [2] Isti principi se primjenjuju od Azije do Afrike, Evrope i Amerike. Ipak, još uvijek nedostaje oblik najčešće prihvaćenog "standardnog" i jedinstvenog skupa definisanih pojmova. Regionalni standardi postoje u Australiji, Novom Zelandu, Kanadi i od nedavno u Velikoj Britaniji, kao i podstudija u drugim zemljama. Tokom posljednjih godina, Radna grupa International Standards Organization (ISO), uz neke poteškoće, pokušava postići konsenzus oko zajedničke globalne definicije za upravljanje rizikom.

3. TEORETSKI I PRAKTIČNI OSNOVI UPRAVLJANJA RIZIKOM

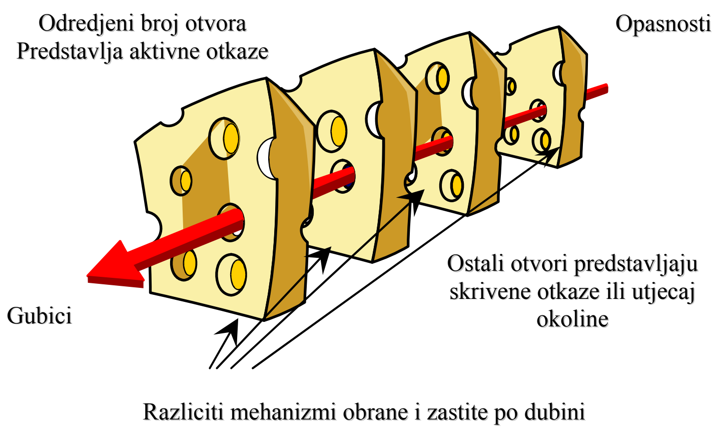
Pod pojmom "upravljanje rizikom" podrazumijeva se čitav niz postupaka i procesa kojima se vrši monitoring stanja rizika, procjenjuje prihvatljivost rizika i sprovode mjere redukcije rizika u oblastima gdje se identificira neprihvatljiv rizik. Drugim riječima, upravljanje rizikom se može definisati kao opća upravljačka funkcija koja nastoji da identifikuje rizike, procijeni rizik i pripremi organizaciju (preduzeće) na uzroke i efekte (posljedice) rizika. Smisao upravljanja rizikom je da se osposobi organizacija da realizuje svoje ciljeve na najdirektniji, najefikasniji i najefektivniji način.

Ni jedna aktivnost se ne može obaviti bez rizika, odnosno sa rizikom nula. Ukoliko postoji bilo kakva mogućnost da dođe do manifestacije hazarda, rizik nije jednak nuli. To ima za posljedicu da je rizik uvijek prisutan, te se rizik koji ostaje nakon svih poduzetih mjera naziva "rezidualni" ili preostali rizik.

Međutim, na početku ćemo pojasniti pojmove šta su to hazardi, a šta rizici. Hazard je opasnost koja može predstavljati "potencijalnu štetu za ljude, imovinu ili okolinu" i kao takvi predstavlja polaznu osnovu za utvrđivanje rizika.

Hazard se prema međunarodnim ISO standardima definiše kao „potencijalni izvor štete ili događaja koji može prouzrokovati gubitak“, dok se rizik definiše kao kombinovani izraz vjerovatnoće da će se desiti hazard i posljedica koje će izazvati njegova realizacija. [3]

Cilj upravljanja rizikom je da se nivo rezidualnog rizika održava ispod postavljene granice kriterija "prihvatljivosti rizika". Kako odrediti prihvatljiv nivo rizika je složen zadatak koji uključuje niz faktora, počev od legislativnih, normativa datim standardima i podzakonskim aktima, poslovne politike kompanije i drugog niza faktora. Moguće je da se za isti rizik imaju različiti nivoi prihvatljivosti, ovisno o tome ko procjenjuje opasnost.



Sl. 1. *Komparacija sigurnosnih sistema odbrane po modelu "švicarskog sira"*[4]

Na gornjoj slici vrlo je pregledno i slikovito prikazan mehanizam djelovanja potencijalne opasnosti koja će u određenom ambijentu (datoj radnoj ili nekoj drugoj sredini), stvoriti pretpostavke da se pretvori u štetnu posljedicu koja će imati svoju, eventualnu mjerljivu težinu i koja će prouzrokovati gubitke. Da se to ne bi desilo, potrebno je uspostaviti različite mehanizme odbrane i zaštiti se od štetnih posljedica. Ukoliko se preduzmu sve predviđene mjere zaštite (zatvore otvori), mogućnosti nastanka štetne posljedice i gubitka su manje. Međutim, stvarnost je uvijek drugačija tako da uvijek ostane prostora za skrivene opasnosti ili jednostavno uticaj okoline koji je nemoguće izbjeći.

4. GENETSKA KLASIFIKACIJA HAZARDA U RUDARSTVU

Ovisno o nastanku (genezi) hazardi u rudarstvu se mogu podijeliti na:

1. Prirodne hazarde, i
2. Antropogene hazarde

Definiranje prirodnih hazarda kao onih kod čijeg pojavljivanja čovjek ne igra ključnu ulogu ili antropogenih kod kojih je ključna uloga čovjeka, je složeno u realnim uslovima, a posebno u granama nauke kakva je rudarstvo uglja.

U praksi je prisutna tendencija da se kvalificiraju kao „prirodne opasnosti" ili „prirodni hazardi" veliki broj hazarda kod kojih je atribut „prirodan" vrlo upitan i ponajprije se odnosi na nemogućnost čovjeka da spozna i definiše uslove pod kojim dolazi do realizacije ovih hazarda.

Tako se u rudarskoj praksi kao prirodna opasnost tretira požar nastao tzv. „samoupalom uglja", na osnovu čega se može izvesti zaključak da su ovakvi požari rezultat prirodne sklonosti uglja „ka samoupali" i izvan su objektivnih utjecaja čovjeka. Međutim, ako se ima u vidu da se ovakve upale dešavaju upravo, zbog neprilagođenosti tehnologije otkopavanja prirodnim osobinama uglja, ovakva vrsta hazarda može se takođe tretirati kao potpuno antropogeni hazard. Zastoji u napredovanju otkopnih fronti, veliki intenziteti potencijala pritiska, ostavljanje izdrobljenog uglja, neadekvatna rana detekcija požara i slično, samo su niz „potpuno ljudskih" uzročnika koji mogu realizirati ovakve hazarde. U tom smislu mnogo je primjereniji izraz „samoupala uglja" zamijeniti izrazom „spontana upala uglja".

Svrstavanje hazarda po genezi u prirodne može imati za posljedicu izostanak mjera redukcije vjerovatnoće realizacije hazarda, odnosno pravdanje „prirodnom pojavom" opasnosti protiv čijeg se pojavljivanja može uspješno boriti danas dostupnim i poznatim metodama zaštite.

4.1. KLASIFIKACIJA PO MEHANIZMU NASTANKA

4.1.1. Tehnološka klasifikacija

Po ovom kriteriju hazardi se kategorišu ovisno o fazama tehnološkog procesa u kojima nastaju ili na koje mogu imati posljedice:

1. Hazardi pri razradi ležišta, izradi i pripremi prostorija.
2. Hazardi pri otkopavanju mineralne sirovine (uglja).
3. Hazardi u transportu mineralne sirovine (uglja).
4. Hazardi u procesu pripreme, prerade ili oplemenjivanja mineralne sirovine(uglja).
5. Hazardi u procesu dopreme repromaterijala.
6. Hazardi u procesu snabdijevanja električnom energijom.
7. Hazardi u procesu odvodnjavanja ili snabdijevanja vodom.
8. Hazardi u procesu funkcionisanja ventilacionog sistema sa svim determinantama.

4.1.2. Klasifikacija po posljedicama

1. Hazardi malih posljedica – odnose se na hazarde pri čijoj realizaciji ne dolazi do značajnije materijalne štete ili povređivanja ljudi. Materijalne štete su manje, a otklanjanje posljedica ovih hazarda može se provesti angažovanjem resursa unutar organizacije u okviru redovnih radnih obaveza.
2. Hazardi srednjih posljedica – su hazardi pri kojima nastaje veća materijalna šteta, lakše ili srednje teške povrede te zastoja u proizvodnju za koji je nepohodna eksterna intervencija kako bi se ponovo uspostavila proizvodnja.
3. Hazardi velikih posljedica – su hazardi pri kojima dolazi do većih materijalnih šteta, teških povreda ili smrti te zastoja u proizvodnji koji zahtijeva reinvenstiranje u otklanjanje posljedica.

4.1.3. Klasifikacija rizika usvojenih u ovom radu

U ovom radu usvojena je podjela koja bi mogla biti neznatno dopunjena ali se može usvojiti pristup koji ne izlazi iz sfere teoretskih podjela. Dakle, rizici koji se mogu javiti u podzemnoj eksploataciji u osnovi mogu biti:

- prirodni rizici i
- antropogeni rizici nastali usljed uticaja ljudi-radne sredine-sredstva rada.

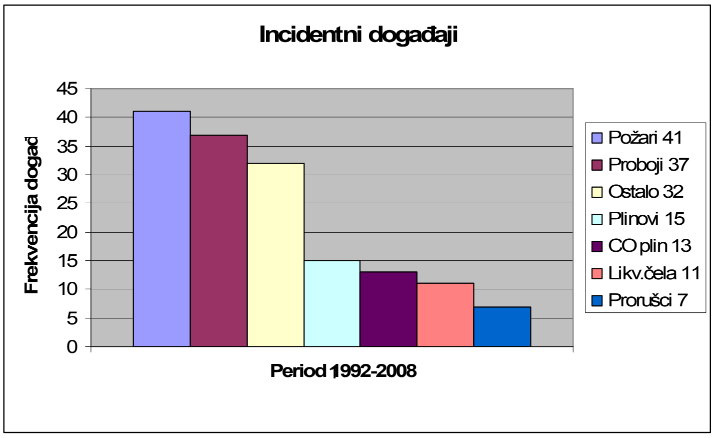
Ovakva podjela je iskustvena i ograničeno upotrijebljiva, a zasnovana je na teoretskim osnovama podjele dopunjenim uticajem još dva neodvojiva faktora koji su vrlo bitan činilac u formiranju ambijenta za rad u složenim radnim uslovima kakav vlada u podzemnoj eksploataciji.

Tabela 1.

PRIRODNI (uslovi radne sredine)	**ANTROPOGENI** (uticajljudi-radne sredine-sredstva rada)
Gasovi (CO_2,CO,CH_4,SO2,H_2S i dr)	**Eksplozije** (smješa gas-vazduh, ugljena prašina, eksplozivna sredstva)
Prašina	**Dinamičke pojave** (zarušavanja, gorski udari, izboji gasa)
Požari -Oksidacije	**Klima** (temperatura, vlaga, brzina)
Prodori vode i žitkih materijala	**Buka**
	Vibracije
	Osvjetljenje

5. EVIDENTIRANJE I ANALIZA RIZIKA I HAZARDA SA VELIKOM SKALOM UTICAJA

U istraživanju za izradu ovog rada, koja se odnose na ambijent RMU Kakanj, analiziran je period od 1992-2008 godine, do kada postoje pisani tragovi u kojima su evidentirane aktivnosti Štaba službe spasavanja. Štab službe spasavanja je krovno tijelo u ovom rudniku koje utvrđuje, analizira, ocjenjuje i donosi odluke kako da se rješavaju nastale krizne situacije. Na osnovu tih saznanja i uvidom u "Knjige štaba službe spasavanja",[5] evidentirano je u proteklom periodu od 16 godina, toliko događaja i slučajeva kojima se bavilo ovo krovno tijelo, koji se s pravom mogu nazvati kriznim ili hazardnim situacijama. U slijedećem grafičkom prikazu može se vidjeti pregled hazardnih i kriznih situacija koje su se desile u periodu od 16. godina. Iz grafika 1. vidi se karakter i frekventnost pojavljivanja određenih događaja u naznačenom periodu.



Grafik 1. *Evidentirani incidentni događaji i frekventnost*

5.1. OPIS INCIDENTNIH DOGAĐAJA

1. **Pojava požara** je incidentni događaj koji se pojavljivao u naznačenom periodu u najvećem broju slučajeva. Na osnovu uvida u izvore informacija, ovaj broj pojavljivanja ne znači da je bilo toliko požarnih procesa, ali je bio na dnevnom redu Štaba službe spasavanja koji se njime bavio. Evidentirani broj pojavljivanja događaja na dnevnom redu, uzet je kao veličina sa kojom se kasnije operisalo u daljim analizama. Požari koji su evidentirani su pojave koje su se dešavale na širokim čelima, starim radovima i trafo stanicama.
2. **Proboji radilišta** su pojave koje su uvrštavane u rasprave za dnevni

red Štaba službe spasavanja, zato što su tretirali proboje u stare radove ili ranije zatvorene prostorije, kao i proboje poslije kojih se vršila regulacija vazduha ili promjena u režimu provjetravanja.

3. **Ostali događaji** imaju veliku zastupljenost, ali njihova tematika nije posebno značajna, izuzev događaja smrtnih udesa na transportnom sistemu koji su svrstani u ovu kategoriju.
4. **Analiza plinskog stanja** je tematika koja je uslijedila nakon pojava metana(CH_4) na pripremnim radilištima u većim koncentracijama ili pojavama ugljendioksida(CO_2) u dubljim dijelovima jame nakon povlačenja vode ili iz starih radova.
5. **Pojava CO plina** je incidentni događaj koji je evidentiran nakon što se CO plin pojavljivao u liniji iza zidova u starim radovima, u širokim čelima ili na drugim mjestima.
6. **Likvidacija širokih čela** predstavlja jednu od najkompleksnijih operacija u rudarskom poslu u podzemnoj eksploataciji. Pri tom procesu dolazi do čestih incidentnih situacija u smislu teškoća prilikom vađenja ili raubovanja, transporta ili u procesu ustrajanja sekcija SHP.
7. **Prorušci** su dinamičke pojave koje su ponekad imale i fatalne posljedice a ne samo teškoće u smislu njihove sanacije.

6. ODREĐIVANJE RIZIKA (VJEROVATNOSTI I POSLJEDICA) TE OCJENA RIZIKA

Nakon popisivanja hazarda i njihovih uzroka, potrebno je procijeniti rizik za svaki od njih. U ovom kontekstu to znači procijeniti vjerojatnosti da hazard uzrokuje štetnu posljedicu i težinu te štetne posljedice. Međutim, u procjenu ulaze i propratni parametri poput učestalosti pojave i trajanja izlaganju hazardu te vjerovatnosti da se štetna posljedica izbjegne.

Pri procjeni rizika potrebno je odrediti može li se hazard manifestovati pod uslovima bez pogreške, uslovima jedne pogreške ili pak uslovima više pogrešaka. Hazardi s teškim posljedicama ne smiju se tolerisati ni pod kojim uslovima.

Sljedeći primjer preuzet je iz norme IEC 60601-1-4. Ona definiše šest nivoa vjerovatnosti pojave štetne posljedice, redom od najnižeg prema najvišem:

- Izrazito nevjerovatna
- Nevjerovatna
- Rijetka
- Povremena

Vjerovatna

- Učestala.

Također, definiše i četiri nivoa težine štetne posljedice:

- Katastrofalna - više mrtvih ili teško ozlijeđenih osoba
- Kritična - jedna ili nekoliko mrtvih ili teško ozlijeđenih osoba
- Granična – moguća ozljeda
- Zanemariva – moguća lakša ili nikakva ozljeda.

Tabela broj 2. prikazuje najjednostavniji način kombiniranja tih parametara. Upravo zbog te jednostavnosti i činjenice da iza njega stoji međunarodna norma, veoma je raširen u upotrebi.[6] Naravno, stručnjak koji ga koristi nije ograničen na gornje definicije te ih može po potrebi mijenjati, proširivati ili skraćivati kako bi postigao optimalnu podjelu za vlastiti slučaj.

Tabela 2.[7]

Vjerovatnost štetne posljedice	Težina štetne posljedice			
	I	**II**	**III**	**IV**
	Zanemar.	**Granična**	**Kritična**	**Katastrof**
A-izričito nevjer	IV-A	III-A	II-A	I-A
B-nevjerovatna	IV-B	III-B	II-B	I-B
C-rijetka	IV-C	III-C	II-C	I-C
D-povremena	IV-D	III-D	II-D	I-D
E-vjerovatna	IV-E	III-E	II-E	I-E
F-učestala	IV-F	III-F	II-F	I-F

Uvrštavajući u prethodnu klasifikaciju nivoa vjerovatnosti štetnih ili incidentnih događaja koji su se desili u posljednjih 16 godina u Rudniku Kakanj, dolazimo do sljedeće slike. Naravno, pri tome uvrštavamo događaje sa težinom njihovim posljedicama, dok pretpostavljamo događaje koji se nisu desili, obzirom na slobodu u datoj normi koja se koristi u našem slučaju. Na osnovu nivoa vjerovatnosti događaja i nivoa koji je zabilježen u našem slučaju imamo sljedeću podjelu:

- A – Izričito nevjerovatan – Eksplozija širokih razmjera (nije se desila u posmatranom periodu)
- B – Nevjerovatan – Eksplozija ograničenog karaktera(nije zabilježeno u posmatranom periodu)
- C – Rijetka – Likvidacija čela (11), Prorušci (7)
- D – Povremena – Pojava ostalih plinova (15), Pojava CO (13)
- E – Vjerovatna – Proboji radilišta (35), Ostalo (32)
- F – Učestala – Pojava požara (41)

Prema težini štetnosti posljedice, evidentirani incidentni događaji mogu se klasificirati po sljedećim nivoima:

- I – Katastrofalan – U evidentiranom periodu pojava prorušaka (7), i likvidacije čela (11), nose najviše smrtnih udesa. (Za pretpostaviti je da bi i eksplozije ograničenog i šireg karaktera imale iste posljedice.)
- II – Kritična – Ostali događaji (32) zbog smrtnosti na trakama
- III – Granična – Pojava požara (41), Pojava ostalih plinova (15), Pojava CO (13)
- IV – Zanemariva – Proboji radilišta (37)

Tabela koja se može formirati na osnovu kombinovanja datih nivoa vjerovatnosti i nivoa štetnosti događaja izgleda ovako:

Tabela 3.[8]

Vjerovatnost štetne posljedice	Težina štetne posljedice			
	IV Zanemar.	**III Granični**	**II Kritičan**	**I Katastrofa**
A-izraz.nevjer				***I-A***
B-nevjerovat				***I-B***
C-rijetko				2xI-C
D-povremeno		2xIII-D		
E-vjerovatno	IV-E		II-E	
F-učestalo		III-F		

7. KRITERIJI ZA ODREĐIVANJE TOLERANTNIH NIVOA RIZIKA U STRATEŠKOM ODLUČIVANJU

Pri izboru jedne od dviju metodologija za procjenu rizika, treba odvagati njene prednosti i nedostatke. Iako nije teško procijeniti rizike u predmetnoj oblasti ovoga rada (eksploatacija uglja) zbog svih prirodnih i stvorenih okolnosti, kao i zbog činjenica da su i manifestirani sa katastrofalnim posljedicama, trud bi trebao da se isplati jer omogućuje procjenu učinka implementiranih mjera da bi se smanjio rizik mogućih štetnih događaja. Kombinacija tih nivoa predstavlja rizik dotičnog hazarda. Nedostatak ove metode leži upravo u toj proizvoljnosti jer cijela analiza ovisi o ponekad previše subjektivnim proizvoljnim odlukama analitičara.[9]

Potencijalna slabost metode jest u nepouzdanosti podataka iz kojih se izvlače vrijednosti, obzirom na karakter djelatnosti u kojoj nema pravila u kontinuitetu ili periodičnosti dešavanja hazardnih događaja.

Mnoštvo metoda može se upotrijebiti za kombinovanje nivoa vjerovatnosti i težine štetne posljedice. Prva je svakako-jednostavno navesti oba parametra.

Nakon procjene, svaki se rizik u sistemu mora evaluirati kako bi se ustanovila njegova prihvatljivost i eventualne mjere za njegovo smanjivanje. Evaluacija rizika izlazi iz striktno tehničkih okvira, jer posjeduje i svoje pravne i etičke aspekte. Cilj joj je pronaći balans, u našem slučaju, između dobitka koji se dobije na kraju procesa, cijene uložene u procese da se eliminišu rizici, zadovoljstva aktera u procesima, usklađenosti sa razvojnim konceptima i ostalih zainteresiranih činilaca u cijelom sistemu grane u kojima se obavlja ova rudarska djelatnost. U kontekstu primijenjenom na uslove rudarske djelatnosti, posebno u podzemnoj eksploataciji uglja, na prvo mjesto u svim razmatranjima dolazi sigurnost neposrednih izvršilaca, odnosno rudara u jamskoj eksploataciji.

Dvije glavne smjernice kojima se treba voditi pri evaluaciji rizika jesu:

- Društvena javnost ima veoma nisku toleranciju na rizik za čije se uklanjanje sredstva jako teško nalaze u trenutnom ekonomskom ambijentu i države i privredne grane.

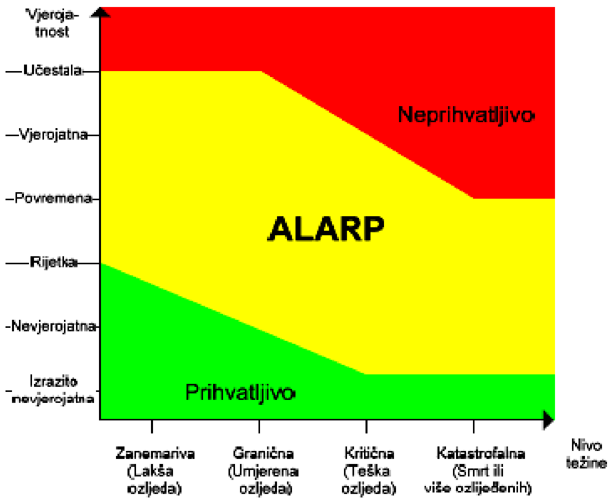
- Tolerancija društva na rezidualni rizik ovisi o koristi i dobrobitima koje donose rudnici u ukupnom privrednom ambijentu, mada se za rizicima u ovoj oblasti saživilo i kao takav je postao društvena zbilja.

Iz njih proizilazi činjenica da evaluacija rizika mora biti kontinuirani proces jer se s vremenom mogu pojaviti nove tehnike za smanjivanje rezidualnog rizika, a samo postojanje takvog procesa pozitivno utiče na svijest javnosti. Treba naglasiti da naše društvo ima veoma nizak prag tolerancije prema riziku, u rudarstvu, pa je sklono "tešku ozljedu" percepirati kao "katastrofalnu".

Slika broj 2. prikazuje grafički prikaz koji pomaže pri donošenju odluke o prihvatljivosti rizika. Lijevo dolje predstavlja područje niskog rizika i svi rizici koji pod njega spadaju, smatraju se prihvatljivima i zahtijevaju stalni nadzor. Desno gore predstavlja područje visokog rizika. Svi rizici u njemu su neprihvatljivi i funkcionisanje sistema o kome je riječ (rudarstvo) je moguće jedino kad se oni odgovarajućim mjerama uklone i prebace u središnje područje **ALARP**[10] (***As Low As Reasonably Possible-kao nisko kao razumno moguće***) rizika. Upravo se u tome području odvija većina odluka u vezi sa rizicima. Osnovni princip jest da se svaki rizik pomjera prema lijevom donjem uglu, dok je to praktično moguće i izvodivo i dok su troškovi sa njihovo izmještanje srazmjerni izvučenoj koristi, jednom riječju razumno. To praktično znači povećanje proizvodnih pokazatelja po svim nivoima uz maksimalnu sigurnost zaposlenih. Također, potrebno je posvetiti mnogo pažnje činjenici da uvođenje mjera koje bi trebale povećati sigurnost sistema, takođe povećava i njegovu kompleksnost što u većini slučajeva negativno utiče na pouzdanost i opću razinu sigurnosti.

Odluka o tome šta je razumno, a šta ne, ključna je za cijeli proces. U sebi obuhvaća cijenu implementacije mjera za redukciju rizika, iznos same redukcije i dobivenu korist. Često odluka postaje subjektivna te se zbog toga preporučuje da je donosi interdisciplinarni tim s više perspektiva na isti problem.

U tabeli broj 4. prikazana je podjela rizika prema normi IEC 61508-5 koja definiše 4 klase rizika u odnosu na prihvatljivost.



Sl. 2. *Područje razine rizika*

Tabela 4.[11] *Parametri rizika prema prihvatljivosti*

Klasa rizika	Tumačenje
NR	Neprihvatljiv
NP	Nepoželjan i prihvatljiv samo ako je redukcija nepraktična ili ako su troškovi poboljšanja veliki
PR	Prihvatljiv ukoliko su troškovi poboljšanja veći od dobitka
ZN	Zanemariv

Klasa prihvatljivog rizika ekvivalentna je istoimenom području na slijedećim tabelama broj 5 i 6, dok žuta boja označava područje ALARP. Crvena boja je područje neprihvatljivog rizika i slijedi reinženjering koji je slijedeći korak u tretmanu rizika ove kategorije. Područje rizika označenih žutom bojom spada u područje upravljanja rizikom i to je glavni zadatak cijelog procesa. Rizici označeni zelenom bojom su u zoni prihvatljivog rizika, ali u našem slučaju zbog učestalosti mogu biti predmet njihove dalje analize.

Tabela 5.

Vjerovatnost štetne posljedice	Težina štetne posljedice			
	IV	III	II	I
	Zanem	Granič	Kritič	Katastr
A-izr.nevjerov	NP	NR	NR	NR
B-nevjerovatn	PR	NP	NR	NR
C-rijetko	PR	PR	NP	NR
D-povremeno	ZN	PR	PR	NP
E-vjerovatno	ZN	ZN	PR	NP
F-učestalo	ZN	ZN	ZN	PR

Tabela 6.

Vjerovatnost štetne posljedice	Težina štetne posljedice			
	IV	III	II	I
	Zanem	Granič	Kritič	Katastr
A-izr.nevjerov				I-A
B-nevjerovatno				I-B
C-rijetko				2xI-C
D-prvremeno		2xIII-D		
E-vjerovatno	IV-E		II-E	
F-učestalo		III-F		

8. SISTEMSKE I OPERATIVNE MJERE REDUKCIJE, TRANSFERA I MITIGACIJE RIZIKA

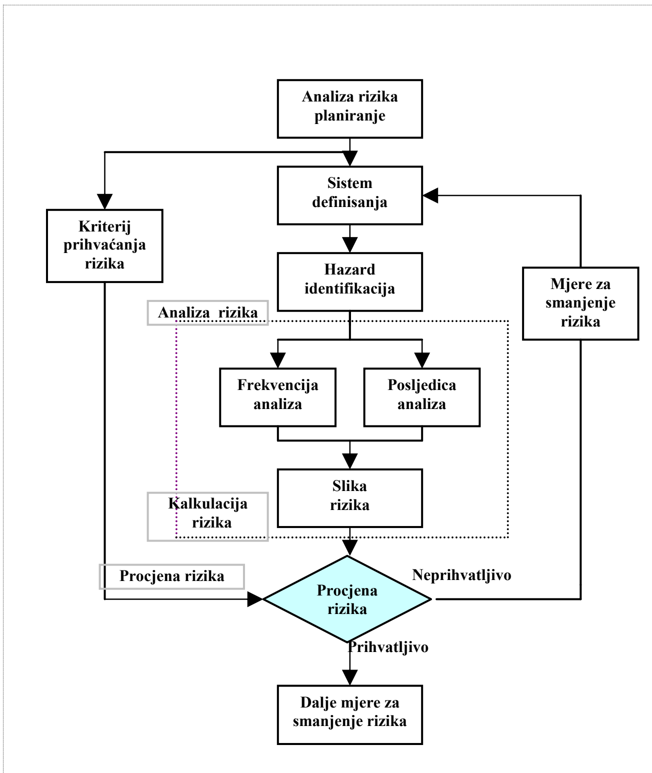
Nakon provedene faze identifikacije i evaluacije rizika, pristupa se njegovu smanjenju za koje postoji gotovo neograničen spektar mogućnosti. Optimalni pristup u pravilu se nazire već kod same analize problema, no često su potrebni kompromisi zbog ekonomske, tehničke i vremenske zahtjevnosti njegove provedbe. U pravilu se odabire najjednostavnija metoda koja rizik svodi na prihvatljiv nivo.

Redukcija rizika ima za cilj korekciju uticaja pojedinih rizika na prihvatljivu ili najmanju moguću mjeru. Pouzdanost analize rizika je važna pretpostavka da rizici budu pravilno identifikovani i valorizovani. Ukoliko nije postignuta visoka pouzdanost u procjenama rizika, nepohodan je pojačani monitoring i poduzimanje širokog aspekta mjera sigurnosti na radu. Nivo rezidualnog rizika određuje se na osnovu niza kriterija. Strogo postavljene granice, odnosno nizak nivo prihvatljivog rizika može dovesti u pitanje ekonomičnost proizvodnog procesa.

Pravilno odmjeravanje rizika koji se mogu prihvatiti te mjere njihovog nadzora tako imaju sa jedne strane veliki uticaj na sigurnost radnika, a sa druge strane na ekonomičnost i uopšte smisao rada.

Na priloženoj shemi upravljanja rizikom, putem iterativnih petlji, što ukazuje na važnost procjene rizika, tj. razmatranje rezultata analize rizika u odnosu na kriterije prihvatljivosti rizika, kao sastavni dio procesa upravljanja sigurnošću. Ako su rezultati neprihvatljiv rizik, onda se stvara nova petlja kroz implementaciju mjera za smanjenje rizika te ažuriranje analiza rizika na način da odražava sliku tih promjena.

Treba napomenuti da su dva ishoda "procjene rizika", okvir su prihvatljivo i neprihvatljivo. To se temelji na pristupu kojim je preuzeto i osigurano poštivanje eksplicitnih kriterija prihvatljivosti rizika kao prve tačke, nakon čega slijedi ALARP evaluacija. To je razlog zašto u shemi postoji stavka "dalje mjere za smanjenje rizika", u slučaju prihvatljivih razina rizika.



Sl. 3. *Opći model određivanja i kontrole rizika* [12]

9. ZAKLJUČNA RAZMATRANJA

Ovim radom se pokušalo ukazati na problem upravljanja rizikom i hazardom u rudnicima uglja. Fokus pažnje tokom istraživanja je ambijent Rudnika Kakanj, sa svim svojim specifičnostima i iskustvima, odnosno evidencijom i analizom događaja koji su se već desili. Da bi se sprovela analiza konkretnih rizika bilo koje vrste i u bilo kojoj oblasti, potrebno je opšte teorijsko istraživanje projektno-metodološkog i sistemskog okvira upravljanja rizicima. Zahtjevi koji su pretpostavljeni u procesu analize rizika i hazarda u rudnicima uglja, na neki način predstavljaju vizionarsko razmišljanje, jer je potrebno u datom ambijentu koji je sam po sebi rizičan i opasan, naći pravu mjeru i način da se minimiziraju neizvjesnosti rizika.

U toj sudbinskoj povezanosti čovjeka, aktera u rudniku, i rudarske sredine koja nosi sve poznate i skrivene opasnosti, potrebno je pravilno identifikovati i ocijeniti rizik, dati mu dimenziju, kvantifikovati ga, kontrolisati ga i upravljati njime u svakodnevnom životu rudnika, promjenjivom okruženju i budućem savremenom ali uvijek kriznom vremenu.

Da je to tako, stalno nas opominju i upozoravaju događaji iz prošlosti koji nose fatalne i katastrofalne posljedice, a rezultat su neadekvatnog pristupa određenim opasnim i kriznim situacijama.

Drugim riječima, ukoliko se ne uspije upravljati svim rizicima i opasnostima koje prijete ili bar onim najvećim, postoji opasnost od nefunkcionisanja ili gašenja cijelog projekta, u ovom slučaju rudnika uz sigurno velike gubitke materijalne i nematerijalne prirode.

Kako ne postoji jedinstvena metodologija koja bi adekvatno obuhvatila sve hazarde, posebno u rudarstvu, potrebno je analizu provesti koristeći sva raspoloživa dostignuća, saznanja i iskustva u svijetu, kako bi se konačno krenulo u pravom smjeru. Naravno, da se pri tome ne očekuju revolucionarni rezultati, ali se treba odlijepiti od stereotipa i tradicionalizma kad su u pitanju rješavanja opće sigurnosti u rudarstvu.

Bez obzira na sve rečeno, u ovom radu i ono što nije rečeno a dobro je poznato, za djelatnost kakva je rudarstvo, posmatrajući svaki njegov dio ili cjelinu, ljudsko znanje i ljudski faktor su ključni segmenti čitavog procesa.

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UDK: 622.8(497.15)(045)=20

*Muhamed Plasto**

ANALYSIS OF RISKS AND HAZARDS REGISTERED IN THE BROWN COAL MINE KAKANJ**

Abstract

Risk and crisis are inevitably tied to mining; this vocation is historically associated with risk, in everyday operations and functioning of the mine as a whole.

The current legislation in Bosnia and Herzegovina is not in accordance with the applicable ISO standards, which themselves have not established models for strategic risk management in mining. Therefore, it is required to insist on establishment the applied models, their regulation through legal documents and introduction of a binding legal framework in this field. The world-wide experiences have shown that the introduction of strategic risk and crisis management led to the improvement of general safety conditions and reduction of incidents with harmful effects.

This paper aims to point out that, in the given conditions, systematic risk and hazard management in mining is possible and necessary, regardless to a lack of established norms.

Key words*: risk, hazard, mining, risk management*

1. INTRODUCTION

Throughout its multi-century existence, mining remained deeply rooted in all areas tied to it by long tradition. This especially refers to the recent period or last more than hundred years, when the coal excavation intensified and practically laid the basis for industrial revolution. From beginning of the 20th century, mining was the basis of economic development in all areas in which people excavated coal. Besides its economic significance, mining also had social influence in these areas. It can be said that it was the "mining civilization" hich manifested itself in all spheres of life: from language and architecture to subculture and sports. In order to survive, this mining culture had to "communicate" with the underground and stand in awe of it. Ignoring the signs of nature inside the pit could cost the lives of whole shift. Taking these implicit and unwritten rules lightly or disrespectfully was often paid by the highest costs. Thus, pits have been regarded with awe and their entrances carried the

* *Brown Coal Mine Kakanj*

** *This paper is based on the author's master's thesis titled "Risk and crisis management in transitional model of strategic decision-making in coal mines of Bosnia and Herzegovina" RGGF Tuzla, March 2010.*

sign saying "GOOD LUCK". This is also the universal greeting of miners around the world.[1]

2. RISK AND HAZARD TREATMENT

In the area of Bosnia and Herzegovina and former Yugoslavia, the issue of risk and hazard in mining was not particularly studied or treated as such. This issue was reduced to an indication of certain hazards and crises that could occur, within the frame of existing legislation and technical regulations. Some changes in technical regulations were adopted prescribing stricter measures to be undertaken in order to avoid incidents and crises with fatal consequences for men and property. It should be pointed out that the new measures were often issued as the result of crises that had happened previously. Unfortunately, such incidents were quite numerous.

However, other parts of the world, as the result of different social environment and property relations, realized that crises should be foreseen, prevented and eliminated and all their elements quantified by complete analysis.

Through history, methods and techniques of risk assessment in technical systems were developed relatively late in comparison to the other fields of engineering.

Lately, in the period of globalization of markets and economy, the risk management ideas and practice spread globally. [2] Today, the same principles are applied from Asia and Africa to Europe and America. However, there is still no generally accepted "standard" and a single set of defined terms. There are regional standards in Australia, New Zealand, Canada and more recently, in Great Britain, as well as the sub-studies in some other countries. In recent years, the working group of the International Standards Organization (ISO) is faced with the certain difficulties in their attempts to reach consensus on the common global definition of risk management.

3. THEORETICAL AND PRACTICAL BASIS OF RISK MANAGEMENT

"Risk management" refers to a set of actions and processes used to monitor risks, to assess their tolerability and to reduce risks identified as intolerable. In other words, risk management can be defined as the general management function aiming to identify risks, assess them and prepare an organization (company) for their causes and effects (consequences). The purpose of risk management is to enable an organization to realize its goals in the most direct, efficient and effective manner.

No activity can be undertaken without risk i.e. with zero risk. If there is any possibility for manifestation of hazard, risk does not equal zero. Therefore, risk is always present and the risk remaining after all the measures have been undertaken is referred to as "residual" or remaining risk. It is also important to define hazard and risk.

Hazard is a danger which can represent "potential harm for humans, property or environment"; as such, it gives an initial basis for determination of risk.

According to the international ISO standard, the definition of hazard is: "potential source of harm or event that may result in loss", while risk is defined as a combination of probability the occurrence of harm and the severity of that harm. [3]

The aim of risk management is to keep the level of residual risk below the limit set by "risk tolerability" criteria. Determination of acceptable level of risk is a complex task involving a series of factors, such as legislation, standards, bylaws, business policy of the company and other. Different levels of tolerability can be assessed for the same risk, depending on the person who assesses it.

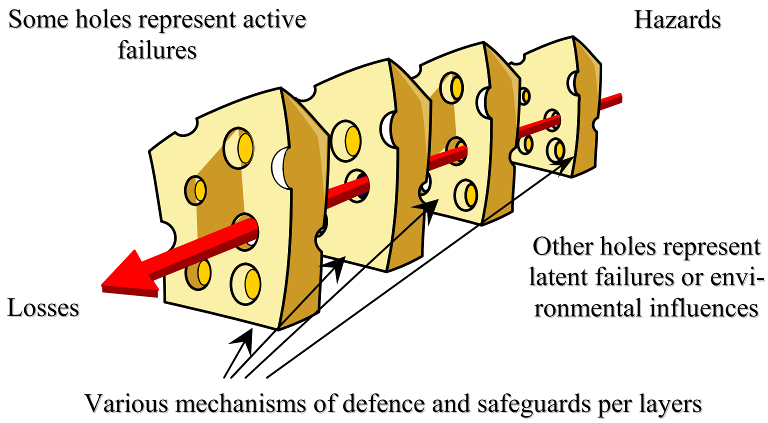

Fig. 1 *Comparison of safeguard systems according to the "Swiss cheese model"*[4]

The above Figure 1 clearly depicts the effect mechanism of potential danger which, in certain environment (the given working or other environment), can create preconditions to become an adverse effect of possibly measurable severity, causing losses. In order to avoid this, it is necessary to establish different mechanisms of defense and safeguards, protecting from adverse consequences. Undertaking of all foreseen defense measures (closing holes) reduces the possibility of occurrence the adverse effects and losses. However, in the real-life situations, there is always a chance of latent dangers or environmental influence which can not be avoided.

4. GENERIC CLASSIFICATION OF HAZARDS IN MINING

According to their genesis, the hazards in mining can be classified into two types:

1. Natural hazards and
2. Anthropogenic (man-made) hazards

Defining natural hazards, as the ones which emerge without key influence by man and anthropogenic hazards as the hazards resulting from the influence of human beings, is complex in the real-life conditions and especially in the fields such as coal mining.

In practice, hazards are often qualified as “natural dangers” or “natural hazards” even though, in many cases, the attribute “natural” is disputable and mainly refer to man's incapability to realize and define conditions in which such hazards occur. Thus, in the mining practice, fire resulting from "self-ignition of coal" is treated as a natural danger which leads to conclusion that such fires result from coal's natural affinity to "self-ignition" and that they are beyond the objective influence of man. However, since such ignitions are occurring due to use of excavation technology which is to natural characteristics of coal, such hazards can also be treated as completely anthropogenic. Stoppages in advancement of excavation line, high intensities of pressure potential, deposition of crushed coal, inadequate early detection of fire and so on, all represent a series of "completely man made" causes which could lead to fire. In this sense, it would be appropriate to use the term "spontaneous coal ignition" instead of "self-ignition of coal". Classifying hazards as natural can result in absence of measures to reduce probability of hazard occurrence, i.e. hazards which could be successfully reduced using the available and recognized methods of defense could be justified by "natural causes".

4.1. CLASSIFICATION ACCORDING TO THE OCCURENCE MECHANISM

4.1.1. Technological classification

According to this criterion, the hazards are classified depending on phases of technological process in which they occur or on which they influence:

1. hazards during development of deposits and preparation of rooms,
2. hazards during excavation of coal,
3. hazards during transportation of coal,
4. hazards during the process of preparation, treatment or dressing of coal,
5. hazards during the process of delivery of treated material,
6. hazards during the process of electricity supply,
7. hazards during the process of drainage or water supply.
8. hazards during the process of functioning of ventilation system with all determinants.

4.1.2. Classification according to severity

1. Low-consequence hazards – low probability of occurrence of significant property damage or injury. Property damage is minor and the effects can be remedied using the company's internal resources, in the frame of regular working duties.
2. Medium-consequence hazards – probability of occurrence of major property damage, mild or medium injuries and production stoppages that require external intervention, in order to re-establish production.
3. High-consequence hazards – probability of occurrence of major property damage, serious injuries or fatalities and stoppages in production requiring reinvestment in order to remedy the effects.

4.1.3. Classification of risks adopted in this paper

This paper adopts a slightly adapted theoretical classification. Thus, the risks which can occur in the underground exploitation can be:

- natural risks, and
- anthropogenic risks occurring as the result of influence of man – workplace – equipment.

This classification is empirical and of limited applicability; it is based on theoretical classification and supplemented by two inseparable factors (workplace and equipment), which significantly influence the complex working environment in theunderground mining.

Table 1.

NATURAL (workplace conditions)	ANTHROPOGENIC (man-made influence – workplace – equipment)
Gases (CO_2,CO,CH_4,SO2,H_2S, etc.)	**Explosions** (gas-air mixture, coal dust, explosive materials)
Dust	**Dynamic phenomena** (collapses, rock bursts, gas penetrations)
Fires - Oxidation	**Climate** (temperature, humidity, speed)
Penetration of water and liquid material	**Noise**
	Vibration
	Illumination

5. RECORDINGAND ANALYSIS OF RISK AND HAZARD WITH HIGH SCALE OF INFLUENCE

The research encompasses the period from 1992 to 2008 in the Brown Coal Mine Kakanj, based on data on the activities of the Rescue Service Headquarters. This Service is the Mine's topmost authority, which determines, analyses, assesses and makes decisions regarding crises. Based on these records and upon inspection of "The Book of the Rescue Service Headquarters",[5] we find a number of cases this authority has dealt with in the last 16 years which can freely be denoted as crises or hazardous situations. The chart below shows an overview of crises and hazardous situations happened in the mentioned 16-year-period. Chart 1 presents the character and frequency of occurrence the certain incidents in this period.

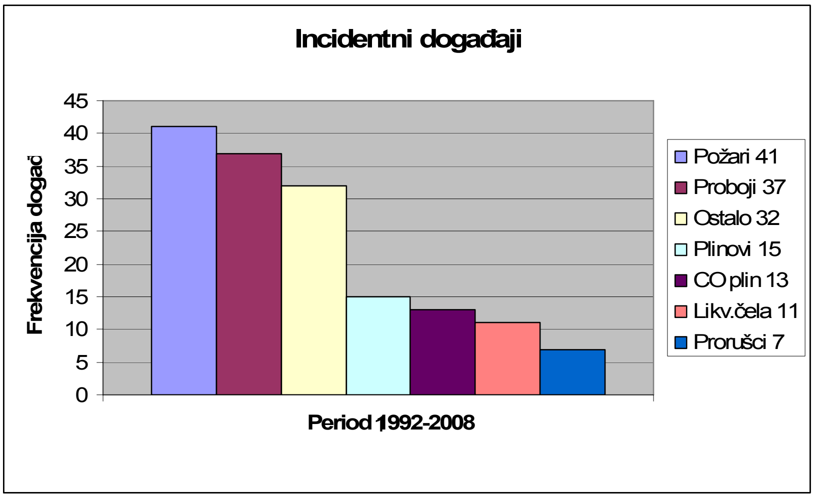

Chart 1. *Recorded incidents and their frequency*

5.1. description of incidental events

1. **Fire** was the most frequent incident in this period. Based on inspection of data sources, it was found that the registered number does not refer to the actual fire occurrences, but this issue was on the agenda of the Rescue Service Headquarters. Registered number of occurrences in the agenda was taken as the basis for further analyses. Registered fires occurred at longwall faces, old sites and power transformer stations.
2. **Penetrations** were also frequent on the meeting agendas. The registered number includes penetrations to the old mining sites and already closed rooms, as well as penetrations that required air regulation or changes in ventilation regime.
3. **Other incidents** were highly frequent, but are not of great importance, except for the cases of fatalities at conveyors, which are also classified in this category.
4. **Gas situation analysis** followed occurrence of high concentrations of methane (CH_4) at preparatory sites or occurrence of carbon dioxide (CO_2) in deeper parts of pits, after withdrawal of water or from old mining sites.
5. **CO gas occurrence** refers to occurrence of CO gas in the fronts behind walls at old mining sites, at longwall faces and elsewhere.
6. **Closure of longwall face** is one of the most complex operations in underground mining. In this process, there are often incidents in terms of difficulties during excavation, transportation or in persistence process of self-propelled hydraulic support sections.
7. **Cavities** are dynamic occurrences with possibly fatal consequences, along with reparation difficulties.

6. RISK DETERMINATION (PROBABILITIES AND EFFECTS) AND RISK ASSESSMENT

After listing hazards and their causes, it is necessary to assess the risks for each of them. In this context, it means to assess the probabilities that the adverse effects will occur from exposure to hazard and to assess the severity of such effects. However, assessment also includes accompanying criteria, such as frequency of occurrence and duration of exposure to hazard, as well as likelihood of avoiding adverse effects.

In the risk assessment, it is necessary to determine whether hazard can manifest itself in conditions without errors, with one error and with several errors. Hazards with severe effects can not be tolerated under any circumstances.

The following classification is in accordance with the IEC 60601-1-4 Standard. It defines six degrees of likelihood of occurrence of adverse effect, from lowest to highest.

- very unlikely
- unlikely
- seldom
- occasional
- likely
- frequent.

Four degrees of severity of adverse effect are also defined:

- catastrophic – several fatalities and serious injuries
- critical – one or few fatalities and serious injuries
- marginal – possible injuries
- negligible – possible mild or no injuries.

Table 2 shows a simple way of combining these criteria. This is a widespread approach, due to its simplicity and the fact that it is included in the International Standard.[6] However, a professional usage of this approach is not limited to the definitions given above and it can change, expand or shorten them in order to achieve the optimum classification in the case it works on.

Table 2.[7]

Degree of probability	**Degree of severity**			
	I	**II**	**III**	**IV**
	Negligible	**Marginal**	**Critical**	**Catastrophic**
A- very unlikely	IV-A	III-A	II-A	I-A
B- unlikely	IV-B	III-B	II-B	I-B
C- seldom	IV-C	III-C	II-C	I-C
D- occasional	IV-D	III-D	II-D	I-D
E- likely	IV-E	III-E	II-E	I-E
F- frequent	IV-F	III-F	II-F	I-F

The above classification was applied to incidents that occurred at Kakanj Coal Mine in the last 16 years. According to the degree of probability, they can be classified as follows:

- A – Very unlikely – Wide range explosion (not happened in the observed period)
- B – Unlikely – Limited explosion (not happened in the observed period)
- C – Seldom – Closure of longwall face (11), cavities(7)
- D – Occasional – Occurrence of other gases (15), occurrence of CO (13)
- E – Likely – Penetrations (35), other (32)
- F – Frequent – Fire (41)

According to the degree of severity, the recorded incidents can be classified as follows:

- I – Catastrophic – In the observed period, cavities (7) and closure of longwall face (11), produced most fatalities (it can be assumed that wide range and limited explosions would produce the same consequences.)

- II – Critical – Other incidents (32), due to fatalities on conveyors
- III – Marginal – Fire (41), Occurrence of other gases (15), occurrence of CO (13)
- IV – Negligible – Penetrations (37)

Table 3 can be combines on the basis of combination the given degrees of probability and severity as follows:

Table 3.[8]

Degree of probability	Degree of severity			
	IV Negligible	III Marginal	II Critical	I Catastrophic
A-very unlikely				***I-A***
B-unlikely				***I-B***
C-seldom				2xI-C
D-occasional		2xIII-D		
E-likely	IV-E		II-E	
F-frequent		III-F		

7. CRITERIA FOR DETERMINATION OF TOLERABLE RISK LEVEL IN THE STRATEGIC DECISION MAKING

Risk assessment methodology should be selected based on weighing of its advantages and disadvantages. It is not easy to assess the risks in coal exploitation, due to all natural and man-made conditions. However, it should be rewarding since it enables to assess the effectiveness of measures implemented in order to reduce the risk of possible harmful incidents. Combination of t degrees represents the risk of the hazard in question. However, this method's disadvantage lies in its arbitrariness, since complete analysis depends on sometimes too subjective and arbitrary decisions of the analyst.[9]

Another possible weakness of this method can be unreliability of the used data, considering the fact that, when it comes to mining, there are no rules in terms of continuity or periodicity of hazardous incidents.

A number of methods can be used to combine the degree of probability and degree of severity. The simplest approach is to state the both values.

Upon evaluation, each risk in the system need to be assessed so that its tolerability can be established and possible measures for its reduction adopted. Assessment of risk surpasses strictly technical frame, since there are also legal and ethical aspects to it. In this case, the aim is to reach the balance between the improvement gained at the end of the process, the investment into elimination of risks, the satisfaction of actors in the process, the conformity with developmental concepts and other factors in the overall system. In the context of the mining activity and especially underground mining, safety of direct actors, i.e. miners in the underground mining are the most important factor in all considerations.

Two main guidelines that need to be observed in assessment of risk are:

public has low risk tolerance, and resources for risk elimination are hard to find in the current economic environment, in the country and industry, tolerance of society for residual risk depends on the benefits that mines bring to the overall economy. However, risks in this field have become a social reality and society has learned to live with them.

These lead to a fact that risk assessment has to be a continuous process, since time can bring new techniques for reduction the residual risk and existence of such process itself has a positive effect to the public consciousness. It should be underlined that our society has low level of tolerance towards risks in mining and that people are prone to perceiving a "serious injury" as a "catastrophic injury".

Figure 2 gives a graphic representation that would be used as an aid in decision making regarding risk tolerability. Lower left region represents the region of low risk and all risks in this region are considered tolerable and require constant supervision. Upper left is the region of high risk. All risks in this area are intolerable and the system in question (mining) can only function if they are eliminated using appropriate measures and transferred to the central region, known as **ALARP**[10] **(*As Low As Reasonably Possible*)**. This is the region where the most decision making regarding risks takes place. The basic principle is to transfer each risk towards the lower left angle, as much as it is practical and feasible and as long as the costs of such transfer are proportionally to the improvement gained, i.e. reasonable. In practice, this means the increase of production indicators at all levels, with the maximum safety of employees. Also, it should be noted that introduction of measures which increase the safety of a system also increases its complexity and, in most cases, negatively influences its reliability and general safety level.

Making decision on what is reasonable and what isn't is crucial to the entire process. This decision includes the cost of implementation of risk reduction measures, the extent of reduction and the improvement gained. Such decisions are often subjective, and it is recommended that they should be made by interdisciplinary team, which has multiple perspectives of the same problem.

Table 4 shows classification of risks according to the IEC 61508-5 Standard which defines 4 classes of risks in terms of tolerability.

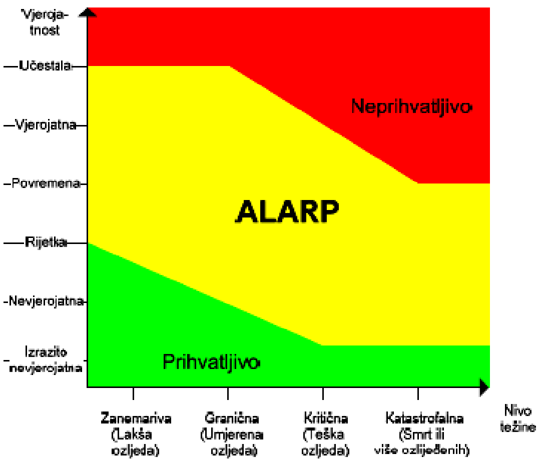

Fig. 2. *Risk level regions*

Table 4.[11] *Risk criteria according to tolerability*

Risk class	Interpretation
IR	Intolerable risk
UR	Undesirable risk, acceptable only if risk reduction is impracticable or if of the costs of improvement are high
TR	Tolerable risk if the costs of risk reduction higher than the profit
NR	Negligible risk

Tolerable risk is represented by green in Tables 5 and 6, while yellow represents the ALARP region. Red represents the region of intolerable risk and re-engineering as the next step in the treatment of risks classified in this category. Region marked yellow is the region of risk management, as the main task of entire process. Risks marked green are in the region of tolerable risk. However, in our case, they can be further analyzed, depending on their frequency.

Table 5.

Degree of probability	Degree of severity IV Negligible	III Marginal	II Critical	I Catastrophic
A-very unlikely	UR	IR	IR	IR
B-unlikely	TR	UR	IR	IR
C-seldom	TR	TR	UR	IR
D-occasional	NR	TR	TR	UR
E-likely	NR	NR	TR	TR
F-frequent	NR	NR	NR	TR

Table 6.

Degree of probability	Degree of severity IV Negligible	III Marginal	II Critical	I Catastrophic
A-very unlikely				I-A
B-unlikely				I-B
C-seldom				2xI-C
D-occasional		2xIII-D		
E-likely	IV-E		II-E	
F-frequent		III-F		

8. SYSTEMATIC AND OPERATIVE MEASURES OF REDUCTION, TRANSFER AND MITIGATION OF RISK

After the phase of identification and assessment of risk, its reduction is approached as a phase with almost unlimited range of possibilities. The optimum approach can usually be selected during the problem analysis phase itself, but compromise is often required due to economic, technical and time requirements of its implementation. In general, the simplest method is selected which reduces risk to an acceptable level.

Reduction of risk aims to correct the influence of individual risks to acceptable or as low as possible measure. Reliability of risk analysis is an important precondition of proper risk identification and evaluation. If high reliability of risk assessment was not reached, it is necessary to undertake the additional monitoring and wide range of occupational safety measures. A level of residual risk is determined based on a series of criteria. Strictly set limits, i.e. low level of risk tolerability, can bring into question the cost-effectiveness of production process.

Proper determination of tolerable risks

and measures of their control can have a great influence to safety of employees and to cost-effectiveness and purport of work in general.

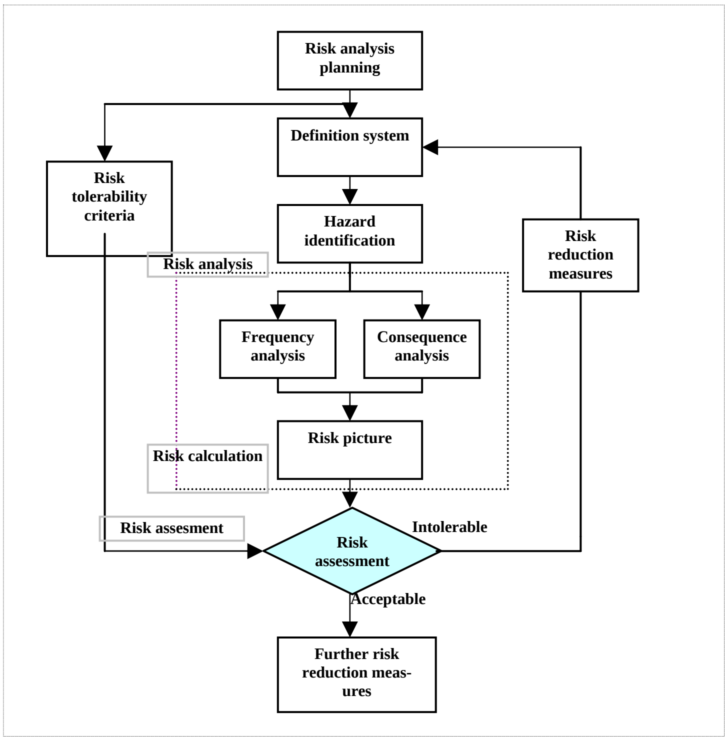

Diagram 1. *General model of risk determination and control*[12]

Diagram 1 of risk management uses iterative loops to present a review of risk analysis results in relation to risk tolerability criteria, as an integral part of safety management process. If it results in intolerable risk, the new loop is created for implementation the risk reduction measures and updates the risk analysis, so that it would reflect the changes.

There are two possible outcomes of "risk assessment": tolerable and intolerable. This is based on the approach which ensures appreciation of explicit criteria of risk tolerability, as the first phase, followed by an ALARP assessment. For this reason, the above diagram includes "further risk reduction measures", in case of tolerable risk levels.

9. CONCLUSION

This paper aims to draw attention to the issue of risk and hazard management in the coal mines. The focus of this research was the environment of the Brown Coal Mine Kakanj, with its specificities and experiences, based on the analysis of recorded incidents. In order to conduct an analysis of specific risks of any kind, in any given field, we need to conduct a general theoretic research of design, methodology and system frame of risk management. The assumed requirements in risk and hazard analysis represent visionary thinking, since it is hard to find the right measure and way to minimize the uncertainty of risk in a risky and hazardous environment as this one.

In this destined correlation between man, actor in a mine, and mining environment, with its known and hidden dangers, we need to make a proper identification and assessment of risk, give the risk a proper dimension, quantify it, control it and manage it in everyday life in a mine, taking into consideration the variability of the environment and future time crises.

Incidents from the past remain a reminder and warning, with their fatal and catastrophic consequences as a result of inadequate approach to certain hazards and crises.

In other words, unless there is no control of the risks and hazards, or at least the major ones, the entire project, i.e. the Coal Mine could stop functioning and cease to exist, with huge losses in property and other.

Since there is no single methodology that would adequately encompass all the hazards, especially in mining, we need to conduct an analysis using all available knowledge and experience from around the world in order to head in the right direction. Certainly, it is not expected that the results would be revolutionary, but it is necessary to walk away from the stereotypes and traditional approaches when it comes to the general safety solutions in mining.

Notwithstanding what has and has not been said in this paper, in activity such as mining, seen partially or as a whole, the human knowledge and human factor are the key segments of the process.

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EKONOMIJA POSLOVANJA RTB BOR U PERIODU TRANZICIJE**

Izvod

Rudarsko topioničarski basen Bor je naša kompanija poznata po proizvodnji bakra i plemenitih metala. Sa velikim brojem uposlenih radnika, organizovana na principu reproceline, važila je za uglednog privrednog subjekta na prostoru bivše Jugoslavije, po profitabilnom poslovanju, pogotovu u delu izvoza. U isto vreme, RTB je činio okosnicu privrednog razvoja Timočkog regiona, pa i šire.

Početkom devedesetih godina prošlog veka, zbog raspada bivše Jugoslavije, ratova u okruženju, a pogotovu rigoroznih sankcija UN, kompaniju, kao uostalom i privredu cele zemlje, zahvata velika kriza. To je dovelo do pada proizvodnje, otežanog izvoza, smanjenja broja zaposlenih i njihovog životnog standarda. Presahle su investicije, a poslovanje sa gubitkom je sve izraženije.

U cilju poboljšanja efikasnosti poslovanja, u kompaniji su preduzete mnoge aktivnosti na planu njenog restruktuiranja. Iz njenog sastava izdvojene su pojedine fabrike i zadržan samo bazni deo proizvodnje bakra. U međuvremenu, dva puta je pokušana privatizacija, odnosno prodaja kompanije, ali bezuspešno, tako da danas ona ima status državnog preduzeća.

Poslednjih godina čine se napori na unapređenju ekonomije poslovanja kompanije. U toku su ozbiljni investicioni zahvati – rekonstrukcija topionice i izgradnja fabrike sumporne kiseline, nabavka rudarske mehanizacije, izgradnja infrastrukturnih objekata i dr. Uz to, uvećava se proizvodnja, izvoz raste, a kompanija je, posle dužeg perioda, dobrim delom i zbog povoljnog stanja na tržištu bakra, u 2010. godini iskazala pozitivno poslovanje.

***Ključne reči**: tranzicija, ekonomska kriza, restruktuiranje, ekonomija poslovanja.*

UVOD

Rudarenje na području Bora i Majdanpeka ima dugu tradiciju. Prve količine bakra iskopane su davne 1903. godine. Radi se o bogatom rudnom telu „Čoka Dulkan“. Inače, prvo geološko istraživanje na ovom području izvršeno je 1897. godine u oblasti Tilva Roš.

Svoj ubrzani razvoj RTB Bor doživljava posle drugog svetskog rata. Izvršeno je otvaranje nekoliko rudnika i izgrađen veći broj prerađivačkih kapaciteta. Time je stvoren privredni gigant sa preko 20.000 zaposlenih, prepoznatljiv po proizvodnji visokokvalitetnog katodnog bakra.

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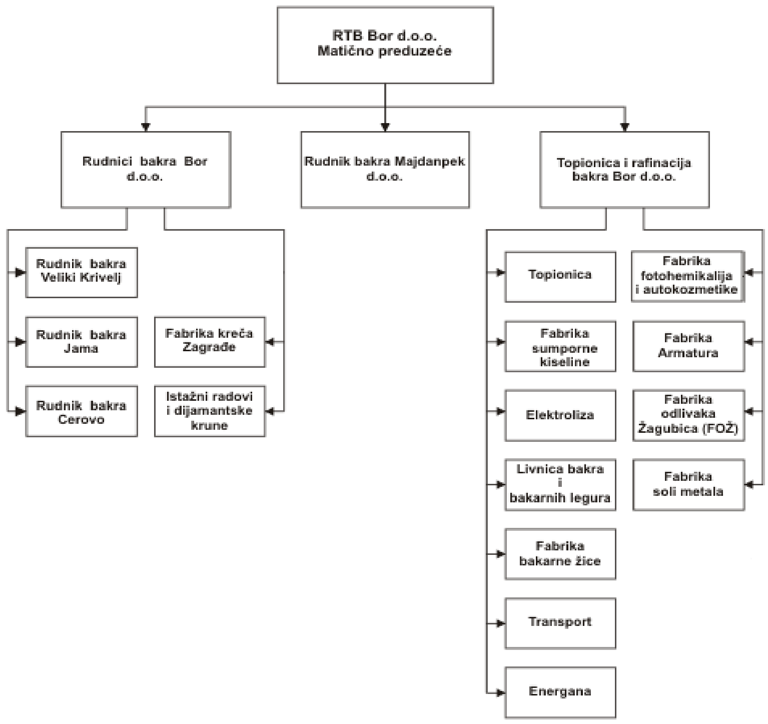
** *Ovaj rad je deo projekta broj TR 33038 koji finansira Ministarstvo za prosvetu i nauku Republike Srbije, a u okviru projekta „Usavršavanje tehnologija eksploatacije i prerade rude bakra sa monitoringom životne i radne sredine u RTB Bor Grupa“*

U toku je preispitivanje postojećeg stanja unutrašnje organizovanosti. Teži se iznalaženju takvog modela organizovanja koji će biti zasnovan na tržišnim principima i načelima i obezbediti veću efikasnost i profitabilnost u poslovanju.

Tokom svog egzistiranja, kompanija je menjala svoj oblik organizovanja, prilagođavjući se promenama u privrednom sistemu zemlje. Najpre posluje kao državno i društveno preduzeće, zatim SOUR, Holding, da bi danas opet bila u vlasništvu države. To nije konačan status, obzirom da predstoji svojinsko prestruktuiranje kompanije.



Sl. 1. *Organizaciona šema RTB Bor Grupe* **[8]**

Danas kompaniju čine matično i tri zavisna preduzeća – Rudnici bakra Bor, Rudnik bakra Majdanpek i Topionica i rafinacija bakra Bor. Unutrašnje ustrojstvo je podređeno proizvodnji bakra i funkcioniše kao reprocelina.

U radu se ukazuje na neke karakteristike ekonomije poslovanja RTB Bor u periodu tranzicionih promena.

RASPOLOŽIVE RUDNE REZERVE

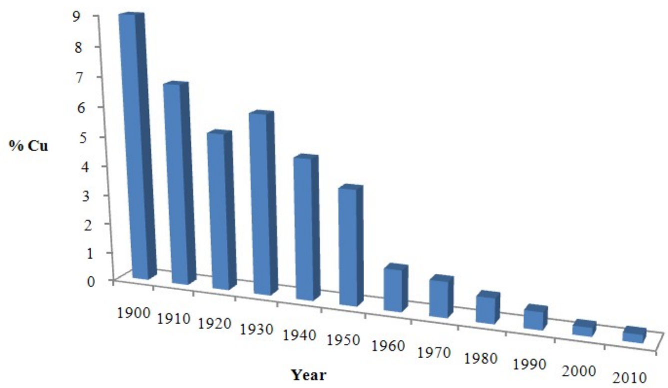
Borska metalogenetska zona raspolaže značajnim rezervama rude bakra. Prema raspoloživim podacima, rudne rezerve u ležištima aktivnih rudnika RTB Bor iznose oko 1,2 milijarde tona, čijom preradom bi se moglo dobiti 4.663.321 t bakra, 158.446 kg zlata i 1.243.228 kg srebra. Upravo to je i razlog interesovanja mnogih međunarodnih kompanija za izvođenje istražnih radova na pojedinim lokalitetima. Procenjuje se da Republika Srbija učestvuje sa 2% u ukupnim svetskim rezervama bakra.

Tabela 1. *Rudne rezerve u ležištima aktivnih rudnika RTB BOR* [6]

Ležište	Ruda, t	Bakar, t	Zlato, kg	Srebro, kg
Jama, tekući zahvat	7,262,726	70,079	1,727	11,711
Jama, Borska Reka	319,969,179	1,599,846	65,274	518,350
Veliki Krivelj	465,150,392	1,511,726	31,584	180,478
Čoka Marin	220,714	4,767	1,307	8,945
Južni Revir - Majdanpek	246,082,778	881,904	46,654	353,684
Cerovo	170,000,000	595,000	11,900	170,000
Ukupno	1,208,685,789	4,663,321	158,446	1,243,228

Najveće rezerve koncentrisane su na tri lokaliteta – Veliki Krivelj, Jama – Borska reka i Južni revir – Majdanpek. Pri tome, najperspektivnije, odnosno ležište najbogatije rudom je Borska reka.

Međutim, nepovoljna strana ovih rezervi je stalno trend smanjenja sadržaja metala u rudi. Od 9% u prvim godinama eksploatacije, do današnjih 0,27%.



Sl. 2. *Kretanje sadržaja bakra u rudi*

Posmatrano po ležištima, sadržaj bakra u rudi je dosta različit. Tokom 2010. godine, u Jami Bor se eksploatisala ruda sa sadržajem od 0,92%, pa čak do 5,65%. Za rudnik Veliki Krivelj srednji sadržaj je 0,247%, a u rudniku bakra Majdanpek 0,252%. Uključivanjem ležišta Borska reka u redovnu eksploataciju, ukupan srednji sadržaj bakra će biti povećan.

OSTVARENA PROIZVODNJA

Sve do devedesetih godina prošlog veka proizvodnja bakra, uz određene oscilacije, ima trend stalnog uvećanja. Najveća proizvodnja katodnog bakra iz sopsvenih sirovina ostvarena je 1988. godine, i iznosila je 105.390 t, dok je ukupna najveća proizvodnja iz sopstvenih i uvoznih sirovina dostignuta 1990. godine, kada je proizvedeno 151.395 t katodnog bakra. Od devedesetih godina, iz objektivnih razloga, ali i mnogih unutrašnjih slabosti, proizvodnja drastično opada, najpre u Majdanpeku, a zatim i na rudnicima u Boru.

Najniža proizvodnja iz sopstvenih izvora ostvarena je u periodu 2003. do 2005. godine, oko desetak hiljada tona katodnog bakra. Upravo je to razdoblje kada se kompanija našla u najdubljoj ekonomskoj krizi. Od 2006. godine proizvodnja bakra se oporavlja, da bi 2010. godine dostigla 21.240 t. Na drugoj strani, proizvodnja bakra iz uvoznih sirovina naglo opada, u 2010. godini proizvedeno je svega 963 t.

Tabela 2. *Kretanje proizvodnje katodnog bakra* [3]

Godina	Katodni bakar iz sopstvenih sirovina, t	Katodni bakar iz uvoznih sirovina, t	Ukupna proizvodnja katodnog bakra, t
1990	102,222	49,173	151,395
1991	95,077	38,702	133,779
1992	78,561	36,203	114,764
1993	43,410	7,765	51,175
1994	66,308	5,841	72,149
1995	70,992	6,459	77,451
1996	60,015	43,985	104,000
1997	64,264	42,319	106,583
1998	61,587	32,809	94,396
1999	42,611	7,411	50,022
2000	30,357	15,278	45,632
2001	17,403	14,962	32,605
2002	20,984	14,913	35,897
2003	9,914	4,115	14,029
2004	9,343	2,654	11,997
2005	9,916	21,368	31,284
2006	11,120	31,434	42,554
2007	16,062	15,136	31,198
2008	18,550	15,201	33,751
2009	18,875	8,537	27,412
2010	21,240	963	22,203

Kod eksploatacije bakra, poseban značaj ima učešće pratećih metala i ostalih korisnih elemenata u rudi. Smatra se da se u rudi bakra može naći najmanje 14 pratećih metaličnih i nemetaličnih elemenata, čija eksploatacija može biti ekonomski opravdana (A.Šutulov). Njihovom proizvodnjom dobijaju se korisna dobra, što se odražava na uvećanje ukupne vrednosti proizvodnje, a u isto vreme, zbog smanjenja fiksnih troškova pojedinici proizvoda, ostvaruje se niža cena koštanja bakra. Naravno, pod uslovom da prerada pratećih elemenata ne uvećava troškove proizvodnje bakra.

Tabela 3. *Proizvodnja pratećih proizvoda* [7]

Naziv	Jedinica mere	2005.	2006.	2007.	2008.	2009.	2010.
Zlato	kg	414	581	504	1006	628	356
Srebro	kg	3.501	3.933	4.160	6.812	3.314	1.884
Bakar sulfat	t	792	1.120	899	949	850	759
Selen	kg	10.607	17.169	15.704	16.827	19.075	10.592
Platina	kg	4	-	-	-	12	-
Paladijum	kg	22	7	9	70	38	22

Najveća proizvodnja plemenitih metala (zlata i srebra) ostvarena je 2008. godine. Zadnjih godina njihova proizvodnja se naglo smanjuje, u prvom redu zbog smanjene prerade uvoznih sirovina. Kod ostalih pratećih proizvoda zapaža se osetna oscilacija u proizvodnji.

POSLOVNI REZULTAT

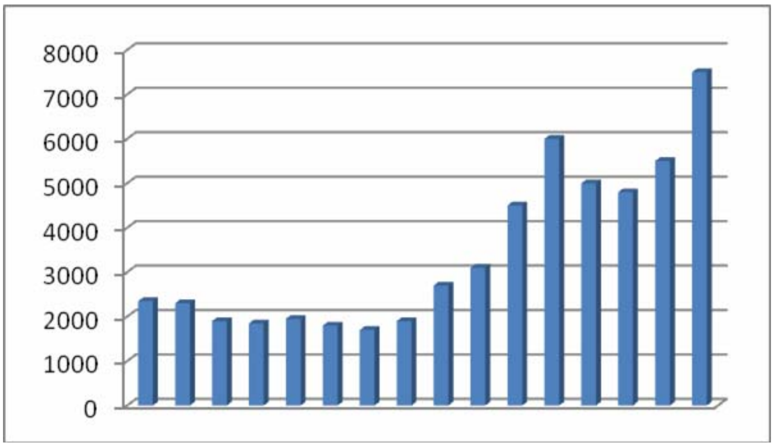
Smanjenje poslovnih aktivnosti neposredno se odrazilo na poslovni rezultat kompanije. Posle perioda uspešnog poslovanja, preduzeće upada u duboku ekonomsku i finansijsku krizu. Ostvareni prihodi nisu u stanju da pokriju nastale rashode, pa je sve izraženije negativno poslovanje. Zadnjih godina gubitak je izuzetno veliki u odnosu na ostvareni obim poslovanja.

Tabela 4. *Konsolidovani bilans uspeha* [7]

Pozicija	2007	2008	2009	2010
1. Poslovni prihodi	8,766,420	8,938,164	8,809,555	18,389,847
2. Poslovni rashodi	10,864,803	11,620,925	12,042,666	15,620,359
3. Poslovni dobitak-gubitak	-2,098,383	-2,682,761	-3,233,111	2,769,488
4. Finansijski prihodi	1,387,617	892,107	165,130	1,210,901
5. Finansijski rashodi	1,225,935	4,528,311	2,521,466	6,081,677
6. Neposlovni i vanredni prihodi	217,100	86,406	81,832	2,972,185
7. Neposlovni i vanredni rashodi	376,455	399,908	326,856	794,283
8. Dobitak-gubitak iz redovnog poslovanja	-2,096,056	-6,632,467	-5,834,471	76,614
9. Neto gubitak poslovanja koje se obustavlja	-54,046	-	-	-48,883
10. Neto dobitak-gubitak	-2,150,102	-6,632,467	-5,834,471	27,731

U 2010. godini došlo je do vidnog poboljšanja poslovnih aktivnosti. Ukupan prihod je više nego udvostručen, što je uz daleko sporiji rast rashoda omogućilo da kompanija posle dužeg perioda iskaže pozitivno poslovanje. Ostvarena dobit od 27.731.000 dinara nije velika u odnosu na obim poslovanja, ali je to možda znak da kompanija polako izlazi iz ekonomske i finansijske krize.

Treba istaći da je ovakvom poslovnom rezultatu u 2010. godini umnogome doprinela i povoljna tržišna cena bakra i plemenitih metala na svetskom tržištu.



Grafikon 2. *Kretanje cene bakra u priodu 1909-2010 g.(us$/t)*

Početkom devedesetih godina cena bakra je iznosila 2.716 US$/t, da bi u 1999.godini pala na najniži nivo, svega 1.572 US$/t; zatim, uz određene oscilacije, počinje da raste, naročito od 2004. godine, da bi u 2010. godini dostigla 7.576 US$/t, sa tendencijom daljeg uvećanja.

Međutim, dosta solidna cena bakra bila je i prethodnih godina (2007-2008), pa je kompanija negativno poslovala. Pored uvećanja poslovnih rashoda, na poslovni rezultat umnogome utiču i veliki finansijski rashodi. Oni u 2010.godini dostižu iznos od 6.081.677.000 dinara. U pitanju su kursne razlike i plaćene kamate.

STANJE ZAPOSLENOSTI I ZARADE

Početkom devedesetih godina RTB Bor zapošljava 24.096 radnika. Najviše ih je redilo u TIR-u (5.308), RBN-u (4.572), RBM-u (4.085), IPM-u (2.247), FOD-u (1.639) i FKZ-u (1.040). Obzirom na delatnost poslovanja, kvalifikaciona struktura zaposlenih bila je dosta povoljna.

Vremenom, broj zaposlenih radnika stalno opada. Posle izvršenih promena i restruktuiranja, u RTB Bor danas radi nešto manje od pet hiljada radnika.

Tabela 5. *Broj zaposlenih radnika* [7]

Preduzeće	Stanje na kraju godine (31.12.)		
	2008.	**2009.**	**2010.**
RBB Bor	1.986	1.872	2.088
RBM Majdanpek	988	952	962
TIR Bor	1.830	1.731	1.706
Matično preduzeće	84	93	114
Ukupno	4.888	4.648	4.870

Poslednjih godina broj zaposlenih dosta varira, sa izraženom fluktuacijom tokom godine. Sa poboljšanjem poslovnih aktivnosti, očekuje se i uvećanje broja zaposlenih.

Prosečne neto zarade zaposlenih imaju tendenciju usporenog rasta. One su nešto veće od prosečnih zarada u privredi Srbije, što je i normalno, imajući u vidu uslove poslovanja u kompaniji.

Tabela 6. *Prosečne neto zarade zaposlenih (prosek januar-decembar, u RSD)* [7]

Preduzeće	2008.	2009.	2010.
RBB Bor	34.676	37.027	40.619
RBM Majdanpek	34.026	35.811	40.056
TIR Bor	34.633	37.165	40.574
Matično preduzeće	42.055	45.138	50.722
RTB Bor	34.651	36.983	40.701
Republički prosek	32.746	31.733	34.009
Indeks, %	105,8	116,5	119,7

Prosečna isplaćena neto zarada u RTB Bor u 2010. godini iznosi 40.701 dinar i veća je od republičkog proseka za 19,7%. Po proizvodnim preduzećima zarade zaposlenih su skoro ujednačene.

INVESTICIJE

Ekonomska i finansijska kriza, nepovoljna ekonomija poslovanja i nedostatak finansijskih sredstava onemogućili su realizaciju mnogih investicionih projekata u kompaniji. Uz to, godinama se nije ulagalo ni u zamenu postojeće, amortizovane opreme. To se nepovoljno odrazilo na stanje tehničke opremljenosti rada i primenu savremene tehnologije u procesu proizvodnje.

Posle dužeg perioda, prva značajnija investiciona ulaganja izvršena su u 2010. godini. Nabavljena je i stavljena u funkciju visokokapacitetna rudarska utovarna i transportna oprema za potrebe rudnika Veliki Krivelj i Majdanpek. Ukupna vrednost svih ulaganja u oblasti rudarstva i metalurgije iznose 63.524.000 US$. Time započinje novi investicioni ciklus u ovom preduzeću.

Za 2011. godinu, plan investicionih aktivnosti je još ambiciozniji. Očekuju se ulaganja u iznosu od 272 miliona US$, od toga 103.800.000 u rudarstvo, 163.200.000 u metalurgiju i 5.000.000 u ostale oblasti. Najveća ulaganja odnose se na rekonstrukciju topionice i izgradnju fabrike sumporne kiseline. Time bi se stvorili uslovi za uvećanje proizvodnje, poboljšane uslove rada i rešavanje sadašnjih ekoloških problema u Boru.

ZAKLJUČAK

Od devedesetih godina prošlog veka RTB Bor posluje u izuzetno složenim i otežanim uslovima. Tome su doprinele mnoge okolnosti – raspad Jugoslavije, sankcije UN, ratovi u okruženju, NATO agresija, zatim tranzicioni procesi u zemlji, te brojne unutrašnje slabosti u kolektivu. U pitanju je, svakako, jedna od najtežih kriza u koju je zapala kompanija tokom svog egzistiranja dužeg od jednog veka.

Osnovne karakteristike sadašnjeh poslovanja kompanije su nizak sadržaj bakra u rudi, mala proizvodnja, visoka cena koptanja proizvoda, nepovoljna ekonomija poslovanja. Tu je i visok stepen nelikvidnosti, velika zaduženost, pa i ozbiljni ekološki problemi.

Posle višegodišnje agonije, 2010. godina kao da označava izvesnu prekretnicu u daljem egzistiranju preduzeća. Proizvodnja iz sopstvenih sirovina raste, tržišna cena u znatnoj meri nadmašuje cenu koštanja proizvodnje bakra, pa je ostvareni poslovni rezultat, posle dužeg perioda, pozitivan. Izvršena su značajna investiciona ulaganja, a očekuje se da i ona u narednom periodu budu u znatno većem obimu. No, mnogi nerešeni problemi iz prošlosti i dalje opterećuju poslovanje kompanije.

Zapaža se i veća zainteresovanost države za sređivanje stanja u ovoj kompaniji. To se posebno odnosi na aktivnosti oko rekonstrukcije topionice i izgradnje fabrike sumporne kiseline, kao i na poslovnu i finansijsku konsolidaciju preduzeća. To daje nadu da RTB Bor, uz povoljan poslovni ambijent i eliminisanje mnogih unutrašnjih slabosti, pre svega neracionalnosti u poslovanju, može da prevaziđe krizu i postane profitabilna, uspešna kompanija.

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BUSINESS ECONOMY OF RTB BOR IN TRANSITION PERIOD**

Abstract

RTB Bor is our known company for production of copper and precious metals. With a large number of employees, organized on a principle of production complex, it was a reputable business entity in the former Yugoslavia with a profitable business, especially in the area of export. At the same time, RTB was a backbone of economic development in the Timok region and beyond.

In 90's, the company fell into deep crisis due to a disintegration of the former Yugoslavia, civil wars in the neighborhood and tough economic sanctions by UN. It led to a drop of production, difficult export, reduced number of employees as well as their living standards. Investments were stopped and business losses became bigger and bigger.

In order to improve the business efficiency, the company took several steps in its restructuring. Some down-stream factories were disported and only the base of copper production was kept. In the meantime, there were two attempts of company privatization, but both were unsuccessful, so the company is currently state-owned.

Measures for improvement the company business economy are taken in the last couple of years. Some serious investments are in progress, such as reconstruction of the Smelter Plant and construction of the Sulfuric Acid Plant, procurement of mining equipment, infrastructural works, etc. Besides this, the production and export constantly increase and the company, after a long period of time, managed to finish 2010 with positive business results due to a favorable condition of the copper market.

***Key words**: transition, economic crisis, restructuring, business economy*

INTRODUCTION

Mining has a long tradition in the area of Bor and Majdanpek. First tones of copper ore were mined in 1903. It is a rich ore body Coka Dulkan. Namely, the first geological exploration of this area was carried out in 1897 in the area of Tilva Ros.

RTB Bor was developed strongly after the World War II. During this period, several mines were opened along with processing and smelting plants. After years of growth, company became one of the largest producers of high quality cathode copper with over 20,000 employees.

A review of the current situation of internal organization is undergone. It aims to find an organization model that will be based on the market principles and provide higher efficiency and profitability of the business.

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During the years, the company had changed its form, thus adjusting to changes into economic systems of the country. At first, it was state-owned, then it was self-managed working organization, then it was holding company and finally, now it is state-owned, again. This is not final status, since the company has to face the permanent ownership restructuring.

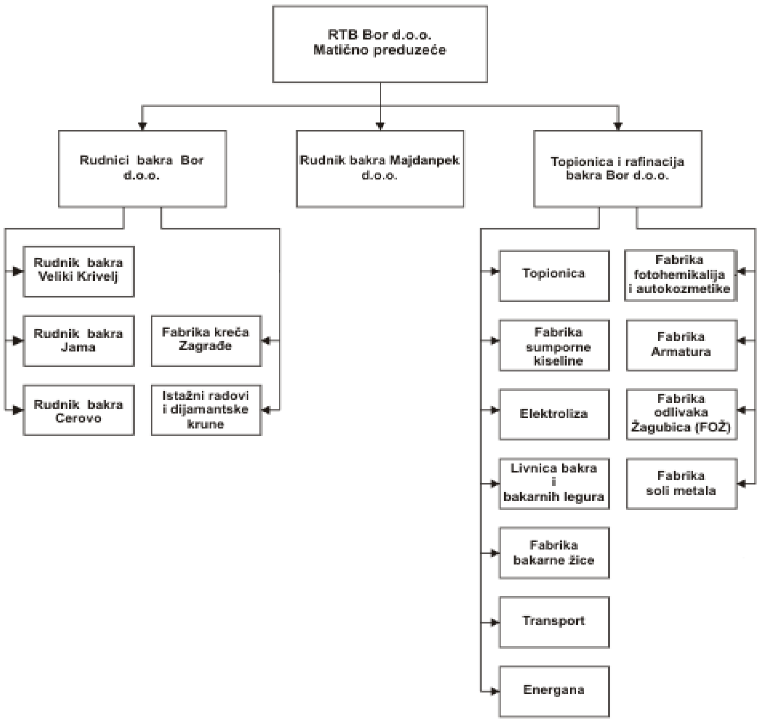

Fig. 1. *Organization scheme of RTB Bor Group* [8]

Currently, the company consists of a parent company and three dependent companies –Copper Mines Bor, Copper Mine Majdanpek and Copper Smelter and Refinery Bor. Relations between units is managed in order to function as a single company.

This paper considers some characteristics of RTB Bor business economy in the transition period.

THE AVAILABLE ORE RESERVES

The Bor metalogenetic zone includes significant copper ore reserves. According to the available data, the ore reserves in deposits of active mines of RTB Bor are 1.2 billion tons, what means that 4,663,321 t of copper, 158,446 kg of gold and 1,243,228 kg of silver could be extracted. That is why numerous international companies show interest for the exploratory works at some locations. It is estimated that some 2% of global copper ore reserves lay in Serbia.

Table 1. *Ore reserves in the active mines of RTB Bor [6]*

Mine	Ore, t	Copper, t	Gold, kg	Silver, kg
Jama, current operation	7,262,726	70,079	1,727	11,711
Jama, ore body Borska Reka	319,969,179	1,599,846	65,274	518,350
Veliki Krivelj	465,150,392	1,511,726	31,584	180,478
Coka Marin	220,714	4,767	1,307	8,945
Juzni Revir	246,082,778	881,904	46,654	353,684
Cerovo	170,000,000	595,000	11,900	170,000
Total	1,208,685,789	4,663,321	158,446	1,243,228

The most of ore reserves are concentrated in three deposits – Veliki Krivelj, Jama (Bor River) and South Mining District (Majdanpek). Between these three, most of the copper reserves lay in the ore body Bor River.

However, the ore reserves have a constant trend of decrease the metal content in the ore. It started with 9% at the beginning, and now it is 0.27%.

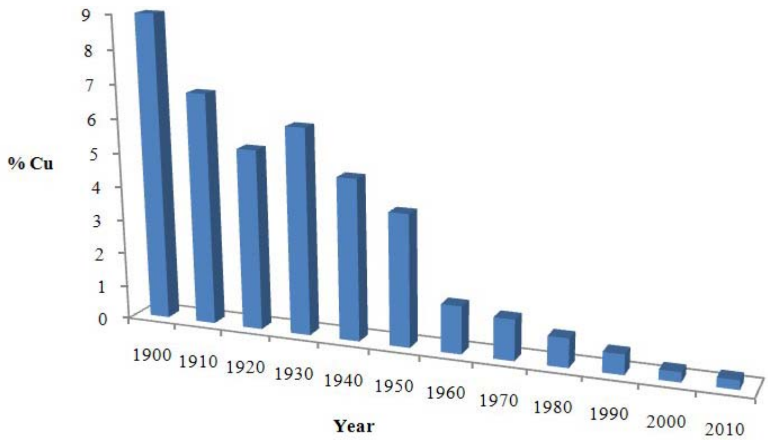

Fig. 2. *Variation of copper content in the ore*

REALIZED PRODUCTION

Until last decade of the last century, the copper production had a trend of constant increase, beside minor variations. The highest production from own ore deposits was reached in 1988 – 105,390 tons of copper, while the best results from own and imported copper ore were obtained in 1990, when 151,395 t was produced in RTB Bor. From the start of the 90's, due to the objective reasons, the production has fallen rapidly, first in Majdanpek, and then in the mines in Bor.

The lowest production from own resources was realized in period between 2003 and 2005, about ten thousand tons of cathode copper. At the same time, that was the period of biggest economic crisis in the company. Starting from 2006, the copper production has started to recover, to reach over 21,000 t in 2010, while production from imported ore decreases to just 963 t in 2010.

Table 2. *Variation of cathode copper production, 1990 – 2010[3]*

Year	Copper production from own copper ore, t	Copper production from imported ore, t	Total copper production, t
1990	102,222	49,173	151,395
1991	95,077	38,702	133,779
1992	78,561	36,203	114,764
1993	43,410	7,765	51,175
1994	66,308	5,841	72,149
1995	70,992	6,459	77,451
1996	60,015	43,985	104,000
1997	64,264	42,319	106,583
1998	61,587	32,809	94,396
1999	42,611	7,411	50,022
2000	30,357	15,278	45,632
2001	17,403	14,962	32,605
2002	20,984	14,913	35,897
2003	9,914	4,115	14,029
2004	9,343	2,654	11,997
2005	9,916	21,368	31,284
2006	11,120	31,434	42,554
2007	16,062	15,136	31,198
2008	18,550	15,201	33,751
2009	18,875	8,537	27,412
2010	21,240	963	22,203

Besides the exploitation of copper, the accompanying minerals and other useful elements in the ore have a special importance. It is considered that at least 14 accompanying metallic and nonmetallic elements could be found in the ore, whose extraction would be economically justified (A.Šutulov). Their production gives the useful goods, what is reflected to an increase in the total value of production, while at the same time, due to the reduction of fixed costs of individual products, a lower cost of copper is achieved. Certainly, under the condition that processing of accompanying elements does not increase the costs of copper production.

Table 3. *Production of accompanying products [7]*

Name	Unit	2005.	2006.	2007.	2008.	2009.	2010.
Gold	kg	414	581	504	1006	628	356
Silver	kg	3.501	3.933	4.160	6.812	3.314	1.884
Copper sulphate	t	792	1.120	899	949	850	759
Selenium	kg	10.607	17.169	15.704	16.827	19.075	10.592
Platinum	kg	4	-	-	-	12	-
Paladium	kg	22	7	9	70	38	22

The highest production of precious metals (gold and silver) was achieved in 2008. In recent years it decreases significantly, due to the reduced processing of imported raw materials, Production of other accompanying products varies significantly,

BUSINESS RESULTS

Decrease of business activities had a strong influence on the company business results, After a long period of successful operation, the company sinks into a deep economical and financial crisis,

Realized revenues are not able to cover the incurred expenses, and the business is an increasingly negative, In recent years, the loss is very large in relation to the realized volume of business,

Table 4. *Consolidated balance of success* [7]

Position	2007	2008	2009	2010
1. Incomes	8,766,420	8,938,164	8,809,555	18,389,847
2. Outcomes	10,864,803	11,620,925	12,042,666	15,620,359
3. Profit-loss	-2,098,383	-2,682,761	-3,233,111	2,769,488
4. Financial incomes	1,387,617	892,107	165,130	1,210,901
5. Financial outcomes	1,225,935	4,528,311	2,521,466	6,081,677
6. Non-business and extra incomes	217,100	86,406	81,832	2,972,185
7. Non-business and extra outcomes	376,455	399,908	326,856	794,283
8. Profit-loss from regular activity	-2,096,056	-6,632,467	-5,834,471	76,614
9. Aborted business loss	-54,046	-	-	-48,883
10. Net profit-loss	-2,150,102	-6,632,467	-5,834,471	27,731

As we can see, there was a significant improvement in 2010. Incomes were doubled, which, along with slightly increased outcomes, brought positive economic results to the company after many years. Although 27,731,000 RSD profit isn't too big related to overall business volume, it is still a sign that company finds its way out of business and financial crisis.

We should mention that one of the key factors of good financial result in 2010 was favorable price of copper and precious metals at the world market.

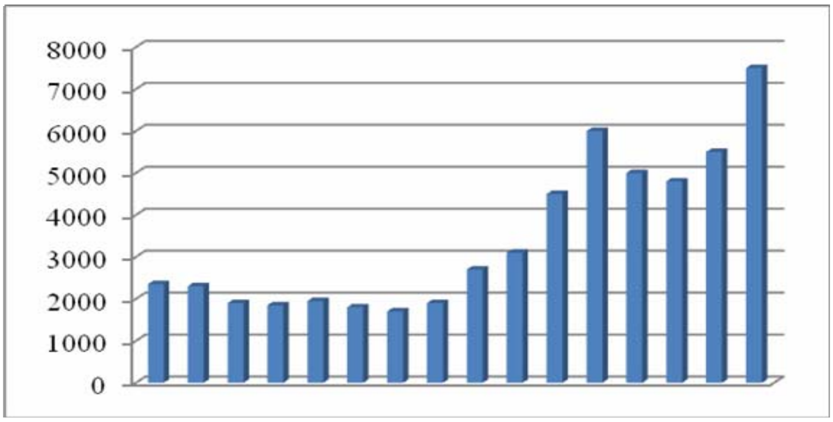

Fig. 3. *Variation of the copper prices in a period between 1990-2010, in US$/t*

In early 90's, the copper price was 2,716 US$/t and in 1999 it dropped down to the lowest level of 1,572 US$/t, After that, its price recovered gradually and since 2004 the increase was rapid, In 2010, it reached 7,516 US$/t, with a tendency of further increase,

However, the favorable metal price was also in the previous years (2007-2008), but the company had negative business results, Overall business results are strongly influenced by the financial outputs, In 2010, they reached 6,081,677,000 RSD, These outcomes are mainly related to exchange differences and paid interests,

STATE OF EMPLOYMENT AND WAGES

In early 90's RTB Bor had 24,096 employees, Most of them were employed in TIR (5,308), then RBN (4,572), RBM (4,085), IPM (2,247), FOD (1,639) and FKZ (1,040), Considering the type of industry, qualification structure of employees was quite good,

After that, the number of employees is in constant decrease, After the transition period and restructuring, there are less than 5,000 of employee in RTB Bor,

Table 5. *Number of employees* [7]

Unit	State of employment at the year end (31.12.)		
	2008.	2009.	2010.
RBB Bor	1.986	1.872	2.088
RBM Majdanpek	988	952	962
TIR Bor	1.830	1.731	1.706
Company management	84	93	114
Total	4.888	4.648	4.870

In recent years, the number of employees varies with significant fluctuation during the year; with improvements in business activities, it is expected that the number will rise.

The average net wages have a tendency of slow increase. They are a bit higher than the average wages in the industry of Serbia, what is normal having in mind the business conditions in the company.

Table 6. *Net wages (anual average in RSD)* [7]

Unit	2008.	2009.	2010.
RBB Bor	34.676	37.027	40.619
RBM Majdanpek	34.026	35.811	40.056
TIR Bor	34.633	37.165	40.574
Company management	42.055	45.138	50.722
RTB Bor	34.651	36.983	40.701
Serbian average	32.746	31.733	34.009
Index, %	105,8	116,5	119,7

The average paid net wage in RTB Bor in 2010 is 40,701 RSD per month and it is higher than the average wage in Serbia by 19.7%. By the production units inside the company, the wages are almost equal.

INVESTMENTS

Economic and financial crisis, unfavorable business economy and lack of financial means disabled the realization of many investment projects in the company. Besides that, there were no investments into replacement of old equipment. As a consequence, the technical level of production was very low and applied technologies were obsolete.

After a long period, the first major investments were realized in 2010. In mining, a new high-capacity loading and transport equipment was put into operation for the needs of the Veliki Krivelj and Majdanpek mines. Total value of all investments in the field of mining and metallurgy reached 63,524,000 US$. Thus, a new investment cycle has started in this company.

Plan of investments for 2011 is even more ambitious. The expected investments have reached the total of 272 million US$, out of which 103,800,000 US$ in mining sector, 163,200,000 in metallurgy and 5,000,000 in the other fields. The highest investments are related to the reconstruction of Smelter Plant and construction a new Sulfuric Acid Plant. These investments are very important because they will enable the increase of production, improvement of working conditions and solving the existing environmental problems in Bor.

CONCLUSION

Since 90's, RTB Bor operates in extremely complex and tough conditions. Many circumstances had their role in it – disintegration of Yugoslavia, the UN sanctions, civil wars in the neighborhood, NATO campaign, transition processes in the country and finally many problems inside the company. This is certainly one of the most serious crisis in which the company found itself during its existence longer than a century.

The main characteristics of recent production were low graded ore, low production, high metal price and unfavorable business economy. Also, here is a high degree of liquidity, high indebtedness and serious environmental problems.

After years of agony, 2010 brought some changes and it might be considered as the breaking point in company existence. Production of copper from own resources rises, copper price significantly exceeds the production costs and overall financial results are, after very long period, positive. This is a period of huge investments, and it is expected that it will be continued in future. On the other hand, there are still many problems remained from the past that make more difficult the business activities of company.

It is important to mention the largest interest of the government in recovery process of RTB Bor. All of that are encouraging signs that the company will eventually be able to completely overcome years of crisis and become strong, profitable and successful.

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PLANIRANJE VREMENA REALIZACIJE INVESTICIONOG PROJEKTA METODOM ZA POREĐENJE FUZZY BROJEVA

Izvod

Planiranje je jedna od najvažnijih funkcija menadžmenta građevinske kompanije. Efekat planiranja zavisiće od toga koliko su tačno usvojene pretpostavke na kojima budući plan treba da počiva, tj. sa koliko razumevanja su korišćena stečena iskustva. Da bi se planiranje moglo uspešno provoditi neophodna je stalna kontrola i analizira procesa realizacije, kao i sprovodenje principa permanentnog usavršavanja. Veliki broj faktora utiče na to da se u procesu planiranja mora uzeti u obzir neizvesnost ili nepreciznost u manjoj ili većoj meri. Najznačajniji alternativan pristup zasnovan je na konceptu rasplinutih (fuzzy) skupova.
Ključne reči: *planiranje, teorija mogućnosti, rasplinuti (fuzzy) skupovi, verovatnoća.*

UVOD

Planiranje vremena realizacije investicionog projekta jedna je od najvažnijih funkcija menadžmenta građevinske kompanije. Bez planiranja, realizacija je prepuštena stihijskom odvijanju koje u nekim slučajevima može da dovede do prekida u realizaciji projekta i raskida ugovornih odnosa. Da bi planiranje bilo realno, racionalno i ekonomično, treba da odgovara proizvodnim mogućnostima kompanije, da koristi ažurirane baze podataka (o realizovanim projektima i istraživanjima tržišta) i da se oslanja na savremenu matematičku teoriju.

Efekti planiranja zavise od tačnosti i preciznosti pretpostavki na kojima plan treba da počiva, tj. od načina korišćenja prikupljenih informacija i stečenih iskustava. Da bi planiranje bilo uspešno, neophodna je stalna kontrola i analiza procesa realizacije, permanentno praćenje i primena novih tehnoloških rešenja i inovacija, kao i sprovođenje usavršavanja obuke i edukacije zaposlenih. Uočene greške kod planiranja i organizacije na jednom objektu treba prikupiti, sistematizovati sistematizovati i analizirati, naći adekvatna rešenja i u skladu sa njima preduzimati mere da se greške više ne ponove. To je racionalan put ka unapređenju proizvodnje.

Veliki broj faktora utiče na to da se u procesu planiranja neizvesnost ili nepreciznost mora uzeti u obzir. Zbog toga, deterministički model koji se najčešće koriste (CPM metoda) postaje sasvim neodgovarajući i neprimenljiv. Klasičan pristup pri kvantitativnom tretiranju neizvesnosti koristi matematički aparat teorije verovatnoće (odnos povoljnih prema ukupnom broju mogućih ishoda). Pristup teorije verovatnoće ima ograničene mogućnosti primene i izvesne slabosti pri razmatranju problema kod kojih se

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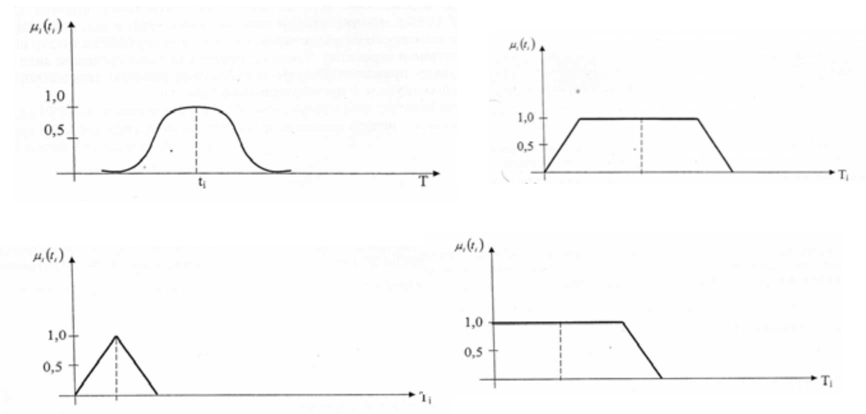
pojavljuju tipovi neodređenosti drugačiji od onih koji se računaju kao odnos broja povoljnih i broja mogućih ishoda.

Najznačajniji alternativan pristup razvio je kalifornijski profesor L. Zadeh [1]. Taj pristup dozvoljava opisivanje „rasplinutih“ pojava i znanja, operacije nad njima, izvođenje zaključaka i predstavlja osnovu za razvoj nove matematičke teorije rasplinutih (fuzzy) skupova. Fuzzy upravljanje je korisno u slučajevima kada su tehnološki procesi složeni za analizu uz pomoć poznatih metoda ili kada su dostupne informacije interpretirane kvalitativno, ali neodređeno [2].

TEORIJA RASPLINUTIH (FUZZY) SKUPOVA I POJAM MOGUĆNOSTI

Teorija rasplinutih skupova obezbeđuje formalni sistem za predstavljanje i razumevanje situacija prilikom pojave nesigurnih, subjektivnih i nepreciznih informacija. U klasičnom modelovanju veze su izražene matematičkim funkcijama. Kako sistemi postaju komplikovaniji postaje otežano primenjivati matematičko modelovanje, pa se za ove situacije koriste rasplinuti fuzzy modeli.

Za zadati skup T čiji su elementi t realni brojevi, postoji podskup $T_i \in T$, kojima se pridružuju vrednosti neke funkcije $\mu(ti)$ čije su vrednosti realni brojevi u intervalu (0,1). Podskup T_i predstavlja rasplinuti skup ili takozvanu rasplinutu restrikciju (fuzzy restriction) na skupu T. Funkcija $\mu(ti)$ se naziva funkcija pripadnosti (membership function) elemenata ti na skupu T_i. Oblik funkcije pripadnosti može biti potpuno proizvoljan. Na slici 1. prikazane su standardne funkcije pripadnosti. Na osnovu eksperimentalnih istraživanja došlo se do zaključka da se standardne funkcije pripadnosti mogu koristiti za rešavanje većine zadataka.



Sl. 1. *Standardne funkcije pripadnosti fuzzy skupa*

U procesu realizacije građevinskih projekata pored ocene trajanja kao i verovatnoća trajanja pojedinih aktivnosti i završetka projekta u celini ili pojednih njegovih delova (faza), važno je, takođe da se odredi i mogućnost izvršioca (izvođača radova) da završi predviđene aktivnosti, delove projekta ili projekat u celini u predviđenom ili ugovorenom roku. Pojam mogućnosti vezuje se za sposobnost i spremnost subjekta (realizatora projekta) da u datim uslovima i u predviđenom vremenu izvrši preduzete obaveze ili zadatke, i razlikuje se od pojma verovatnoće koji se vezuje za statističke podatke [3].

Dalje se definiše funkcija distibucije mogućnosti π_i za koju važi:

$$\pi_i(t_i) = Poss\{T_i = t_i\} = \mu(t_i)$$

i izražava mogućnost da element $t_i \in T_i$.

Za projekat koji se sastoji od m aktivnosti čija su trajanja t_i elementi nekog rasplinutog skupa T_i funkcija pripadnosti μ_i predstavlja mogućnost nekog izvršioca da tu aktivnost uradi u toku nekog vremena *ti*. Funkcija π_i izražava stepen mogućnosti izvršioca i kada *je* $\pi_i(t_i)=0$ onda ne postoji mogućnost da se aktivnost i obavi u toku vremena. Ako je $\pi_i(t_i) = 1$, onda je ta mogućnost maksimalna.

U determinističkom postupku CPM metode vrednost ove funkcije je:

$$\pi_i(t_i) = \begin{Bmatrix} 1 \; za \; t_i = a_i \\ 0 \; za \; t_i \neq a_i \end{Bmatrix}$$

gde je:

a_i - neka zadata ili utvrđena vrednost trajanja aktivnosti *i*.

Trajanje aktivnosti t_i kao rasplinute varijable i stepeni mogućnosti izvršenja π_i procenjuje se na osnovu iskustva.

PRORAČUN TRAJANJA PROJEKTA KADA SU TRAJANJA AKTIVNOSTI FUZZY BROJEVI

Neka su dati fuzzy brojevi:

$$\tilde{A} = \left\{ x, \mu_{\tilde{A}}(x) \middle| x \in R \right\} \text{ i}$$

$$\tilde{B} = \left\{ y, \mu_{\tilde{A}}(y) \middle| y \in R \right\}.$$

Funkcija pripadnosti razmatranih fuzzy brojeva su neprekidne i njihove vrednosti pripadaju intervalu (0,1).

Neka je sa * označena operacija na fuzzy brojevima. Tada je: $\tilde{A} * \tilde{B}$ takođe fuzzy broj koji je označen kao $\tilde{C} = \tilde{A} * \tilde{B}$, tako da

$$\tilde{C} = \left\{ z, \mu_{\tilde{c}}(z) \middle| z \in R \right\}$$

gde je:

*z=x*y* - a funkcija pripadnosti se računa prema principu proširenja, tj.

$$\mu_{\tilde{C}}(z) = \sup_{z=x+y} \min(\mu_{\tilde{A}}(x), \mu_{\tilde{B}}(y)).$$

U specijalnom slučaju kada su fuzzy brojevi linearni, odnosno kada su funkcije pripadnosti oblika trougla, tada su izrazi pomoću kojih izračunavamo zbir, razliku, proizvod i količnik fuzzy brojeva znatno jednostavniji.

Za svaki α presek fuzzy brojevi se predstavljaju sa:

$$\tilde{A} = \left[x_L^\alpha, x_D^\alpha \right] \text{ and } \tilde{B} = \left[y_L^\alpha, y_D^\alpha \right]$$

Tada se operacije sa trougaonim fuzzy brojevima definišu izrazima [5]:

$$\tilde{C} = \tilde{A} + \tilde{B} = \left\{ z, \mu_{\tilde{C}}(z) \middle| z \in R, \right\}$$

$$z = \left[x_L^\alpha + y_L^\alpha, x_R^\alpha + y_R^\alpha \right]; \mu_{\tilde{C}}(z) = \alpha; \; \alpha = [0,1]$$

$$\tilde{C} = \tilde{A} - \tilde{B} = \left\{ z, \mu_{\tilde{C}}(z) \middle| z \in R, \right\}$$

$$z = \left[x_L^\alpha - y_R^\alpha, x_R^\alpha - y_L^\alpha \right]; \mu_{\tilde{C}}(z) = \alpha; \; \alpha = [0,1]$$

$$\tilde{C} = \tilde{A} \cdot \tilde{B} = \left\{ z, \mu_{\tilde{C}}(z) \middle| z \in R, \right\}$$

$$z = \left[x_L^\alpha \cdot y_L^\alpha, x_R^\alpha \cdot y_R^\alpha \right]; \mu_{\tilde{C}}(z) = \alpha; \; \alpha = [0,1]$$

$$\tilde{C} = \tilde{A} : \tilde{B} = \left\{ z, \mu_{\tilde{C}}(z) \middle| z \in R, \right\}$$

$$z = \left[x_L^\alpha / y_R^\alpha, x_R^\alpha / y_L^\alpha \right]; \mu_{\tilde{C}}(z) = \alpha; \; \alpha = [0,1]$$

Primer:

Dati su strogo pozitivni fuzzy brojevi

$$\tilde{A} = \left\{ x, \mu_{\tilde{A}}(x) \middle| x \in [6,10] \right\} \text{ i}$$

$$\tilde{B} = \left\{ y, \mu_{\tilde{A}}(y) \middle| y \in [8,10] \right\}.$$

$$\mu_{\tilde{A}}(x) = \begin{Bmatrix} \frac{1}{2}x - 3, \; 6 \le x \le 8 \\ -\frac{1}{2}x + 5, \; 8 \le x \le 10 \end{Bmatrix}$$

$$\mu_{\tilde{B}}(x) = \begin{cases} y-8, & 8 \le y \le 9 \\ -y+10, & 9 \le x \le 10 \end{cases}$$

Odrediti: $\tilde{C} = \tilde{A} + \tilde{B}$

Da bi izvršili naznačene operacije nad datim trougaonim fuzzy brojevima potrebno je odrediti levu i desnu granicu intervala poverenja za svaki nivo uverenja $\alpha \in [0,1]$. Drugim rečima potrebno je odrediti ekstremne vrednosti u α preseku fuzzy brojeva A i B.

Leva granična vrednost fuzzy broja $\tilde{A}$ za nivo uverenja $\alpha \in [0,1]$ dobija se prema izrazu x_L^α :

$$\frac{1}{2}x_L^\alpha - 3 = \alpha \rightarrow x_L^\alpha = 6 + 2\alpha$$

Desna granična vrednost fuzzy broja $\tilde{A}$ za nivo uverenja $\alpha \in [0,1] \cdot x_R^\alpha$ dobija se prema izrazu :

$$-\frac{1}{2}x_R^\alpha + 5 = \alpha \rightarrow x_R^\alpha = 10 - 2\alpha$$

α presek fazi broja je :

$$\frac{1}{2}A_\alpha = \left[x_L^\alpha, x_R^\alpha\right] = [6 + 2\alpha, 10 - 2\alpha]$$

Analogno prethodnom dobijamo za α presek fuzzy broja $\tilde{B}$:

$$B_\alpha = \left[y_L^\alpha, y_R^\alpha\right] = [8 + \alpha, 10 - \alpha]$$

Izračunajmo zbir fuzzy brojeva $\tilde{A}$ i $\tilde{B}$ koji je označen sa $\tilde{C}$. Fuzzy broj $\tilde{C}$ se formalno zapisuje $\tilde{C} = \left\{z, \mu_{\tilde{C}}(z)\right\}$.

Prema pravilu o sabiranju trouglastih fuzzy brojeva sledi:

$$\tilde{C} = [(6 + 2\alpha) + (8 + \alpha), (10 - \alpha) + (10 - 2\alpha] =$$
$$= [14 + 3\alpha, 20 - 3\alpha]$$

Jednačine koje predstavljaju levu i desnu stranu fuzzy broja $\tilde{C}$:

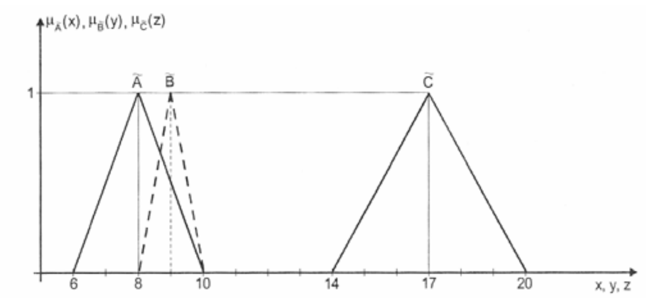
$$14 + 3\alpha = z^\alpha \rightarrow \alpha = \frac{1}{3}z^\alpha - \frac{14}{3}$$

$$20 - 3\alpha = z^\alpha \rightarrow \alpha = -\frac{1}{3}z^\alpha - \frac{20}{3}$$

Funkcija pripadnosti fuzzy broja $\tilde{C}$ je takođe oblika trougla i formalno se predstavlja analitičkim izrazom:

$$\mu_{\tilde{C}}(z) = \begin{cases} \frac{1}{3}z - \frac{14}{3}, & 14 \le z \le 17 \\ -\frac{1}{3}z + \frac{20}{3}, & 17 \le z \le 20 \end{cases}$$

$\tilde{A}$ i $\tilde{B}$ Fuzzy brojevi kao i njihov zbir, tj. fuzzy broj $\tilde{C}$ prikazani su na slici 2.



Sl. 2. *Fuzzy brojevi A, B, C*

Na sličan način se računa i razlika, proizvod i količnik fuzzy brojeva.

Ako su aktivnosti Ai, čije je trajanje *ti* fuzzy broj, prikazane pomoću krugova ili pravougaonika (precedence dijagram), onda se vremena njihovih najranijih i najkasnijih završetaka RZ_i I RK_i izračunavaju pomoću sledećih izraza:

$$RZ_i = \max_p \left(RZ_p + t_i\right)$$

$$\pi(RZ_i) = \sup_p \left\{ \min\left[\pi(RZ_p), \pi(t_i)\right]\right\}$$

$$KZ_i = \min_n (KZ_n - t_i)$$

$$\pi(KZ_i) = \sup \left\{ \min[\pi(KZ_n), \pi(t_i)]\right\}$$

$i = 1, 2, ..., m;\ p = 1, 2, .., m-1;\ n = 2, 3, ..., m$

Ako se vremena trajanja aktivnosti razmatraju kao kontinualne konvkesne fuzzy promenljive, onda se početak i završetak aktivnosti koja je takođe kontinualna lako određuju.

POREĐENJE FUZZY BROJEVA

Problem poređenja fuzzy brojeva je zadatak koji se javlja u problemima odlučivanja vrlo često. Na primer, kada su alternative opisane fuzzy brojevima, postavlja se pitanja kako da odredimo koja je alternativa bolja od druge. Ovom problemu posvećen je veći broj radova u literaturi [4].

U slučaju određivanje vremena (roka) realizacije projekta kod svake aktivnosti koja ima više prethodnih aktivnosti susreli bi se sa problemom poređenja fuzzy brojeva, jer su trajanja aktivnosti kao i njihovi rani i kasni završeci takođe fuzzy brojevi. Jedna od metoda kojom se možemo poslužiti u tom slučaju je metoda Kaufmanna i Gupte [4] za poređenje fuzzy brojeva. Ovo je jednostavna metoda za poređenje fuzzy brojeva koja se realizuje u tri koraka.

Korak 1

U ovom koraku vrši se poređenje "pomerenosti" fuzzy brojeva. Neka je dat fuzzy broj $\tilde{M} = \left\{x, \mu_{\tilde{M}}(x),\right\}$ tako da je x vrednost u domenu fuzzy broja $\tilde{M}$ i $x \in X$.

Donja, odnosna gornja granica u domenu X neka je označena kao $\underline{x}$, $\overline{x}$, respektivno $\mu_{\tilde{M}}(x)$ je funkcija raspodele mogućnosti fuzzy broja $\tilde{M}$.

Da bi odredili "pomerenost" fuzzy broja $\tilde{M}$ u odnosnu na realnu vrednost k treba prvo da definišemo termine:

- "leva pomerenost ", $R_L(\tilde{M}, k)$, i
- "desna pomerenost ", $R_D(\tilde{M}, k)$.

"Leva pomerenost" $R_L(\tilde{M}, k)$ se izračunava kao površina ispod krive funkcije pripadnosti fuzzy broja $\widetilde{M}$ od donje granice domena fuzzy broja M i skalara k, što se predstavlja izrazom:

$$R_L(\tilde{M}, k) = \int_{\underline{x}}^{k} \mu_{\tilde{M}}(x)$$ za kontinualne fazi brojeve.

$$R_L(\tilde{M}, k) = \sum_{i=2}^{k} \frac{\mu_{\tilde{M}}(x_{i-1}) + \mu_{\tilde{M}}(x_i)}{2} \cdot (x_i - x_{i-1})$$

za diskretne fazi brojeve

"Desna pomerenost", $R_D(\tilde{M}, k)$ se izračunava kao površina ispod krive funkcije pripadnosti fazi broja $\widetilde{M}$ od skalara k do gonje granice domena fazi broja M, što se predstavlja izrazom:

$$R_D(\tilde{M}, k) = \int_{k}^{\overline{x}} \mu_{\tilde{M}}(x)$$ za kontinualne fazi brojeve.

$$R_D(\tilde{M}, k) = \sum_{i=k+1}^{\overline{x}} \frac{\mu_{\tilde{M}}(x_{i-1}) + \mu_{\tilde{M}}(x_i)}{2}$$

za diskretne fazi brojeve

Ukupna ”pomerenost” fuzzy broja $\widetilde{M}$ u odnosu na realni broj k se izračunava prema izrazu:

$$R(\tilde{M}, k) = \frac{R_L(\tilde{M}, k) + R_D(\tilde{M}, k)}{2}$$

Za slučaj da fuzzy broj $\widetilde{M}$ ima funkciju pripadnosti oblika trougla (k=0), tada se koristi pola Hamingove distance:

$$R(\tilde{M},k) = \frac{\underline{x} + 2x' + \overline{x}}{4}$$

gde su:

$\underline{x}, x', \overline{x}$ - apscise odgovarajućih temena trougaonog fuzzy broja.

Neka su sada data dva fuzzy broja

$\tilde{M} = \{x, \mu_{\tilde{M}}(x),\}$ i

$\tilde{N} = \{y, \mu_{\tilde{N}}(y)\}$

Smatra se da je fuzzy broj $\tilde{M}$ manji od fuzzy broja $\tilde{N}$ ako i samo ako

$R(\tilde{M},k) < R(\tilde{N},k)$ važi: i obrnuto.

Korak 2

Ukoliko nije moguće u prvom koraku odrediti meru da je jedan fuzzy broj manji ili veći od drugog tada se prelazi na drugi korak. U ovom koraku se vrši poređenje vrednosti domena oba fuzzy broja kojima su pridružene najveće vrednosti funkcija raspodele mogućnosti.

Formalno, drugi korak se predstavlja:

- $\max\left(\mu_{\tilde{M}}(x)\right)$ je pridružena vrednost domena fuzzy broja $\tilde{M}$ koja je označena kao $x^*_{\tilde{M}}$
- $\max\left(\mu_{\tilde{N}}(y)\right)$ je pridružena vrednost domena fuzzy broja $\tilde{N}$ koja je označena kao $x^*_{\tilde{N}}$

Neka su sada data dva fuzzy broja $\tilde{M} = \{x, \mu_{\tilde{M}}(x),\}$ i $\tilde{N} = \{y, \mu_{\tilde{N}}(y)\}$

Smatra se da je fuzzy broj $\widetilde{M}$ manji od fuzzy broja $\widetilde{N}$ ako i samo ako važi: $x^*_{\tilde{M}} < x^*_{\tilde{N}}$

Korak 3

Ovaj korak se realizuje onda kada u prva dva koraka nismo u mogućnosti da odredimo koliko je jedan fuzzy broj veći ili manji od drugog. U ovom koraku se vrši poređenje "baza" fuzzy brojeva. Termin "baza" označava dužinu osnovice fuzzy broja.

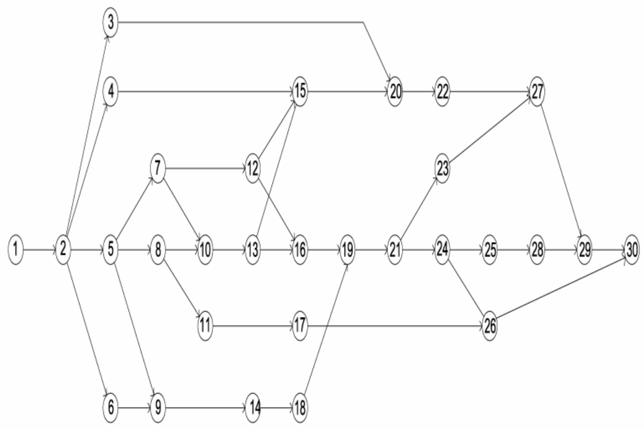
PRIMENA METODE ZA POREĐENJE FUZZY BROJEVA NA PRIMERU IZ PRAKSE

Za jednu industrijsku halu dat je spisak generalnih aktivnosti sa trajanjem u danima (tabela 1.), kojim su obuhvaćeni radovi na gradilištu kao i radovi na prefabrikaciji montažnih elemenata.

Tabela 1. *Spisak aktivnosti sa trajanjem u danima*

Broj aktivnosti u mreznom planu	Opis aktivnosti	l	m	r
1.	Ispunjenje ugovornih obaveza prema izvođaču	2	3	4
2.	Pripremni radovi (izgradnja privrednog gradilišta)	5	7	9
3.	Prefabrikacija betonskih fasadnih elemenata	24	30	35
4.	Prefabrikacija betonskih stubova i olučnih greda	14	16	18
5.	Skidanje sloja humusa i nivelisanje lokacije	3	4	5
6.	Izrada glavnih krovnih nosača (rešetke)	7	10	12
7.	Izrada saobraćajnica oko objekta	9	12	14

8.	Iskop jama za temeije samce	1	2	3
9.	Izrada sekundarnih krovnih nosača (rožnjače, spregovi)	13	15	17
10.	Izrada podloge za podnu ploču hale	3	4	5
11.	Iskop kanala za spoljne instalacije	3	4	5
12.	Izrada habajućeg sloja saobraćajnica	1	2	3
13.	Betoniranje temelja samaca i temeljnih greda	8	10	12
14.	Transport i deponovanje čelične konstrukcije	1	3	4
15.	Montaža betonskih stubova i olučnih greda	2	3	4
16.	Izrada podne ploče hale sa hidroizolacijom	4	6	7
17.	Povezivanje delova režetke u celinu	1	2	3
18.	Postavljanje spoljnih instalacija	13	15	18
19.	Montaža glavnih krovnih nosača (rešetke)	1	2	3
20.	Montaža betonskih fasadnih elemenata	4	5	7
21.	Montaža sekundarnih krovnih nosača	4	5	7
22.	Ugrađivanje ostakljene fasadne bravarije	6	8	10
23.	Montaža kranskih staza za mostni kran	3	4	5
24.	Postavljanje krovnog pokrivača i oluka hale	7	10	12
25.	Ugradivanje krovnih svetlosnih traka	2	3	4
26.	Postavljanje unutrašnjih instaiacija hale	10	11	12
27.	Montaža mostnih kranova	8	10	13
28.	Molersko - farbarski radovi u hali	6	7	9
29.	Tehnički prijem objekta	2	3	4
30.	Puštanje u probni rad	8	10	12



Sl. 3. *Analiza strukture mrežnog plana*

$\tilde{Rz}1 = \tilde{t}1$

$\tilde{Rz}1 = [\alpha + 2; 4 - \alpha]$

$\tilde{Rz}2 = \tilde{Rz}1 + \tilde{t}2$

$\tilde{t}2 = [2\alpha + 5; 9 - 2\alpha]$

$\tilde{Rz}2 = [\alpha + 2 + 2\alpha + 5; 4 - \alpha + 9 - 2\alpha]$

$\tilde{Rz}2 = [3\alpha + 7; 13 - 3\alpha]$

$\tilde{Rz}3 = \tilde{Rz}2 + \tilde{t}3$

$\tilde{Rz}3 = [3\alpha + 7 + 6\alpha + 24; 13 - 3\alpha + 35 - 5\alpha]$

$\tilde{Rz}3 = [9\alpha + 31; 48 - 8\alpha]$

$\tilde{Rz}4 = \tilde{Rz}2 + \tilde{t}4$

$\tilde{Rz}4 = [3\alpha + 7; 13 - 3\alpha] + [2\alpha + 14; 18 - 2\alpha]$

$\tilde{Rz}4 = [5\alpha + 21; 31 - 5\alpha]$

$\tilde{Rz}5 = \tilde{Rz}2 + \tilde{t}5$

$\tilde{Rz}5 = [3\alpha + 7; 13 - 3\alpha] + [\alpha + 3; 5 - \alpha]$

$\tilde{Rz}5 = [4\alpha + 10; 18 - 4\alpha]$

$\tilde{Rz}6 = \tilde{Rz}2 + \tilde{t}6$

$\tilde{Rz}6 = [3\alpha + 7; 13 - 3\alpha] + [3\alpha + 7; 12 - 2\alpha]$

$\tilde{Rz}6 = [6\alpha + 14; 25 - 5\alpha]$

$\tilde{Rz}1 = \tilde{t}1$

$\tilde{Rz}1 = [\alpha + 2; 4 - \alpha]$

$\tilde{Rz}2 = \tilde{Rz}1 + \tilde{t}2$

$\tilde{t}2 = [2\alpha + 5; 9 - 2\alpha]$

$\tilde{Rz}2 = [\alpha + 2 + 2\alpha + 5; 4 - \alpha + 9 - 2\alpha]$

$\tilde{Rz}2 = [3\alpha + 7; 13 - 3\alpha]$

$\tilde{Rz}3 = \tilde{Rz}2 + \tilde{t}3$

$\tilde{Rz}3 = [3\alpha + 7 + 6\alpha + 24; 13 - 3\alpha + 35 - 5\alpha]$

$\tilde{Rz}3 = [9\alpha + 31; 48 - 8\alpha]$

$\tilde{Rz}4 = \tilde{Rz}2 + \tilde{t}4$

$\tilde{Rz}4 = [3\alpha + 7; 13 - 3\alpha] + [2\alpha + 14; 18 - 2\alpha]$

$\tilde{Rz}4 = [5\alpha + 21; 31 - 5\alpha]$

$\tilde{Rz}5 = \tilde{Rz}2 + \tilde{t}5$

$\tilde{Rz}5 = [3\alpha + 7; 13 - 3\alpha] + [\alpha + 3; 5 - \alpha]$

$\tilde{Rz}5 = [4\alpha + 10; 18 - 4\alpha]$

$\tilde{Rz}6 = \tilde{Rz}2 + \tilde{t}6$

$\tilde{Rz}6 = [3\alpha + 7; 13 - 3\alpha] + [3\alpha + 7; 12 - 2\alpha]$

$\tilde{Rz}6 = [6\alpha + 14; 25 - 5\alpha]$

$\tilde{Rz}7 = \tilde{Rz}5 + \tilde{t}7$

$\tilde{Rz}7 = [4\alpha + 10; 18 - 4\alpha] + [3\alpha + 9; 14 - 2\alpha]$

$\tilde{Rz}7 = [7\alpha + 19; 32 - 6\alpha]$

$\tilde{Rz}8 = \tilde{Rz}5 + \tilde{t}8$

$\tilde{Rz}8 = [4\alpha + 10; 18 - 4\alpha] + [\alpha + 1; 3 - \alpha]$

$\tilde{Rz}8 = [5\alpha + 11; 21 - 5\alpha]$

$$\tilde{Rz}9 = \max\left[\tilde{Rz}5 + \tilde{t}9; \tilde{Rz}6 + \tilde{t}9\right]$$

Ovde primenjujemo postupak za poređenje fuzzy brojeva, odnosno nalazimo najveću vrednost fuzzy brojeva:

$\tilde{Rz}5 + \tilde{t}9 = [4\alpha + 10; 18 - 4\alpha] + [2\alpha + 13; 17 - 2\alpha] = [6\alpha + 23; 35 - 6\alpha]$

$\tilde{Rz}6 + \tilde{t}9 = [6\alpha + 14; 25 - 5\alpha] + [2\alpha + 13; 17 - 2\alpha] = [8\alpha + 27; 42 - 7\alpha]$

$$R(\tilde{Rz}5 + \tilde{t}9) = \frac{23 + 2 \cdot 29 + 35}{4} = 29,0$$

$$R(\tilde{Rz}6 + \tilde{t}9) = \frac{27 + 2 \cdot 35 + 42}{4} = 34,75$$

$$R(\tilde{Rz}6 + \tilde{t}9) \succ R(\tilde{Rz}6 + \tilde{t}9)$$

Iz zadnje relacije sledi da je rani završetak za aktivnost 9 sledeći fuzzy broj: $\tilde{Rz}9 = [8\alpha + 27; 42 - 7\alpha]$

Pokazani postupak zatim analogno primenjujemo na sve aktivnosti uvažavajući strukturu (slika 3.) datog mrežnog plana. Na taj način dolazimo do predposlednje i poslednje aktivnosti datog mrežnog plana koje se proračunavaju:

$$\tilde{Rz}29 = \max\left[\tilde{Rz}27 + \tilde{t}29; \tilde{Rz}28 + \tilde{t}29; \tilde{Rz}26 + \tilde{t}29\right]$$

$$\tilde{Rz}27 + \tilde{t}29 = [17\alpha + 57; 92 - 18\alpha] +$$
$$+[\alpha + 2; 4 - \alpha] = [18\alpha + 59; 96 - 19\alpha]$$

$$\tilde{Rz}28 + \tilde{t}29 = [19\alpha + 61; 99 - 19\alpha] +$$
$$+[\alpha + 2; 4 - \alpha] = [20\alpha + 63; 103 - 20\alpha]$$

$$\tilde{Rz}26 + \tilde{t}29 = [18\alpha + 63; 98 - 17\alpha] +$$
$$+[\alpha + 2; 4 - \alpha] = [19\alpha + 65; 102 - 18\alpha]$$

$$R(\tilde{Rz}27 + \tilde{t}29) = \frac{59 + 2 \cdot 77 + 96}{4} = 77,25$$

$$R(\tilde{Rz}28 + \tilde{t}29) = \frac{63 + 2 \cdot 83 + 103}{4} = 83,0$$

$$R(\tilde{Rz}26 + \tilde{t}29) = \frac{65 + 2 \cdot 84 + 102}{4} = 83,75$$

$$\tilde{Rz}29 = [19\alpha + 65; 102 - 18\alpha]$$

$$\tilde{Rz}30 = \tilde{Rz}29 + \tilde{t}30$$

$$\tilde{Rz}30 = [19\alpha + 65; 102 - 18\alpha] +$$
$$+[2\alpha + 8; 12 - 2\alpha] = [21\alpha + 73; 114 - 20\alpha]$$

$$\tilde{Rz}30 = [21\alpha + 73; 114 - 20\alpha]$$

Fuzzy broj koji prestavlja poslednju aktivnost projekta *Rz30* definiše nam funkciju mogućnosti završetka projekta. U prethodnom izrazu je fuzzy broj koji prestavlja poslednju aktivnost definisan preko svojih α preseka.

Analitički oblik funkcije mogućnosti dobijamo na sledeći način:

$$\bar{R}z30 = [x_L^\alpha, x_R^\alpha] = [21\alpha + 73, 114 - 20\alpha]$$

$$x_L^\alpha = 21\alpha + 73 \rightarrow \alpha = \frac{x_L^\alpha - 73}{21}$$

$$x_D^\alpha = 114 + 20\alpha \rightarrow \alpha = \frac{114 - x_D^\alpha}{20}$$

Odakle dobijamo analitički izraz za funkciju mogućnosti:

$$\pi(t) = \begin{cases} \frac{t-73}{21} = 0,0476t - 3,4762, & 73 \le t \le 94 \\ \frac{114-t}{20} = 5,7 - 0,05t, & 94 \le t \le 114 \\ 0, & t \notin [73,114] \end{cases}$$

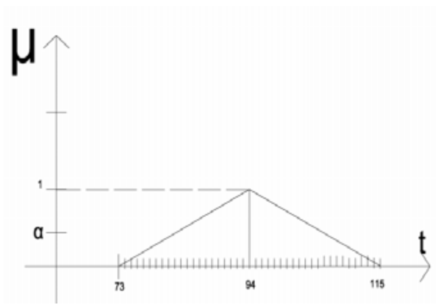
Grafička prestava ovog izraza data je na slici 4.

Razlika u proračunu između proračuna za različite konkretne vrednosti α i proračuna gde se α javlja kao parametar javila se samo kod računjanja ranog završetka Rz29. (kod upoređenja Hamingove distance za: $\tilde{Rz}28 + \tilde{t}29$ i $\tilde{Rz}26 + \tilde{t}29$).

Zbog toga se javila neznatna razlika kod završetka projekta.

Sličan proračun bi se izveo i za proračun kasnog završetka pojedinih aktivnosti, kod proračuna vremenske rezerve, itd.

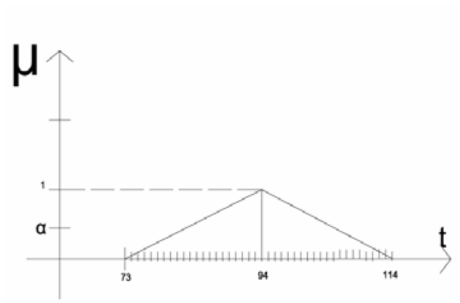
Sl. 4. *Prikaz funkcije mogućnosti π(t)*



Završetak projekta dobijen preko α preseka gde nisu zamenjivane konkretne vrednosti

Autori ovog rada su za dati primer odredili vreme realizacije projekta i probabilističko-posibilističkim postupkom prema [1]. Razlika jednog i drugog proračuna sastoji se u tome što je primenom metode za poređenje fuzzy brojeva potrebno proračunati mrežni plan samo jednom, nakon čega možemo da definišemo funkciju mogućnosti (slika 4.).

Kod proračuna fukcije mogućnosti preko probabilističko-posibilističkog postupka, potrebno je proračunati ceo mrežni plan vise puta za konkretne vrednosti α parametra (α=0; 0,25; 0,50; 0,75; 1,0). Drugim rečima. neophodno je proračunati mrežni plan za svaku vrednost parametra po dva puta osim za parametar α=1 kada je potrebno jednom proračunati mrežni plan (slika 5).



Sl. 5. *Prikaz funkcije mogućnosti π(t) Završetak projekta (dobijen višestrukim proračunom mrežnog plana preko konkretnih vrednosti α (α=0; α=0,25; α= 0,50; α= 0,75; α=1,0)*

ZAKLJUČAK

Postupkom prikazanim u radu i kroz konkretan primer ilustrovana je primena teorije mogućnosti kod planiranja vremena građenja investicionog objekta. Za pojedinačne aktivnosti čija je funkcija mogućnosti poznata i predstavljena odgovarajućim α-presecima određena je funkcija mogućnosti završetka projekta. Ovim postupkom se mogu odrediti i funkcije mogućnosti izvršenja pojedinih faza projekta. Prilikom definisanja fukcije mogućnosti završetka projekta korišćena je metoda za poređenje fuzzy brojeva koja je i detaljnije obrazložena. Primer koji je ilustrovan sadržao je ukupno 30 generalnih aktivnosti i krajni rezultat je ukazao da u odnosu na druge metode, koje su autori primenjivali, ovaj postupak pruža lakši put do rezultata, naročito u realnim slučajevima kada je broj aktivnosti znatno veći od 30. Formiranjem baza podataka i njihovim ažuriranjem omogućava se pun doprinosovog postupka kod planiranja završetka projekta i eliminiše se moguća subjektivnost u proceni trajanja pojedinih aktivnosti.

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PLANNING THE TIME OF INVESTMENT PROJECT REALIZATION USING THE FUZZY NUMBER COMPARISON METHOD

Abstract

Planning is one of the most important functions of a construction company management. The planning effectiveness will depend on how accurate the assumptions of the future plan are, in other words to what extent the understanding of previous experiences has been used. In order for the planning to be carried out successfully, it is necessary to constantly monitor and analyze the implementation process, as well as to carry out permanent improvements. A large number of factors influence the fact that a certain degree of uncertainty and imprecision must be taken into account in the process of planning. The most important alternative approach is based on the fuzzy set concept.
Key words*: planning, Possibility Theory, fuzzy sets, probability*

INTRODUCTION

Investment project completion time planning is one of the most important functions of a construction company management. Without planning, the realization is left to disorganized events which in some cases may lead to the interruption in project realization and termination of contracts. In order for the planning to be realistic, rational and economical, it should conform to production capabilities of a company, it should use updated data bases (of projects already completed and market research) and to rely upon contemporary mathematical theory.

Planning effects depend on both accuracy and precision of the assumptions on which the plan should be based, in other words on how the gathered information and acquired experiences are used. In order for the planning to be successful, it is necessary to constantly monitor and analyse the process of realization, to permanently moni-tor and apply new technological solutions and innovations, as well as to carry out improvement, training and education of the personnel. The mistakes that have been noted in planning and organization on one facility should be gathered, systematized and analyzed, so that the adequate solutions would be found and in accordance with them the measures taken to prevent the mistakes from happening again. This is a rational way towards production improvement.

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A large number of factors influence that planning process must take into accountuncertainty or imprecision. This is why deterministic model, which is used most frequently (CPM) becomes quite inappropriate and inapplicable. The classical approach with quantitative treatment of uncertainty uses mathematical tools of Probability Theory (the relationship of favourable and total number of possible outcomes). The Probability Theory approach is of limited application possibilities and there are certain weaknesses in considering the problem where types of uncertainties are different from those calculated as a ratio of the number of favourable and the number of possible outcomes.

The most significant alternative approach was developed by the Californian Professor L. Zadeh [1]. This approach allows for the description of fuzzy events and knowledge, operations over them and drawing conclusions and also represents the basis for the development of the fuzzy set mathematical theory. Fuzzy management is useful in cases when technological processes are complex for the analysis by means of the known methods or when the information available are interpreted qualitatively but uncertainly [2].

FUZZY SET THEORY AND THE NOTION OF POSSIBILITY

Fuzzy set theory provides for the formal system of representation and comprehension of situations when unsecure, subjective and imprecise information appear. In classical modelling the relations are expressed by mathematical functions. As the systems become more complex, it becomes more difficult to apply mathematical modelling, and therefore fuzzy models are used in these situations.

For any given set T whose elements are t real numbers there is a sub-set $T_i \in T$, whose elements are assigned the values of a function $\mu(ti)$ the values of which are real numbers in the interval (0, 1). The sub-set T_i represents a fuzzy set or the so-called fuzzy restriction on the set T. The function $\mu(ti)$ is called the membership function of ti elements on the set T_i. The membership function shape can be entirely arbitrary. Figure 1. represents standard membership functions. Based on the experimental research, the conclusion has been drawn that the standard membership functions can be used to solve the majority of tasks

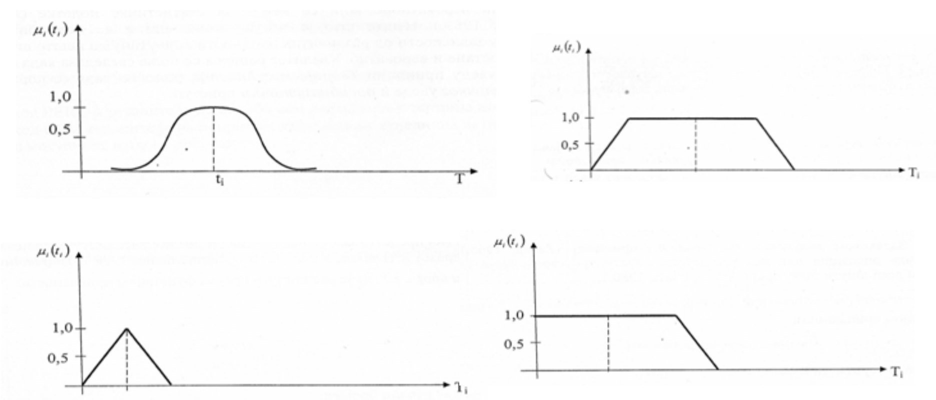

Fig. 1. *Standard membership functions of a fuzzy set*

In the course of construction project realization, in addition to the assessment of its duration as well as the probability of duration of individual activities and the completion of the project entirely or someof its stages, it is also important to determine the possibility of the contractor to complete the foreseen activities, parts of the project or the entire project within the set or contract deadline. The notion of possibility is connected to the capability and readiness of a subject (project contractor) to complete under the set conditions and within the foreseen time the obligations or tasks undertaken and it is different from the notion of probability which is connected to statistical data [3].

The possibility distribution function πi is further defined, for which the following applies:

$$\pi_i(t_i) = Poss\{T_i = t_i\}\,\mu(t_i)$$

and it expresses the possibility that the element $T_i \in T_i$.

For the project consisting of m activities the t_i durations of which are the elements of a T_i fuzzy set, the membership function μ_i represents the possibility of a contractor to complete this activity within some time limit t_i. The function π_i represents a degree of possibility of a contractor and when $\pi_i(t_i)=0$, it is not possible to complete the activity within a time limit. If $\pi_i(t_i)=1$, then the possibility is maximum.

Within the deterministic procedure of the CPM method, the value of this function is:

$$\pi_i(t_i) = \begin{Bmatrix} 1 \; za \; t_i = a_i \\ 0 \; za \; t_i \neq a_i \end{Bmatrix}$$

where a_i is a set or determined value of i activity duration.

The duration of activity t_i as a fuzzy variable and the degree of completion possibility π_i are estimated based on experience.

CALCULATION OF PROJECT DURATION WHEN ACTIVITY DURATIONS ARE FUZZY NUMBERS

Let the given fuzzy numbers be

$\tilde{A} = \left\{x, \mu_{\tilde{A}}(x) \middle| x \in R\right\}$ and

$\tilde{B} = \left\{y, \mu_{\tilde{A}}(y) \middle| y \in R\right\}$. The membership functions of the considered fuzzy numbers are continuous and their values belong to the interval (0, 1).

Let ∗ denote the operation over fuzzy numbers. Then $\tilde{A} * \tilde{B}$ is also a fuzzy number denoted as $\tilde{C} = \tilde{A} * \tilde{B}$, so that $\tilde{C} = \left\{z, \mu_{\tilde{c}}(z) \middle| z \in R\right\}$

where:

$z=x*y$ and the membership function is calculated according to the expansion principle, i.e.

$$\mu_{\tilde{C}}(z) = \sup_{z=x+y} \min(\mu_{\tilde{A}}(x), \mu_{\tilde{B}}(y)).$$

In a special case when fuzzy numbers are linear, in other words when the membership functions are triangular in shape, then the expressions by which we calculate the sum, the difference, the product and the quotient of fuzzy numbers are considerably simpler.

For every α intersection the fuzzy numbers are represented by :

$$\tilde{A} = \left[x_L^\alpha , x_D^\alpha \right] \text{ and } \tilde{B} = \left[y_L^\alpha , y_D^\alpha \right]$$

Then the operations with triangular fuzzy numbers are defined by the following expressions [5].

$$\tilde{C} = \tilde{A}+\tilde{B} = \left\{ z, \mu_{\tilde{C}}(z) \middle| z \in R, \right\}$$

$$z = \left[x_L^\alpha + y_L^\alpha , x_R^\alpha + y_R^\alpha \right]; \ \mu_{\tilde{C}}(z) = \alpha; \ \alpha = [0,1]$$

$$\tilde{C} = \tilde{A}-\tilde{B} = \left\{ z, \mu_{\tilde{C}}(z) \middle| z \in R, \right\}$$

$$z = \left[x_L^\alpha - y_R^\alpha , x_R^\alpha - y_L^\alpha \right]; \mu_{\tilde{C}}(z) = \alpha; \ \alpha = [0,1]$$

$$\tilde{C} = \tilde{A} \cdot \tilde{B} = \left\{ z, \mu_{\tilde{C}}(z) \middle| z \in R, \right\}$$

$$z = \left[x_L^\alpha \cdot y_L^\alpha , x_R^\alpha \cdot y_R^\alpha \right]; \ \mu_{\tilde{C}}(z) = \alpha; \quad \alpha = [0,1]$$

$$\tilde{C} = \tilde{A} : \tilde{B} = \left\{ z, \mu_{\tilde{C}}(z) \middle| z \in R, \right\}$$

$$z = \left[x_L^\alpha / y_R^\alpha , x_R^\alpha / y_L^\alpha \right]; \ \mu_{\tilde{C}}(z) = \alpha; \ \alpha = [0,1]$$

Example:

There are strictly positive fuzzy numbers given $\tilde{A} = \left\{ x, \mu_{\tilde{A}}(x) \middle| x \in [6,10] \right\}$ and $\tilde{B} = \left\{ y, \mu_{\tilde{A}}(y) \middle| y \in [8,10] \right\}$.

$$\mu_{\tilde{A}}(x) = \begin{Bmatrix} \frac{1}{2}x - 3, \ 6 \le x \le 8 \\ -\frac{1}{2}x + 5, \ 8 \le x \le 10 \end{Bmatrix}$$

$$\mu_{\tilde{B}}(x) = \begin{Bmatrix} y - 8, \ 8 \le y \le 9 \\ -y + 10, \ 9 \le x \le 10 \end{Bmatrix}$$

Determine: $\tilde{C} = \tilde{A} + \tilde{B}$

In order to make the marked operations over the given triangular fuzzy numbers, it is necessary to determine the left and right confidence limit for every confidence level $\alpha \in [0,1]$. In other words, it is necessary to determine the extreme values in α intersection of A and B fuzzy numbers.

The left limit value of $\tilde{A}$ fuzzy number for the $\alpha \in [0,1]$ confidence level x_L^α is obtained according to the expression:

$$\frac{1}{2}x_L^\alpha - 3 = \alpha \to x_L^\alpha = 6 + 2\alpha$$

The right limit value of $\tilde{A}$ fuzzy number for the $\alpha \in [0,1]$ confidence level x_R^α is obtained according to the expression:

$$-\frac{1}{2}x_R^\alpha + 5 = \alpha \to x_R^\alpha = 10 - 2\alpha$$

α intersection of a fuzzy number is:

$$\frac{1}{2}A_\alpha = \left[x_L^\alpha , x_R^\alpha \right] = [6 + 2\alpha, 10 - 2\alpha]$$

Analogue to the previous expression we obtain for α intersection of $\tilde{B}$ fuzzy number:

$$B_\alpha = \left[y_L^\alpha , y_R^\alpha \right] = [8 + \alpha, 10 - \alpha]$$

Let us calculate the sum of $\tilde{A}$ and $\tilde{B}$ fuzzy numbers which is marked as $\tilde{C}$. $\tilde{C}$ fuzzy number is formally written down as $\tilde{C} = \left\{ z, \mu_{\tilde{C}}(z) \right\}$.

According to the rule of addition of triangular fuzzy numbers, it follows that:

$$\tilde{C} = [(6 + 2\alpha) + (8 + \alpha), (10 - \alpha) + (10 - 2\alpha] = \\ = [14 + 3\alpha, 20 - 3\alpha]$$

The equations representing the left and right side of the fuzzy number $\tilde{C}$:

$$14 + 3\alpha = z^{\alpha} \rightarrow \alpha = \frac{1}{3} z^{\alpha} - \frac{14}{3}$$

$$20 - 3\alpha = z^{\alpha} \rightarrow \alpha = -\frac{1}{3} z^{\alpha} - \frac{20}{3}$$

The membership function of the fuzzy number $\tilde{C}$ is also triangular in shape and it is formally represented by the following analytical expression:

$$\mu_{\tilde{C}}(z) = \begin{cases} \frac{1}{3} z - \frac{14}{3}, & 14 \le z \le 17 \\ -\frac{1}{3} z + \frac{20}{3}, & 17 \le z \le 20 \end{cases}$$

$\tilde{A}$ and $\tilde{B}$ fuzzy numbers as well as their sum $\tilde{C}$ i.e. fuzzy number are presented in figure 2.

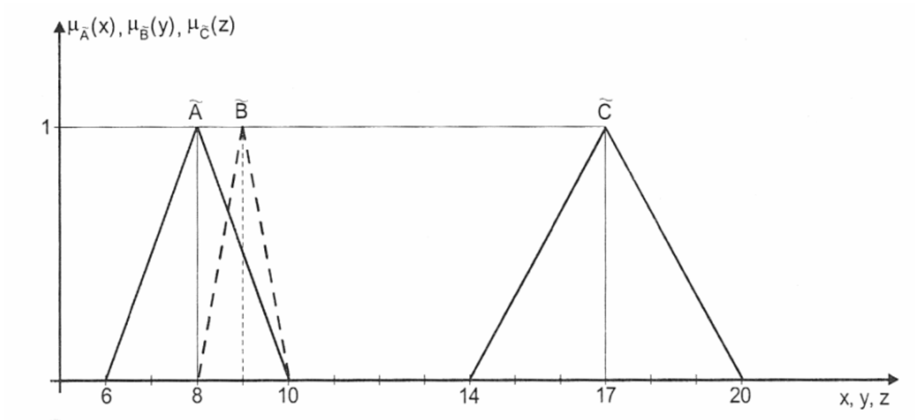

Fig. 2. *Fuzzy numbers* $\tilde{A}, \tilde{B}, \tilde{C}$

The difference, the product and the quotient of fuzzy numbers are calculated similarly.

If the activities Ai, the t_i duration of which is a fuzzy number, are represented by circles or rectangles (precedence diagram), then the time of their earliest and latest completions RZ_i and RK_i are calculated by the following expressions:

$$RZ_i = \max_p \left(RZ_p + t_i \right)$$

$$\pi(RZ_i) = \sup_p \left\{ \min\left[\pi\left(RZ_p \right), \pi(t_i) \right] \right\}$$

$$KZ_i = \min_n (KZ_n - t_i)$$

$$\pi(KZ_i) = \sup \left\{ \min[\pi(KZ_n), \pi(t_i)] \right\}$$

$i = 1, 2, ..., m;\ p = 1, 2, .., m-1;\ n = 2, 3, ..., m$

If the times of activity durations are considered as continuous convex fuzzy variables, then the beginning and ending of the activity which is also continuous are also determined easily.

FUZZY NUMBER COMPARISON

The problem of fuzzy number comparison is the task which is rather frequent in decision-making. For instance, when the alternatives are described by fuzzy numbers, there is a question of how we shall determine which alternative is better than the other. Many works in the literature are dedicated to this problem [4].

In case of determining the time (deadline) of project completion for every activity which is preceded by many other activities, we are faced with the problem of fuzzy number comparison, because the activity durations as well as their early and late completions are also fuzzy numbers. One of the methods we could use in this case is Kaufmann and Gupta's method [4] for fuzzy number comparison. This is a simple method of fuzzy number comparison which is performed in three steps.

Step 1

In this step, we comparet, the „removal" of fuzzy numbers. It the given fuzzy number is $\tilde{M} = \{x, \mu_{\tilde{M}}(x),\}$ so that the *x* value is within the scope of fuzzy number $\tilde{M}$ and $x \in X$.

It the lower or upper limit within the X domain is marked as $\underline{x}$, $\overline{x}$, respectively $\mu_{\tilde{M}}(x)$ is the possibility distribution function of the fuzzy number $\tilde{M}$.

In order to determine „the "removal" of the fuzzy number $\tilde{M}$ in comparison with the real value *k*, we should first define the terms:

- "left removal", $R_L(\tilde{M}, k)$, and
- "right removal", $R_D(\tilde{M}, k)$.

"Left removal" $R_L(\tilde{M}, k)$ is calculated as a surface below the curve of the membership function of the $\tilde{M}$ fuzzy number between the lower limit of the *M* fuzzy number scope and scalar *K*, which is represented by the following expressions:

$R_L(\tilde{M},k) = \int_{\underline{x}}^{k} \mu_{\tilde{M}}(x)$ for continuous fuzzy numbers.

$R_L(\tilde{M},k) = \sum_{i=2}^{k} \frac{\mu_{\tilde{M}}(x_{i-1}) + \mu_{\tilde{M}}(x_i)}{2} \cdot (x_i - x_{i-1})$ for discreet fuzzy numbers.

"Right removal", $R_D(\tilde{M}, k)$ is calculated as a surface below the curve of the membership function of the $\tilde{M}$ fuzzy number between the scalar k to the upper limit of M fuzzy number scope, which is represented by the following expressions:

$R_D(\tilde{M},k) = \int_{k}^{\overline{x}} \mu_{\tilde{M}}(x)$ for continuous fuzzy numbers.

$R_D(\tilde{M},k) = \sum_{i=k+1}^{\overline{x}} \frac{\mu_{\tilde{M}}(x_{i-1}) + \mu_{\tilde{M}}(x_i)}{2}$ for discreet fuzzy numbers.

The total "removal" of $\tilde{M}$ fuzzy number in comparasion to the real number k is calculated according to the expression:

$$R(\tilde{M},k) = \frac{R_L(\tilde{M},k) + R_D(\tilde{M},k)}{2}$$

In case that $\tilde{M}$ fuzzy number has a triangular membership function (k=0), then a half Hamming distance is used:

$$R(\tilde{M},k) = \frac{\underline{x} + 2x' + \overline{x}}{4}$$

where:

$\underline{x}, x', \overline{x}$ - are abscises of the corresponding vertices of a triangular fuzzy number.

Now it the two fuzzy numbers are given be $\tilde{M} = \{x, \mu_{\tilde{M}}(x),\}$ and $\tilde{N} = \{y, \mu_{\tilde{N}}(y)\}$. It is considered that the fuzzy number $\tilde{M}$ is smaller than the fuzzy number $\tilde{N}$ if and only if the following is valid:

$R(\tilde{M},k) < R(\tilde{N},k)$ and vice versa.

Step 2

If it is not possible to determine by step 1 if one fuzzy number is smaller or larger than the other, then we proceed to step 2. This step compares the scope values of both fuzzy numbers which are assigned the highest values of possibility distribution functions.

Formally, step 2 is represented as follows:

- $\max\left(\mu_{\tilde{M}}(x)\right)$ is the assigned value of the fuzzy number $\tilde{M}$ scope which is denoted as $x^*_{\tilde{M}}$
- assigned value of the fuzzy number $\tilde{N}$ scope which is denoted as $x^*_{\tilde{N}}$

Now, it the two fuzzy numbers are given be $\tilde{M} = \left\{x, \mu_{\tilde{M}}(x),\right\}$ and $\tilde{N} = \left\{y, \mu_{\tilde{N}}(y)\right\}$.

It is considered that the fuzzy number $\tilde{M}$ is smaller than the fuzzy number $\tilde{N}$ if and only if the following is valid: $x^*_{\tilde{M}} < x^*_{\tilde{N}}$

Step 3

This step is performed when it is not possible to determine in the first two steps how much one fuzzy number is bigger or smaller than the other. In this step we compare the "bases" of fuzzy numbers.

The term "base" determines a length of the fuzzy number basis.

PRACTICAL USE THE FUZZY NUMBER COMPARISON METHOD

There is a list of general activities with duration in days for an industrial hall (Table 1) which includes the works on the construction site as well as the works on prefabrication the assembling elements.

Table 1. *List of general activities with duration in days*

No. of activities in network layout	Description of activities	l	m	r
1.	Fulfilling the contract obligations towards the contractor	2	3	4
2.	Preliminary works (building of commercial construction site)	5	7	9
3.	Prefabrication of concrete facade elements	24	30	35
4.	Prefabrication of concrete columns and rain-water girders	14	16	18
5.	Removal of humus topsoil and location levelling	3	4	5
6.	Fabrication of the main roof beams (truss)	7	10	12
7.	Construction of transport routes around the facility	9	12	14
8.	Spot footing pits excavation	1	2	3
9.	Fabrication of secondary roof beams (purlins, bracings)	13	15	17
10.	Construction the base for hall floor plate	3	4	5
11.	Excavation of external installation ducts	3	4	5
12.	Making of transport route wearing course	1	2	3
13.	Concreting of spot footings and ground beams	8	10	12
14.	Transport and stockpiling of steel structure	1	3	4
15.	Erection of concrete columns and rain-water girders	2	3	4
16.	Construction of the hall floor slab with waterproofing	4	6	7
17.	Connecting the truss parts into a whole	1	2	3

18.	Laying of external installations	13	15	18
19.	Assembly of the main roof beams (truss)	1	2	3
20.	Assembly of concrete facade elements	4	5	7
21.	Assembly of secondary roof beams	4	5	7
22.	Installation of vitrified facade joinery	6	8	10
23.	Assembly of crane-track support for bridge crane	3	4	5
24.	Assembly of roof covering and hall rain gutters	7	10	12
25.	Installation of skylights	2	3	4
26.	Laying of internal hall installations	10	11	12
27.	Assembly of bridge cranes	8	10	13
28.	Painting and decorating works in the hall	6	7	9
29.	Acceptance of the finished works on the facility	2	3	4
30.	Trial run	8	10	12

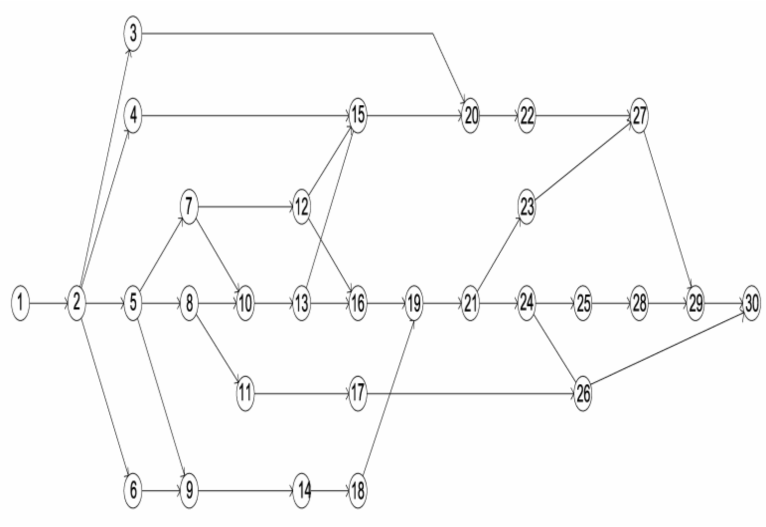

Fig. 3. *Network layout structure analysis*

$$\tilde{R}z1 = \tilde{t}1$$

$$\tilde{R}z1 = [\alpha + 2; 4 - \alpha]$$

$$\tilde{R}z2 = \tilde{R}z1 + \tilde{t}2$$

$$\tilde{t}2 = [2\alpha + 5; 9 - 2\alpha]$$

$$\tilde{R}z2 = [\alpha + 2 + 2\alpha + 5; 4 - \alpha + 9 - 2\alpha]$$

$$\tilde{R}z2 = [3\alpha + 7; 13 - 3\alpha]$$

$$\tilde{R}z3 = \tilde{R}z2 + \tilde{t}3$$

$$\tilde{R}z3 = [3\alpha + 7 + 6\alpha + 24; 13 - 3\alpha + 35 - 5\alpha]$$

$$\tilde{R}z3 = [9\alpha + 31; 48 - 8\alpha]$$

$$\tilde{R}z4 = \tilde{R}z2 + \tilde{t}4$$

$$\tilde{R}z4 = [3\alpha + 7; 13 - 3\alpha] + [2\alpha + 14; 18 - 2\alpha]$$

$$\tilde{R}z4 = [5\alpha + 21; 31 - 5\alpha]$$

$$\tilde{R}z5 = \tilde{R}z2 + \tilde{t}5$$

$$\tilde{R}z5 = [3\alpha + 7; 13 - 3\alpha] + [\alpha + 3; 5 - \alpha]$$

$$\tilde{R}z5 = [4\alpha + 10; 18 - 4\alpha]$$

$$\tilde{R}z6 = \tilde{R}z2 + \tilde{t}6$$

$$\tilde{R}z6 = [3\alpha + 7; 13 - 3\alpha] + [3\alpha + 7; 12 - 2\alpha]$$

$$\tilde{R}z6 = [6\alpha + 14; 25 - 5\alpha]$$

$$\tilde{R}z1 = \tilde{t}1$$

$$\tilde{R}z1 = [\alpha + 2; 4 - \alpha]$$

$$\tilde{R}z2 = \tilde{R}z1 + \tilde{t}2$$

$$\tilde{t}2 = [2\alpha + 5; 9 - 2\alpha]$$

$$\tilde{R}z2 = [\alpha + 2 + 2\alpha + 5; 4 - \alpha + 9 - 2\alpha]$$

$$\tilde{R}z2 = [3\alpha + 7; 13 - 3\alpha]$$

$$\tilde{R}z3 = \tilde{R}z2 + \tilde{t}3$$

$$\tilde{R}z3 = [3\alpha + 7 + 6\alpha + 24; 13 - 3\alpha + 35 - 5\alpha]$$

$$\tilde{R}z3 = [9\alpha + 31; 48 - 8\alpha]$$

$$\tilde{R}z4 = \tilde{R}z2 + \tilde{t}4$$

$$\tilde{R}z4 = [3\alpha + 7; 13 - 3\alpha] + [2\alpha + 14; 18 - 2\alpha]$$

$$\tilde{R}z4 = [5\alpha + 21; 31 - 5\alpha]$$

$$\tilde{R}z5 = \tilde{R}z2 + \tilde{t}5$$

$$\tilde{R}z5 = [3\alpha + 7; 13 - 3\alpha] + [\alpha + 3; 5 - \alpha]$$

$$\tilde{R}z5 = [4\alpha + 10; 18 - 4\alpha]$$

$$\tilde{R}z6 = \tilde{R}z2 + \tilde{t}6$$

$$\tilde{R}z6 = [3\alpha + 7; 13 - 3\alpha] + [3\alpha + 7; 12 - 2\alpha]$$

$$\tilde{R}z6 = [6\alpha + 14; 25 - 5\alpha]$$

$$\tilde{R}z7 = \tilde{R}z5 + \tilde{t}7$$

$$\tilde{R}z7 = [4\alpha + 10; 18 - 4\alpha] + [3\alpha + 9; 14 - 2\alpha]$$

$$\tilde{R}z7 = [7\alpha + 19; 32 - 6\alpha]$$

$$\tilde{R}z8 = \tilde{R}z5 + \tilde{t}8$$

$$\tilde{R}z8 = [4\alpha + 10; 18 - 4\alpha] + [\alpha + 1; 3 - \alpha]$$

$$\tilde{R}z8 = [5\alpha + 11; 21 - 5\alpha]$$

$$\tilde{R}z9 = \max\left[\tilde{R}z5 + \tilde{t}9; \tilde{R}z6 + \tilde{t}9\right]$$

Here we apply the procedure of fuzzy number comparison, in other words we find the largest value of fuzzy numbers:

$$\tilde{R}z5 + \tilde{t}9 = [4\alpha + 10; 18 - 4\alpha] + [2\alpha + 13; 17 - 2\alpha] = [6\alpha + 23; 35 - 6\alpha]$$

$$\tilde{Rz}6 + \tilde{t}9 = \left[6\alpha + 14; 25 - 5\alpha\right] +$$
$$\left[2\alpha + 13; 17 - 2\alpha\right] = \left[8\alpha + 27; 42 - 7\alpha\right]$$

$$R(\tilde{Rz}5 + \tilde{t}9) = \frac{23 + 2 \cdot 29 + 35}{4} = 29{,}0$$

$$R(\tilde{Rz}6 + \tilde{t}9) = \frac{27 + 2 \cdot 35 + 42}{4} = 34{,}75$$

$$R(\tilde{Rz}6 + \tilde{t}9) \succ R(\tilde{Rz}6 + \tilde{t}9)$$

It follows from the last relation for early completion for activity no. 9 is the following fuzzy number:

$$\tilde{Rz}9 \ = \left[8\alpha + 27; 42 - 7\alpha\right]$$

The presented procedure is then analogously applied to all activities taking into account the structure of the given network layout. By this way, we come to the last two activities of the given network layout which are calculated as follows:

$$\tilde{Rz}29 \ = \max\left[\tilde{Rz}27 + \tilde{t}29; \tilde{Rz}28 + \tilde{t}29; \tilde{Rz}26 + \tilde{t}29\right]$$

$$\tilde{Rz}27 + \tilde{t}29 = \left[17\alpha + 57; 92 - 18\alpha\right] +$$
$$+\left[\alpha + 2; 4 - \alpha\right] = \left[18\alpha + 59; 96 - 19\alpha\right]$$

$$\tilde{Rz}28 + \tilde{t}29 = \left[19\alpha + 61; 99 - 19\alpha\right] +$$
$$+\left[\alpha + 2; 4 - \alpha\right] = \left[20\alpha + 63; 103 - 20\alpha\right]$$

$$\tilde{Rz}26 + \tilde{t}29 = \left[18\alpha + 63; 98 - 17\alpha\right] +$$
$$+\left[\alpha + 2; 4 - \alpha\right] = \left[19\alpha + 65; 102 - 18\alpha\right]$$

$$R(\tilde{Rz}27 + \tilde{t}29) = \frac{59 + 2 \cdot 77 + 96}{4} = 77{,}25$$

$$R(\tilde{Rz}28 + \tilde{t}29) = \frac{63 + 2 \cdot 83 + 103}{4} = 83{,}0$$

$$R(\tilde{Rz}26 + \tilde{t}29) = \frac{65 + 2 \cdot 84 + 102}{4} = 83{,}75$$

$$\tilde{Rz}29 \ = \left[19\alpha + 65; 102 - 18\alpha\right]$$

$$\tilde{Rz}30 \ = \tilde{Rz}29 + \tilde{t}30$$

$$\tilde{Rz}30 \ = \left[19\alpha + 65; 102 - 18\alpha\right] +$$
$$+\left[2\alpha + 8; 12 - 2\alpha\right] = \left[21\alpha + 73; 114 - 20\alpha\right]$$

$$\tilde{Rz}30 \ = \left[21\alpha + 73; 114 - 20\alpha\right]$$

The fuzzy number, representing the last activity of Rz30 project, defines the project completion possibility function. In the previous expression, the fuzzy number, representing the last activity, is defined by its α intersections.

Analytical shape of the possibility function is obtained by the following manner:

$$\bar{R}z30 = \left[x_L^{\alpha}, x_R^{\alpha}\right] = \left[21\alpha + 73, 114 - 20\alpha\right]$$

$$x_L^{\alpha} = 21\alpha + 73 \rightarrow \alpha = \frac{x_L^{\alpha} - 73}{21}$$

$$x_D^{\alpha} = 114 + 20\alpha \rightarrow \alpha = \frac{114 - x_D^{\alpha}}{20}$$

whence we get the analytical expression for possibility function:

$$\pi(t) = \begin{cases} \dfrac{t - 73}{21} = 0{,}0476t - 3{,}4762, & 73 \le t \le 94 \\ \dfrac{114 - t}{20} = 5{,}7 - 0{,}05t, & 94 \le t \le 114 \\ 0, & t \notin [73{,}114] \end{cases}$$

Graphic representation of this expression is given in Figure 4.

The difference in computation between the calculation for various specific α values and the calculation where α appears as parameter occurring only in the calculation of Rz29 early completion.
(in comparison the Hamming distance for: $\tilde{R}z28+\tilde{t}29$ and $\tilde{R}z26+\tilde{t}29$)

This is why a slight difference occurred for the project completion.

Similar calculation will be deduced for the calculation of late completion of some activities, for calculation of time reserve, etc.

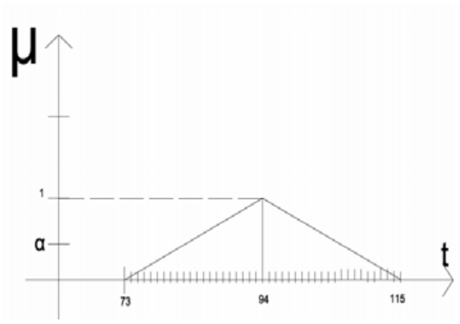

Fig. 4. *Representation of possibility function π(t)*

Project completion obtained by means of α intersection where concrete values were not replaced

The authors of the paper have determined the time of project realization for the given example by probabilistic-possibilistic procedure according to [3]. The difference of the two calculations is that when we apply the fuzzy number comparison method it is necessary to calculate the network layout only once after which the possibility function can be defined (Figure 4).

When we calculate the possibility function using the probability-possibility probabilistic-possibilistic procedure, it is necessary to calculate the entire network layout several times for concrete α parameter values (α=0; 0,25; 0,50; 0,75; 1,0). In other words, it is necessary to calculate the network layout for each α value twice, except for the value α=1, when it is necessary to calculate the network layout only once (Figure 5).

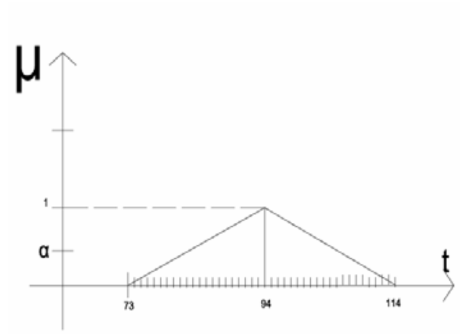

Fig. 5 .*Representation of possibiltiy function π(t)*

Project completion obtained by multiple calculation of network layout by means of α concrete values

(α=0; α=0,25; α= 0,50; α= 0,75 ;α=1,0)

CONCLUSION

The procedure presented in the paper and the specific examples have illustrated the use of Possibility Theory in planning the time of facility completion. The possibility function of the project completion was determined for those respective activities of possibility function, which is known and represented by the appropriate α-sections. This procedure can determine the possibility functions of execution the individual stages of the project. The fuzzy number comparison method, described in detail, was used in order to define the project completion possibility function. The illustrated example contained the total of 30 general activities and the end result suggested that, compared with other methods, the authors used to apply, this procedure which offers the easiest way to the end result, particularly in the real cases when the number of activities exceeds considerably 30. Establishing the data bases and their updating provides the full contribution of this procedure to the project completion planning and eliminates the subjectivity in assessing the possible duration of individual activities.

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IZBOR VARIJANTE TRASE PUTA VIŠEKRITERIJUMSKOM OPTIMIZACIJOM

Izvod

Optimizacija složenih sistema je izuzetno kompleksan proces u kome se objedinjuju teorijska i iskustvena znanja stručnjaka iz više disciplina. Da bi se sa svih stanovišta razmotrio problem optimizacije sistema u građevinarstvu, potrebna su raznorodna razmatranja kao što su inženjerska, ekološka, ekonomska, socijalna i institucionalna. Rezultat optimizacije ima veliku šansu da bude prihvaćen kao dobar kompromis između različitih interesa učesnika u odlučivanju, a jedan od načina da se to postigne jeste nalaženje kompromisnog rešenja. U radu je za izbor optimalne trase autoputa koriščena metoda višekriterijumske optimizacije – metoda kompromisnog programiranja i višekriterijumsko kompromisno rangiranje alternativnih rešenja. Definisani su ciljevi, izvršena je tehno ekonomska analiza varijantnih rešenja, formirani kriterijumi i na kraju prikazano je dobijeno kompromisno resenje .

Ključne reči: *optimizacija, kompromisno programiranje, varijante, kriterijumi, kompromisno rešenje.*

1. UVOD

Autoput Beograd – Južni Jadran predstavlja krak Trans-evropske magistrale (TEM) koji na području Srbije i Crne Gore povezuje osnovni pravac TEM-a (od Gdanjska do Atine i Istambula) sa Jadranskim morem. Na teritoriju Crne Gore iz pravca Srbije trasa autoputa ulazi kod mesta Boljare, a zatim pravcem Berane – Andrijevica – Mateševo – Podgorica – Tanki rt i već izgrađenim tunelom ispod masiva Sozina izlazi na Jadransku obalu, odnosno Luku Bar. Idejnim projektom urađeno je više varijanti pojedinih deonica na koridoru autoputa Beograd – Južni Jadran.

U tom smislu potrebno je izvršiti analizu izbora varijanti trase za dalju razradu u glavnom projektu.

U ovom radu razmatrane su i tehno ekonomski vrednovane dve varijante trase koridora autoputa kroz Crnu Goru na potezu Smokovac (Podgorica) - Uvče koje sadrže veliki broj vijadukata, mostova i tunela, što značajno utiče na troškove projekta. Analiza varijanti i procena troškova imaju za cilj da pomognu investitoru u donošenju odluka o daljim fazama realizacije projekta.

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2. TEHNOEKONOMSKA ANALIZA

Predmet analize je vrednovanje sa tehničkog i ekonomskog stanovišta varijanti autoputa na potezu od Smokovca (Podgorice) do Uvča i to u varijantama definisanim na sledeći način:

1. Varijanta V+V, ide trasom visoke varijante od (km 0+000 - km 9+500) i do Uvča ide takođe varijantom nazvanom Visoka varijanta (L=36,35 km);
2. Varijanta V+N, ide trasom visoke varijante od (km 0+000 - km 9+500), i dalje do Uvča nastavlja trasom nazvanom Niska varijanta (40,80 km).

U okviru ovog rada istražena su varijantna rešenja trase, sa ciljem da se na osnovu upoređenja i vrednovanja izabere povoljnije rešenje trase. Za osnovne kriterijume koje treba da ostvari optimalna varijanta autoputa, a obzirom na kompleksnost tehnoekonomskih zahteva, usvojeni su sledeći ciljevi:

- minimum troškova građenja;
- minimum troškova održavanja predmetne deonice;
- minimum eksploatacionih troškova korisnika;
- maksimum sigurnosti, bezbednosti i udobnosti na predmetnoj deonici;
- maksimalni pozitivni uticaj na ukupan razvoj područja;
- maksimum u pogledu očuvanja prostora i ekologije na datom području.

3. SAOBRAĆAJNI I TEHNIČKI PARAMETRI PO VARIJANTAMA

Kvalitet varijantnog rešenja deonice autoputa u velikoj meri može se opisati saobraćajnim i tehničkim parametarima varijante. Neki od najvažnijih parametara dati su u tabelama 1, 2, 3 i 4.

Tabela 1. *Geometrijske karakteristike varijanti*

Varijanta	Ukupna dužina [km]	Minimalni radijus [m/broj primena]	Maksim. Uzdužni nagib [% na km]
V+V	40,81	450/2	6% - 1,829 km
V+N	36,12	450/2	6% - 0,887 km

Tabela 2. *Nadmorska visina za varijante*

Varijanta	Kote		Nadmorska visina					
	max	min	0-200 [km/%]	200-400 [km/%]	400-600 [km/%]	600-800 [km/%]	800-1000 [km/%]	1000-1200 km/%
V+V	40813	1189	5385 13%	4537 11%	6125 15%	4743 12%	3333 8%	16690 41%
V+N	36124	1189	5385 15%	4383 12%	3962 11%	4116 11%	5381 15%	12897 36%

Tabela 3. *Nagibi nivelete*

Varijanta	Ukupna dužina trase - m	Nagibi nivelete		
		≤2%	2-5%	>5%
V+V	40.813	13.094	19.054	8.664
V+N	36.124	8.689	17.758	9.666

Tabela 4. *Zastupljenost objekata na trasi*

Varijanta	Dužina	Vijadukti i mostovi na levom i desnom kolovozu		Tuneli na levom i desnom kolovozu	
	[km]	broj	[km]	broj	[km]
V+V	40,81	32	10,09	22	21,96
V+N	36,12	38	9,18	26	27,43

4. SAOBRAĆAJNO OPTEREĆENJE

Saobraćajno opterećenje u baznoj godini određeno je na osnovu izveštaja o brojanju saobraćaja Bioče (Luis Berger, oktobar 2007.), odnosno empirijskog i modelskog prosečnog godišnjeg dnevnog saobraćaja (PGDS) u 2007. godini za put M-2, deonica Podgorica – Bioče i put R-19, deonica Bioče – Mateševo. Struktura saobraćajnog toka na budućem autoputu je određena na osnovu permanentnih sedmodnevnih brojanja saobraćaja (tabela 5) na putu M-2, deonica Podgorica – Bioče u toku meseca oktobra 2007. godine. Na osnovu navedenih podataka i pretpostavki sračunato je saobraćajno opterećenje (PGDS) za buduću deonicu autoputa Smokovac – Uvač (tabela 6.) u periodu 2008 – 2027.

Tabela 5. *Struktura saobraćajnog toka*

Kategorija	PA	BUS	LT	ST	TT	AV	Ukupno
Učesće %	79.7	2.5	4.4	5.0	1.5	6.9	100

Tabela 6. *Prognoze za PGDS*

Godina	PA	BUS	LT	ST	TT	AV	PGDS (voz/dan)
2007	4623	143	257	292	86	399	5800
2008	5085	157	283	321	95	439	6380
2009	5594	173	311	353	104	483	7018
2010	6153	190	342	389	115	531	7720
2011	6769	209	377	427	126	584	8492
2012	7073	218	394	447	132	610	8874
2013	7391	228	411	467	138	638	9273
2014	7724	239	430	488	144	667	9691
2015	8072	249	449	510	150	697	10127
2016	8378	259	466	529	156	723	10511
2017	8697	269	484	549	162	751	10911
2018	9027	279	502	570	168	779	11325
2019	9370	289	521	592	175	809	11756
2020	9726	300	541	614	181	839	12203
2021	10096	312	562	637	188	871	12666
2022	10479	324	583	662	195	904	13148
2023	10878	336	605	687	203	939	13647
2024	11291	349	628	713	210	974	14166
2025	11720	362	652	740	218	1012	14704
2026	12165	376	677	768	227	1050	15263
2027	12628	390	703	797	235	1090	15843

5. TROŠKOVI IZGRADNJE

Procena troškova izgradnje urađena je na osnovu strukture trase i objekata (mostova, vijadukata i tunela itd.) i procene cena za ove objekte. Procena cena (tabela 7.) urađena je na osnovu do sada urađenih projekata, odnosno tržišnih cena za ovu vrstu radova. Jedinične cene za mostove utvrđene su kao prosečne cene na osnovu pojedinačno utvrđenih cena za svaki most. Procena troškova radova na tunelima izvršena je na osnovu prosečne cene 1 m tunelske cevi (za levi, odnosno desni kolovoz u zavisnosti od dužine i usvojena je ista za tunele na visokoj, odnosno niskoj trasi). Na sličan način određeni su i troškovi građenja ostalih objekata, na osnovu tih elemenata su definisani troškovi građenja.

Tabela 7. *Ukupni troškovi građenja po varijantama*

Red. br.	Oznaka varijante	Ukupna dužina [km]	Ukupan iznos troškova građenja (€)	Prosečna cena po km (€/km)
1	V+V	40,80	649.056.603	15.903.182,88
2	V+N	36,10	639.725.443	17.709.153,00

6. TROŠKOVI ODRŽAVANJA

Pod troškovima održavanja podrazumevaju se troškovi:

- redovnog održavanja,
- investicionog održavanja i
- zimskog održavanja.

Redovno održavanje obuhvata sanaciju oštećenja: kolovoza, rigola, ostalih objekata za odvodnjavanje, saobraćajne signalizacije i dr. **Investiciono održavanje** obuhvata obnovu habajućeg sloja asfalta. **Zimsko održavanje** obuhvata održavanje puteva u zadovoljavajućem stanju u toku zimskog perioda. Ukupni troškovi održavanja po varijantama sračunati su prema [3] i dati u tabeli 8.

Tabela 8. *Ukupni troškovi održavanja po varijantama*

Redni broj	Naziv varijante	Ukupna dužina [km]	Ukupni troškovi održavanja (€/god)
1	V+V	40,80	1.403.036,00
2	V+N	36,10	1.246.085,00

7. EKSPLOATACIONI TROŠKOVI

Troškovi eksploatacije koji su razmatrani u ovim radu obuhvataju sledeće troškove:

- troškove goriva
- troškove maziva,
- troškove pneumatika,
- troškove održavanja i popravke vozila.

Troškovi goriva, maziva, pneumatika, održavanja i popravki vozila izračunati su prema izrazima [3] i oni iznose (Vrednosti u tabeli 9.)

Tabela 9. *Prosečni eksploatacioni troškovi po varijantama*

Red. broj	Naziv varijante	Ukupna dužina [km]	Ukupni prosečni ekspl. troškovi (€/god)
1	V+V	40,80	28.869.724
2	V+N	36,10	26.139.172

8. TROŠKOVI SAOBRAĆAJNIH NEZGODA

Ukupni ekonomski troškovi koje izazovu sve saobraćajne nesreće na potezu puta u toku jedne godine, određuju se prema formuli prema [3] :

$$T_{su} = L \times \sum_k N_k \times C_k \quad (€/god)$$

gde je:

k - oznaka vrste nezgode (1 - nezgode sa smrtonosnim povredama; 2 - nezgode sa teškim telesnim povredama; 3 - nezgode bez teških telesnih posledica)

N_k - prosečan broj saobraćajnih nezgoda po kilometru godišnje, za određenu vrstu nezgode k (nezgoda/km.god). Ova vrednost zavisi od tipa puta i PGDS.

L - dužina dela varijante (km),

C_k - prosečni ekonomski troškovi po jednoj nezgodi za k - tu vrstu nezgode (€)

Pregled ovih troškova dat je u tabeli 10.

Tabela 10. *Troškovi saobraćajnih nezgoda*

Redni broj	Naziv varijante	Ukupna dužina [km]	Prosečni troškovi saobraćajnih nezgoda (€/god)
1	V+V	40,80	261.692,00
2	V+N	36,10	231.627,00

9. UTICAJ NA UKUPAN RAZVOJ PODRUČJA

Parametri koji utiču na ukupan razvoj područja vrednovani su kroz sledeće stavke:

a) trasa u prostornom sukobu (sukob sa prostornim planovima vrednuje se kroz dužinu takve trase ili bodovima);
b) očuvanje postojećih naselja i podsticanje buduće urbanizacije (vrednovanje bodovima);
c) očuvanje poljoprivrednih i šumskih površina (vrednuje se bodovima);
d) realnost izvođenja, koja se vrednuje na osnovu potrebe za raseljavanjem, mogućnosti nabavke potrebnog materijala (za nasipe) i sl..

Ocene vrednovanja su date u tabeli 11.

Tabela 11.

Red. broj	Varijante	OCENA POKAZATELJA PO VARIJANTAMA			
		Trasa u prostornom sukobu sa usvojenim PP	Očuvanje postojećih naselja, podsticanje urbanističkog uređenja	Očuvanje poljoprivrednih i šumskih površina	Realnost izvođenja
		1	2	3	4
1	Visoka varijanta od 0,0 km do 9,5 km + Visoka do Uvča	100	100	45	100
2	Visoka varijanta od 0,0 km do 9,5 km + Niska do Uvča	100	100	100	100

10. PROSTORNO-EKOLOŠKE POSLEDICE

Razmatrano je i analizirano više parametara:

- **aerozagađenje -** na osnovu broja objekata u zoni autoputa izloženih aerozagađenju, **zagađenje površinske vode, podzemne vode i izvorišta vode za piće** - na osnovu blizine trase i vodotoka, presecanja vodotokova trasom autoputa, blizine izvorišta,
- **gubitak i zagađenje poljoprivrednog i šumskog zemljišta** - na osnovu površine zemljišta zahvaćenog trasom autoputa,
- **biotički faktor u tokom građenja i u toku eksploatacije -** na staništa flore i faune uticaj trase autoputa je vrednovan na osnovu dužine trase na otvorenom (tuneli nemaju uticaja),
- **zdravlje stanovništva** - na delovima gde trasa autoputa prolazi kroz ili pored naseljenih mesta,
- **sociološke prilike** - raseljavanja ili dislociranje stambenih i drugih objekata; ukidanje, dislociranje ili presecanje postojećih komunikacija; izmenjeni uslovi života usled smeštaja u prostor novih fizičkih struktura,
- **buka i vibracije** - definisane su dužine na kojima su te pojave izražene i izvršeno je njihovo vrednovanje,
- **zaštićeno prirodno nasleđe** - postojanja kolizionih tačaka trase autoputa sa prirodnim objektima,
- razmatrano je postojanje lokaliteta koji su svrstani u zaštićene **kulturno-istorijske spomenike** na trasama varijanti autoputa,
- **promena prirodnog izgleda terena-pejzaža** javlja se na onim delovima trase koja je vidljiva odnosno na onim deonicama na kojima se put izvodi u useku, nasipu, kao i gde se prepreke savlađuju mostovima, nadvožnjacima i drugim nadzemnim konstrukcijama.

Ocene su date u tabeli 12.

Tabela 12. *Ocene vrednovanja prostorno-ekoloških kriterijuma*

Red. broj	Varijante	Min. aeroza-gađenje	Min.zag ađenja voda	Min. gubitak i zagađenja zemljišta	Min uticaja na biotički faktor	Min. uticaja na popula-ciono zdravlje i sociološke faktore	Min. buke i vibracija	Min. dodir sa zaštiće-nim prirod-nim područjima	Min. negativnih uticaja na kulturno-istorijske spomenike	Min. uticaja na pejzaž
+	+	+	+	+	+	+	+	+	+	+
1.	Visoka varijanta od 0,0 km do 9,5 km + Visoka do Uvča	90	85	65	70	85	85	95	100	50
2.	Visoka varijanta od 0,0 km do 9,5 km + Niska do Uvča	90	85	80	80	85	85	95	100	60

**povoljnije varijante su ocenjene većom ocenom(bodovima)*

11. KRITERIJUMI VREDNOVANJA I PRIMENJENE METODE

Za određivanje optimalne varijante potrebno je uzeti u obzir sve navedene saobraćajne i tehničke parametre i na osnovu njih formirati kriterijume.

Mera ostvarenja ciljeva može se iskazati definisanjem sledećih kriterijuma:

- minimalni troškovi građenja;
- minimalni troškovi održavanja;
- minimalni eksploatacioni troškovi;
- maksimalna sigurnost, bezbednost i udobnost saobraćaja, (što odgovara minimalnim troškovima saobraćajnih nezgoda);
- maksimalan uticaj na razvoj područja;
- minimalne prostorno-ekološke posledice (što odgovara maksimalnoj zaštićenosti od dejstva negativnog uticaja).

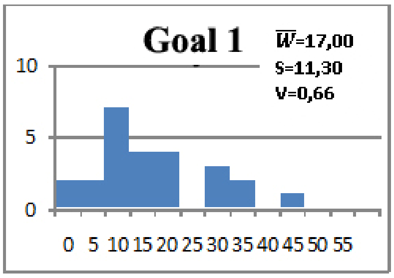
Tabela 13. *Raspodela odgovora za cilj 1 i cilj 2*

Red. broj	Kriterijum vrednovanja	Oznaka kriterijuma	Relativna težina kriterijuma
1.	Minimum troškova građenja	w_1	0.17
2.	Minimum troškova održavanja	w_2	0.16
3.	Maksimum dobiti za korisnike puta (minimalni troškovi eksploatacije)	w_3	0.164
4.	Maksimum sigurnosti, bezbednosti i udobnosti saobraćaja (minimalni troškovi saobraćajnih nezgoda)	w_4	0.24
5.	Maksimum uticaja na razvoj područja	w_5	0.146
6.	Minimum uticaj na prostorno – ekološke posledice (maksimalna zaštićenost od dejstva negativnih uticaja)	w_6	0.12

Težine kriterijumskih (tabela 13.) funkcija mogu se odrediti na više različitih načina. U ovom radu izbor težina baziran je na primeni DELFI metode. S obzirom da se radi o ekspertskoj oceni (slika 1 i 2) jednog multidiscliplinarnog projekta, anketirani učesnici (eksperti) njih 30 su izabrani tako da svojim znanjem i iskustvom koje su stekli na sličnim problemima, u najvećoj meri mogu odgovoriti zahtevima analize. Relativne težinske vrednosti kriterijuma W_j određene su ekspertnim analizama

Obzirom na heterogenost pokazatelja vrednovanja varijanti, primenjena je metoda višekriterijumske optimizacije – metoda kompromisnog programiranja i višekriterijumsko kompromisno rangiranje alternativnih rešenja.

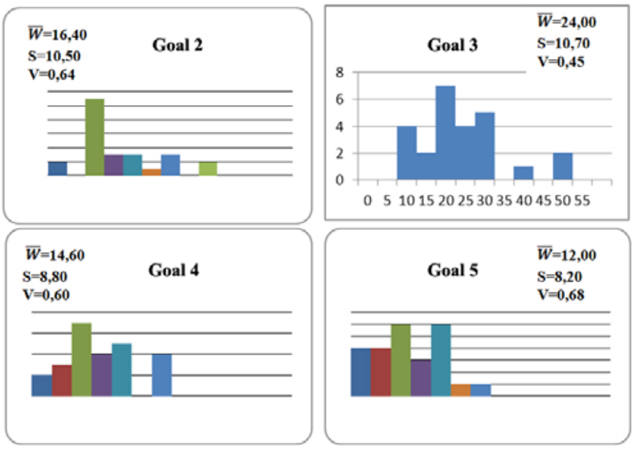
Ovom metodom prvo se određuju rešenja koja su optimalna po pojedinim kriterijumima, a zatim se određuju kompromisna rešenja, koja se predlažu donosiocu odluke.



Sl. 1. *Raspodela odgovora za cilj 1 i 2*

Donosilac odluke usvaja jedno konačno rešenje, a u mogućnosti je da sagleda sve dobiti i nezadovoljenje pojedinih kriterijuma što pruža dobru osnovu za rad.

Zadavanjem raznih vrednosti težina (značaja) kriterijuma može se analizirati stabilnost pozicije alternative na višekriterijumskoj rang listi u zavisnosti od konkretnih zahteva donosioca odluke.



Sl. 2. *Raspodela odgovora za ciljeve 3,4, 5 i 6*

Tabela 14. *Težine ciljeva i kriterijumskih funkcija*

Cilj	W	Pokazatelji	Wrel	Krit.f.	Wrel	fi	Wi
Minimalni troškovi građenja	0,17			Ukupni troškovi građenja u €		1	0,17
minimalni troškovi održavanja	0,16			Troškovi održavanja u €/god		2	0,16
minimalni eksplotacioni troškovi	0,164			Eksploatacioni troškovi u €/god		3	0,164
Minimalni troškovi saobr.nezgoda (maksimalna sigurnost i bezbednost)	0,24			Troškovi saobraćajnih nezgoda u €/god		4	0,24
Maksimalni pozitivni uticaj na razvoj područja	0,146	Trasa u prostornom sukobu sa usvojenim PP		Usklađenost sa PP *	0,15	5	0,022
		Očuvanje postojećih naselja i podsticanje urbanističkog uređenja		Ocena očuvanja i podsticanja budućeg urban.uređenja *	0,20	6	0,029
		Očuvanje poljop. I šumskih površina		Površina zemljišta pod nepovolj.uticajem*	0,30	7	0,044
		Realnost izvođenja		Potrebe za raseljavanjem, mogućnost nabavke materijala, etapnost gradnje *	0,35	8	0,051
Minimalne Prodstorno-ekološke posledice	0,12	Min. aerozagađenje		Broj objekata izloženih zagađenju u zoni autoputa izražena u bodovima**	0,12	9	0,014
		Min.zagađenja voda		Dužina trase u blizini vodotoka**	0,13	10	0,016
		Min. gubitak i zagađenja zemljišta		Površina zemljišta pod nepovolj.uticajem**	0,13	11	0,016
		Min uticaja na biotički faktor		Dužina trase u usecima i nasipima**	0,10	12	0,012
		Min. uticaja na populac.zdravlje i soc.faktore		Ocena uticaja na populac.zdravlje i soc.faktore	0,12	13	0,014
		Min. buke i vibracija		Broj objekata u zoni autoputa**	0,10	14	0,012
		Min. dodir sa zaštić. prirodnim područjima		Dužina trase koja preseca zašt.prir.područje**	0,10	15	0,012
		Min. Negat.uticaja na kult.-istor.spomenike		Broj kult.-istorij.spomenika na trasi autoputa**	0,10	16	0,012
		Min. uticaja na pejzaž		Dužina trase u useku,nasipu, nadzem.k-jama**	0,10	17	0,012

**povoljnije varijante su ocenjene većim ocenama (bodovima)*

Tabela 15. *Vrednosti kriterijumskih funkcija*

	Kriterijumska funkcija	jedinica	ekst.	varijanta VV	Varijanta VN	f_i^*	f_i^-
1.	Ukupni troškovi građenja u €	€	min	649056603,00	639725443,00	639725443,00	649056603,00
2.	Troškovi održavanja	€/god	min	1403036,00	1246085,00	1246085,00	1403036,00
3.	Troškovi eksploatacije	€/god	min	28869724,00	26139172,00	26139172,00	28869724,00
4.	Troškovi saobraćajnih nezgoda u €/god	€/god	min	261692,00	231627,00	231627,00	261692,00
5.	Usklađenost sa Prostornim Planom *	bod	max	100,00	100,00	100,00	100,00
6.	Ocena očuvanja i podsticanja budućeg urbanističkog uređenja *	bod	max	100,00	100,00	100,00	100,00
7.	Površina zemljišta pod nepovoljnim uticajem*	bod	max	100,00	45,00	100,00	45,00
8.	Potrebe za raseljavanjem, mogućnost nabavke materijala, etapnost gradnje *	bod	max	100,00	100,00	100,00	100,00
9.	Broj objekata izloženih zagađenju u zoni autoputa izražena u bodovima**	bod	max	90,00	90,00	90,00	90,00
10.	Dužina trase u blizini vodotoka**	bod	max	85,00	85,00	85,00	85,00
11.	Površina zemljišta pod nepovolj.uticajem**	bod	max	80,00	65,00	80,00	65,00
12.	Dužina trase u usecima i nasipima**	bod	max	80,00	70,00	80,00	70,00
13.	Ocena uticaja na populac.zdravlje i soc.faktore**	bod	max	85,00	85,00	85,00	85,00
14	Broj objekata u zoni autoputa**	bod	max	85,00	85,00	85,00	85,00
15.	Dužina trase koja preseca zašt.prir.područje**	bod	max	95,00	95,00	95,00	95,00
16.	Broj kult.-istorij.spomenika na trasi autoputa**	bod	max	100,00	100,00	100,00	100,00
17.	Dužina trase u useku,nasipu, nadzem.k-jama**	bod	max	60,00	50,00	60,00	50,00

***povoljnije varijante su ocenjene većim ocenama (bodovima)*

Primenom kompjuterskog programa zasnovanog na metodi VIKOR (Tabela 16) dobijamo sledeće:

Lista alternativa: A 1. VV varijanta, A 2. VN varijanta

Tabela 16. *Rang liste po varijantama*

QR – Minimax strategija	Q – Kompromis	QS – Vecinska korist
R.L.QR	R.L.Q i Q(J)	R.L.QS
A 2 0.044	A 2 0.000	A 2 0.084
A 1 0.240	A 1 1.000	A 1 0.734

Tabela 17. *Analiza preferentne stabilnosti*

F(i)	WD1	WO(i)	WGl	F(i)	WD1	WO(i)	WGl
F 1	0.000	0.170	1,000	F10	0.000	0.016	1,000
F 2	0.000	0.160	1,000	F11	0.000	0.016	0.196
F 3	0.000	0.164	1,000	F12	0.000	0.012	0.195
F 4	0.000	0.240	1,000	F13	0.000	0.014	1,000
F 5	0.000	0.022	1,000	F14	0.000	0.012	1,000
F 6	0.000	0.029	1,000	F15	0.000	0.012	1,000
F 7	0.000	0.044	0.201	F16	0.000	0.012	1,000
F 8	0.000	0.051	1,000	F17	0.000	0.012	0.195
F 9	0.000	0.014	1,000				

W0(i) su normalizovane vrednosti ulaznih-zadatih težina. WD1 ≤ w ≤ WG1 je interval težine u kojem alternativa sa prve pozicije ostaje na njoj (stabilna pozicija). Promena prve pozicije za alternativu **A 2** može nastati ako dođe do promene težine kriterijuma F7, F11, F12, F17 odnosno ako vrednosti težina za te kriterijume (tabela 17.) budu veće od 0,201; 0,196; 0,195; 0,195 respektivno.

12. ZAKLJUČAK

Potreba za kompromisnim rešenjem je izraženija za rešavanje zadataka sa konfliktnim i heterogenim kriterijumima (suprostavljenim i izraženim u različitim jedinicama mere) kao što je slučaj u ovom radu. Rezultat VKO ima veliku šansu da bude prihvaćen kao dobar kompromis izmedju različitih interesa učesnika u odlučivanju ako je ono prihvatljivo od većine u procesu odlučivanja, ali i da nema loše krtiterijumske pokazatelje zbog kojih bi «oponenti» imali izraziti razlog da ga ne prihvate.

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SELECTION OF THE HIGHWAY ROUTE VARIANT BY MULTICRITERION OPTIMIZATION

Abstract

Optimization of complex systems is extremely complex which brings together theoretical and experimental knowledge of experts from multiple disciplines. In order to consider from all aspects the optimization problem of system in construction, diverse considerations are needed as engineering, environmental, economic, social and institutional. The optimization result has a great chance to be accepted as a good compromise between different interests of participants in decision making, and one of the ways to achieve this is to find a compromise solution. The method of multicriterion optimization, i.e. the method of compromise programming and multicriterion compromise ranking of alternative solutions, is used in this work for selection the optimum route of highway. The objectives were defined, a techno-economic analysis of variant solutions was carried out, the criteria were established and, at the end, the obtained compromise solution is shown.

Key words: *optimization, compromise programming, variants, criteria, compromise solution*

1. INTRODUCTION

The highway Belgrade – South Adriatic is a branch of the Trans-European highway (TEHW) that, on the territory of Serbia and Montenegro, connects the main line of TEHW (from Gdansk to Athens and Istanbul) to the Adriatic Sea. On the territory of Montenegro, from direction of Serbia, the highway route enters near place of Boljare, and then the route of Berane – Andrijevica – Mateševo – Podgorica – Tanki rt and with already built tunnel under the massif of Sozina gets out to the Adriatic coast, respectively the Port of Bar. The preliminary design has done several versions of the certain sections in the corridor of Beolgrade – South Adriatic highway.

In this regard, it is necessary to analyze the choice of route options for further development in the main project.

This work also considered the techno-economically evaluated two route variants of the highway corridor through Montenegro on the move to Smokovac (Podgorica) - Uvče containing a great number of viaducts, bridges and tunnels, what significantly affects the project costs. Variant analysis and estimation of costs are intended to assist the investors in decision making on further stages of the project implementation.

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2. TECHNO-ECONOMIC ANALYSIS

The subject of analysis is to evaluate, from technical and economical point of view, the variants of highway on the move from Smokovac (Podgorica) to Uvča, in the variants defined as follows:

1. Variant V+V, goes through the route of high variant from (km 0+000 - km 9+500) and to Uvča also goes with the variant called the High variant (L=36.35 km);
2. Variant V+N, goes through the route of high variant from (km 0+000 - km 9+500), and still continues to the route of Uvča, called the Low variant (40.80 km).

Within the scope of this work, the alternative solutions of route were investigated, in order to select more favorable solution of the route, based on comparison and evaluation. For basic criteria that should be achieved by the optimum variant of highway, and regarding to the complexity of techno-economic requirements, the following objectives are adopted:

- Minimum costs of construction;
- Minimum maintenance costs of the relevant section;
- Minimum exploitation costs of the user;
- Maximum safety, security and comfort on the relevant section;
- Maximum positive impact on overall development of the area;
- Maximum in terms of area and environmental protection in the given area.

3. TRAFFIC AND TECHNICAL PARAMETERS ACCORDING TO THE VARIANTS

The quality of variant solution of the highway section to a large extent can be described by traffic and technical parameter of variant. Some of the most important parameters are given in Tables 1, 2, 3 and 4.

Table 1. *Geometrical characteristics of variants*

Variant	Total length [km]	Minimum radius [m/no. of usages]	Maximum longitudinal slope [% per km]
V+V	40.81	450/2	6% - 1.829 km
V+N	36.12	450/2	6% - 0.887 km

Table 2. *Altitude variations*

Variant	Elevations		Altitude					
	max	min	0-200 [km/%]	200-400 [km/%]	400-600 [km %]	600-800 [km/%]	800-1000 [km/%]	1000-1200 km/%
V+V	408 13	118 9	5385 13%	4537 11%	6125 15%	4743 12%	3333 8%	16690 41%
V+N	361 24	118 9	5385 15%	4383 12%	3962 11%	4116 11%	5381 15%	12897 36%

Table 3. *Slopes of level*

Variant	The total length of the route - m	Slopes of the level		
		≤2%	2-5%	>5%
V+V	40.813	13.094	19.054	8.664
V+N	36.124	8.689	17.758	9.666

Table 4. *Inclusion of facilities along the route*

Variant	Length	Viaducts and bridges on the left and right roadway		Tunnels on the left and right roadway	
	[km]	Number	[km]	Number	[km]
V+V	40.81	32	10.09	22	21.96
V+N	36.12	38	9.18	26	27.43

Table 5. *Structure of traffic flow*

Category	PA	BUS	LT	ST	TT	AV	TOTAL
Participation %	79.7	2.5	4.4	5.0	1.5	6.9	100

4. TRAFFIC LOAD

Traffic load in the base year is determined on the basis of reports of traffic counting Bioče (Louis Berger, October 2007), or empirical and modeling annual average daily traffic (AADT) in 2007 for the road M-2, section Podgorica – Bioče and the road R-19, section Bioče – Mateševo.

Structure of traffic flow in the future highway is determined based on permanent seven-day traffic count (Table 5) on the road M-2, section Podgorica – Bioče in October 2007.

Based on the mentioned data and assumptions, the traffic load (AADT) for future highway section Smokovac – Uvač (Table 6) was calculated in the period 2008 – 2027.

5. CONSTRUCTION COSTS

Estimation of construction costs was made on the basis of route structures and facilities (bridges, viaducts and tunnels, etc.) and price evaluation for these facilities. Price estimation (Table 7) was made on the basis of previously realized projects, respectively the market prices for this type of works. Unit prices for bridges are determined as the average prices based on individually determined prices for each bridge. Estimation the cost of works on tunnels was carried out on the basis of the average price 1 m of tunnel tube (for the left or right roadway depending on length, and the same was adopted for tunnels at high or low route).

Table 6. *Forecasts for AADT*

Year	PA	BUS	LT	ST	TT	AV	PGDS (drive/day)
2007	4623	143	257	292	86	399	5800
2008	5085	157	283	321	95	439	6380
2009	5594	173	311	353	104	483	7018
2010	**6153**	**190**	**342**	**389**	**115**	**531**	**7720**
2011	6769	209	377	427	126	584	8492
2012	7073	218	394	447	132	610	8874
2013	7391	228	411	467	138	638	9273
2014	7724	239	430	488	144	667	9691
2015	8072	249	449	510	150	697	10127
2016	8378	259	466	529	156	723	10511
2017	8697	269	484	549	162	751	10911
2018	9027	279	502	570	168	779	11325
2019	9370	289	521	592	175	809	11756
2020	**9726**	**300**	**541**	**614**	**181**	**839**	**12203**
2021	10096	312	562	637	188	871	12666
2022	10479	324	583	662	195	904	13148
2023	10878	336	605	687	203	939	13647
2024	11291	349	628	713	210	974	14166
2025	**11720**	**362**	**652**	**740**	**218**	**1012**	**14704**
2026	12165	376	677	768	227	1050	15263
2027	12628	390	703	797	235	1090	15843

Table 7. *Total construction costs by variants*

Ord.No.	**Designation of variant**	**Total length**	**Total amount of construction costs**	**Average price per km**
		[km]	**(€)**	**(€/km)**
1	V+V	40.80	649,056,603	15,903,182.88
2	V+N	36.10	639,725,443	17,709,153.00

6. MAINTENANCE COSTS

The maintenance costs include the costs of:

- regular maintenance,
- investment maintenance, and
- winter maintenance.

Regular maintenance includes the repair of damage: the roadway, gutters, other drai age facilities, traffic signals, etc. **Investment maintenance** includes the restoration of asphalt wearing layer. **Winter maintenance** includes the maintenance of roads in satisfactory condition during the winter period. Total maintenance costs are calculated by variants in [3] and given in Table 8.

Table 8. *Total maintenance costs by variants*

Ord.No.	Designation of variant	Total length [km]	Total costs of maintenance (€/year)
1	V+V	40.80	1,403,036.00
2	V+N	36.10	1,246,085.00

7. EXPLOITATION COSTS

Exploitation costs, discussed in this paper, include the following costs:

- fuel costs
- costs of lubricants,
- costs of pneumatics,
- maintenance costs and repair of vehicles.

The costs for fuel, lubricants, pneumatics, vehicle maintenance and repair are calculated according to the expressions [3] to the amount of (values in Table 9):

Table 9 *Average exploitation costs by variants*

Ord. No.	Designation of variant	Total length [km]	Total average exploitation costs (€/year)
1	V+V	40.80	28.869.724
2	V+N	36.10	26.139.172

8. COSTS OF TRAFFIC ACCIDENTS

Total economic costs caused by all traffic accidents on the move of road in one year, are determined by the formula [3] :

$$T_{su} = L \times \sum_{k} N_k \times C_k \quad (€/god)$$

where:

k – indication of accident type (1 –accident with deadly injuries; 2 – accidents with serious body injuries; 3 – accidents without serious body injuries).

Table 10. *Average exploitation costs by variants*

Ord. No.	Designation of variant	Total length [km]	Average costs of traffic accidents (€/year)
1	V+V	40.80	261.692,00
2	V+N	36.10	231.627,00

N_k – average number of accidents per kilometer per year, for the certain types of accidents k (accident/km/year). This value depends on the type of road and AADT.

L - length of a part of variant (km),

C_k- average economic costs per accident for k – this type of accident (€)

Overview of these costs is given in Table 10.

9. IMPACT ON THE OVERALL DEVELOPMENT OF AREA

Parameters that affect the overall development of the area have been avaluated through the following items:

- route in the spatial conflict (conflict with regional plans is evaluated through the length of such track, or points);
- preservation of existing settlements and encouragement of future urbanization (evaluation of points);
- preservation of ugricultural and forest areas (is evalued by points);
- the reality of performance, which is evaluated based on the need for resettlement, the possibility of obtaining the necessary material (for embankments), etc..

Assessments for evaluation are given in Table 11.

Table 11. *Ratings of individual criteria evaluation indicators, impact on the overall development of area*

Ord. No.	Variants	EVALUATION INDICATORS BY VARIANTS			
		Route in spatial conflict with the adopted PP	Preservation of the existing settlements, encouragement of urban planning	Preservation of agricultural and forest areas	Reality of realization
		1	2	3	4
1	**High variant from 0.0 km to 9.5 km + High to Uvča**	100	100	45	100
2	**High variant from 0.0 km to 9.5 km + Low to Uvča**	100	100	100	100

9. SPATIAL-ECOLOGICAL CONSEQUENCES

Several parameters were considered and analyzed:

- **air pollution –** based on the number of facilities in the highway zone exposed to air pollution, **pollution of surface water, ground water and sources of drinking water** – based on vicinity of route and watercourses, intersection of watercourses by the highway route, vicinity of water sources,
- **loss and pollution of agricultural and forest land** – based on the surface of affected land by the highway route,
- **biotic factor during construction and exploitation -** on living habitat of flora and fauna, impact of the motorway was evaluated on the basis of the highway route length in the open (tunnels have no effect),
- **health of population** – in the parts where the highway route passes through or near settlements,
- **sociological opportunities** – displacement or dislocation of housing and other facilities; suspension, dislocation or interception the existing communication; changed living conditions due to housing in the area of new physical structures,
- **noise and vibration** – lengths were defined at which this phenomenon is expressed and their evaluation was made,
- **protected natural heritage** – the existence of collision points of the highway route with natural objects,
- existence of sites were discussed that are classified as the **cultural and historical monuments** on the routes of highway variants,

- **changes in natural look of terrain-landscape** occurs in those parts of the route that is visible, respectively in those sections where the road runs in the cut, embankment, and where the obstacles are overcome by bridges, overpasses and other overhead constructions.

Ratings are given in Table 12.

Table 12. *Ratings of evaluation the spatial-ecological criteria*

Ord. No.	Variants	Minimum air pollutin	Minimum water pollution	Minimum loss and land pollution	Minimum impact on biotic factor	Minimum impact on population health and sociological factors	Minimum noise and vibration	Minimum contact with protected natural areas	Minimum negative impact on cultural-historical monuments	Minimum impact on landscape
+	+	+	+	+	+	+	+	+	+	+
1.	High variant from 0.0 km to 9.5 km + High to Uvča	90	85	65	70	85	85	95	100	50
2.	High variant from 0.0 km to 9.5 km + Low to Uvča	90	85	80	80	85	85	95	100	60

**favorable variants are rated with higher grade (points)*

10. EVALUATION CRITERIA AND THE APPLIED METHODS

To determine the optimum variant, it is necessary to take into account all traffic and technical parameters and to form the criteria based on them.

Measure of achievement the objectives can be expressed by defining the following criteria:

- Minimum construction costs;
- Minimum maintenance costs;
- Minimum exploitation costs;
- Maximum security, safety and traffic comfort (which corresponds to minimum costs of accidents);
- Maximum impact on development of the area;
- Minimum spatial-ecological effects (which corresponds to maximum protection against impact of negative effects).

Table 13. *Overview of criteria and relative weight of criteria*

Ord. No.	Criterion of evaluation	Designa-tion of criteria	Relative weight of criteria
1.	Minimum construction costs	w_1	0.17
2.	Minimum maintenance costs	w_2	0.16
3.	Maximum profit for road users (minimum of exploitation costs)	w_3	0.164
4.	Maximum security, safety and traffic comfort (minimum costs of traffic accidents)	w_4	0.24
5.	Maximum impact on development of area	w_5	0.146
6.	Minimum impact on the spatial – ecological consequences (maximum protection from the effects of negative impacts)	w_6	0.12

Difficulty of criterion functions (Table 13) can be defined by many different ways. In this paper, the choice of difficulty is based on the use of DELFI method. Since it is concerned to an expert assessment (Figures 1 and 2) of the multidisciplinary project, the questioned participants (experts).

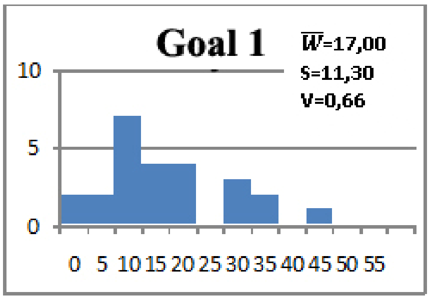

Figure 1. *Distribution of responses for Goal 1 and Goal 2*

Considering the heterogeneity of indicators for evaluation the variant - the method of several criteria optimization, i.e. the method of compromise programming and multicriterion compromise ranking of alternative solutions, is used.

This method first determines the optimum solutions for particular criteria and then determines compromise solutions, which are proposed to the decision maker.

The decision maker adopts the final solution, and is able to see all profit and unsatisfied criteria what provides a good basis for work.

By setting different values to the difficulty (importance) of criteria, the stability of the alternative solutions on multicriterion rankings can be analyzed there depending on the specific requirements of decision-maker.

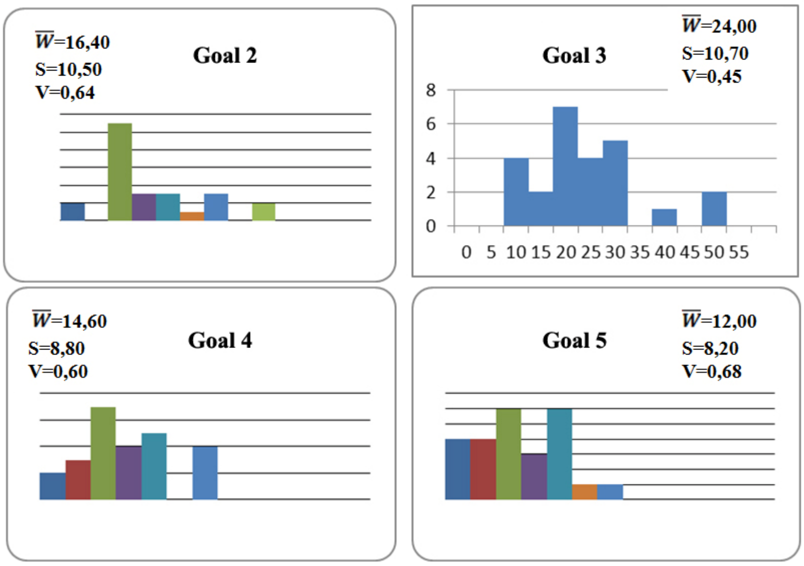

Fig. 2. *Distribution of responses for goals 3,4,5 and 6*

Table 14. *Difficulties of goals and criterion functions*

Goal	W	Indicators	W rel	Crit. F.	Wrel	fi	Wi
Minimum costs of construction	0.17			Total construction costs in Euro		1	0.17
Minimum costs of maintenance	0.16			Construction costs in Euro/year		2	0.16
Minimum costs of exploitation	0.164			Exploitation costs in Euro/year		3	0.164
Minimum costs of of traffic accidents (maximum security and safety)	0.24			Costs of traffic accidents in Euro/year		4	0.24
Maximum positive impact on the development of the area	0.146	The route in spatial conflict with the adopted SP Preservation of existing settlements and encouragement of urban planning Preservation of agricultural and forest areas The reality of performance		Compliance with SP	0.15	5	0.022
				Preservation and promotion rating of the future urban planning	0.20	6	0.029
				Land area under unfavorable influence	0.30	7	0.044
				The needs for displacement, possibility of material procurement, construction in stages	0.35	8	0.051

Minimum spatial ecological consequences	0.12	Minimum air pollution Minimum water pollution Minimum loss and soil pollution Minimum impact on the biotic factor Minimum impact on population, health and social factors Minimum noise and vibration Minimum contact with the protected natural areas Minimum negative impact on the cultural and historical monuments Minimum impact on landscape		Number of buildings exposed to pollution in the highway area expressed in points	0.12	9	0.014
				Length of the route near the watercourse	0.13	10	0.016
				Land area under unfavorable influence	0.13	11	0.016
				Length of the route in the cuts and embankments	0.10	12	0.012
				Assessment of impact on population, health and social factors	0.12	13	0.014
				Number of buildings in the highway area	0.10	14	0.012
				Length of route that crosses the protected natural area	0.10	15	0.012
				Number of cultural and historical monuments on the route of the highway	0.10	16	0.012
				Length of route in the cut, embankment, above-ground k-hole	0.10	17	0.012

**favorable variants are graded with higher grades (points)*

Tabela 15.

	Criterion function	Unit	Ext	Variant W	Variant VN	f_i^*	f_i^-
1.	Total costs of building in Euro	€	min	649056603.60	639725443.00	639725443.00	649056603.00
2.	Costs of maintenance	€/yr.	min	1403036.00	1246085.00	1246085.00	1403036.00
3.	Costs of exploitation	€/yr.	min	28869724.00	26139172.00	26139172.00	28869724.00
4.	Costs of traffic accidents in Euro/year	€/yr.	min	261692.00	231627.00	231627.00	261692.00
5.	Compliance with the Spatial Plan*	point	max	100.00	100.00	100.00	100.00
6.	Preservation and promotion rating of the future urban planning*	point	max	100.00	100.00	100.00	100.00

7.	Land area under the unfavorable influence*	point	max	100.00	45.00	100.00	45.00
8.	The needs for displacement, possibility of material procurement, construction in stages*	point	max	100.00	100.00	100.00	100.00
9.	Number of buildings exposed to pollution in the highway area expressed in points**	point	max	90.00	90.00	90.00	90.00
10.	Length of route near the watercourse**	point	max	85.00	85.00	85.00	85.00
11.	Land are under the unfavorable influence**	point	max	80.00	65.00	80.00	65.00
12.	Length of soil in the cuts and embankments**	point	max	80.00	70.00	80.00	70.00
13.	Assessment of impact on population, health and social factors**	point	max	85.00	85.00	85.00	85.00
14.	Number of buildings in the highway area**	point	max	85.00	85.00	85.00	85.00
15.	Length of route that crosses the protected natural area**	point	max	95.00	95.00	95.00	95.00
16.	Number of cultural and historical monuments on the route of the highway**	point	max	100.00	100.00	100.00	100.00
17.	Length of the route in the cut, embankment and above ground pits**	point	max	60.00	50.00	60.00	50.00

***favorable variants are rated with higher grades (points)*

Using the computer program, based on the method of VIKOR (Table 16), the following is obtained:

List of alternative: A 1. VV variant, A 2. VN variant

Table 16. *Rang liste po varijantama*

QR – Minimax strategija	Q – Kompromis	QS – Vecinska korist
R.L.QR	R.L.Q i Q(J)	R.L.QS
A 2 0.044	A 2 0.000	A 2 0.084
A 1 0.240	A 1 1.000	A 1 0.734

Table 17. *Analysis of the preferential stability*

F(i)	WD1	WO(i)	WGl	F(i)	WD1	WO(i)	WGl
F 1	0.000	0.170	1,000	F10	0.000	0.016	1,000
F 2	0.000	0.160	1,000	F11	0.000	0.016	0.196
F 3	0.000	0.164	1,000	F12	0.000	0.012	0.195
F 4	0.000	0.240	1,000	F13	0.000	0.014	1,000
F 5	0.000	0.022	1,000	F14	0.000	0.012	1,000
F 6	0.000	0.029	1,000	F15	0.000	0.012	1,000
F 7	0.000	0.044	0.201	F16	0.000	0.012	1,000
F 8	0.000	0.051	1,000	F17	0.000	0.012	0.195
F 9	0.000	0.014	1,000				

W0(i) are normalized values of the input-given weight. WD1≤w≤WG1 is the interval weight in which the first alternative remains in its position (stable position).

Changing the first position for alternative **A 2** can occur if there is a change of weight criteria F7, F11, F12, F17, or if the value of weight to these criteria (Table 17) is respectively higher than 0.201;0.196;0.195;0.195.

11. CONCLUSION

The need for a compromise solution is more pronounced for solving tasks with conflicting and heterogeneous criteria (opposed and expressed in different units of measure) as it is the case in this paper. The result of VKO has a great chance to be accepted as a good compromise between the different interests of participants in deciding if it is acceptable to the majority in decision-making process, but also that there are no bad criterion indicators that would make «opponents» not to accept it.

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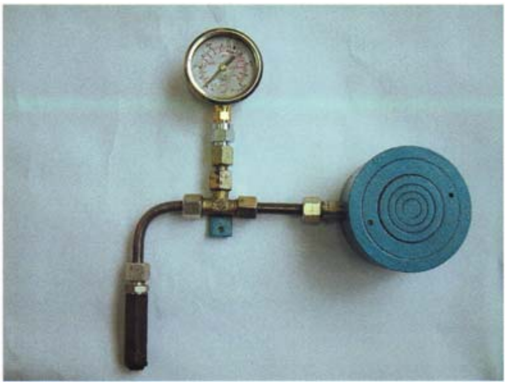

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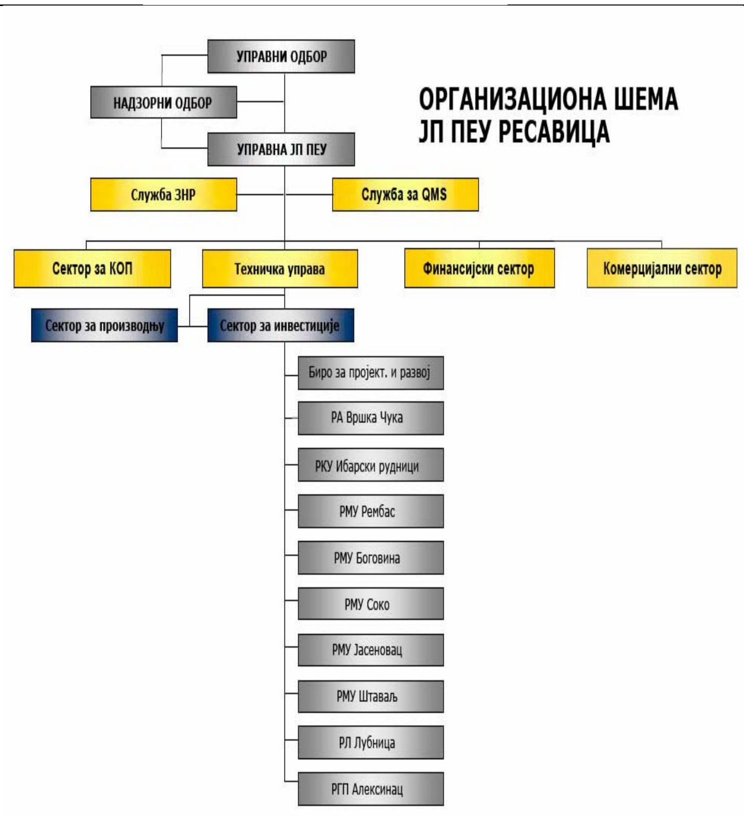

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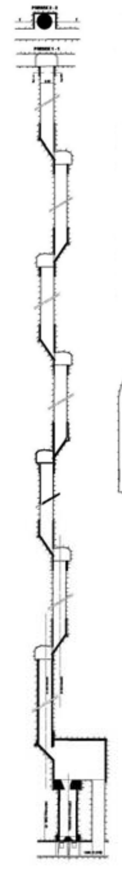

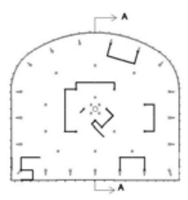

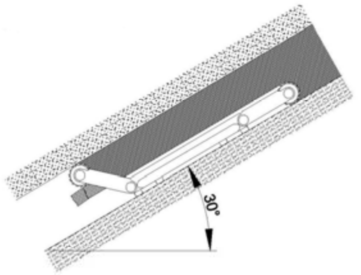

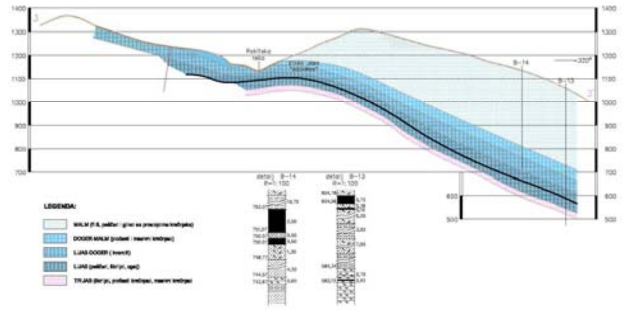

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[3] www: http://www.vanguard.edu/psychology/apa.pdf *(za web dokument)*

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Svim autorima se zahvaljujemo na saradnji.

INSTRUCTIONS FOR THE AUTHORS

MINING ENGINEERING Journal 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)

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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.

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We are thankful for all authors on cooperation