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Vesna Ljubojev, Dušan Tašić*, Slađana Krstić**

PETROGRAFSKE, HEMIJSKE I FIZIČKE KARAKTERISTIKE UGLJA UGLJEVIČKOG BASENA IZ LEŽIŠTA „UGLJEVIK ISTOK - II FAZA“

Izvod

Ugljevički basen predstavlja važan energetski resurs Republike Srpske i bazu za rad termoelektrane Ugljevik. Stepen istraženosti ugljevičkog basena, revir Bogutovo Selo, na krajnjem SI padinama planine Majevice i deo južnog revira ležišta Bogutovo Selo prostor „Jablan“ su kompletno geološki istraženi, a nastavljena su geološka istraživanja na području ležišta uglja Ugljevik-istok. U radu su prikazani rezultati petrografskih, hemijskih i fizičkih karakteristika uzoraka uglja iz ležišta „Ugljevik istok-II faza“. Ispitivanja uzoraka uglja pokazala su heterogeni sastav (litotipovi, mikrolitotipovi, macerali), i različit stepen karbonifikacije, kao i fizičko-hemijske karakteristike uglja (tehničke i silikatne analize).

Ključne reči: *macerali, litotipovi, tehnička analiza uglja, Ugljevički basen, Republika Srpska.*

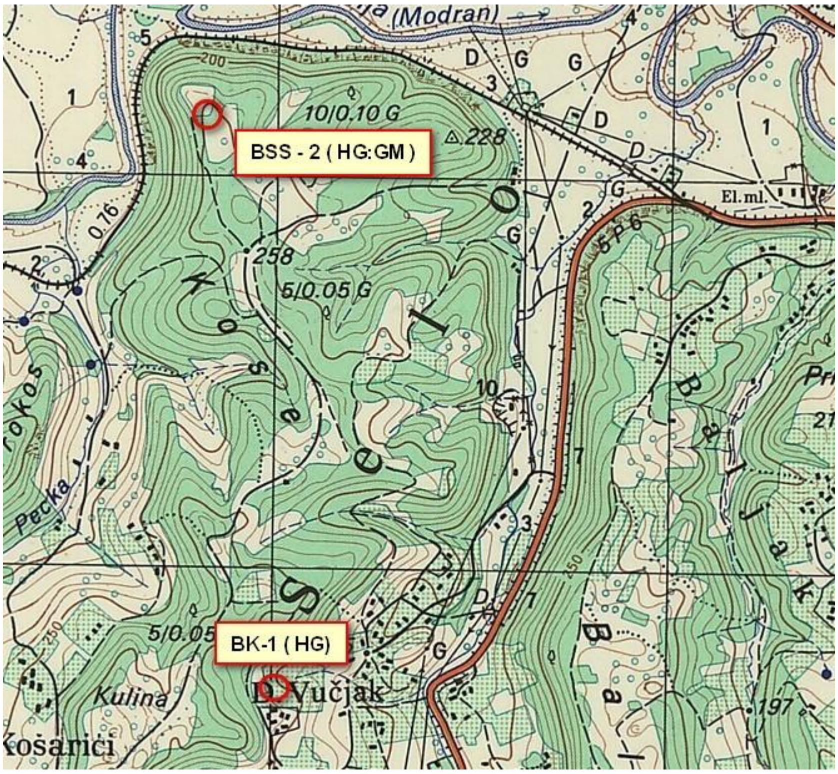
UVOD

Ugljevički basen predstavlja važan energetski resurs Republike Srpske i bazu za rad termoelektrane Ugljevik. Za dobijanje validnih podataka o rezervama i kvalitetu mineralne sirovine, vrši se nastavak detaljnih istraživanja na prostoru ležišta Ugljevik. Ta istraživanja predstavljaju nastavak kompleksnih istraživanja izvedenih od 1977 do 1990 god. kao i najnovija 2006 i 2007/2011 godine. Ispitivani su uzorci glavnog ugljenog sloja, I i II krovni ugljeni sloj, različitim metodama petrografskih i mineraloških proučavanja (makroskopska, mikroskopija u odbijenoj i propuštenoj svetlosti), kao i različite metode fizičko-hemijskih analiza.

GEOGRAFSKO, MORFOLOŠKO - HIDROGRAFSKE, GEOLOŠKE KARAKTERISTIKE PODRUČJA

Područje Ugljevičkog ugljonosnog basena kome pripada ležište Ugljevik - istok nalazi se na krajnjim severoistočnim padinama planine Majevice. Sa zapada je ograničeno rekom Mezgrajom, sa istoka Ugljevičkim potokom, dok je na severu otvoreno prema Posavini, odnosno Semberiji. (slika 1).

* *Institut za rudarstvo i metalurgiju Bor*



Sl. 1. *Pregledna geografska karta ležišta uglja Ugljevik*

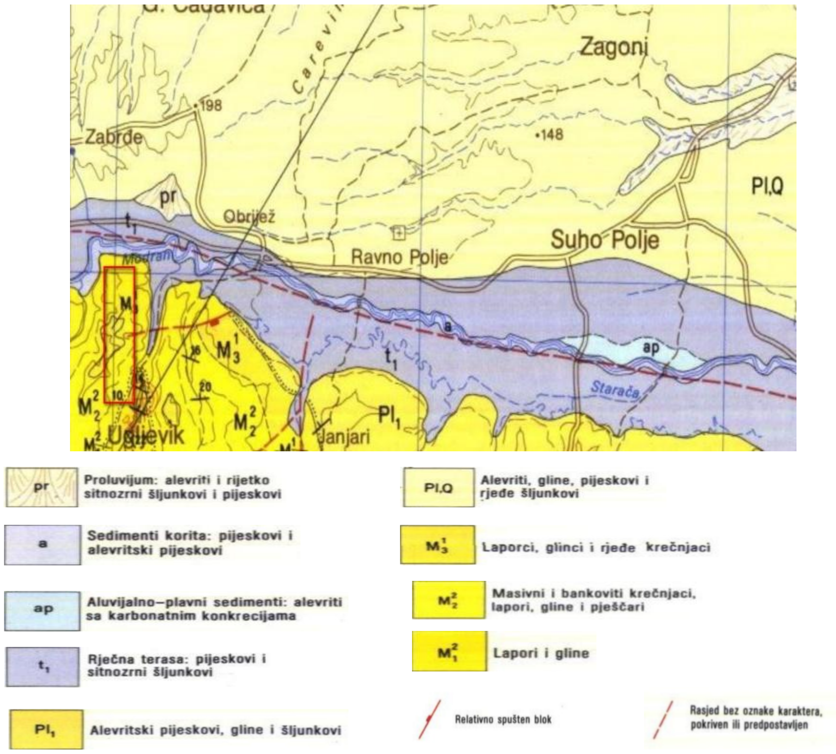
Ovaj prostor se nalazi između potoka Vučjak (Ugljevička reka) na zapadu i ugljevičkog potoka na istoku.

Pristup istražnom prostoru je moguć asfaltnim putem koji povezuje Teočak sa naseljem Stari Ugljevik i dalje se regionnalnim putem povezuje sa magistralnim pravcem Tuzla - Bijeljina. U pojedinim delovima istražnog prostora komunikacija se odvija lokalnim seoskim, kolskim putevima.

U morfološkom pogledu područje istraživanja karakterišu blago zatalasani tereni sa malim visinskim razlikama. Na užem području se ističu vrhovi Vučjak (318 m), Baljak (324 m) i Prokos (339 m) koji su izgrađeni od lajtovačkih krečnjaka.

Glavni recipijent površinskih i podzemnih voda je reka Janja koja protiče ispod severnog podnožja brda Vučjak i Baljak.

U geološkoj građi šireg prostora zastupljene su stene paleozojske, mezozojske, paleogene i neogene starosti. U geološkoj građi istražnog prostora učestvuju naslage eocena, kompleks slatkovodnih ugljonosnih sedimenata i neogeni marinski sediment, (Slika 2).



Sl. 2. *Geološka karta ležišta uglja Ugljevik*

MAKROSKOPSKE I MIKROSKOPSKE KARAKTERISTIKE

Nastajanje uglja je složen geološki proces koji je uslovljen postojanjem povoljnih pleoklimatskih, paleoflorističkih i paleoekoloških uslova.

Karakteristike neorganskih sedimenata u Ugljevičkoj ugljonosnoj formaciji (u podini, krovini i u samim ugljenim slojevima) ukazuju da su isti deponovani u slatkovodnoj jezerskoj sredini. Ugljevi ugljevičkog područja uglavnom su nastali od močvarnog regiona šumske vegetacije i zona žbunova.

Ugalja Ugljevičkog basena je sličnih mineraloško-petrografskih karakteristika, predstavlja mrki ugalj niskog stepena ugljenifikacije i koji izgrađuju komadi ugljene materije različite strukture (očuvana biljna struktura, drvenasto tkivo, gelificirano tkivo i sl.), uz ugljenu materiju zastupljena je i u vidu primesa i mineralna materija.

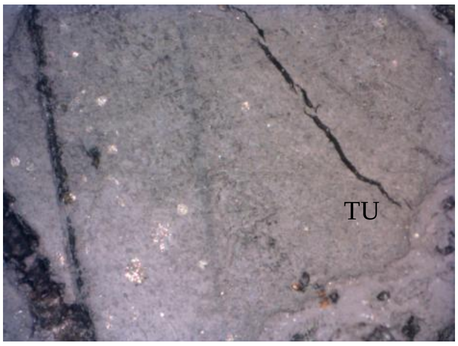
Makroskopskom determinacijom ugljenog sloja u bušotini izdvajaju se glinovite, laporovite alevrolitne primese u uglju. Glinovite primese su predstavljene žutosmeđe sivim i sivo zelenim glinama. Laporovite primese su determinisane kao peskoviti laporci, sivo zeleni glinoviti laporci. Takođe se javljaju laporci sa fosilnim ostacima.

Ugalj je sličnih mineraloško-petroloških karakteristika, mrko-crne boje, bez sjaja-mat, čokoladnog ogreba. Ravnog i glatkog preloma. Trakaste teksture, slabe ugljenifikacije, različite strukture. Na pojedinim uzorcima drvenasto-ksilitna komponenta javlja se u vidu ksilitnih fragmenata nepravilno i haotično raspoređena u detritusu. Ksilitne komponente imaju braon boju, detritus je crne boje i mat sjaja. Javljaju se u vidu ksilitnih fragmenata kao ksilit-detro (xD) i detro-ksilit (dX) (Slika 3, 4).

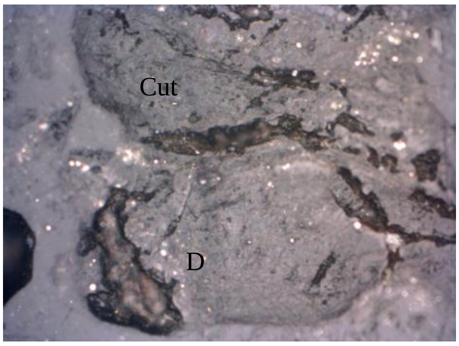
Sl. 3. *Ksilit, binokular, uvećanje 6,5 x*

Sl. 4. *Detro-ksilit (dX), binocular, uvećanje 6,5 x*

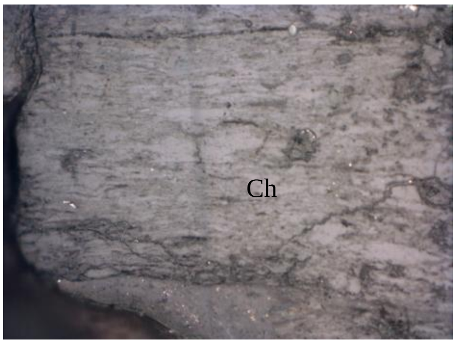
U ispitivanim uzorcima uglja mikroskopskim ispitivanjem su identifikovane sledeće maceralne grupe: telohuminiti, detrohuminiti, gelohuminiti, liptiniti. Ispitivani uzorci uglja su različitog stepena karbonifikacije i ukazuju na heterogeni petrografski sastav. Prosečan petrografski sastav ispitivanih uzoraka uglja je sledeći: Konstatovani macerali subgrupe telohuminita su: tekstinit, ulminit, tekstoulminit, zastupljeni su sa 38,72 %. Macerali subgrupe detrohuminita su: densinit i atrinit, a zastupljeni su sa 52,88 %. Macerali grupe liptinita zastupljeni su sa 2,73 % i macerali gelohuminita sa 5,67 %, (Slika 5, 6, 7).



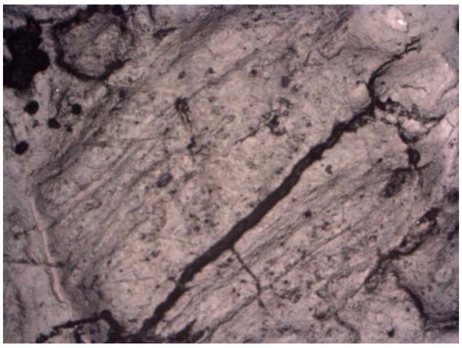
Sl. 5. *Tekstoulminit (TU), uvećanje 200 x*



Sl. 6. *Densinit (D), kutinit (Cut) i pirit (Px), uvećanje 200 x*



Sl. 7. *Tekstinit (T) sa korpohuminitom (Ch), uvećanje 200 x*



Sl. 8. *Tekstinit, uvećanje 200 x*

Mineralna materija (jalovina) je pretežno silikatno-karbonatnog sastava. Od sulfida se zapaža pirit u vidu samostalnih (izdvojenih) zrna ili u vidu agregata.

FIZIČKO-HEMIJSKE KARAKTERISTIKE

Ugalj Ugljevičkog basena je sličnih karakteristika i u pogledu parametara tehničkih i hemijskih analiza. Prosečni sadržaji su: vlaga 19,28 %, pepela 24,67 %, sagorljive materije 56,03 %, isparljive materije 38,25 %, koksni ostatak 45,29 %, C-fix 20,61 %, S-ukupni 4,72 %, S-vezani 1,064 %, S-sagorljivi 3,08 %. Prosečne vrednosti gornje i donje toplotne energije su 15739 i 14943. Prosečne vrednosti elementarnih analiza uglja (sa ukupnom vlagom) su: C = 30.33 %, H = 1.6 %, S = 1,19 % i O+N = 9,03 %.

Zapreminska masa uglja se kreće od 1,290 do 1,307 g/cm^3.

Određivanjem meljivosti uglja konstatovano je da se radi o mekim ugljevima. Vrednosti meljivosti po Mardgroveu HGI krecu se od 38,69 do 75,68.

ZAKLJUČAK

Lignit Ugljevičkog basena predstavlja važnu energetsku sirovinu za Republiku Srpsku. Petrografska analiza pokazala je da glavni deo organskog materijala se sastoji od huminita posebno od macerala ulminita i tekstinita. Sadržaj macerala grupe liptinita i gelohuminita je nizak. Varijacije u petrografskom sastavu i sadržajima mikrolitotipova i macerala kao i mineralne materije (glina, laporac, pirit) mogu da utiču na proces sagorevanja uglja u termoelektrani. Generalno ugalj pripada grupi lignita sa drvenastom strukturom.

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Vesna Ljubojev, Dušan Tašić*, Sladjana Krstić**

PETROGRAPHIC, CHEMICAL AND PHYSICAL CHARACTERISTICS OF COAL FROM THE COAL BASIN OF THE DEPOSIT "UGLJEVIK EAST-PHASE II"

Abstract

Ugljevik Basin is an important energy resource of the Republic Srpska and base for operation the power plant Ugljevik. Level of exploration the Ugljevik Basin, Mining District Bogutovo Selo, at the far NE slopes of the mountain Majevica and a part of the South Mining District of the deposit Bogutovo Selo, the area "Jablan", are completely geologically explored, and geological explorations are continued in the area of coal deposit Ugljevik-East. This work presents the results of petrographic, chemical and physical characteristics of coal samples from the deposit "Ugljevik East-Phase II." Testing of coal samples showed the heterogeneous composition (lithotypes, mikrolithotypes, macerai), and varying degrees of carbonization as well as physical-chemical characteristics of coal (technical and silicate analysis).

Keywords: *macerai, lithotypes, technical analysis of coal, Ugljevik Basin, the Republic Srpska*

INTRODUCTION

Ugljevik Basin is an important energy resource base and the Republic Srpska and base for operation the power plant Ugljevik. to work. To obtain the valid data on reserves and quality of mineral resources, a continuation of detailed explorations is carried out in the area of the deposit Ugljevik. These explorations represent a continuation of complex explorations conducted from 1977 to 1990, and the latest from 2006 and 2007/2011. The samples were taken of the main coal seam, the I and II roof seam, using various methods of petrographic and mineralogical testing (macroscopic, microscopic in declined and missed light), as well as different methods of physico-chemical analyses.

GEOGRAPHICAL, MORPHOLOGICAL - HYDROGEOGRAPHIC, GEOLOGICAL CHARACTERISTICS OF THE AREA

The area of Ugljevik coal bearing basin which includes the deposit Ugljevik-East is located on the far north slopes of the mountain Majevica. It is limited by the river Mezgraja river on the west, the Ugljevik stream on the east, while it is open to the Posavina and Semberija on the north (Figure 1).

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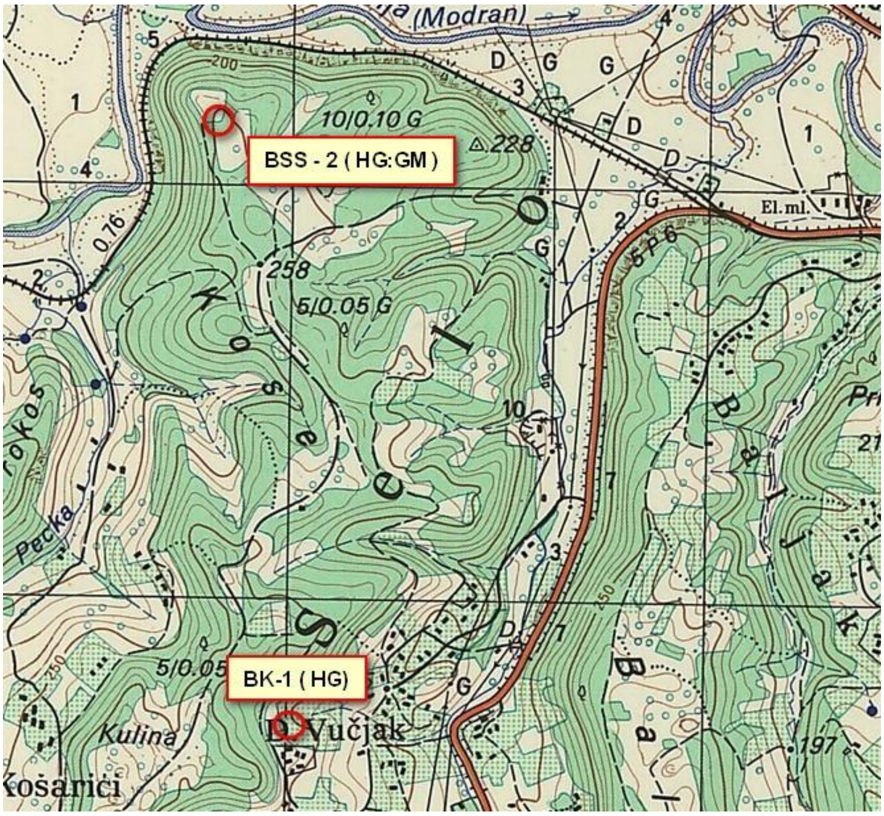

Figure 1 *General geographic map of the coal deposit Ugljevik*

This area is located between the stream Vučjak (Ugljevik River) on the west and the stream Ugljevik on the west.

Access to the exploration area is possible by asphalt road that connects Teočak with the settlement Stari Ugljevik and further is connected by the regional road to the main road Tuzla-Bijeljina. In some parts of the exploration area, the communication is developed by the local village roads.

Morphologically, the exploration area is characterized by slightly rolling fields with small differences in height. In the inner area, there are the peaks Vučjak (318 m), Baljak (324 m) and Prokos (339 m), which are built from the lajtovac limestone.

The main recipient of surface and ground water is the river Janja that flows beneath the northern foot of the hills Vučjak and Baljak.

Geological structure of wider area is represented by the rocks of Paleozoic, Mesozoic, Paleogene and Neogene age. Geological structure of exploration area involves the Eocene sediments, complex of freshwater coal bearing sediments and Neogene marine sediments (Figure 2).

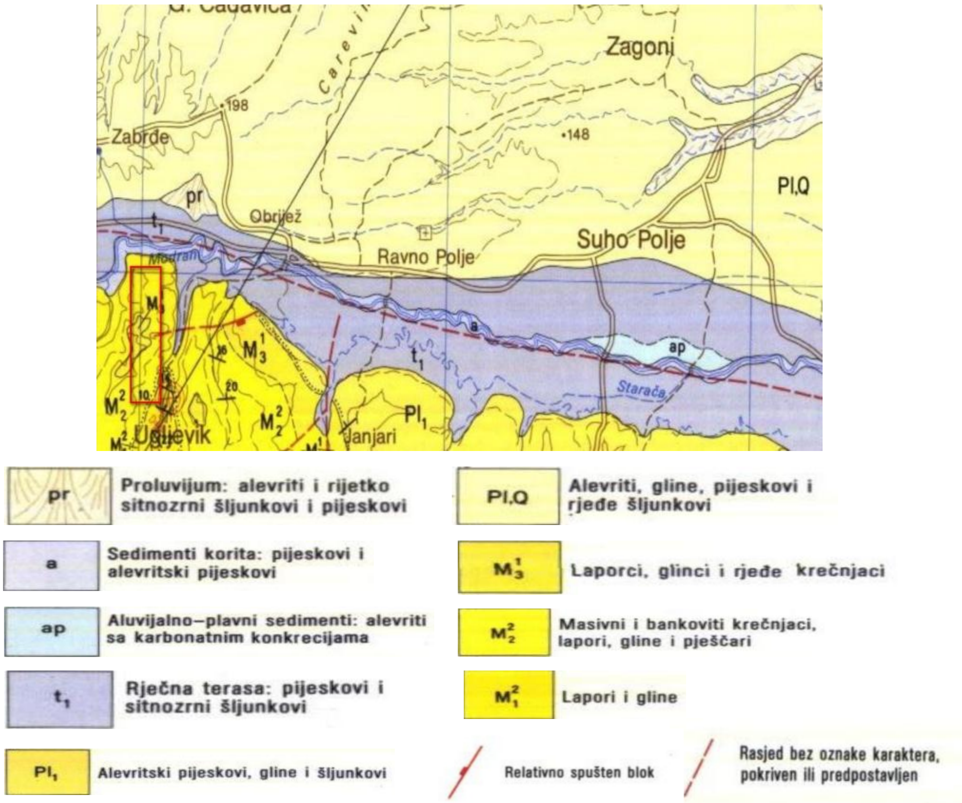

Figure 2 *Geological map of the coal deposit Ugljevik*

MACROSCOPIC AND MICROSCOPIC CHARACTERISTICS

Coal formation is a complex geological process that is implied with presence of favorable pleo climatic, paleo floristic and paleo ecological conditions.

Characteristics of inorganic sediments in the Ugljevik coal bearing formation (in the floor, and roof of coal seams themselves) indicate that they were deposited in freshwater lacustrine environment. Coals of the Ugljevik field are created from the marshland region of forest vegetation and zones of shrubs.

Coal of the Ugljevik field with similar mineralogical and petrographic characteristics, presents the low-grade carbonification brown coal, formed of pieces of carbon material with various structure (preserved plant structure, woody tissue, gelificied tissue, etc.) with the coal substance is present in the form of impurities and mineral substances.

Macroscopic determination of coal seam in the drill hole has separated clay, marl siltatone impurities in coal. Clayey impurities are present by tawny gray and gray-green clay. Marly impurities are determined as sandy marls, gray-green clay marls. Marls also appear with fossil remains.

Coal has similar mineralogical-petrological characteristics, brownish-black, dull-matte, chocolate scratch, flat and smooth fracture, banded texture, weak carbonification of various structure. O some samples, the woody-xylite component appears in a form of xylite fragments, irregularly and chaotically distributed in the detritus. Xylitic components are brown, detritus is black with matte shine. They appear in the form of xylitic fragments as xylite-Detro (xD) and detro-xylite (dX) (Figures 3 and 4).

Figure 3 *Xylite, binocular, magnification 6.5 x*

Figure 4 *Detro-xylite (dX), binocular, magnification 6.5 x*

In tested samples of coal, the microscopic testing has identified the following ma-ceral groups telohumics, detrohumics, gelohumics, liptinites. Tested samples of coal have different degrees of carbonization and indicate a heterogeneous petrographic composition. The average petrographic composition of coal samples is as follows: stated macerai subgroup of telohumics as: texstinite, ulminite, textoulminite, represented with 38.72 %. Macerai subgroups detrohumics are densinite and atrinite, represented with 52.88 %. Macerai liptinite groups are represented with 2.73 % and macerai gelohumincs with 5.67 % (Figures 5, 6, 7).

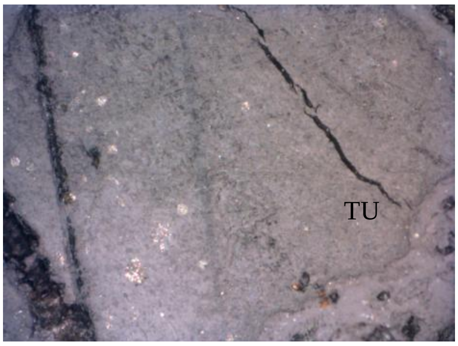

Figure 5 *Textoulminite (TU), magnification 200 x*

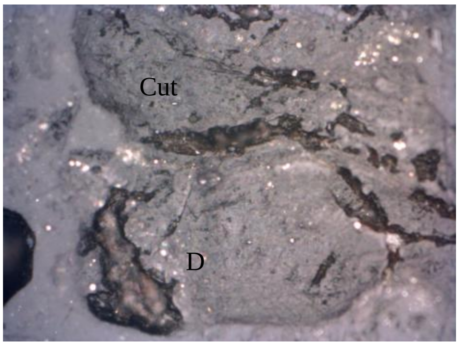

Figure 6 *Densinite (D), cutinite (Cut) and pyrite (Px), magnification 200 x*

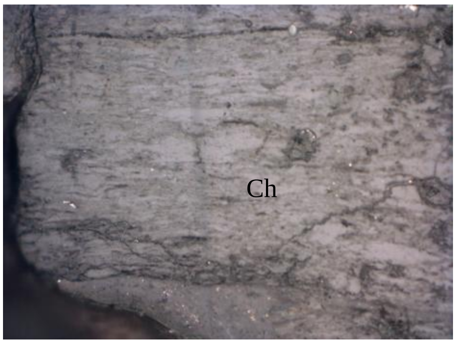

Figure 7 *Textinite (T) with corpohuminitics (Ch), magnification 200 x*

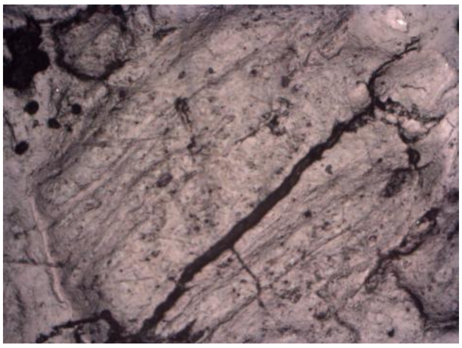

Figure 8 *Textinite, magnification 200 x*

Minerals (waste rock) are mainly siliceous-carbonate composition. Since sulfides are pyrite observed in the form of independent (isolated) or in the form of grain aggregates

PHYSICO-CHEMICAL CHEMICAL CHARACTERISTICS

Coal of the Ugljevik Coal Basin has similar characteristics in terms of technical parameters and chemical analyses. The average contents are 19.28% moisture, 24.67% ash, combustible matters 56.03%, volatile matters 38.25%, coke residue 45.29%, C-fix 20.61%, S-total 4.72%, S-related 1.064%, S-combustible 3.08%. The average values of the upper and lower heat energy are 15739 and 14943. The average values of elemental analyses of coal (with total moisture) are: C=30.33%, H=1.6%, S=1.19% and O+N=9.03%.

Volumetric mass of coal ranges from 1.290 to 1.307 g/cm^3.

By determining the grindability of coal, it was found that those are soft coals. Values of grindability per the Mardgrove HGI range from 38.69 to 75.68.

CONCLUSION

Lignite of the Ugljevik Bssin is an important energy source for the Republic Srpska. Petrographic analysis showed that the main part of the organic material consists of huminics, especially especially macerai ulminite and textinite. Content of macerai group and liptinite gelohuminics is low. Variations in petrographic composition and content micro lithotypes and macerai as well as the mineral matter (clay, marl, pyrite) may affect the combustion process of coal in power plant. Generally, coal belongs to the group of lignite with woody structure.

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KARAKTERIZACIJA UZORKA IZ LEŽIŠTA „ANDENZITSKI PRST“ POVRŠINSKOG KOPA „JUŽNI REVIR“ U RUDNIKU BAKRA MAJDANPEK**

Izvod

U radu su prikazani rezultati geološko-minerološke i fizičko-hemijske karakteristike uzorka iz ležišta „Andenzitski prst” površinskog kopa „Južni revir“ u Rudniku bakra Majdanpek. Prema mineraloškom sastavu korisnih metala orudnjenje je sastavljeno od halkopirita, magnetita, pirita i molibdenita.

Sadržaji bakra u ležištu rastu od 0,1 % na granici gnajsa i škriljaca ka andezitima i kreću se do 0,5 % u silifikovanim andezitima i gnajsgranitima. Orijentacioni sadržaj molibdena kreće se od 10 do 100 ppm-a u zavisnosti od položaja i dubine na kojoj se nalazi. Geološke rezerve bakra u ležištu Južni revir iznose: ruda 463.127.844 t, srednji sadržaj bakra u rudi 0,316 % tj. količina Cu 1.465.556 t, srednji sadržaj zlata u rudi 0,178 g/t tj. količina Au 82.156 t, srednji sadržaj srebra u rudi 1,365 g/t tj. količina Ag 632.274 t.

Na osnovu tehnoloških karakteristika formiranog uzorka rude potrebno je izvršiti dalja ispitivanja kolektivne i selektivne flotacije za radi dobijanja optimalnih tehnoloških parametara flotacijskog procesa i ostvarivanja većeg iskorišćenja svih korisnih komponenti.

Ključne reči: *Majdanpek, Andezitski prst, ruda, karakterizacija, ruda bakra*

UVOD

Rudnik bakra Majdanpek nalazi se u sastavu kompanije Rudarsko topioničarski basen Bor Grupa, proizvodnja i prerada rude bakra u RBM-u odvija se na dva površinska kopa Severni revir i Južni revir.

Ležište bakra „Južni revir“ – Majdanpek, nalazi se u neposrednoj blizini grada Majdanpeka u slivu reke Mali Pek. U neposrednoj okolini ležišta nalazi se postrojenje za preradu rude, odlagališta jalovine (otkrivke) i flotacijske jalovine. Površinski kop Južni revir je glavni nosioc proizvodnje rude bakra u RBM-u od 1961 god. sa planiranim godišnjim kapacitetom na otkopavanju i preradi rude od 8,5 miliona tona. Takođe, ovaj ovaj površinski kop će predstavljati glavnog nosioca proizvodnje rude bakra i u narednom periodu.

Količine utvrđenih geoloških rezervi rude bakra u ležištu Južni revir, čine ovo ležište veoma značajnim sa aspekta dugoročne i stabilne proizvodnje bakra i

* *Institut za rudarstvo i metalurgiju Bor*

** *Ovaj rad je proistekao kao rezultat projekta TR33023 “Razvoj tehnologija flotacijske prerade ruda bakra i plemenitih metala radi postizanja boljih tehnoloških rezultata” finansiranog od strane Ministarstva prosvete, nauke i tehnološkog razvoja Republike Srbije*

plemenitih metala u kompaniji RTB Bor. Geološke rezerve bakra u ležištu Južni revir iznose: ruda 463.127.844 t, srednji sadržajem bakra u rudi 0,316 % tj. količina Cu 1.465.556 t, srednji sadržaj zlata u rudi 0,178 g/t tj. količina Au 82.156 t, srednji sadržaj srebra u rudi 1,365 g/t tj. 632.274 t. Vek površinskog kopa Južni revir, prema najnovijoj tehnološkoj dokumentaciji, a za definisane ulazne tehno ekonomske parametre iznosiće oko 23 godine. [1,2]

Imajući u sve ovo u vidu, kao i da nakon dužeg zastoja proizvodnje i prerade rude sa površinskog kopa „Južni revir“ u RBM-u, nisu rađena tehnološka ispitivanja sa ciljem sagledavanja mogućnosti prerade ove sirovine, te da se početak eksploatacije rude sa površinskog kopa „Južni revir“ u RBM-u planira sa lokaliteta „Andezitski prst“ koji u svom sastavu ima respektabilne količine, pored osnovnih minerala bakra i određene količine Mo, neophodno je bilo da se sprovedu tehnološka ispitivanja. Ista su izvedena u IRM Bor na rudi sa lokaliteta „Andezitski Prst“ sa namerom iznalaženja optimalnih parametara flotacijskog postupka koncentracije korisnih minerala Cu i Mo. Prvo je izvršena laboratorijska karakterizacija formiranog uzorka rude sa sadržajem Cu i Mo čija se eksploatacija predviđa u narednom periodu. Cilj ovih ispitivanja je da se definišu mineraloške, fizičke i hemijske karakteristike rude Cu i Mo iz ležišta sa lokaliteta „Andezitski Prst“ sa površinskog kopa „Južni revir“ RBM-a. Na osnovu te karakterizacije, koja će biti prikazana u ovom radu, u naknadnim ispitivanjima definisali bi se optimalni parametri flotacijske tehnologije za odgovarajuću preradu ove rude za dobijanje koncentrata Cu i koncentrata Mo.

GEOLOŠKE KARAKTERISTIKE LEŽIŠTA JUŽNI REVIR ANDEZITSKI PRST

Na severnom delu Južnog revira orudnjenje se nalazi u andezitima, gnajs-granitima i gnajsevima. Centralni deo orudnjene zone čine andeziti koji probijaju gnajsgranite i gnajseve.

Prema mineraloškom sastavu korisnih metala orudnjenje je sastavljeno od halkopirita, magnetita, pirita i molibdenita.

Sadržaji bakra rastu od 0,1 % na granici gnajsa i škriljaca ka andezitima i kreću se do 0,5 % u silifikovanim andezitima i gnajsgranitima.

Zlato i srebro uglavnom su vezani za halkopirit, pirit i ređe formiraju svoje minerale vezane sa platinom. Molibden se nalazi u molibdenitu koji ima povišen sadržaj u periferiji orudnjenja bakra, najčešće u gnajsevima.

Sadržaj molibdena raste od zapada ka istoku paralelno sa porastom sadržaja bakra da bi u centru orudnjenja naglo opao, a onda ka istoku imao ponovo skok. Počevši od površine terena sadržaj opada sa dubinom.

Orijentacioni sadržaj molibdena od istoka ka zapadu na nivou K +350 m su: zapadni deo od 50 do 60 ppm, centralni deo od 10 do 30 ppm, istočni deo oko od 90 do 100 ppm. Srednji sadržaj na nivou K+350 m je oko od 70 do 80 ppm. Sa dubinom sadržaji se kreću: K +350 m od 70 do 80 ppm, K +275 m od 60 do 70 ppm i K+200 m oko od 30 do 40 ppm.

Za valorizaciju bakra, molibdena i magnetita osnovnih korisnih komponenti važni su i drugi prateći metali koji mogu značajno da poboljšaju rentabilnost proizvodnje. [3]

Za ispitivanje je korišćen uzorak uzet iz dela ležišta tkz. „Andezitski prst“ sa nivoa K +275 m sa težnjom da bude reprezentativan za ovaj deo ležista Južnog revira. Na formiranom uzorku je izvršena detaljna karakterizacija tj. određene su hemijske i fizičke karakteristike koje će biti prikazane dalje u radu.

MINERALOŠKE KARAKTERISTIKE UZORKA

Na osnovu strukturno - teksturnih karakteristika mineralnog sastava i paragenetskih odnosa minerala možemo konstatovati da je na lokalitetu „Andezitski Prst“ na površinskom kopu „Južni revir“ RBM-a prisutna siromašna porfirsko pirit – halkopiritska ruda. Ispitivani uzorci su predstavljeni rudnim preparatima u pleksigalsu koji su dobijeni od navedene samlevene siromašno porfirske pirit – halkopiritske rude, klase krupnoće (-12,7+0,0 mm) i (-3,35+0,0 mm) koje su korišćene za dalja ispitivanja. Ispitivanja su rađena na sledećoj mineraloškoj opremi:

1. Polarizacioni mikroskop za odbijenu i propuštenu svetlost marke “JENAPOL-U”, firme Carl Zeiss-Jena, sa mernim uređajem.
2. Sistem za mikrofotografiju “STUDIO PCTV” (Pinnacle Systems).

Kvalitativna mineraloška analiza rađena je pod navedenim polarizacionim mikroskopom za odbijenu svetlost u vazduhu i imerziji (kedrovo ulje), sa indentifikacijom rudnih i nerudnih minerala.

U daljem tekstu detaljno su prikazani dobijeni rezultati. Tekstualni deo prate odgovarajuće mikrofotografije. Pregledom formiranih rudnih preparata od samlevenog uzorka navedenih klasa krupnoće determinisani su sledeći rudni minerali predstavljeni respektivno prema klasama krupnoće.

REZULTATI MINERALOŠKOG ISPITIVANJA

1. Rudni preparat u pleksiglasu, klase krupnoće: -12,7+0,0 mm

Makroopis: Uzorak je predstavljen mineraloškim preparatom u pleksiglasu (1 komad), na kojem se zapaža intezivna mineralizacija sa piritom. Pod UV-lampom (kratak spektar) ne zapažaju se efekti fluorescencije. Uzorak nije magnetičan.

Mineralni sastav: *halkopirit, pirit, magnetit, rutil, kasiterit, leukoksen, cirkon, kvarc, silikati.*

Minerali su navedeni po učestalosti pojavljivanja.

Mikroopis: Najzastupljeniji sulfidni mineral je pirit. On se javlja u vidu nepravilnih do izometričnih individua, sa čestim uklopcima halkopirita. Po nekad je udružen sa mineralima titana. Halkopirit je slabije zastupljen i uglavnom se javlja u vidu nazubljenih impregnacija u silikatnom matriksu (hlorit). Magnetit je slabije zastupljen, ali je uvek udružen sa halkopiritom. Minerali zlata nisu zapaženi. Jalovina je kvarc-silikatna.

2. Rudni preparat u pleksiglasu, klase krupnoće: -3,35+ 0,0 mm

Makroopis: Uzorak je predstavljen sa stenskim samlevenim sitnozrnim agregatima u pleksiglasu, na kojima se zapaža slabija mineralizacija sa piritom. Pod UV-lampom (kratak spektar) ne zapažaju se efekti fluorescencije. Uzorak nije magnetičan.

Mineralni sastav: *halkopirit, pirit, magnetit, rutil, kasiterit, leukoksen, cirkon, kvarc, silikati.*

Minerali su navedeni po učestalosti pojavljivanja.

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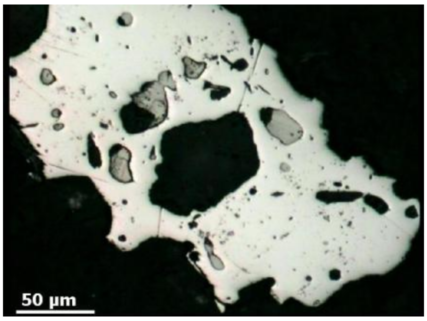
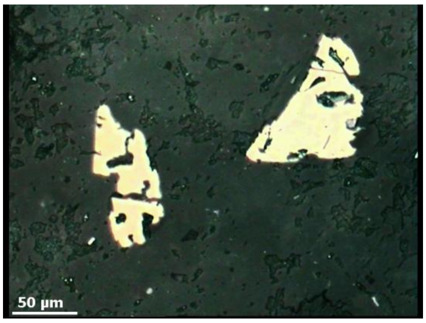
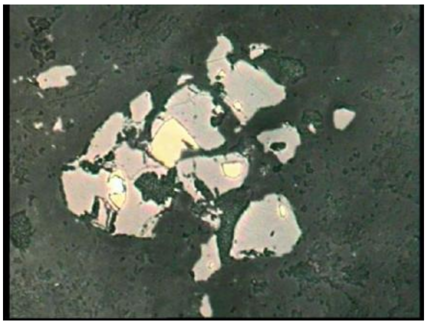
Na slikama 1-4 prikazani su vizuelni argumenti mineraloškog pregleda preparata.



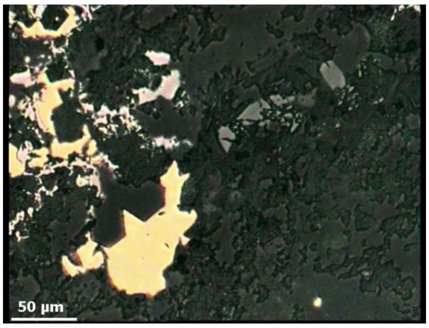
Sl. 1. *Uklopci halkopirita (sivožuto) u piritu (svetložuto), uklopljeno u silikatnu jalovinu (crno). Vazduh, II N.*



Sl. 2. *Agregati halkopirita (žuto) uklopljeni u silikatnoj podlozi (tamnosivo). Vazduh, II N.*



Sl. 3. *Skeletičan magnetit (sivo) sa uklopcima halkopirita (žuto). Vazduh, II N.*



Sl. 4. *Impregnacija halkopirita (žuto) u jalovini sa rutilom (svetlo) i kasiteritom (tamnosivo). Vazduh, II N.*

FIZIČKE KARAKTERISTIKE UZORKA LEŽIŠTA "JUŽNI REVIR" - ANDEZITSKI PRST

Reprezentativan uzorak iz ležišta „Južni revir" – Andezitski prst je formiran na samom rudniku uzimanjem manje količine uzoraka po slobodnom izboru mesta uzorkovanja, a zatim je izvršena njegova homogenizacija, drobljenje i skraćivanje uzorka, da bi kasnije usledila njegova karakterizacija u Institutu za rudarstvo i metalurgiju u Boru.

Uzorak rude na kome su izvršena fizička ispitivanja formiran je kao reprezentativni uzorak predhodno samlevene rude navedenih klasa krupnoće (-12,7+00 mm) i (-3,35+00 mm). Uzimanem dovoljne količine uzorka metodom šah polja formirani su uzorci za predviđena fizička ispitivanja. Zbirni rezultati svih sprovedenih fizičkih ispitivanja predstavljeni su u tabeli 1.

Nasipna masa

Nasipna masa je određena na uzorcima krupnoće 100% -12,7 mm i 100% -3,35 mm, tabela 1. Metoda podrazumeva određivanje mase slobodno nasutog uzorka, bez sabijanja, u sud poznate zapremine V i mase m. Nasipna masa se izračunava po sledećem obrascu:

$$\Delta = \frac{m_1 - m}{V}, \quad (kg/m^3)$$

gde je:

Δ - nasipna masa uzorka,
m_1 - masa uzorka i suda,
m - masa suda,
V - zapremina suda.

Prirodna pH-vrednost uzorka

Prirodna pH-vrednost uzorka rude, tabela 1, određena je merenjem pH vrednosti tečne faze, nakon mešanja pijaće vode (pH = 6,80) sa rudom (Č:T=1:1) u trajanju od 30 minuta, pH rude = 7,46

Gustina uzorka

Gustina uzorka je odredjena, tabela 1, metodom staktenih piknometara sa vakuumiranjem. Srednja vrednost gustine iz tri merenja je,

ρ=2.680 kg/m^3

Specifična gustina rude

Određivanje specifične gustine rude vršeno je u staklenom sudu – piknometru, tabela 1. Specifična gustina se izračunava po sledećem obrascu:

$$\rho = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)} \rho_F^t \ (kg/m^3)$$

gde je:

m_1 - masa praznog piknometra, kg
m_2 - masa piknometra sa uzorkom, kg
m_3 - masa piknometra sa uzorkom i vodom, kg
m_4 - masa piknometra sa vodom, kg
ρ_F^t - gustina fluida (vode) pri temperaturi merenja, (kg/m^3)

Meljivost rude - Bondov radni indeks

Meljivost rude je definisana vrednostima Bondovog radnog indeksa, Wi i određen je standardnim Bondovim testom u Bondovom mlinu sa šipkama i Bondovom mlinu sa kuglama, tabela 1, Dobijene vrednosti su:

$M_š$ = 20,80 kWh/t

M_k = 15,50 kWh/t

Tabela 1. *Fizičke karakteristike uzorka J. revir "Andezitski prst"*

Fizičke karakteristike	Vrednosti
Nasipna masa	*Δ kg/m^3*
Uzorak 100% - 12,7 mm Uzorak 100% - 3,35 mm	$\Delta_{(-12,7\ mm)}$ = 1671,60 kg/m^3 $\Delta_{(-3,35\ mm)}$ = 1468,46 kg/m^3
pH rude	7,46
Gustina rude	ρ = 2680 kg/m^3
Bondov indeks	*Wi (kWh/t)*
Mlin sa šipkama Mlin sa kuglama	$m_š$ = 20,8 m_k = 15,50

Granulometrijski sastav uzorka

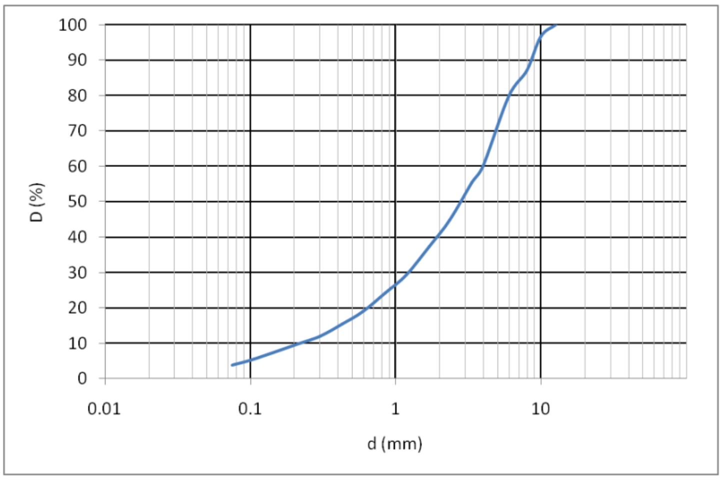
Granulometrijske analize uzoraka rude klase krupnoće -12,7 + 0,0 mm i -3,35 + 0,0 mm su urađene mokrim prosejavanjem na standardnoj seriji sita tipa TYLER (The Tyler Standard Screen Scale), a rezultati dobijenih granulometrijskih sastava su prikazani grafički na slikama 5 i 6 i analitički u tabelama 2 i 3.

Tabela 2. *Granulometrijski sastav uzorka "Andezitski prst", -12,70+0,00 mm*

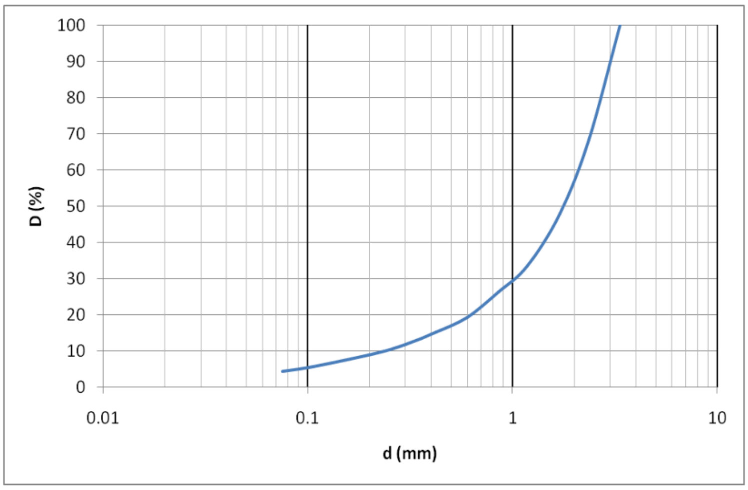
Klasa krupnoće (mm)	m %	R %	D %
-12,70+10	3,30	3,30	100
-10+8	9,49	12,79	96,70
-8+6	7,24	20,03	87,21
-6+4	19,79	39,82	79,97
-4+3,35	4,83	44,65	60,18
-3,35+2,36	10,56	55,21	55,35
-2,36+1,70	7,39	62,60	44,79
-1,70+1,18	8,10	70,70	37,40
-1,18+0,850	4,97	75,67	29,30
-0,850+0,600	5,33	81,00	24,33
-0,600+0,425	3,61	84,61	19,00
-0,425+0,300	3,29	87,90	15,39
-0,300+0,212	2,26	90,16	12,10
-0,212+0,106	4,24	94,40	9,84
-0,106+0,075	1,81	96,21	5,60
-0,075+0,00	3,79	100,00	3,79

Tabela 3. *Granulometrijski sastav uzorka "Andezitski prst", -3,35+0,00 mm*

Klasa krupnoće (mm)	m %	R %	D %
- 3,35+2,36	31,50	31,50	100
-2,36+1,70	20,53	52,03	68,50
-1,70+1,18	14,43	66,46	47,97
-1,18+0,850	7,23	73,69	33,54
-0,85+0,60	6,90	80,59	26,31
-0,6+0,425	4,20	84,79	19,41
-0,425+0,30	3,33	88,12	15,21
-0,30+0,212	2,50	90,62	11,88
-0,212+0,106	3,60	94,22	9,38
-0,106+0,075	1,43	95,65	5,78
-0,075+0,053	4,35	100	4,35



Sl. 5. *Granulometrijski sastav uzorka rude Andezitski prst klase krupnoće, -12,7 + 0,00 mm*

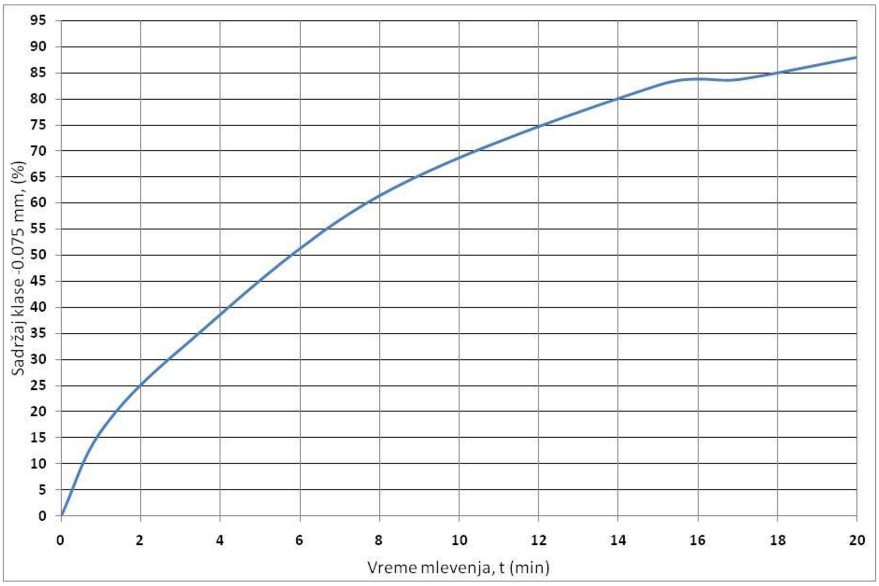


Sl. 6. *Granulometrijski sastav uzorka rude Andezitski prst klase krupnoće, -3,35 + 0,00 mm*

Kinetika mlevenja

Utvrđivanje vremena mlevenja u zavisnosti od finoće mliva je urađeno na laboratorijskom mlinu tipa "Denver".

U cilju utvrđivanja zavisnosti finoće izmlevenog produkta od vremena mlevenja u laboratorijskom mlinu urađeni su ogledi mlevenja sa sledećim vremenima mlevenja: 1, 3, 8 i 16 minuta, tabela 4. Sadržaj klase -0,075 mm u zavisnosti od vremena mlevenja je prikazan na slici 7.



Sl. 7. *Zavisnost sardžaja obračunske klase krupnoće - 75 μm od vremena mlevenja u proizvodima mlevenja.*

Tabela 4. *Granulometrijskih sastav proizvoda mlevenja dobijenih na različitim vremenima mlevenja*

Klasa krupnoće, d (mm)	VREME MLEVENJA																	
	1 min			3 min			8 min			15 min			17 min			20 min		
	m %	R%	D%	m%	R%	D%	m%	R%	D%	m%	R%	D%	m%	R%	D%	m%	R%	D%
- 3,35+2,36	9,2	9,2	100															
2,36+1,70	11,5	20,7	90,8	3,4	3,4	100												
1,70+1,18	11,8	32,5	79,3	2,1	5,5	96,6												
1,18+0,850	8,1	40,6	67,5	2,4	7,9	94,5												
0,85+0,60	10	50,6	59,4	5,2	13,1	92,1												
0,6+0,425	7,6	58,2	49,4	8,5	21,6	86,9												
0,425+0,30	7,2	65,4	41,8	11,3	32,9	78,4	0,7	0,7	100									
0,30+0,212	5,8	71,2	34,6	10,4	43,3	67,1	4,1	4,8	99,3	0,2	0,2	100	0,2	0,2	100			
0,212+0,106	9,2	80,4	28,8	17,5	60,8	56,7	20,9	25,7	95,2	6,7	6,9	99,8	8,2	8,4	99,8	4,8	4,8	100
0,106+0,075	3,5	83,9	19,6	7,3	68,1	39,2	12,8	38,5	74,3	10,6	17,5	93,1	8	16,4	91,6	7,20	12	95,2
0,075+0,053	2,1	86	16,1	4,2	72,3	31,9	8,7	47,2	61,5	10	27,5	82,5	10,6	27	83,6	10	22	88
0,053+0,030	2,1	88,1	14	3,6	75,9	27,7	7,2	54,4	52,8	10,4	37,9	72,5	8,8	35,8	73	10,8	32,8	78
0,038+0	11,9	100	11,9	24,1	100	24,1	45,6	100	45,6	62,1	100	62,1	64,2	100	64,2	67,2	100	67,2

Na osnovu dobijene krive kinetike mlevenja sa slike 7, određeno je vreme mlevenja za sadržaj klase 75 μm od 55%, 65%, 70% i 75%. Pojedine klase krupnoće su hemijski analizirane na sadržaj Cu, Fe, Mo i S. Dobijeni rezultati su prikazani u tabeli 5.

Tabela 5. *Sadržaj Cu, Fe, S i Mo po klasama krupnoće*

Klasa krupnoće, d (mm)	% Cu	% Fe	% S	% Mo
55% -0,075 mm				
-0,300 + 0,212	0,17	2,08	1,60	<0,010
-0,212+0,106	0,19	2,33	2,40	<0,010
-0,106+0,075	0,21	2,33	0,96	0,0024
-0,075+0,053	0,26	2,58	1,28	0,0037
-0,053+0,038	0,37	3,08	2,40	0,0038
-0,038+0	0,41	4,47	1,60	0,0040
65% -0,075 mm				
-0,300 + 0,212	0,34	3,88	-	-
-0,212+0,106	0,16	2,20	1,28	<0,0010
-0,106+0,075	0,20	2,45	1,12	0,0020
-0,075+0,053	0,25	2,45	1,60	0,0019
-0,053+0,038	0,35	3,08	1,12	0,0042
-0,038+0	0,42	4,34	0,80	0,0038
70% -0,075 mm				
-0,300 + 0,212	0,18	4,72	-	0,0021
-0,212+0,106	0,16	2,08	1,12	0,0014
-0,106+0,075	0,18	2,20	1,28	0,0015
-0,075+0,053	0,11	2,22	1,60	0,0020
-0,053+0,038	0,32	2,70	1,60	0,0023
-0,038+0	0,38	3,71	1,12	0,0033
75% -0,075 mm				
-0,300 + 0,212	0,19	7,99	-	0,0025
-0,212+0,106	0,16	2,20	1,12	<0,0010
-0,106+0,075	0,18	2,08	0,48	0,0025
-0,075+0,053	0,22	2,20	2,08	0,0032
-0,053+0,038	0,32	2,58	1,60	0,0016
-0,038+0	0,34	3,71	1,12	0,0033

Utvrđivanje potrebne finoće mliva

U cilju utvrđivanja finoće mliva koja obezbeđuje najpovoljnije oslobađanje korisnih minerala, odnosno najpovoljnije otvaranje sirovine i najbolje tehnološke rezultate flotacijske koncentracije, posebno u pogledu iskorišćenja i sadržaja korisnih komponenti u koncentratu, rađeni su paralelni opiti mlevenja sirovine sa različitim vremenima mlevenja.

Na osnovu dobijenih parametara, usvojena je kao najpovoljnija finoća mlevenja u laboratorijskim uslovima od 75% -0,075 mm, za vreme mlevenja u laboratorijskom mlinu od 12'10". Treba uzeti u obzir da se u industrijskim uslovima prerade rude, imajući u vidu razlike u tehnologiji mlevenja u odnosu na mlevenje u laboratorijskom mlinu, mogu pojaviti određene manje ili veće razlike u potrebnoj finoći mlevenja.

HEMIJSKE KARAKTERISTIKE UZORKA LEŽIŠTA J. REVIR ANDEZITSKI PRST

Uzorak rude na kome su izvršena hemijska ispitivanja formiran je kao reprezentativni uzorak predhodno samlevene rude navedene klase krupnoće (-3,35 + 00 mm). Izuzimanjem dovoljne količine uzorka metodom šah polja dat je uzorak na hemijsku analizu.

Hemijska analiza

Hemijske analize rađene su u IRM-Bor u odelenju za hemijsko tehničku kontrolu. Dobijeni rezultati hemijskih analiza, kao i korišćenih analitičkih metoda i postupaka sprovedenih na reprezentativnom uzorku izdvojenom za hemijska ispitivanja prikazani su u narednim tabelama 6 i 7.

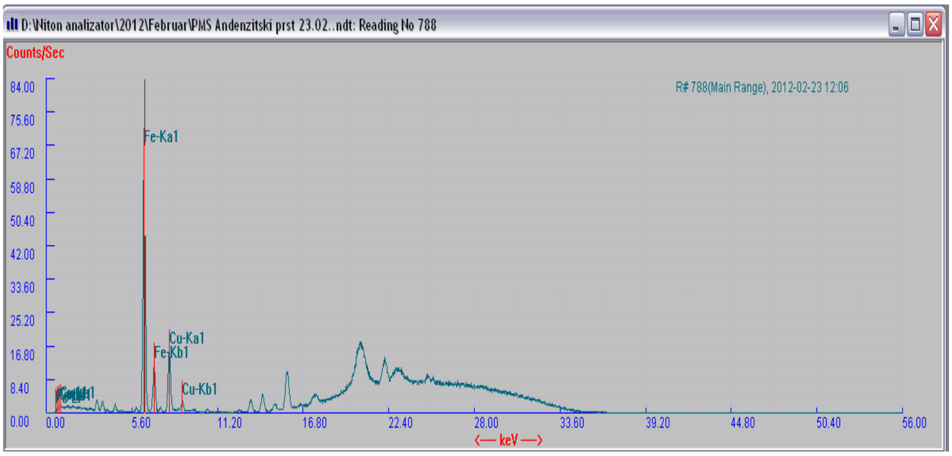
Tabela 6. *Rezultati hemijske analize uzorka*

Oznaka uzorka / **Elementi/jedinjenje**	**Ruda Andezitski prst -ulaz**	**Metoda / Uređaj**	**Analitička metoda**
% Cu	0,34	Atomska apsorpciona spektrofotometrija Atomski apsorpcioni spektrofotometar PERKIN ELMER 2380	AAS
% Cu-ox	0,018	Atomska apsorpciona spektrofotometrija Atomski apsorpcioni spektrofotometar PERKIN ELMER 2380	AAS
% S	1,16	Gasna Volumetrija	S
% Pb	0,008	Atomska apsorpciona spektrofotometrija Atomski apsorpcioni spektrofotometar PERKIN ELMER 2380	AAS
% Zn	0,012	Atomska apsorpciona spektrofotometrija Atomski apsorpcioni spektrofotometar PERKIN ELMER 2380	AAS
g/t Ag	1,3	Plamena analiza plemenitih metala / kupelacija/dokimastička metoda. Peć za kupelaciju	FA
g/t Au	0,2	Plamena analiza plemenitih metala / kupelacija / dokimastička metoda. Peć za kupelaciju	FA
% Na_2O	2,11	Atomska apsorpciona spektrofotometrija Atomski apsorpcioni spektrofotometar PERKIN ELMER 2380	AAS
% K_2O	4,50	Atomska apsorpciona spektrofotometrija Atomski apsorpcioni spektrofotometar PERKIN ELMER 2380	AAS

% Mo	0,0029	Atomska emisiona spektrometrija sa indukovanom kuplovanom plazmom	ICP-AES
% CaO	1,60	Atomska apsorpciona spektrofotometrija Atomski apsorpcioni spektrofotometar PERKIN ELMER 2380	AAS
% MgO	2,25	Atomska apsorpciona spektrofotometrija Atomski apsorpcioni spektrofotometar PERKIN ELMER 2380	AAS
% SiO_2	68,52	Gravimetrija	G
% Al_2O_3	16,19	Atomska emisiona spektrometrija sa indukovanom kuplovanom plazmom	ICP-AES
% Fe	2,81	Atomska apsorpciona spektrofotometrija Atomski apsorpcioni spektrofotometar PERKIN ELMER 2380	AAS
% Hg	*	/	*
% As	< 0,0030	Atomska emisiona spektrometrija sa indukovanom kuplovanom plazmom	ICP-AES
% Fe_3O_4	0,28	Analizator magnetita	AFe_3O_4

*Napomena: * za Hg nema podataka*

Rendgenogram dobijen na predmetnom uzorku predstavljan je na sl. 8. a sa datog rendgenograma t.j. na osnovu detektovanih pikova registrovani su sledeći elementi predstavljeni u tabeli 7.



Sl. 8. *Rendgenogram uzorka ležišta „Andezitski prst“ površinskog kopa „Južni revir“ RBM*

Tabela 7. *Rezultati rendgenske analize uzorka*

Oznaka uzorka / Elementi	Ruda Andezitski prst - ulaz	Analitička metoda/Uređaj	
% Fe	3,56	XRFA	Rendgenska fluoroscentna analiza RENDGEN NITON XL 3t
% Cu	0,311	XRFA	
% Al	3,57	XRFA	
% Si	19,46	XRFA	
% K	6,28	XRFA	
% Zn	0,0096	XRFA	
% Pb	0,0059	XRFA	
ppm As	9,27	XRFA	
ppm Mo	29,73	XRFA	
% Ba	0,043	XRFA	

Rezultati dobijeni hemijskom analitikom i rendgenskom analitičkom metodom XRFA se dosta dobro slažu, izvesna odstupanja su uglavnom u granicama greške hemijske analize.

ZAKLJUČAK

Na reprezentativnog uzorka iz ležišta J. revir RBM-a u urađena su adekvatna laboratorijska istraživanja tehnoloških karakteristika uzorka,

Cilj ovih istraživanja je da se definiše i poboljša tehnologija prerade ovog tipa rude i da se utvrde tehnološki rezultati koji se tokom njene industrijske prerade mogu očekivati primenom flotacijske metode koncentracije,

U cilju utvrđivanja finoće mliva koja obezbeđuje najpovoljnije oslobađanje korisnih minerala, odnosno, najpovoljnije otvarinje sirovine i najbolje tehnološke rezultate flotacijske koncentracije, posebno, u pogledu iskorišćenja sadržaja korisnih komponenti u koncentratu, potrebno je izvršiti dalja tehnološka ispitivnja primenom postupka kolektivnog i selektivnog flotiranja radi što većeg iskorišćenja korisnih komponenti u koncentratu i postizanja boljih tehnoloških rezultata.

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SAMPLE CHARACTERIZATION FROM THE DEPOSIT ANDESITE FINGER OF THE OPEN PIT SOUTH MINING DISTRICT IN THE COPPER MINE MAJDANPEK**

Abstract

This work presents the results of geological-mineralogical and physico-chemical characteristics of a sample from the deposit Andesite Finger of the open pit South Mining District in the Copper Mine Majdanpek. According to the mineralogical composition of valuable metals, the mineralization is composed of chalcopyrite, magnetite, pyrite and molybdenite.

Copper contents of the deposit increase of 0.1% in the border of gneiss and schist to andesites, ranging up to 0.5% in the silicified andesites and gneissgranites. Approximate molybdenum content ranges from 10 to 100 ppm depending on the position and depth at which it is located. Geological reserves of copper in the deposit South Mining District amount: 463,127,844 t of ore, medium copper content in the ore 0.316%, i.e. the amount of Cu 1,465,556 t, medium gold content in the ore 0.178 g /t, i.e. the amount of 82,156 t Au, medium silver content in the ore 1.365 g/t, i.e. the amount of 632,274 t Ag.

Based on technological characteristics of formed ore sample, it is necessary to carry out further testing of collective and selective flotation in order to obtain the optimum technological parameters of the flotation process and higher recovery of all usable components.

Keywords: *Majdanpek, Andesite Finger, characterization, copper ore*

INTRODUCTION

Copper Mine Majdanpek is situated within the company Mining and Smelting Complex Bor Group; production and processing of copper ore in RBM takes place at two open pits - North and Douth Mining District.

Copper deposit South Mining District - Majdanpek is located near Majdanpeka in the int he river basin of Mali Pek. In the vicinity of deposit is situated the Plant for ore processing, waste dump (overburden) and flotation tailing dump. The open pit South Mining District is the main carrier of copper production in RBM since 1961 with the planned annual capacity of ore exploitation and processing of 8.5 million tones. Also, this open pit will be the main carrier of copper production in the future.

The amounts of defined geological reserves of copper ore din the deposit South Mining District, make this deposit very important in terms of long-term and stable production of copper and precious metals in the company RTB Bor. Geological reserves of copper in the deposit South Mining District are: 463,127,844 t of ore, medium copper content in the ore 0.316%, i.e. the amount of Cu 1,465,556 t, medium

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gold content in the ore 0.178 g /t, i.e. the amount of 82,156 t Au, medium silver content in the ore 1.365 g/t, i.e. the amount of 632,274 t Ag. Lifetime of the open pit South Mining District, according to the latest technological documentation, and for defined input techno-economic parameters will be about 23 years [1,2].

Having all this in mind as well as that after a long stoppage in ore production and processing from the open pit Southern Mining District in RBM, the technological research have been performed in order to examine the possibilities of this raw material processing, and that the start of ore mining at the open pit ore South Mining District in RBM is planned from the site Andesite Finger, that has a respectable amounts in its composition, in addition to the main copper minerals copper also the certain amounts of Mo, it is necessary to carry out the technological research. The same was carried out in IRM Bor of the ore from the site Andesite Finger in order to find the optimum parameters of flotation concentration process of useful minerals Cu and Mo.

First, the laboratory characterization of the formed ore sample was carried out with Cu and Mo content, whose exploitation is foreseen in the future. The aim of this research was to define the mineralogical, chemical and physical characteristics of Cu and Mo ore from the deposits of the site Andesite Finger from the open pit South Mining District RBM. Based on this characterization, which will be present in this paper, the subsequent research will define the optimum parameters of flotation technology for suitable processing of this ore to obtain Cu and Mo concentrates.

GEOLOGICAL CHARACTERISTICS OF THE DEPOSIT SOUTH MINING DISTRICT ANDESITE FINGER

In the northern part of South Mining District, mineralization is situated in andesites, gneissgranites and gneiss. The central part of mineralized zone consists of andesite that penetrates gneissgranites and gneiss.

According to the mineralogical composition of useful metals, mineralization is composed of chalcopyrite, magnetite, pyrite and molybdenite.

Copper contents increase from 0.1 % at the border of gneiss and schist to andesites, ranging up to 0.5 % in the silicified andesite and gneissgranite.

Gold and silver are generally associated with chalcopyrite, pyrite and rare form their own minerals associated with platinum. Molybdenum is in molybdenite in which it has higher content in the periphery of copper mineralization, mostly in gneiss.

Molybdenum content increases from west to the east with parallel with increasing copper content, and it declines sharply in the center of mineralization, and then to the east it again has a jump. Starting from the terrain surface, the content decreases with depth.

Approximate molybdenum content from east to the west at a level K+350 m is: the west part of 50 to 60 ppm, central part of 10 to 30 ppm, east part of about 90 to 100 ppm. The mean content at a level K+350 m is about 70 to 80 ppm. Contents with depth range: K +350 m from 70 to 80 ppm, K +275 m from 60 to 70 ppm and K +200 m of about 30 to 40 ppm.

For valorization of copper, molybdenum and magnetite of basic useful components, the other accompanying metals are also important that can significantly improve the profitability of production [3].

A sample taken from a part of so-called deposit Andesite Finger was used for testing at the level of K +275 m aiming to be a representative one for this part of deposit South Mining District. The formed sample was undergone to a detailed characterization, i.e. the chemical and physical characteristics were determined that will be shown later in this paper.

MINERALOGICAL CHARACTERISTICS OF A SAMPLE

Based on the structural and textural characteristics of mineral composition and paragenetic relations of minerals, it can be stated that that at the site Andesite Finger at the open pit Southern Mining District of RBM, the low-grade porphyritic pyrite-chalcopyrite ore is present. Tested samples are presented by mineral preparations in plexiglass, obtained from this ground low-grade porphyritic pyrite-chalcopyrite ore, size class (-12.7+0.0 mm) and (-3.35+0.0 mm) that were used for further testing. Tests were conducted at the following mineralogical equipment:

1. Polarization microscope for reflected and missed light, brand "JENAPOL-U," the company Carl Zeiss-Jena, with a measuring device;
2. System for photomicrography "STUDIO PCTV" (Pinnacle Systems).

Qualitative mineralogical analysis was performed under this polarization microscope for reflected light in air and immersion (cedar oil), with identification of ore and non-ore minerals.

Detailed results are given below. Textual part follows the corresponding micrographs.

The following ore minerals were determined and presented respectively by size class reviewing the formed mineral preparations from a ground sample of given size classes.

MINERALOGICAL TEST RESULTS

1. Mineral preparation in plexiglass, size class: -12.7+0.0 mm

Macro description: Sample is presented by mineralogical preparation in plexiglass (1 piece) where an intensive mineralization with pyrite is observed. Under UV-lamp (short spectrum), the effects of fluorescence are not observed. The sample is non-magnetic.

Mineral composition: *chalcopyrite, pyrite, magnetite, rutile, cassiterite, leucoxene, zircon, quartz, silicates.*

Minerals are listed according to the frequency of occurrence.

Macro description: The most represented sulphide mineral is pyrite. It appears in the form of irregular to isometric individuals with frequent inclusions of chalcopyrite. Sometimes it is associated with the minerals of titanium. Chalcopyrite is less present and usually occurs in the form of jagged impregnating in the silica matrix (chlorite). Magnetite is less present, but it is always associated with chalcopyrite. Gold minerals were not observed. Waste rock is quartz-silicate.

2. Mineral preparation in plexiglass, size class: -3.35+ 0.0 mm

Macro description: Sample is presented by rock ground fine-grained aggregates in plexiglass, in which a weaker mineralization with pyrite is observed. Under UV-lamp (short spectrum), the effects of fluorescence are not observed. The sample is non-magnetic.

Mineral composition: *chalcopyrite, pyrite, magnetite, rutile, cassiterite, leucoxene, zircon, quartz, silicates.*

Minerals are listed according to the frequency of occurrence.

Macro description: The most represented sulphide mineral is pyrite. It appears in the form of irregular to isometric individuals with frequent inclusions of chalcopyrite. Sometimes it is associated with the minerals of titanium. Chalcopyrite is less present and mainly occurs in the form of jagged impregnating in the silica matrix (chlorite?). Magnetite is less present, but it is always associated with chalcopyrite. Gold minerals were not observed. Waste rock is quartz-silicate. The sample is largely identical to the previous sample.

Figures 1 - 4 show visual arguments of mineralogical examination of preparations.

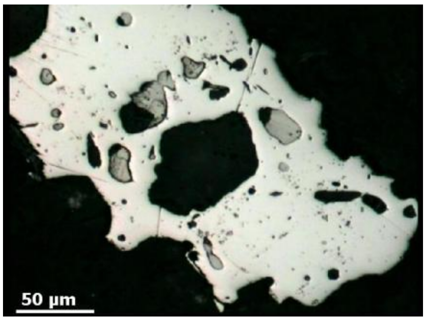

Figure 1 *Inclusions of chalcopyrite (gray-yellow) in pyrite (light-yellow), embedded in silicate waste (black). Air, II N.*

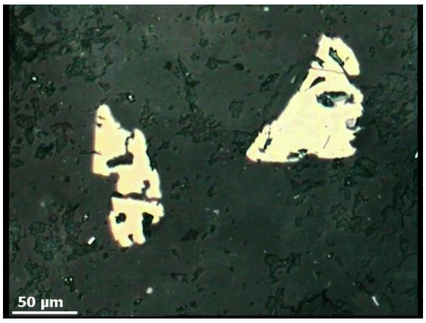

Figure 2 *Aggregates of chalcopyrite (yellow) embedded in silicate substrate (dark-gray).Air, II N.*

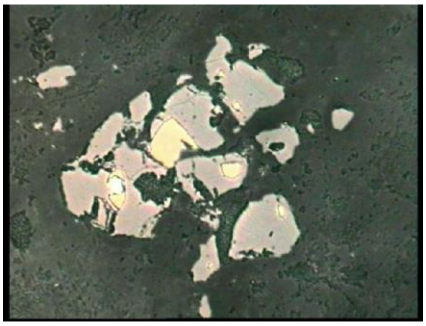

Figure 3 *Skeleton magnetite (gray) with inclusions of chalcopyrite (yellow). Air, II N.*

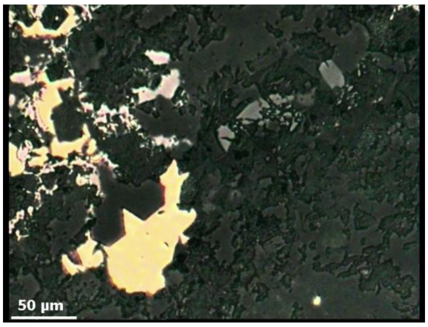

Figure 4 Impregnation *of chalcopyrite (yellow) in waste with rutile (light) and cassiterite (dark gray). Air, II N.*

PHYSICAL CHARACTERISTICS OF A SAMPLE FROM THE DEPOSIT SOUTH MINING DISTRICT - ANDESITE FINGER

Representative sample from the deposit South Mining District - Andesite Finger is formed at the mine by taking small amounts of samples for free selection of sampling points, and then its homogenization was done, crushing and reducing the sample, and later its characterization was done in the Mining and Metallurgy Institute Bor.

A sample of ore, used for physical examination, was formed as a representative sample of previously ground ore of given size classes (-12.7+00 mm) and (-3.35+00 mm). Taking the sufficient amount of sample using the chess field method, the samples were formed for predicted physical examinations. Summary results of conducted physical examinations are present in Table 1.

Bulk density

Bulk density was determined on samples of size class 100 % -12.7 mm and 100 % -3.35 mm, Table 1. The method involves determining the mass of free poured sample, without compression, into a vessel of known volume V and mass m. Bulk density is calculated by the following formula:

$$\Delta = \frac{m_1 - m}{V}, \quad (kg/m^3)$$

where:

- Δ - bulk density of a sample,
- m_1 – mass of a sample and vessel,
- m – mass of vessel,
- V – vessel volume.

Natural pH value of a sample

Natural pH of ore sample, Table 1, was determined measuring the pH of liquid phase, after mixing of drinking water (pH = 6.80) with ore (S:L = 1:1) for 30 minutes, pH of ore = 7.46

Sample density

Density of a sample was determined, Table 1, using the method of glass pycnometers with vacuuming. The mean value of density from three measurements is

ρ=2.680 kg/m^3

Specific ore density

Determining the bulk density of ore was carried out in a glass vessel – pycnometer, Table 1. Bulk density is calculated by the following formula:

$$\rho = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)} \rho_F^t \quad (kg/m^3)$$

where:

- m_1 - mass of empty pycnometer, kg
- m_2 - mass of pycnometer with sample, kg
- m_3 - mass of pycnometer with sample and water, kg
- m_4 - mass of pycnometer with water, kg
- ρ_F^t - fluid density (water) at measuring temperature, (kg/m^3)

Ore grindability –the Bond work index

Ore grindability is defined by the values of the Bond work index, Wi, and it is determined by the standard Bond test in the Bond rod mill bars and Bond ball mill, Table 1. The obtained values are:

M_r = 20.80 kWh/t

M_b = 15.50 kWh/t

Table 1 *Physical characteristics of a sample from the South Mining District Andesite Finger*

Physical characteristics	Values
Bulk density	*Δ kg/m^3*
Sample 100% - 12.7 mm Sample100% - 3.35 mm	$\Delta_{(-12.7\ mm)}$ = 1671.60 kg/m^3 $\Delta_{(-3.35\ mm)}$ = 1468.46 kg/m^3
Ore pH	7.46
Ore density	ρ = 2680 kg/m^3
Bond index	*Wi (kWh/t)*
Rod mill Ball mill	m_r = 20.8 m_b = 15.50

Grain size distribution of a sample

Grain-size analyses of ore samples of size class -12.7+0.0 mm and -3.35+0.0 mm, were carried out by wet sieving on a standard series of sieves, type TYLER

(The Tyler Standard Screen Scale), and the results of obtained grain-size distribution are shown graphically in Figures 5 and 6 and analytically in Tables 2 and 3.

Table 2 *Grain size distribution of a sample Andesite finger, -12.70+0,00 mm*

Size class (mm)	m %	R %	D %
-12.70+10	3.30	3.30	100
-10+8	9.49	12.79	96.70
-8+6	7.24	20.03	87.21
-6+4	19.79	39.82	79.97
-4+3.35	4.83	44.65	60.18
-3.35+2.36	10.56	55.21	55.35
-2.36+1.70	7.39	62.60	44.79
-1.70+1.18	8.10	70.70	37.40
-1.18+0.850	4.97	75.67	29.30
-0.850+0.600	5.33	81.00	24.33
-0.600+0.425	3.61	84.61	19.00
-0.425+0.300	3.29	87.90	15.39
-0.300+0.212	2.26	90.16	12.10
-0.212+0.106	4.24	94.40	9.84
-0.106+0.075	1.81	96.21	5.60
-0.075+0.00	3.79	100.00	3.79

Table 3 *Grain size distribution of a sample Andesite finger, -3.35+0.00 mm*

Size class (mm)	m %	R %	D %
- 3.35+2.36	31.50	31.50	100
-2.36+1.70	20.53	52.03	68.50
-1.70+1.18	14.43	66.46	47.97
-1.18+0.850	7.23	73.69	33.54
-0.85+0.60	6.90	80.59	26.31
-0.6+0.425	4.20	84.79	19.41
-0.425+0.30	3.33	88.12	15.21
-0.30+0.212	2.50	90.62	11.88
-0.212+0.106	3.60	94.22	9.38
-0.106+0.075	1.43	95.65	5.78
-0.075+0.053	4.35	100	4.35

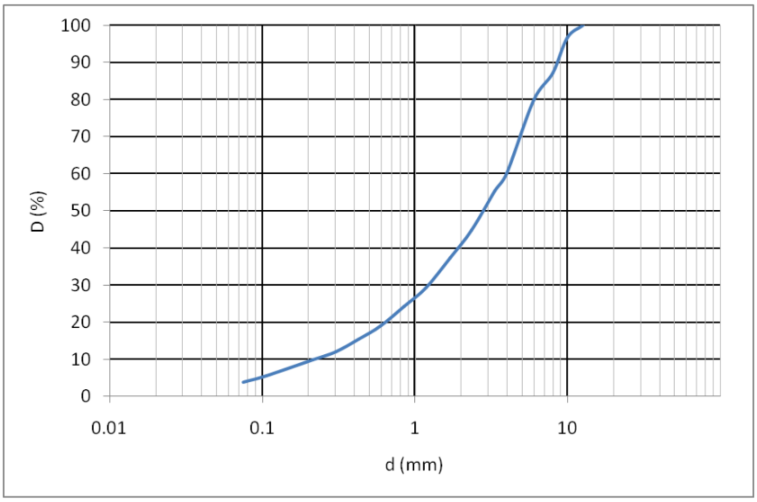

Figure 5 *Grain size distribution of ore sample Andesite Finger, size class -12.7 + 0.00 mm*

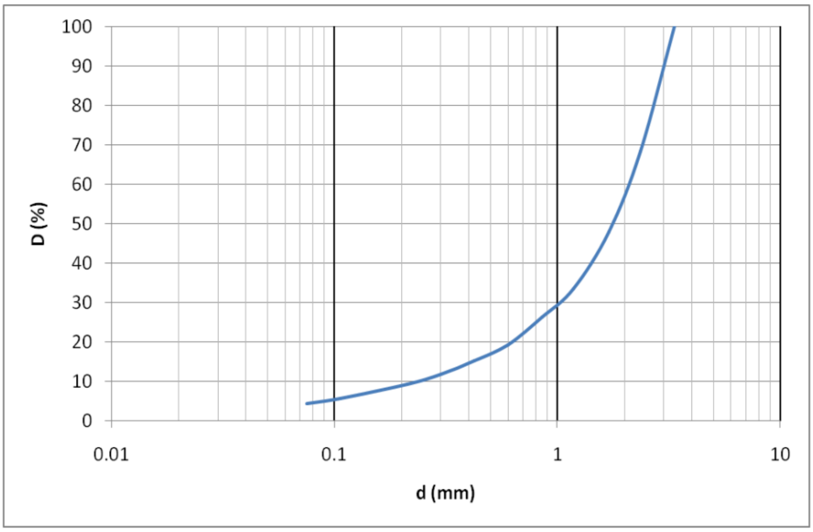

Figure 6 *Grain size distribution of ore sample Andesite Finger, size class -3.35 + 0.00 mm*

Grinding kinetics

Determining the grinding time depending on fineness of grind was done in a laboratory mill type "Denver".

In order to determine the dependence of fineness of ground product on grinding time in a laboratory ball mill, the grinding experiments were carried out with the following grinding times: 1, 3, 8 and 16 minutes, Table 4. Content of the class -0.075 mm, depending on the grinding time, is shown in Figure 7.

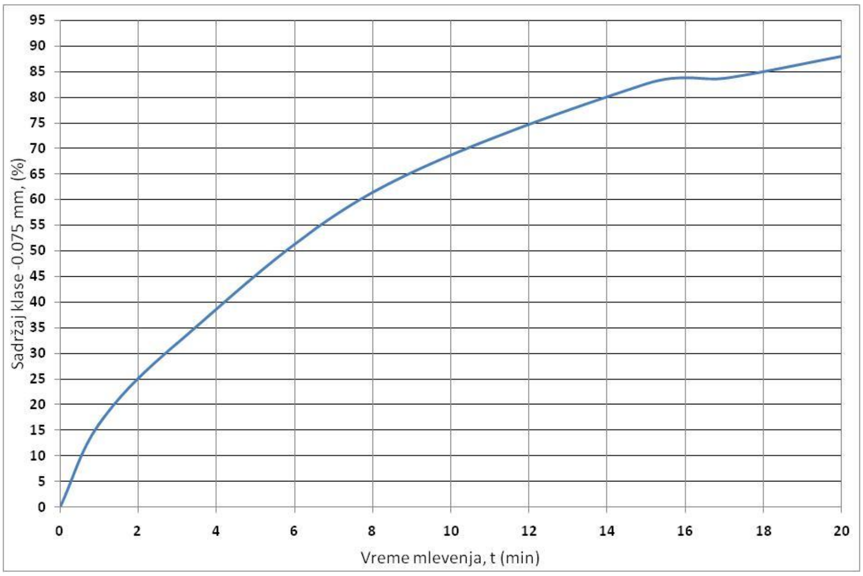

Figure 7 Dependence *of content of accounting size class - 75 µm on grinding time in grinding product*

Table 4 *Grain size distribution of grinding products obtained at various grinding times*

Size class, d (mm)	GRINDING TIME																	
	1 min			3 min			8 min			15 min			17 min			20 min		
	m %	R%	D%	m%	R%	D%	m%	R%	D%	m%	R%	D%	m%	R%	D%	m %	R%	D%
- 3,35+2,36	9,2	9,2	100															
2,36+1,70	11,5	20,7	90,8	3,4	3,4	100												
1,70+1,18	11,8	32,5	79,3	2,1	5,5	96,6												
1,18+0,850	8,1	40,6	67,5	2,4	7,9	94,5												
0,85+0,60	10	50,6	59,4	5,2	13,1	92,1												
0,6+0,425	7,6	58,2	49,4	8,5	21,6	86,9												
0,425+0,30	7,2	65,4	41,8	11,3	32,9	78,4	0,7	0,7	100									
0,30+0,212	5,8	71,2	34,6	10,4	43,3	67,1	4,1	4,8	99,3	0,2	0,2	100	0,2	0,2	100			
0,212+0,106	9,2	80,4	28,8	17,5	60,8	56,7	20,9	25,7	95,2	6,7	6,9	99,8	8,2	8,4	99,8	4,8	4,8	100
0,106+0,075	3,5	83,9	19,6	7,3	68,1	39,2	12,8	38,5	74,3	10,6	17,5	93,1	8	16,4	91,6	7,20	12	95,2
0,075+0,053	2,1	86	16,1	4,2	72,3	31,9	8,7	47,2	61,5	10	27,5	82,5	10,6	27	83,6	10	22	88
0,053+0,030	2,1	88,1	14	3,6	75,9	27,7	7,2	54,4	52,8	10,4	37,9	72,5	8,8	35,8	73	10,8	32,8	78
0,038+0	11,9	100	11,9	24,1	100	24,1	45,6	100	45,6	62,1	100	62,1	64,2	100	64,2	67,2	100	67,2

Based on the obtained curve of grinding kinetics in Figure 7, the grinding time was determined for the class content 75 µm of 55%, 65%, 70% and 75%. Some of the size classes were chemically analyzed for Cu, Fe, Mo and S content. The results are shown in Table 5.

Table 5 *Content of Cu, Fe, S and Mo per size classes*

Size class, d (mm)	% Cu	% Fe	% S	% Mo
55% -0.075 mm				
-0.300 + 0.212	0.17	2.08	1.60	<0.010
-0.212+0.106	0.19	2.33	2.40	<0.010
-0.106+0.075	0.21	2.33	0.96	0.0024
-0.075+0.053	0.26	2.58	1.28	0.0037
-0.053+0.038	0.37	3.08	2.40	0.0038
-0.038+0	0.41	4.47	1.60	0.0040
65% -0.075 mm				
-0.300 + 0.212	0.34	3.88	-	-
-0.212+0.106	0.16	2.20	1.28	<0.0010
-0.106+0.075	0.20	2.45	1.12	0.0020
-0.075+0.053	0.25	2.45	1.60	0.0019
-0.053+0.038	0.35	3.08	1.12	0.0042
-0.038+0	0.42	4.34	0.80	0.0038
70% -0.075 mm				
-0.300 + 0.212	0.18	4.72	-	0.0021
-0.212+0.106	0.16	2.08	1.12	0.0014
-0.106+0.075	0.18	2.20	1.28	0.0015
-0.075+0.053	0.11	2.22	1.60	0.0020
-0.053+0.038	0.32	2.70	1.60	0.0023
-0.038+0	0.38	3.71	1.12	0.0033
75% -0.075 mm				
-0.300 + 0.212	0.19	7.99	-	0.0025
-0.212+0.106	0.16	2.20	1.12	<0.0010
-0.106+0.075	0.18	2.08	0.48	0.0025
-0.075+0.053	0.22	2.20	2.08	0.0032
-0.053+0.038	0.32	2.58	1.60	0.0016
-0.038+0	0.34	3.71	1.12	0.0033

Determining the required fineness of grind

In order to determine the fineness of grind that provides the best release of useful minerals, i.e. the best opening of raw minerals and the best technological results of flotation concentration, especially in terms of efficiency and content of useful components in the concentrate, the parallel experiments of grinding the raw material were carried out with different grinding time.

Based on the obtained parameters, it was adopted as the most favorable fineness of grinding in laboratory conditions of 75% -0,075 mm, for the grinding time in a laboratory mill of 12'10 ". It should be taken into account that in the industrial conditions of ore processing, having in mind the differences in grinding technology compared to the grinding in a laboratory mill, some minor or major differences may appear in the required fineness of grinding.

CHEMICAL CHARACTERISTICS OF THE SAMPLE FROM THE DEPOSIT SOUTH MINING DISTRICT – ANDESITE FINGER

Chemically tested ore samples was formed as a representative sample of pre-ground ore with given size class (-3.35 +00 mm). Excluding a sufficient amount of sample using the method of chess field, a sample was given to the chemical analysis.

Chemical analyses

Chemical analyses were carried out in MMI Bor in Department for Chemical and Technical Control. The obtained results of chemical analyses as well as the used analytical methods and procedures, carried out on a representative sample and separated for chemical testing, are shown in the following Tables.

Table 6 *Results of chemical analyses of samples*

Sample designation / **Element/Compound**	**Ore Andesite Finger-input**	**Method/Device**	**Analytical method**
% Cu	0.34	Atomic absorption spectrophotometry Atomic absorption spectrophotometerPERKIN ELMER 2380	AAS
% Cu-ox	0.018	Atomic absorption spectrophotometry Atomic absorption spectrophotometer PERKIN ELMER 2380	AAS
% S	1.16	Gas Volumetry	S
% Pb	0.008	Atomic absorption spectrophotometry Atomic absorption spectrophotometer PERKIN ELMER 2380	AAS
% Zn	0.012	Atomic absorption spectrophotometry Atomic absorption spectrophotometer PERKIN ELMER 2380	AAS
g/t Ag	1.3	Flame analysis of precious metals/cupellation/dokimastic method. Furnace for cupellation	FA
g/t Au	0.2	Flame analysis of precious metals/cupellation/dokimastic method. Furnace for cupellation	FA
% Na_2O	2.11	Atomic absorption spectrophotometry Atomic absorption spectrophotometer PERKIN ELMER 2380	AAS
% K_2O	4.50	Atomic absorption spectrophotometry Atomic absorption spectrophotometer PERKIN ELMER 2380	AAS
% Mo	0.0029	Atomic absorption spectrophotometry with induced coupled plasma	ICP-AES
% CaO	1.60	Atomic absorption spectrophotometry Atomic absorption spectrophotometer PERKIN ELMER 2380	AAS
% MgO	2.25	Atomic absorption spectrophotometry Atomic absorption spectrophotometer PERKIN ELMER 2380	AAS

% SiO_2	68.52	Gravimetry	G
% Al_2O_3	16.19	Atomic absorption spectrophotometry with induced coupled plasma	ICP-AES
% Fe	2.81	Atomic absorption spectrophotometry Atomic absorption spectrophotometer PERKIN ELMER 2380	AAS
% Hg	*	/	*
% As	< 0.0030	Atomic absorption spectrophotometry with induced coupled plasma	ICP-AES
% Fe_3O_4	0.28	Analyzer of magnetite	AFe_3O_4

*Note: * there are no data for Hg*

Roentgenogram, obtained on the subject sample, is present in Figure 8, and the following elements are registered from the given roentgenogram, i.e. based on the detected peaks and given in Table 7.

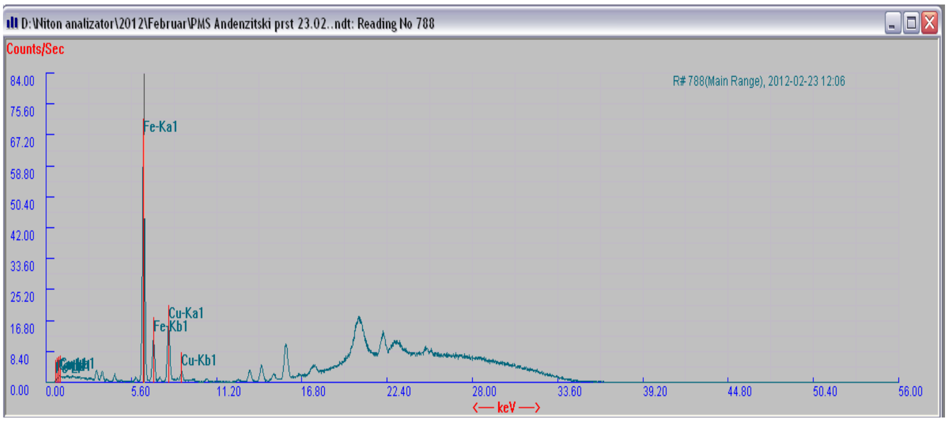

Figure 8 *Roentgenogram of a sample from the deposit Andesite Finger of the open pit South Mining District RBM*

Table 7 *Results of X-ray analysis of a sample*

Elements \ **Sample designation**	**Ore Andesite Finger- input**	**Analytical method/device**	
% Fe	3.56	XRFA	X-ray fluorescence analysis ROENTGEN NITON XL 3t
% Cu	0.311	XRFA	
% Al	3.57	XRFA	
% Si	19.46	XRFA	
% K	6.28	XRFA	
% Zn	0.0096	XRFA	
% Pb	0.0059	XRFA	
ppm As	9.27	XRFA	
ppm Mo	29.73	XRFA	
% Ba	0.043	XRFA	

The results obtained by chemical analysis and X-ray analytical method, XRFA, agree quite well; the certain deviations are generally within the limits of chemical analysis error.

CONCLUSION

The appropriate laboratory research of technological characteristics of sample was carried out on a representative sample from the deposit South Mining District of RBM.

The aim of this research is to define and improve the processing technology of this type of ore and to identify the technological results that can be expected in its industrial processing applying the flotation concentration method,

In order to determine the fineness of grind that provides the best release of useful minerals, i.e. the most favorable opening of raw materials and the best technological results of flotation concentration, especially in terms of utilization the content of useful components in concentrate, it is necessary to carry out further technological testing using the method of collective and selective flotation for as much as possible utilization of useful components in concentrate and to achieve better technological results.

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BOČNI PRITISAK TLA NA POTPORNI ZID PRI DEJSTVU DINAMIČKOG OPTEREĆENJA NA POVRŠINI [**]

Izvod

U radu se analizira uticaj vertikalnog ravnomerno raspoređenog opterećenja P(t) i trenutno delujućeg impulsa S_o na pojavu dinamičkog pritiska na potporni zid.

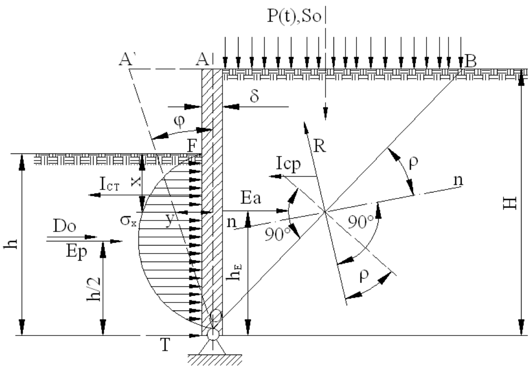
Ključne reči: *vertikalno opterećenje P(t), trenutni impuls S_o, dinamički bočni pritisak na potporni zid, ravnoteža sila*

UVOD

Pri proračunu šipova ili ramovskih potpora veliki praktični značaj ima proračun na dejstvo dinamičkog opterećenja površine tla. Pri rešavanju takvih zahteva neophodno je odrediti aktivni dinamički bočni pritisak tla izazvan vertikalnim ravnomerno raspoređenim opterećenjem P(t) i trenutno raspoređenim impulsom S_o na površini terena.

1. ANALIZA SILA NA ZID I NJEGOVA KINEMATIKA

Na prednjoj strani zida deluje sila reaktivnog pritiska tla E_p i sila otpora D_o. Sila otpora D_o zavisi od trenja i brzine obrtanja zida, slika 1. Za sagledavanje kinematike usvaja se poluga visine H zglobno oslonjena na donjem kraju u tački O. Pomeranje krutog zida određeno je uglom obrtanja njegove ose.



Sl. 1. *Analiza sila na zid od dinamičkog opterećenja P(t) i S_o*

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[**] *Ovaj rad je proistekao iz Projekta broj 33021 „Istraživanje i praćenje promena naponsko deformacionog stanja u stenskom masivu "in-situ" oko podzemnih prostporija sa izradom modela sa posebnim osvrtom na tunel Kriveljske reke i Jame Bor", koga je finansiralo Ministarstvo za prosvetu, nauku i tehnološki razvoj Republike Srbije*

Dubina usađivanja poluge u tlo je h sa koeficijentom posteljice tla

$$k = c_h \cdot b$$

gde je:
- b, dimenzija potpore (upravno na ravan crteža),
- c_h, koeficijent bočnog elastičnog pritiska tla na dubini h.

Na slici 1 prikazane su sile koje deluju na zid OA i na klin mogućeg obrušavanja OAB pri dinamičkom dejstvu opterećenja P(t) na površini tla AB.

Intenzitet otpora σ_x usvaja se da je direktno proporcionalan pomeranju:

$$y = \varphi(h - x)$$

a koeficijent posteljice za proizvoljnu tačku zida x je:

$$k_x = \frac{k}{h} \cdot x$$

Tada je:

$$\sigma_x = k \cdot y = \frac{k}{h} \cdot x\varphi \cdot (h - x) \quad (1)$$

Sila reaktivnog pritiska je:

$$E_p = \int_0^h \sigma_x \cdot dx = \frac{kh^2}{6} \cdot \varphi \quad (2)$$

Sila viskoznog otpora D_o po Fojgtu je:

$$D_0 = t \cdot \varphi' \quad (3)$$

gde je:
- t, koeficijent otpora.

Sila viskoznog otpora određuje proces neuobičajenih vibracija izazvanih veštački eksperimentom. Osim navedenih sila E_p i D_o, na zid deluje i dinamički pritisak tla s leva E_a a takođe i reakcija otpora tla T, slika 1.

Na slici 2 prikazani su uslovi dinamičke ravnoteže zida koji se nalazi pod dejstvom sila aktivnog pritiska tla od sile obrušavanja E_a, sile inercije zida I_{ct}, sile otpora tla E_p, amortizujućeg otpora D_o i od reakcije T zglobnog oslonca u obliku sume momenata u odnosu na odgovarajući centar obrtanja.

$$\sum M_o = 0$$

Iz napred rečenog, lako je formirati jednačinu ravnoteže:

$$(E_p + D_o)\frac{h}{2} - I_{ct} \cdot \frac{2H}{3} - E_a \cdot h_E = 0$$

Iz prethodne jednačine, lako je odrediti silu aktivnog pritiska tla E_a

$$E_a = (E_p + D_o)\frac{h}{2h_E} - I_{ct} \cdot \frac{2H}{3h_E} =$$

$$= (E_p + D_o)a_2 - I_{ct} \cdot a_1 \quad (4)$$

gde je:
- h_E, krak dejstva sile E_a, koji se određuje popoložaju centra težišta dijagrama napona, slika 1,
- a_1 i a_2, koeficijenti koji se određuju na sledeći način:

$$a_1 = \frac{2H}{3h_E}; \qquad a_2 = \frac{h}{2h_E}$$

Sile E_p i D_o određuju se po izrazima (2) i (3). Sila inercije je:

$$I_{ct} = -\int_0^H \bar{m} y'' \cdot dz = - \int_0^H \bar{m} z\varphi'' \cdot dz = -\frac{\bar{m} H^2}{2} \cdot \varphi'' \quad (5)$$

gde je:
- $\bar{m}$, pokretna masa potpore:

$$\bar{m} = \frac{\gamma \cdot b \cdot \delta}{g}$$

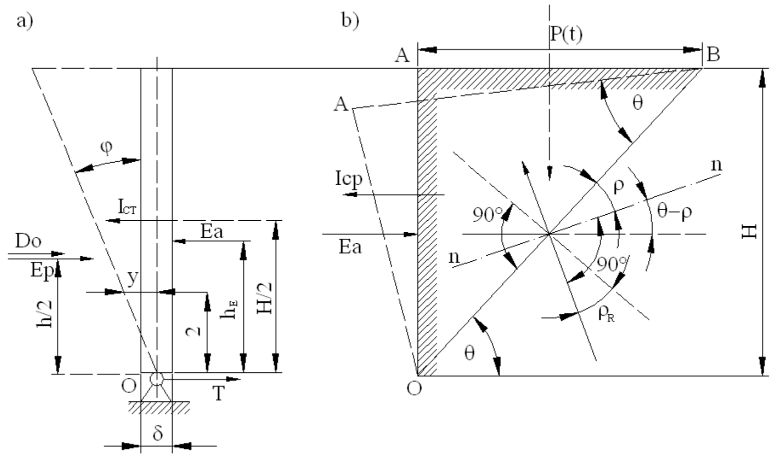
gde je:
- δ, debljina zida,
- g, ubrzanje sile teže,
- b, dužina zida.

Uvrštavanjem (2), (3), (5) u (4) dobija se:

$$E_a = \frac{\bar{m} H^2}{2} \cdot a_1 \varphi'' + t a_2 \varphi' + \frac{kh^2}{6} \cdot a_2 \varphi \quad (6)$$

Razmatrajući ravnotežu klina obrušavanja, slika 2b, uočavaju se četiri sile:

- E_a, aktivni pritisak,
- I_{cp}, sila inercije klina obrušavanja,
- P(t), ravnodelujuće dinamičko opterećenje,
- R, reakcija na klin obrušavanja od pravca nepokretnog dela tla



Sl. 2. *Uslovi dinamičke ravnoteže zida*

Primenjujući i za dinamičko opterećenje, teorija graničnog stanja Kulona, određuje se ugao nagiba θ linije obrušavanja, koristeći statički proračun.

Ugao unutrašnjeg trenja ρ, koji predstavlja otklon od normale na pravac OB u kojem deluje sila R, slika 2b.

Projektujući sve sile koje deluju u klinu OAB na osu nn, tj. Upravna na pravac sile R, čija je projekcija u tom slučaju jednaka nuli, dobija se:

$$E_a \cdot cos(\theta - \rho) = I_{cp} \cdot cos(\theta - \rho) + P(t) \cdot sin(\theta - \rho) \quad (7)$$

gde je:

$$P(t) = p(t) \cdot H \cdot ctg\theta \cdot b$$

- b, treća dimenzija zida.

Iz izraza (7) se dobija:

$$E_a = P(t) \cdot tg(\theta - \rho) + I_{cp} \quad (8)$$

gde je:

$$I_{cp} = -\frac{\gamma \cdot H^2 ctg\theta}{2g} \cdot \frac{2}{3} H b \varphi'' = -m_{cp} \cdot \varphi''$$

Sada je ubrzanje premeštanja centra obrušavanja ($2/3H\varphi''$). Umesto h dobija se:

$$E_a = P(t) \cdot tg(\theta - \rho) - \frac{\gamma \cdot H^3 b}{3g} ctg\theta \cdot \varphi'' = P(t) \cdot tg(\theta - \rho) - m_{cp} \cdot \varphi'' \quad (9)$$

gde je:

$$m_{cp} = -\frac{\gamma \cdot H^3 b}{3g} ctg\theta \quad (10)$$

Izjednačujući (6) i (9) i objedinjujući član sa φ'', dobije se:

$$\left(\frac{\bar{m} H^2}{2} \cdot a_1 + m_{cp}\right)\varphi'' + t a_2 \varphi' + \frac{kh^2}{6} \cdot a_2 \varphi = P(t) \cdot tg(\theta - \rho) \quad (11)$$

Množenjem sa φ'', moguće je razmotriti kao prisjedinjenu masu sistema potpora-klin obušavanja. Označavajući ga sa m_{pr}, dobija se:

$$m_{pr}\cdot\varphi''+ta_2\varphi'+\frac{kh^2}{6}\cdot a_2\varphi=$$
$$=P(t)\cdot tg(\theta-\rho) \qquad (12)$$

Deljenjem oba izraza (12) sa m_{pr} i praveći izvod po kružnoj frekvenciji vibracija ω dobija se:

$$\varphi''+2\varepsilon\varphi'+\omega^2\varphi=\frac{P(t)\cdot tg(\theta-\rho)}{m_{pr}} \qquad (13)$$

gde je:

$$2\varepsilon=\frac{ta_2}{m_{pr}}, \qquad \varepsilon-\text{koeficijent prigušenja}$$

$$\omega=\sqrt{\frac{kh^2\cdot a_2}{6m_{pr}}} \qquad (14)$$

$$m_{pr}=\frac{\bar{m}\,H^2}{2}\cdot a_1+m_{cp}=$$
$$=\frac{\bar{m}\,H^2}{2}\cdot a_1+\gamma\frac{H^3\,b}{3g}ctg\theta \qquad (15)$$

Usvajajući da je opterećenje konstantno P(t) = P_o, tada je:

$$q_o=\frac{P_o tg(\theta-\rho)}{m_{pr}} \qquad (16)$$

Konačno se dobija rešenje diferencijalne jednačine (13) za trenutno dejstvo opterećenja pri početku trenutnog impulsa S_o.

$$\varphi=\frac{f_o}{\omega_1}\cdot e^{-\varepsilon t}\cdot sin\omega_1 t+\frac{q_o}{\omega_2}$$
$$\left[1-e^{-\varepsilon t}\cdot\left(cos\,\omega_1 t+\frac{\varepsilon}{\omega_1}sin\,\omega_1 t\right)\right] \qquad (17)$$

gde je:

$$\left.\begin{aligned} f_o&=\frac{S_o H\cdot b\cdot ctg\theta}{m_{pr}}\cdot tg(\theta-\rho)\\ \omega_1&=\sqrt{\omega^2-\varepsilon^2}\end{aligned}\right\} \qquad (18)$$

- S_o, trenutno opterećenje raspoređeno na površini AB trenutnog impulsa S_o, površine b·H·ctgθ.

Dobijeno je rešenje za φ po izrazu (17) i određivanje ubrzanja φ'' u izrazu (9) za određivanje dinamičkog pritiska. Posle diferenciranja izraza (17) i rešenja po (9), dobija se

$$E_a=P(t)\cdot tg(\theta-\rho)+m_{cp}\cdot e^{-\varepsilon t}$$
$$\left[f_o\cdot\left(\frac{\omega_1^2-\varepsilon^2}{\omega_1}\cdot sin\omega_1 t+2\varepsilon\cdot cos\omega_1 t\right)+\right.$$
$$\left.+q_o\cdot\left(\frac{\varepsilon}{\omega_1}\cdot sin\,\omega_1 t-cos\omega_1 t\right)\right] \qquad (19)$$

Ovde se mora naglasiti da vrednosti m_{pr} i ω zavise od h_E i shodno tome, različiti su za slučaj dejstva impulsa ili trenutnog pritiska.

Po izrazu (19), moguće je odrediti dinamički bočni pritisak tla od trenutnog impulsa ili od trenutno priloženog dejstva opterećenja, pri čemu se određuje maksimalna vrednost E_a kao funkcija vremena.

Na primeru potpornog zida u području Slobomira, Semberija, prikazaće se proračun dinamičkog pritiska tla na potporni zid.

Primer:

Ravnomerno raspoređeno trenutno opterećenje P_o = 48,0 [kN/m^2], H = h = 3,0 [m], dužina zida b = 1,0 [m], ugao unutrašnjeg trenja ρ = 30˚, zapreminska težina tla γ_H=17,65[kN/m^3], zapreminska težina potpore γ_{PP} = 23,54 [kN/m^3]. Presek zida bxδ = 1,0 x 0,3 [m^2], slika 2a takođe treba odrediti i dinamički pritisak tla od trenutnog vertikalnog impulsa S_o = 4,0 [kNs/m^2]. Koeficijent elastičnog bočnog pritiska tla C_h = 20.000 [kN/m^3]. Krak od dejstva pritiska h_E = 1,33 [m], a od dejstva impulsa h_E = 1 [m].

- ugao θ = 45˚+ρ/2 = 60˚

tg (θ - ρ) = tg 30˚ = 0,5774;

ctg θ = 0,5774

- pokretna masa zida:

$$\bar{m} = \frac{1{,}0 \cdot 0{,}3 \cdot 23{,}54}{9{,}81} =$$

$$= 0{,}72\ [kNs^2/m^2]$$

- masa prizme obrušavanja po OB:

$$m_{OB} = \frac{17{,}65 \cdot 3^3 \cdot 0{,}5774}{3 \cdot 9{,}81} =$$

$$= 9{,}35\ [kNs^2]$$

- koeficijent posteljice:

k=20.000·1=20.000 [kN/m²].

- Pri dejstvu trenutno delujućeg pritiska:

$$a_1 = \frac{2H}{3h_E} = \frac{6}{3{,}99} = 1{,}50$$

$$a_2 = \frac{h}{2h_E} = \frac{3}{2{,}66} = 1{,}13$$

- Masa sistema potpora - klin obrušavanja:

$$m_{pr} = \frac{\bar{m}\ H^2}{2} \cdot a_1 + m_{cp} =$$

$$= \frac{\bar{m}\ H^2}{2} \cdot a_1 + \gamma \frac{H^3 b}{3g} ctg\theta$$

$$m_{pr} = \frac{0{,}72 \cdot 3^2}{2} \cdot 1{,}5 +$$

$$+ \frac{17{,}65 \cdot 3^3 \cdot 1{,}0}{3 \cdot 9{,}81} \cdot 0{,}5774 =$$

$$= 14{,}21\ [kNs^2]$$

- kružna frekvencija

$$\omega = \sqrt{\frac{kh^2 \cdot a_2}{6m_{pr}}} =$$

$$= \sqrt{\frac{20.000 \cdot 3^2 \cdot 1{,}13}{6 \cdot 14{,}21}} =$$

$$= 48{,}84\ [1/s]$$

- koeficijent prigušenja

$$\varepsilon = \frac{1}{10} \cdot \omega = 4{,}88$$

- pri dejstvu trenutnog impulsa S_o:

$$a_1 = \frac{2H}{3h_E} = \frac{6}{3} = 2{,}0$$

$$a_2 = \frac{h}{2h_E} = \frac{3}{2} = 1{,}5$$

$m_{pr} = 15{,}83\ [kNs^2]$

$\omega = 52{,}7\ [1/s];\ \varepsilon = 5{,}3$

$$q_0 = \frac{P_o tg(\theta - \rho)}{m_{pr}} = \frac{48}{14{,}21} =$$

$$= 3{,}38\ [1/s^2]$$

$$P_o \cdot tg(\theta - \rho) = 48\ [kN/m^2]$$

- bočni pritisak od trenutka priloženog opterećenja po izrazu (19) pri $e^{-\varepsilon t}$ = 0,69, ako je:

$cos\omega_1 t = -1$ (pri $\omega_1 t = \pi$)

$$E_a = P_o tg(\theta - \rho) + m_{OB} \cdot e^{-\varepsilon t} \cdot q_0 \cdot 1$$

$$E_a = 48 + 9{,}35 \cdot 0{,}69 \cdot 3{,}38 = 69{,}8$$

Pri dejstvu raspoređenog impulsa S_o = 4,0 [kNs/m²].

$$f_o = \frac{S_o \cdot H \cdot b \cdot ctg\theta}{m_{pr}} \cdot tg(\theta - \rho)$$

$$f_o = \frac{4 \cdot 3 \cdot 1 \cdot 0{,}5774^2}{15{,}83} =$$

$$= 0{,}253\ [m/s]$$

Dinamički pritisak od delujućeg impulsa S_o po (19) pri $\omega_1 t = \pi/2$ pri čemu je $sin\ \omega_1 t = 1$, tada je $e^{-\varepsilon t}$ = 0,815.

$$E_a = m_{OB} \cdot e^{-\varepsilon t} \cdot f_o \cdot \omega$$

$$= 9{,}35 \cdot 0{,}815 \cdot 0{,}253 \cdot 52{,}7$$

$$E_a = 101{,}6\ [kN]$$

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SIDE PRESSURE OF SOIL ON A SUPPORTING WALL AT THE EFFECT OF DYNAMIC LOAD ON THE SURFACE**

Abstract

This paper analyzes the impact of vertical uniformly distributed load P(t) and currently acting impulse S_o on the appearance of dynamic pressure on a supporting wall.

Keywords: *vertical load P(t), current impulse S_o, dynamic side pressure on a supporting wall, balance of forces*

INTRODUCTION

In the calculation of piles or frame supports, the calculation on effect the dynamic load of soil surface has a great practical importance. In solving such claims, it is necessary to determine the active dynamic side pressure of soil, caused by uniformly distributed vertical load P(t) and currently distributed impulse S_o on the field surface.

1 ANALYSIS OF FORCES ON A WALL AND ITS KINEMATICS

The force of reactive soil pressure E_p and resistance force D_o act on the front side of wall. Resistance force D_o depends on friction and rotation speed of the wall, Figure 1. For analyzing the kinematics, the lever, height H, hinged at the lower end at the point O, is adopted. Moving the solid wall is determined by the angle of rotation of its axis.

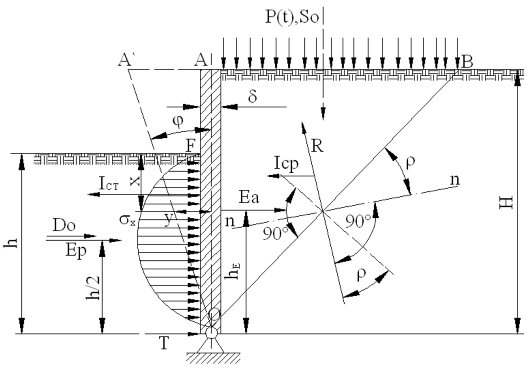

Figure 1 *Analysis of forces on a wall of dynamic load P(t) and S_o*

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Depth of lever implantation into the soil is h with coefficient of soil subgrade

$$k = c_h \cdot b$$

where:

- b, support dimension (perpendicular to the plane of drawing),
- c_h, coefficient of side elastic pressure of soil at depth h.

Figure 1 shows the forces acting on the wall of OA and wedge of potential collapse OAB at dynamic effect of load P(t) on the soil surface AB.

Intensity of resistance σ_x is adopted as directly proportional to displacement:

$$y = \varphi(h - x)$$

and the coefficient of subgrade for the wall arbitrary point x is:

$$k_x = \frac{k}{h} \cdot x$$

Then it is:

$$\sigma_x = k \cdot y = \frac{k}{h} \cdot x\varphi \cdot (h - x) \quad (1)$$

Force of reactive pressure is:

$$E_p = \int_0^h \sigma_x \cdot dx = \frac{kh^2}{6} \cdot \varphi \quad (2)$$

Force of viscous resistance D_o by Foigtu is:

$$D_o = t \cdot \varphi' \quad (3)$$

where:

- t, resistance coefficient

The force of viscous resistance determines the process of unusual vibrations artificially induced by the experiment. In addition to these forces, E_p and D_o, dynamic soil pressure acts on the wall from left E_a and also the reaction of soil resistivity T, Figure 1

Figure 2 shows the conditions of dynamic equilibrium of the wall, which is under the effect of active soil pressure forces of the collapse force E_a, wall inertia force I_{ct}, the resistance force of soil E_p, damping resistance D_o and reaction of T joint support in the form of moment sum regarding to the corresponding rotation center.

$$\sum M_o = 0$$

From the foregoing, it is easy to form a balance equation:

$$\left(E_p + D_o\right)\frac{h}{2} - I_{ct} \cdot \frac{2H}{3} - E_a \cdot h_E = 0$$

From the previous equation, it is easy to determine the force of active soil pressure E_a

$$E_a = \left(E_p + D_o\right)\frac{h}{2h_E} - I_{ct} \cdot \frac{2H}{3h_E}$$

$$= \left(E_p + D_o\right)a_2 - I_{ct} \cdot a_1 \quad (4)$$

where:

- h_E, arm of the force E_a, which is determined by position of center of gravity intensity diagram, Figure 1,
- a_1 and a_2, coefficients, which are determined as follows:

$$a_1 = \frac{2H}{3h_E}; \qquad a_2 = \frac{h}{2h_E}$$

Forces E_p and D_o are determined by the expressions (2) and (3). The force of inertia is:

$$I_{ct} = -\int_0^H \bar{m} y'' \cdot dz =$$

$$= -\int_0^H \bar{m} z \varphi'' \cdot dz =$$

$$= -\frac{\bar{m} H^2}{2} \cdot \varphi'' \quad (5)$$

where:

- $\bar{m}$, movable mass of support:

$$\bar{m} = \frac{\gamma \cdot b \cdot \delta}{g}$$

where:

- δ, wall thickness,
- g, acceleration of gravity,
- b, wall length.

Including (2), (3), (5) into (4), the following is obtained:

$$E_a = \frac{\bar{m} H^2}{2} \cdot a_1 \varphi'' + t a_2 \varphi' + \\ + \frac{kh^2}{6} \cdot a_2 \varphi \qquad (6)$$

Considering the balance of collapse wedge, Figure 2b, four forces are observed:

- E_a, active pressure,
- I_{cp}, force of inertia of collapse wedge,
- P(t), straight acting dynamic loading,
- R, reaction to the collapse wedge from a direction of stationary soil part.

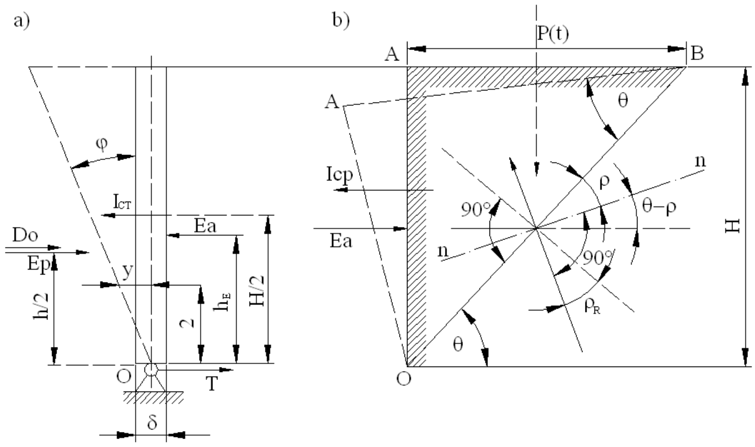

Figure 2 *Conditions of dynamic equilibrium of the wall*

Applying for dynamic loading the Coulomb limit state theory, the slope angle θ of collapse line is determined using the static calculation. The angle of internal friction ρ presents a deviation from normal to the direction OB in which the force R acts, Figure 2b.

Projecting of all forces acting on the wedge OAB on axis nn, i.e. perpendicular to the direction of force R, whose projection in this case is equal to zero, the following is obtained:

$$E_a \cdot \cos(\theta - \rho) = \\ = I_{cp} \cdot \cos(\theta - \rho) + \\ + P(t) \cdot \sin(\theta - \rho) \qquad (7)$$

where:

$$P(t) = p(t) \cdot H \cdot ctg\theta \cdot b$$

- b, third dimension of the wall

From equation (7), the following is obtained:

$$E_a = P(t) \cdot tg(\theta - \rho) + I_{cp} \qquad (8)$$

where:

$$I_{cp} = -\frac{\gamma \cdot H^2 ctg\theta}{2g} \cdot \frac{2}{3} H b \varphi'' = \\ = -m_{cp} \cdot \varphi''$$

Now, it is the acceleration of movement the collapse center ($2/3H\varphi''$). Instead of h, the following is obtained:

$$E_a = P(t) \cdot tg(\theta - \rho) - \frac{\gamma \cdot H^3 b}{3g} ctg\theta \cdot \varphi'' = \\ = P(t) \cdot tg(\theta - \rho) - m_{cp} \cdot \varphi'' \qquad (9)$$

where:

$$m_{cp} = -\frac{\gamma \cdot H^3 b}{3g} ctg\theta \qquad (10)$$

Equating (6) and (9) and combining a member with φ'', the following is obtained:

$$\left(\frac{\bar{m}\,H^2}{2}\cdot a_1 + m_{cp}\right)\varphi'' +$$
$$+ta_2\varphi' + \frac{kh^2}{6}\cdot a_2\varphi =$$
$$= P(t)\cdot tg(\theta-\rho) \qquad (11)$$

Multiplying by φ'', it can be considered as the incorporated mass of a support-wedge collapse system. Marking it with m_{pr}, the following is obtained:

$$m_{pr}\cdot\varphi'' + ta_2\varphi' + \frac{kh^2}{6}\cdot a_2\varphi =$$
$$= P(t)\cdot tg(\theta-\rho) \qquad (12)$$

By dividing the both expressions (12) with m_{pr} and making derivative on a circular vibration frequency ω, the following is obtained:

$$\varphi'' + 2\varepsilon\varphi' + \omega^2\varphi = \frac{P(t)\cdot tg(\theta-\rho)}{m_{pr}} \qquad (13)$$

where:

$$2\varepsilon = \frac{ta_2}{m_{pr}},$$
$$\varepsilon - damping\ coefficient$$
$$\omega = \sqrt{\frac{kh^2\cdot a_2}{6m_{pr}}} \qquad (14)$$

$$m_{pr} = \frac{\bar{m}\,H^2}{2}\cdot a_1 + m_{cp} =$$
$$= \frac{\bar{m}\,H^2}{2}\cdot a_1 + \gamma\frac{H^3 b}{3g}ctg\theta \qquad (15)$$

Adopting that the load is constant $P(t) = P_o$, then:

$$q_o = \frac{P_o tg(\theta-\rho)}{m_{pr}} \qquad (16)$$

Finally, the solution of differential equation (13) is obtained for the immediate effect of load at the start of immediate impulse S_o.

$$\varphi = \frac{f_o}{\omega_1}\cdot e^{-\varepsilon t}\cdot sin\omega_1 t + \frac{q_o}{\omega_2}$$
$$\left[1 - e^{-\varepsilon t}\cdot\left(cos\omega_1 t + \frac{\varepsilon}{\omega_1}sin\omega_1 t\right)\right] \qquad (17)$$

where:

$$\left.\begin{aligned} f_o &= \frac{S_o H\cdot b\cdot ctg\theta}{m_{pr}}\cdot tg(\theta-\rho) \\ \omega_1 &= \sqrt{\omega^2-\varepsilon^2} \end{aligned}\right\} \qquad (18)$$

- S_o, immediate load distributed on a surface AB of immediate impulse S_o, surface b·H·ctgθ.

The solution is obtained φ by expression (17) and determining the acceleration φ'' in the expression (9) for determining the dynamic pressure. After differentiating the expression (17) and solutions by (9), the following is obtained

$$E_a = P(t)\cdot tg(\theta-\rho) + m_{cp}\cdot e^{-\varepsilon t}$$
$$\left[f_o\cdot\left(\frac{\omega_1^2-\varepsilon^2}{\omega_1}\cdot sin\omega_1 t + 2\varepsilon\cdot cos\omega_1 t\right) +\right.$$
$$\left.+q_o\cdot\left(\frac{\varepsilon}{\omega_1}\cdot sin\omega_1 t - cos\omega_1 t\right)\right] \qquad (19)$$

It must be noted here that the values m_{pr} and ω depend on h_E and consequently, they are different in the case of effect the impulse or immediate pressure.

From the expression (19), it is possible to determine the dynamic side soil pressure on immediate impulse or immediate action of supplied, where maximum value E_a is determined as a function of time.

On the example of support wall the area of Slobomir, Semberija, a calculation will be displayed of dynamic soil pressure on a support wall.

Example:

Uniformly distributed immediate load current P_o = 48.0 [kN/m^2], H = h = 3.0 [m], the wall length b = 1.0 [m], internal friction angle ρ = 30˚, soil bulk density γ_H=17.65 [kN/m^3], bulk density of a support γ_{PP} = 23.54 [kN/m^3]. The intersection of the wall bxδ = 1.0 x 0.3 [m^2], Figure 2a, also needs determining the dynamic soil pressure from immediate vertical impulse S_o = 4.0 [kNs/m^2]. Coefficient of elastic side soil pressure is C_h = 20,000 [kN/m^3]. The arm of pressure effect is h_E = 1.33 [m], and the effect of impulse is h_E = 1 [m].

- angle θ = 45˚+ρ/2 = 60˚

  tg (θ - ρ) = tg 30˚ = 0.5774;

  ctg θ = 0.5774

- movable wall mass

$$\bar{m} = \frac{1.0 \cdot 0.3 \cdot 23.54}{9.81} = $$
$$= 0.72\ [kNs^2/m^2]$$

- mass of collapse prism per OB:

$$m_{OB} = \frac{17.65 \cdot 3^3 \cdot 0.5774}{3 \cdot 9.81} = $$
$$= 9.35\ [kNs^2]$$

- coefficient of bedding:

  k = 20.000·1=20.000 *[kN/m^2]*.

- At the effect of currently acting pressure:

$$a_1 = \frac{2H}{3h_E} = \frac{6}{3.99} = 1.50$$

$$a_2 = \frac{h}{2h_E} = \frac{3}{2.66} = 1.13$$

- Mass of the support-wedge collapse system:

$$m_{pr} = \frac{\bar{m}\,H^2}{2} \cdot a_1 + m_{cp} =$$
$$= \frac{\bar{m}\,H^2}{2} \cdot a_1 + \gamma \frac{H^3 b}{3g} ctg\theta$$

$$m_{pr} = \frac{0.72 \cdot 3^2}{2} \cdot 1.5 +$$
$$+ \frac{17.65 \cdot 3^3 \cdot 1.0}{3 \cdot 9.81} \cdot 0.5774 =$$
$$= 14.21\ [kNs^2]$$

- circular frequency

$$\omega = \sqrt{\frac{kh^2 \cdot a_2}{6m_{pr}}} = \sqrt{\frac{20{,}000 \cdot 3^2 \cdot 1.13}{6 \cdot 14.21}} =$$
$$= 48.84\ [1/s]$$

- damping coefficient

$$\varepsilon = \frac{1}{10} \cdot \omega = 4.88$$

- at the effect of moment impulse S_o:

$$a_1 = \frac{2H}{3h_E} = \frac{6}{3} = 2.0$$

$$a_2 = \frac{h}{2h_E} = \frac{3}{2} = 1.5$$

m_{pr} = 15.83 *[kNs^2]*

ω = 52.7 *[1/s]*; ε = 5.3

$$q_o = \frac{P_o tg(\theta - \rho)}{m_{pr}} = \frac{48}{14{,}21} =$$
$$= 3.38\ [1/s^2]$$

$$P_o \cdot tg(\theta - \rho) = 48\ [kN/m^2]$$

- side pressure from the moment of the applied load by the expression (19) at $e^{-\varepsilon t}$ = 0.69, if:

$cos\omega_1 t = -1$ (et $\omega_1 t = \pi$)

$$E_a = P_o tg(\theta - \rho) +$$
$$+ m_{OB} \cdot e^{-\varepsilon t} \cdot q_0 \cdot 1$$

$$E_a = 48 + 9.35 \cdot 0.69 \cdot 3.38 = 69.8$$

At the effect of distributed impulse $S_o = 4{,}0$ [kNs/m^2].

$$f_o = \frac{S_o \cdot H \cdot b \cdot ctg\theta}{m_{pr}} \cdot tg(\theta - \rho)$$

$$f_o = \frac{4 \cdot 3 \cdot 1 \cdot 0.5774^2}{15.83} =$$

$$= 0.253\ [m/s]$$

Dynamic pressure of acting impulse S_o per (19) at $\omega_1 t = \pi/2$ where $\sin \omega_1 t = 1$, then $e^{-\varepsilon t} = 0.815$.

$$E_a = m_{OB} \cdot e^{-\varepsilon t} \cdot f_o \cdot \omega =$$

$$= 9.35 \cdot 0.815 \cdot 0.253 \cdot 52.7$$

$$E_a = 101.6\ [kN]$$

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PROSTORNI REFERENTNI SISTEM REPUBLIKE SRBIJE

Izvod

Postojeći državni referentni sistem Republike Srbije, koji je u upotrebi već više od 70. godina, zasniva se na negeocentričnom Besselovom elipsoidu i Gaus - Krügerovoj projekciji meridijanskih zona. Sistem je praktično realizovan trigonometrijskim tačkama različitih redova, čije su koordinate odredjivane tokom dugog vremenskog perioda, uz upotrebu različite merne tehnologije i metodologije. S obzirom na dostignuća i u geodetskoj metodologiji i u tehnologiji mernih instrumenata, može se reći da važeći državni referentni sistem Srbije ni po definiciji, ni po realizaciji više ne odgovara savremenim zahtevima tačnosti i pouzdanosti.

Keywords: *GPS, geoinformatika, prostorni referentni sistemi, geoprostorni podaci*

1. UVOD

Suština orijentacije triangulacije sastoji se u odredjivanju geografskih koordinata jedne tačke i azimuta strane koja iz nje polazi. Ta tačka se naziva *fundamentalna tačka*, a njene koordinate i azimut strane nazivaju se početni podaci triangulacije. Naša triangulacija nema sopstvenu fundumentalnu tačku niti elipsoid koji bi se najbolje prilagodio teritoriji Srbije. Trigonometrijska mreža I reda Srbije naslonjena je na mrežu I reda bivšeg Bečkog vojnogeografskog instituta, čime je odredjen njen položaj na elipsoid Bessela. Mreža ima istu orijentaciju kao i mreža bivše Austro - Ugarske. Državni koordinatni sistem Srbije definisan je astronomskom latitudom i longitudom bazne tačke Herrmannskogel kod Beča astronomskim azimutom strane Herrmannskogel - Hundsheimerberg i parametrima Besselovog elipsoida. Koordinate Hermanskogela, odredjene 1892. godine su istovremeno i fundamentalna tačka triangulacije Srbije. U okviru državnog koordinatnog sistema Srbije definiše se:

- Prostorni (trodimenzionalni) referentni sistem;
- Horizontalni (dvodimenzionalni) referentni sistem;
- Vertikalni (jednodimenzionalni) referentni sistem;
- Gravimetrijski referentni sistem;
- Astronomski referentni sistem.

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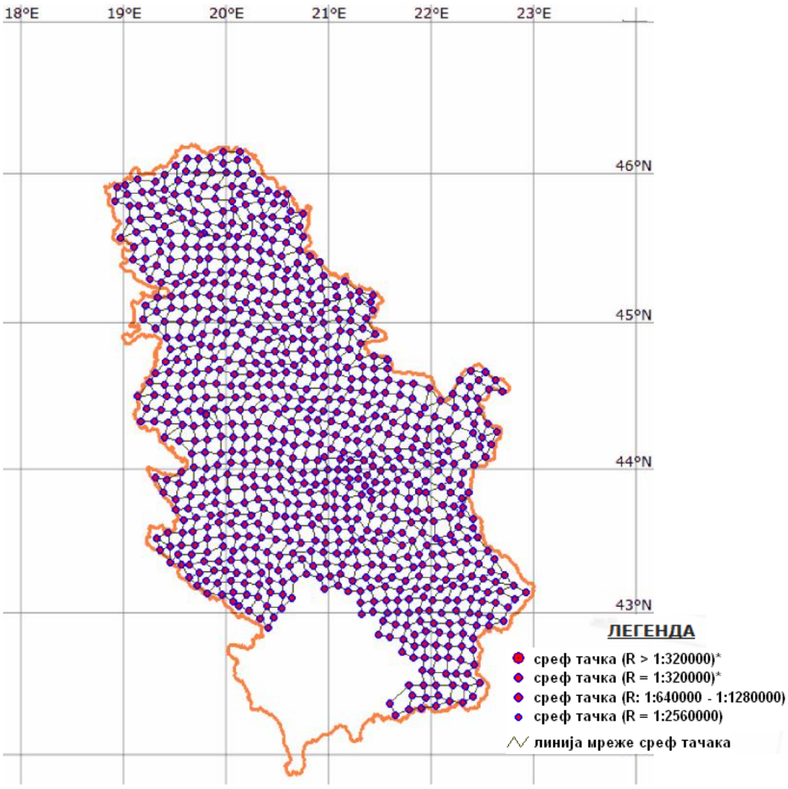
2. PROSTORNI (TRODIMENZIONALNI) REFERENTNI SISTEM

U okviru državnog referentnog sistema bivše SFRJ ova sistemska komponenta nije nikad ni definisana. Razlozi su pre svega istorijskog karaktera, jer je geodetsko pozicioniranje tačaka i objekata bilo tradicionalno razdvojeno na horizontalno i vertikalno. Pojava savremene GPS merne tehnike za globalno pozicioniranje, nametnula je potrebu preciznog definisanja prostornog referentnog sistema. S obzirom na rastuće geodetske primene GPS u Srbiji za prostorni referentni sistem u službenoj upotrebi [4], uspostavljen je od 01. januara 2011. godine Terestrički trodimenzionalni koordinatni sistem koji se po definiciji koordinatnog početka, orijentaciji koordinatnih osa, razmeri, jedinici dužine i vremenskoj evoluciji, podudara sa Evropskim terestričkim referentnim sistemom European Terrestrial Reference System - ETRS89. Za realizaciju novog sistema predvidjen je okvir ETRF2000 kao konvencijalni okvir predložen od strane relevantnih medjunarodnih organizacija kao što su International GNSS Service - IGS i EUREF Permanent Network-EPN. Realizacija novog državnog referentnog sistema Srbije, koji se od postojećeg razlikuje po položaju, po orijentaciji i po razmeri, podrazumevao je pre svega realizaciju sledećih aktivnosti:

1. Uspostavljanje relativno homogenog polja tačaka na celoj državnoj teritoriji, sa fizičkom materijalizacijom i pripadajućim koordinatama koje će realizovati novi državni referentni sistem;
2. Formulisanje odgovarajućeg transformacionog modela kojim se ostvaruje veza izmedju postojećeg i novog državnog referentnog sistema u oba pravca, i obuhvataju u najvećoj meri distorzije i deformacije u realizaciji jednog ili oba sistema.

Prvi od navedenih zadataka praktično je već realizovan na celoj teritoriji Srbije. Naime, septembra meseca 1998. izvedena je u Srbiji EUREF GPS merna kampanja u sklopu kampanje BALKAN98, koja je obuhvatila Bosnu i Hercegovinu, tadašnju Saveznu Republiku Jugoslaviju (Srbiju i Crnu Goru) i Albaniju, a sa ciljem proširenja i progušćenja Evropskog terestričkog referentnog okvira. Na teritoriji Republike Srbije uključeno je tom prilikom ukupno 6 trigonometrijskih tačaka prvog reda (brojevi tačaka dodeljeni su tokom merne kampanje): 818 – Bele Vode; 819 – Ćelije; 820 – Vrška Čuka; 821 – Gudurički Vis; 822 – Jautinski Vis; 823 – Kaćanski Salaš. Tačnost horizontalnih položaja tačaka ocenjena je na 3 mm, a tačnost dobijenih elipsoidnih visina na oko 7 mm. Koordinate tačaka odnosile su se na referentni okvir ITRF96 za epohu 1998. Radi progušćavanja EUREF mreže Srbije, Republički geodetski zavod (RGZ) organizovao je niz mernih kampanja u periodu od 1997 do 2003. god. u okviru kojih je na celoj državnoj teritoriji uspostavljena homogena Referentna mreža Republike Srbije-SREF, pasivna geodetska referentna osnova, odnosno mreža od 838 tačaka na prosečnom medjusobnom rastojanju od 10 km.



Sl. 1. *Referentna mreža Republike Srbije - SREF (http://www.rgz.gov.rs/)***.**

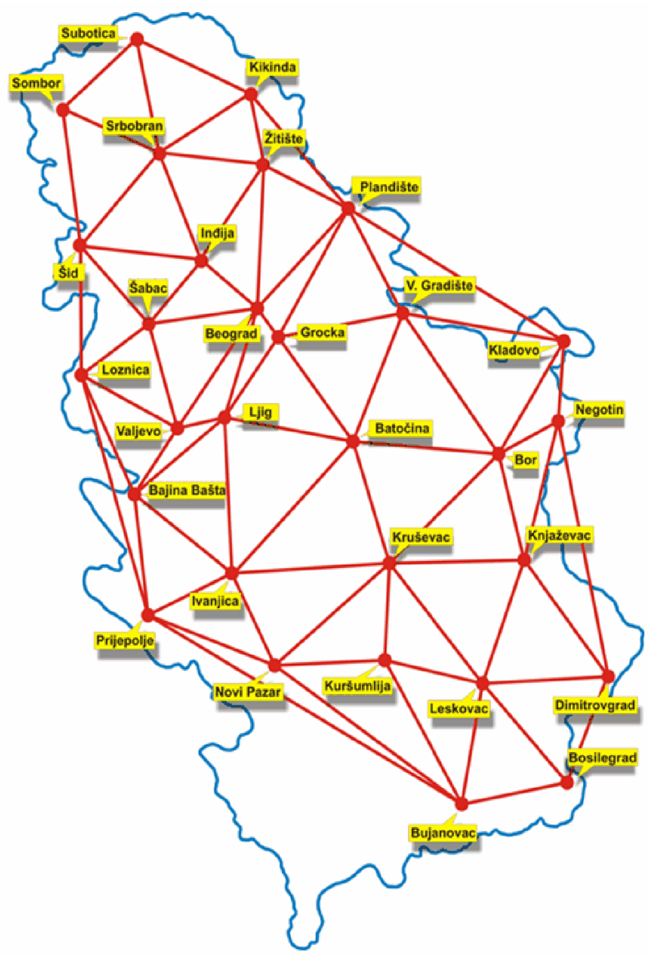
U periodu od 15. do 21. avgusta 2010. godine Republički geodetski zavod-Sektor za osnovne geodetske radove, u saradnji sa Centrom za katastar nepokretnosti na čijim se teritirijama nalaze tačke na kojima su vršena merenja i angažovanje Vojske Republike Srbije, izvršile su merenja u okviru merne kampanje EUREF2010. Kampanja EUREF2010 sprovodi se sa ciljem:

- Progušćenja evropskog terestričkog referentnog okvira na teritoriji Republike Srbije;
- Kontrole stabilnosti državnog referentnog sistema realizivanog u prêthodnim kampanjama;
- Realizacije visoko precizne referentne osnove koja će se koristiti u naučne svrhe kao i u okviru poslova u nadležnosti Republičkog geodet-skog zavoda;
- Evropske geodetske integracije Republike Srbije.

U istom periodu je realizovan i niz lokalnih prostornih gradskih mreža. S obzirom na hijerarhijski pristup, koordinate ovih tačaka odnosile su se takodje na referentni okvir ITRF96 za epohu 1998. U periodu od 2003. do 2006. godine RGZ uspostavio je na teritoriji Srbije Aktivnu geodetsku referentnu osnovu - AGROS, odnosno mrežu od 32 permanentne GNSS stanice na prosečnom medjusobnom rastojanju od oko 60 km.

Njihove lokacije odredjene su relativno u odnosu na tačke EUREF odnosno SREF mreže, tako da se i one odnose na referentni okvir ITRF96 za epohu 1998. Na taj način je na državnoj teritoriji Srbije materijalizovano više od 1000 tačaka sa centimetarski tačno odredjenim koordinatama u referentnom okviru ITRF96.

Njihova transformacija u predloženi novi državni referentni sistem ETRS89 ne predstavlja nikakvu teškoću jer su transformacioni parametri izmedju realizacija sistema ITRS i ETRS89 poznati i već definisani.



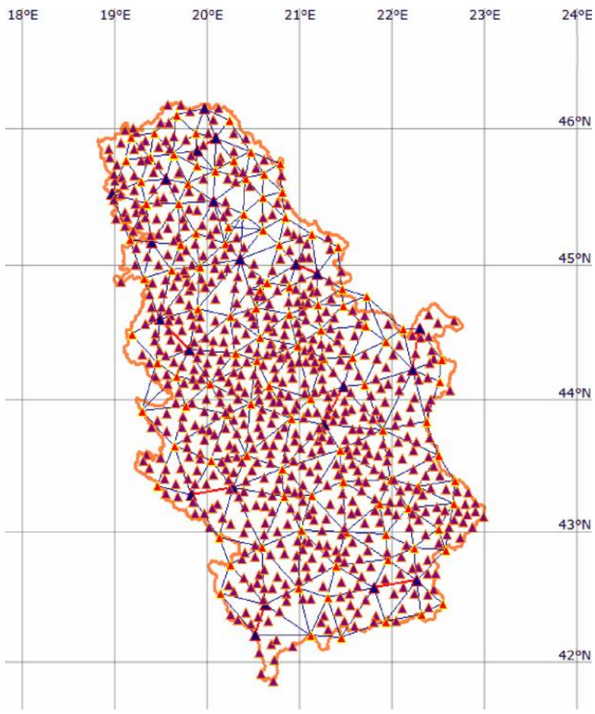
Sl. 2. *Aktivna geodetska referentna osnova Srbije – AGROS (http://www.rgz.gov.rs/).*

Najveći problem je formulisanje odgovarajućeg transformacionog modela kojim bi se uspostavila matematička veza izmedju važećeg i novog državnog referentnog sistema Srbije. RGZ je sve koordinate sračunate u ovom sistemu, preračunao u novi sistem ETRS89 - ETRF2000 i stavio ih u službenu upotrebu 2011. godine. Potrebni parametri transformacije izmedju ITRF96 i ETRF2000 sračunati su i dostupni na sajtu http://www.rgz.gov.rs/.

3. HORIZONTALNI (DVODIMENZIONALNI) REFERENTNI SISTEM

Horizontalni referentni sistem predstavlja dvodimenzionalni koordinatni podskup prostornog referentnog sistema u kome se položaj tačaka izražava dvodimenzionalnim, krivolinijskim koordinatama, odnosno geodetskom dužinom i širinom u odnosu na referentni dvoosni obrtni elipsoid geodetskog referentnog sistema Geodetic Reference System 1980 (GRS80) koji se odredjuje za matematički model Zemlje u Republici Srbiji.

Dakle, novi horizontalni referentni sistem Srbije predstavlja podskup prostornog sistema i treba da ima funkciju sistema referenci potrebnih za jedinstveno i precizno opisivanje dvodimenzionalnih položaja tačaka i objekata. S druge strane, horizontalni ETRS89 položaji tačaka i objekata praktično se izražavaju pravouglim pravolinijskim koordinatama u ravni. Položaj tačaka u horizontalnom referentnom sistemu u Srbiji izražava se dvodimenzionalnim, pravolinijskim koordinatama u ravni konformne Univerzalne Transverzalne Merkatorove projekcije-UTM (Universal Transverse Mercator) na usvojeni elipsoid GRS80. Na osnovu člana 17. Pravilnika za osnovne geodetske radove [**2**] definisano je da se: *Merenja i obrada podataka merenja u osnovnoj referentnoj mreži izvode svakih pet godina u cilju osiguranja integriteta i praćenja vremenske evolucije prostornog koordinatnog referentnog sistema*.



Sl. 3. *Trigonometrijska mreža 1. i 2. reda (http://www.rgz.gov.rs/)*

Utvrdjivanje kvaliteta trigonometrijske mreže koja realizuje postojeći horizontalni referentni sistem Srbije u opštem slučaju se može postići kada su za odredjeni broj trigonometrijskih tačaka na raspolaganju etalonske koordinate.

Pod etalonskim koordinatama podrazumevaju se one koje su odredjene sa superiornom tačnošću u odnosu na koordinate u upotrebi. Za potrebe utvrdjivanja kvaliteta postojeće horizontalne osnove iskorišćen je skup od 3.400 zajedničkih tačaka na teritoriji Srbije, pod osnovnom pretpostavkom da numerički pokazatelji kvaliteta njene trigonometrijske mreže podjednako važe za sve delove mreže bivše SFRJ.

Ovaj skup tačaka, rezultat je napora RGZ da na celokupnoj teritoriji Srbije obezbedi zajedničke tačke sa prosečnim medjusobnim rastojanjem od 5 km, a za potrebe odredjivanja optimalnog modela transformacije izmedju postojećeg i novog državnog referentnog sistema. Korišćeni skup od 3.400 zajedničkih tačaka sastoji se od trigonometrijskih tačaka svih redova. GPS merenja na ovim tačkama izveli su stručnjaci RGZ u više mernih kampanja u periodu od 1997. godine do 2008. godine, i to uglavnom u sledeće dve faze:

- Približno polovina tačaka odredjena je u statičkom režimu rada tokom mernih kampanja u okviru realizacije pasivne geodetske referentne državne mreže Republike Srbije - SREF u periodu od 1997. do 2003. godine;
- Druga polovina odredjena je u mrežnom RTK režimu rada, počev od 2003. godine kada su započeli radovi na realizaciji aktivne geodetske referentne osnove Republike Srbije - AGROS.

Procenjeno je da je tačnost horizontalnih položaja tačaka odredjenih statičkom metodom oko 1 cm, a da je tačnost mrežnog RTK pozicioniranja bolja od 2 cm. Pošto su prilikom radova kao referenca služile tačke SREF i AGROS mreže, svi rezultati GNSS pozicioniranja odnose se na referentni okvir ITRF96 za epohu 1998. 7. Imajući u vidu da se očigledno radi o visokoj pozicionoj tačnosti, koordinate ovih tačaka mogu poslužiti kao etalonske u odnosu na koordinate koje se odnose na važeći državni referentni sistem.

S obzirom na to da su za svih 3.400 zajedničkih tačaka poznate sa jedne strane koordinate u Gaus - Krügerovoj projekciji (y, x, i visine H u državnom sistemu visina), a sa druge strane pravougle trodimenzionalne koordinate (X, Y, Z) koje se odnose na referentni okvir ITRF96, sproveden je postupak MNK ocenjivanja parametara Helmertove transformacije sličnosti. Rezultate ocenjivanja predstavljaju izmedju ostalog i odstupanja (reziduali) na zajedničkim tačkama. U toku GPS merne kampanje, koja je imala za cilj progušćenje osnovnog skupa zajedničkih tačaka radi homogene pokrivenosti državne teritorije, dobijena su dva skupa podataka zajedničkih tačaka:

- osnovni skup od ukupno 4.484 zajedničkih tačaka;
- dopunski skup od ukupno 430 zajedničkih tačaka.

Osnovni skup korišćen je za ocenjivanje parametara transformacionog modela. Dopunski skup zajedničkih tačaka odnosi se uglavnom na poligonske tačke skoncentrisane u pojedinim naseljenim mestima. Na osnovu iskontrolisanog skupa zajedničkih tačaka odredjeni su parametri globalne Helmertove transfor-macije, koji se odnose na celokupnu teritoriju Srbije. Rezultat odredjivanja predstavljao je jedinstveni skup od 7 parametara (3 parametra translacije, 3 parametra rotacije i parametar razmere). Nove tačke mogu se transformisati iz novog referentnog sistema Srbije u postojeći i obratno, na jedan od sledeća dva načina, u zavisnosti od toga kako su odredjeni transformacioni parametri:

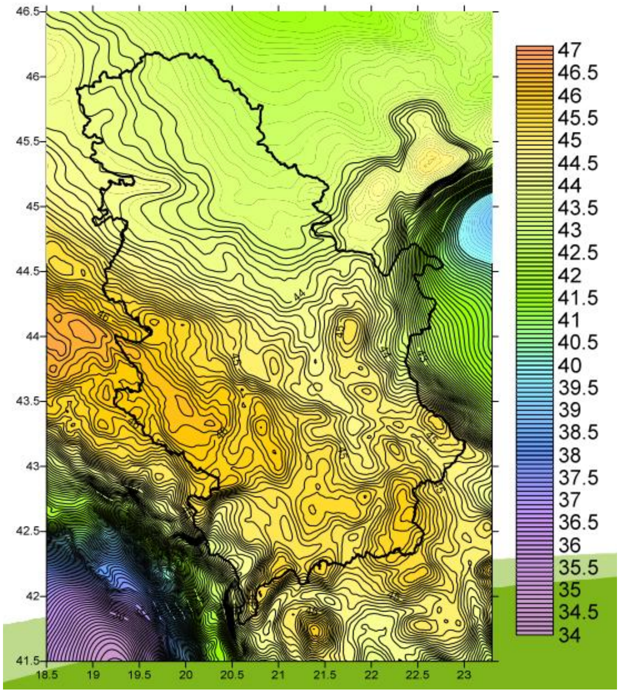
- Pomoću globalnih transformacionih parametara za celu teritoriju Srbije i grida reziduala,

- Pomoću lokalnih transformacionih parametara pojedinačnih konačnih elemenata.

Što se tiče zemalja Evropske Unije one su uglavnom u poslednjih desetak godina prešle na novi sistem. Usvojeni transformacioni model treba da omogući povezivanje državnog referentnog sistema sa evropskim referentnim sistemom, i kao najvažnije pružio bi osnovu za rešavanje problema državnog premera, katastra nepokretnosti, inženjerskih - tehničkih radova i GIS aplikacija.

4. VERTIKALNI REFERENTNI SISTEM

Vertikalni referentni sistem predstavlja jednodimenzionalni koordinatni podskup prostornog referentnog sistema unutar kojeg se definišu referentne površi u odnosu na koje se izražavaju visine tačaka. Vertikalni referentni sistem koji se zasniva na elipsoidnoj referentnoj površi označava se kao geometrijski. Položaji tačaka i objekata u geometrijskom vertikalnom referentnom sistemu Srbije izražavaju se jednodimenzionalnim koordinatama, odnosno geodetskim visinama u odnosu na referentni dvoosni obrtni elipsoid geodetskog referentnog sistema GRS80. Kao izabrana referentna površ na koju se odnose geodetske visine može se koristiti i Bessel-ov elipsoid. Vertikalni referentni sistem koji se zasniva na referentnoj površi definisanoj u realnom Zemljinom gravitacionom polju označava se kao prirodni. U Srbiji, referentnu površ prirodnog vertikalnog referentnog sistema predstavlja površ kvazigeoida.



Sl. 4. *Prikaz novog gravimetrijskog modela kvazigeoida*

Površ kvazigeoida definiše se kao površ u čijoj je svakoj tački vertikalno rastojanje do referentnog dvoosnog obrtnog elipsoida geodetskog referentnog sistema GRS80, jednako rastojanju izmedju tačke fizičke površi Zemlje i tačke na istoj normali u kojima realni i normalni potencijal Zemljinog gravitacionog polja imaju istu vrednost. Položaji tačaka i objekata u prirodnom vertikalnom referentnom sistemu Republike Srbije izražavaju se jednodimenzionalnim koordinatama, odnosno normalnim visinama u odnosu na površ kvazigeoida. U praktičnim primenama, veza dva sistema visina elipsoidnog i državnog (koji se u Republici Srbiji odnosi na srednji nivo Jadranskog mora, odredjen merenjem morskog nivoa jednim mareografom u toku samo jedne godine), odredjuje se definesanjem modela referentne površi visina koji se kod relativno ravnih površi praktično tretira kao površ paralelna elipsoidu.

Ukoliko su poznate elipsoidne visine tačaka, visine tačaka u državnom sistemu u upotrebi računaju se primenom interpolacionog polinoma prvog stepena (Uredba o primeni GPS tehnologije u premeru nepokretnosti RGZ, 2002), koji glasi:

$$H = h + A + B \cdot Y + C \cdot X,$$

gde je:

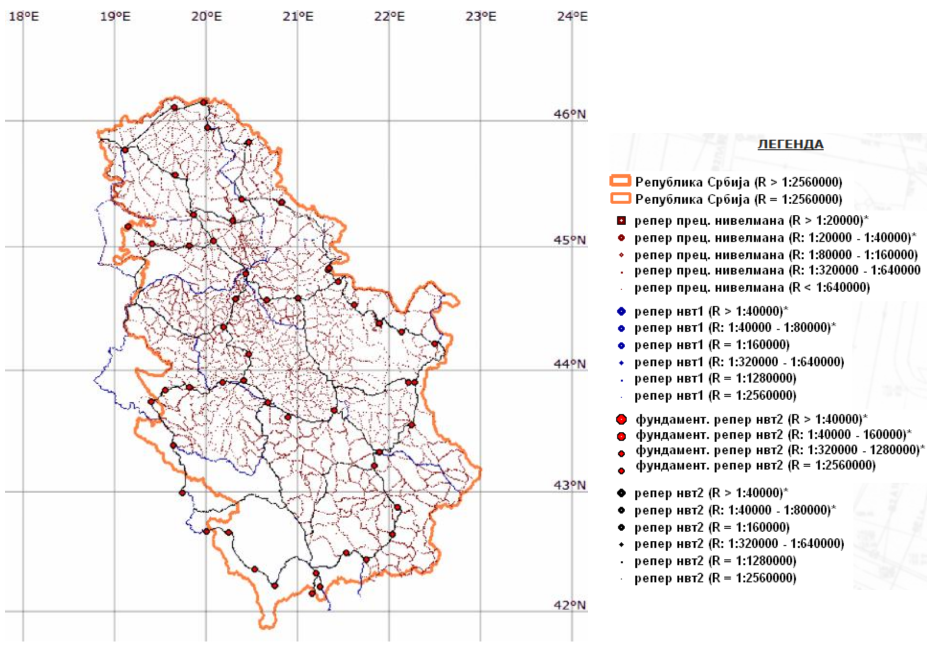
H - visina u državnom sistemu,

h - elipsoidna visina,

Y, X - koordinate tačaka u državnom sistemu,

A, B, C - nepoznati parametri polinoma.

Nepoznati parametri polinoma A, B i C odredjuju se na osnovu poznatih visina u oba sistema po metodi najmanjih kvadrata, pri čemu minimalni broj zajedničkih tačaka ne sme biti manji od četiri. Raspored poznatih tačaka mora biti pravilan (jedna tačka na površini od 2 x 2 km). Sve mreže i dalje se stabilizuju na način koji je primenjen kod drugog nivelmana visoke tačnosti bivše SFRJ (NVT2), primenom fundamentalnih i radnih repera. Još uvek je u Srbiji u upotrebi nivelmanska mreža koja se odnosi na reper na mareografu u Trstu, mreža drugog nivelmana nije nikada uvedena u upotrebu niti je uključena u UELN, a Srbija nije participirala unutar EUVN i EUVN_DA.



Sl. 5. *Precizni nivelman i Nivelman visoke tačnosti (NVT1 i NVT2) (http://www.rgz.gov.rs/).*

5. GRAVIMETRIJSKI REFERENTNI SISTEM

Gravimetrijska merenja se u geodeziji koriste za rešavanje problema vezanih za definisanje oblika i veličine Zemlje kao i spoljašnjeg gravitacionog polja. Prva gravimetrijska merenja na našim prostorima izvedena su krajem XIX veka na teritoriji tadašnje Austro - Ugarske monarhije. U periodu izmedju dva svetska rata Vojno geografski institut (VGI) je odredio razliku ubrzanja sile teže izmedju Potsdama i Beograda. Radovi na uspostavljanju gravimetrijske mreže I reda vršeni su u periodu izmedju 1952. i 1953. godine. Mrežu čine 15 tačaka, ima oblik centralnog sistema sa 14 zatvorenih trouglova i tačkom Beograd (aerodrom Zemun) kao osnovnom. Gravimetrijska mreža II reda razvijena je za potrebe pogušćavanja gravimetrijske mreže I reda. Mreža je imala oblik zatvorenog poligona sa čvornim tačkama. U periodu od 1964. do 1967. godine SGU (Savezna geodetska uprava) izvršila je formiranje i merenja u Osnovnoj gravimetrijskoj mreži. Mreža je uključila osnovnu tačku Beograd kao i bazu Beograd - Skoplje. Uporedo sa realizacijom gravimetrijskih mreža I i II reda, vršen je i detaljni gravimetrijski premer, tako da danas raspolažemo podacima premera izvodjenog u dužem periodu od 1952. do 1980. godine, koji je uradjen na preko 80.000 gravimetrijskih tačaka. Raspored tačaka je neravnomeran i kreće se od dve tačke po km^2 na prostoru Vojvodine, do jedne tačke na 3 km^2 u delovima zapadne i južne Srbije. Odredjivanje relativnih ubrzanja sile Zemljine teže u okviru pomenutih gravimetrijskih premera izvedena su vrlo kvalitetno i saglasno tada važećim svetskim standardima (1950 - 1970), dok su dalja pogušćenja radjena u cilju lokalnih geofizičkih istraživanja. Ovakva situacija u pogledu nesaglasnosti sa postojećim svetskim standardima, kao i nesprovodjenje organizovanih regionalnih i lokalnih gravimetrijskih premera, otežava njihovo korišćenje u naučne i tehničke svrhe. Gravimetrijski referentni sistem predstavlja sistem u kojem se vrše gravimetrijska odredjivanja apsolutnog i relativnog ubrzanja sile Zemljine teže i računanja gravimetrijskih veličina. Gravimetrijski referentni sistem definišu sledeći referentni sistemi:

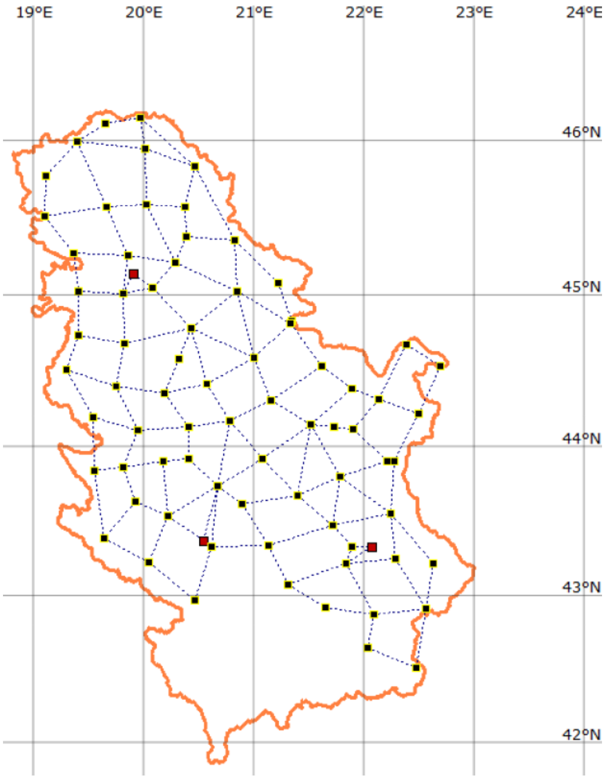
- Referentni sistem gravimetrijskih odredjivanja;
- Referentni sistem normalnog gravitacionog polja.

Referentni sistem gravimetrijskih odredjivanja definisan je realnim gravitacionim poljem Zemlje, odnosno svakom pojedinačno odredjenom vrednošću apsolutnog ubrzanja sile zemljine teže. Realizacijom UNIGRACE projekta izvršeno je merenje apsolutnih vrednosti ubrzanja u velikom broju evropskih zemalja u periodu od 1996 - 2000. godine. Referentni sistem gravimetrijskih odredjivanja realizuje se gravimetrijskim referentnim okvirom Srbije, odnosno skupom materijalizovanih tačaka i njihovih vrednosti apsolutnog ubrzanja sile zemljine teže koje se odnose na odredjenu vremensku epohu. Merenja apsolutnih vrednosti ubrzanja sile teže u Srbiji izvršena su u periodu od 10. do 26. oktobra 2007. godine. Geografska lokacija tri tačke na kojima su vršena merenja bili su manastiri: Grgeteg na Fruškoj Gori (AG1), Gradac kod Raške (AG2) i Sveta Bogorodica u Sićevačkoj klisuri (AG3). Gravimetrijski referentni okvir Srbije predstavlja Osnovna gravimetrijska mreža, koja je uskladjena sa sistemom Medjunarodne standardne gravimetrijske mreže IGSN71 (eng. International Gravity Standardization Network 1971).

Osnovna gravimetrijska mreža sastoji se iz sistema od 60 zatvorenih poligona, dok je ukupan broj veza Δg=137 (slika 5). Osnovna gravimetrijska mreža ima 78 tačaka i to:

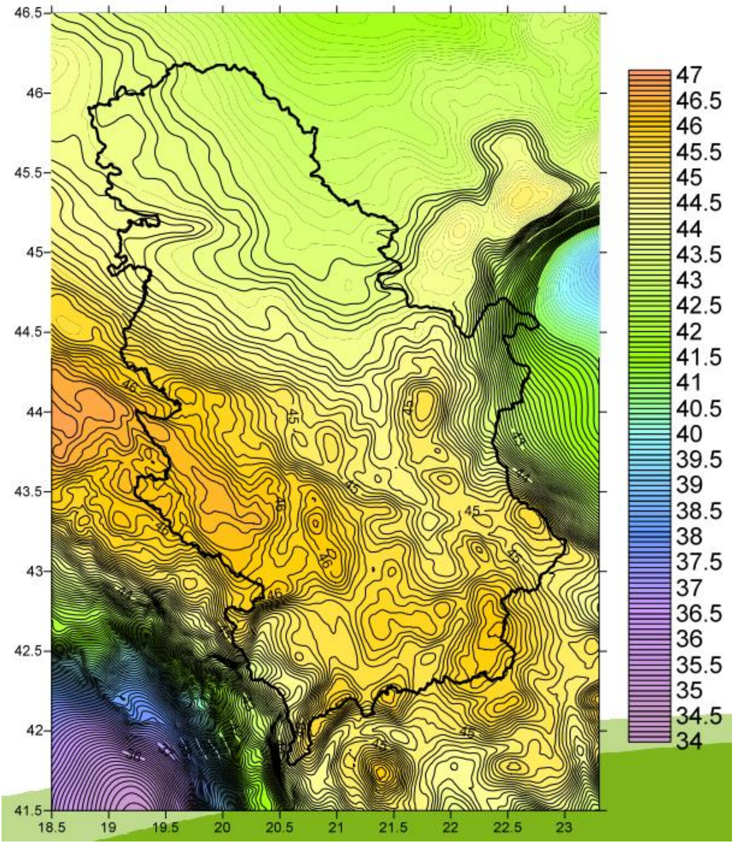
- 3 date tačke sa apsolutnim vrednostima ubrzanja (AG1, AG2 i AG3).
- 37 tačaka Referentne mreže Republike Srbije (SREF).
- 37 fundamentalnih repera Drugog Nivelmana Visoke Tačnosti (NVT2).
- 1 tačka (GT251).

Osnovna gravimetrijska mreža povezana je sa datim tačkama preko šest tačaka.



Sl. 6. *Osnovna gravimetrijska mreža* (http://www.rgz.gov.rs/).

Na prostoru cele Srbije isplanirano je 2.317 novih tačaka regionalnog premera na približnom medjusobnom rastojanju od 5 km, a merenje se vrši i na 838 tačaka Referentne mreže Srbije, kao i na 42 fundamentalna repera, što ukupno iznosi 3.196 tačaka. S obzirom na jedinstveni pristup gravimetrijskim radovima koji se primenjuju u svim zemljama Evrope, naročito u zemljama Evropske Unije, možemo zaključiti da je stanje gravimetijskih radova u Srbiji u potpunosti saglasno sa pristupom koji se primenjuje u Evropi.



Sl. 7. *Srpski model kvazigeoida iz 2011.g.*

Za gravimetrijski referentni sistem i njegovu realizaciju može se reći da će kroz već realizovanu nultu i osnovnu gravimetrisjku mrežu, kao i gravimetrijski premer koji je u toku, u narednih nekoliko godina dostići nivo drugih evropskih država.

6. ZAKLJUČAK

Postojeći državni referentni sistem Srbije zasniva se na negeocentričnom Besselovom elipsoidu i Gaus-Krügerovoj projekciji meridijanskih zona. S obzirom na dostignuća i u geodetskoj metodologiji i u tehnologiji mernih instrumenata, može se reći da važeći državni referentni system Srbije ni po definiciji, ni po realizaciji više ne odgovara savremenim zahtevima tačnosti i pouzdanosti. Što se tiče zemalja Evropske Unije one su uglavnom u poslednjih desetak godina prešle na novi referentni sistem. Usvojeni transformacioni model treba da omogući povezivanje našeg referentnog sistema sa evropskim referentnim sistemom, i kao najvažnije pružio bi osnovu za rešavanje problema državnog premera, katastra nepokretnosti, inženjerskih - tehničkih radova i GIS aplikacija.

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SPATIAL REFERENCE SYSTEM OF SERBIA

Abstract

The existing national reference system in Serbia, used for over 70 years, is based on the non – geocentric Bessel ellipsoid and Gauss – Kruger projection of meridian zones. Practically, system was realized through trigonometric points of different classes, whose coordinates have been determined for a long period of time, using different surveying technologies and methodologies. Considering the achievements, both in geodetic methodology and surveying technology, it is obvious that the existing Serbian reference system does not match the actual demands on accuracy and reliability, whether by definition or realization.

***Key words**: GPS, spatial reference systems, geospatial data*

1 INTRODUCTION

The essence of triangulation orientation consists of determination the point coordinates and azimuth of a line originated from that point. This point is called the *fundamental point,* and its coordinates and line azimuth are basic triangulation data. Our national triangulation does not have a fundamental point or ellipsoid that could accurately describe the Serbian territory. The first class trigonometric network of Serbia is based on the first class network of former Vienna Geographic Institute, thus determining its position on the Bessel ellipsoid. Network has the same orientation as the former Austro – Hungarian network. National coordinate system of Serbia is defined by astronomic latitude and longitude of the basic point Herrmannskogel near Vienna, astronomic azimuth of Herrmannskogel – Hundsheimerberg line and parameters of the Bessel ellipsoid. Coordinates of Herrmannskogel, defined in 1892, also represent the fundamental point of Serbian triangulation. National coordinate system of Serbia is defined by the following:

- Spatial (3D) reference system;
- Horizontal (2D) reference system;
- Vertical (1D) reference system;
- Gravimetric reference system;
- Astronomic reference system.

2 SPATIAL (THREE-DIMENSIONAL) REFERENCE SYSTEM

In the national reference system of former Yugoslavia, this system component hadnever been defined. The reasons were mainly historical, since geodetic positioning of points and objects was traditionally divided to the horizontal and vertical. Modern GPS surveying technology brought demands for accurate determination of spatial reference system. Due to rise of GPS application in geodetic survey in Serbia, a new reference system was defined [4], starting from 1 January 2011. It is a terrestrial 3D coordinate

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system which coincides with the European Terrestrial Reference System ETRS89 by determination of coordinate system origin, coordinate axes orientation, scale, length unit and time evolution. ETRF2000 frame is used to realize the new system, recommended by the relevant international institutions, such as the International GNSS Service (IGS) and EUREF Permanent Network (EPN). Realization of the new national reference system, which differs from the existing one by position, orientation and scale, included the following activities:

1. Establishing the relatively homogenous field of points throughout entire national territory, with physical materialization and belonging coordinates which would realize the new national reference system;
2. Defining the suitable transformation model in order to provide a connection between the existing and new national reference system in both directions and process distortions and deformations in realization of one or both systems.

The first activity was practically already realized on the whole territory of Serbia. Namely, in 1998, the EUREF GPS surveying campaign was performed, as a part of BALKAN98 campaign. GPS campaign included Bosnia and Herzegovina, former Federal republic of Yugoslavia (Serbia and Montenegro) and Albania, in order to expand and increase the scale of the European Reference Frame. Six first class trigonometric points from Serbian territory were included (point numbers were assigned during campaign): 818 – Bele Vode; 819 – Celije; 820 – Vrska Cuka; 821 – Guduricki Vis; 822 – Jautinski Vis; 823 – Kacanski Salas. The accuracy of horizontal positions of points was 3 mm, while the accuracy of ellipsoid heights was 7 mm. Coordinates of points were referred to ITRF96 reference frame for epoch 1998. In order to increase density of the EUREF network in Serbia, the National Geodetic Bureau (NGB) organized a number of surveying campaigns in the period between 1997 and 2003. The result was establishment of homogenous Serbian Reference Network (SREF), passive geodetic reference base, i.e. network made of 838 points at 10 km average spacing.

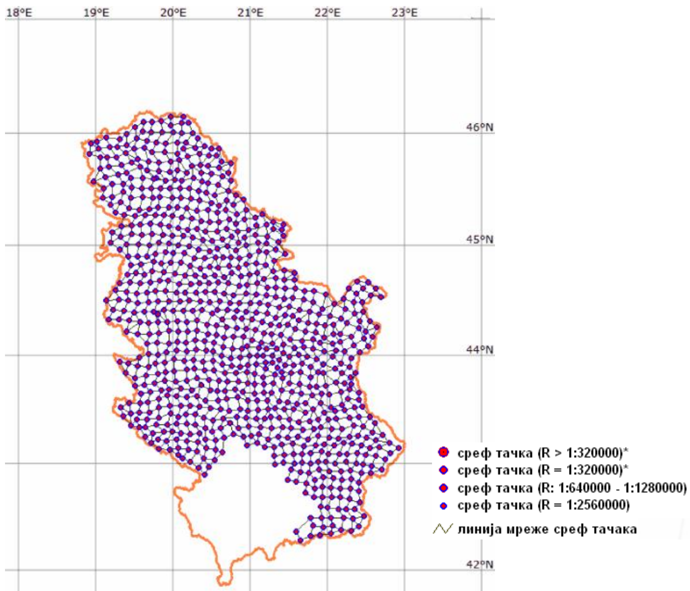

Figure 1 *Serbian Reference Network (SREF) (http://www.rgz.gov.rs/).*

In the period between 15 and 21 August 2010, the Serbian Geodetic Bureau, supported by the Serbian Army, performed the survey included in the EUREF2010 campaign. This campaign has been implemented with the aim of:

- Increase the scale of European Reference Frame on Serbian territory;
- Control the stability of Serbian Reference System realized in the previous campaigns;
- Realize highly accurate reference frame, which will be used for scientific purposes and activities of the National Geodetic Bureau;
- European geodetic integration of Serbia.

At the same time, numerous local spatial city networks were also realized. Considering the hierarchical approach, the coordinates of points from these networks were also referred to the ITRF96 frame for epoch 1998. In the period between 2003 and 2006, NGB established the Active Geodetic Reference Frame – AGROS, a frame with 32 permanent GNSS stations at 60 km average spacing.

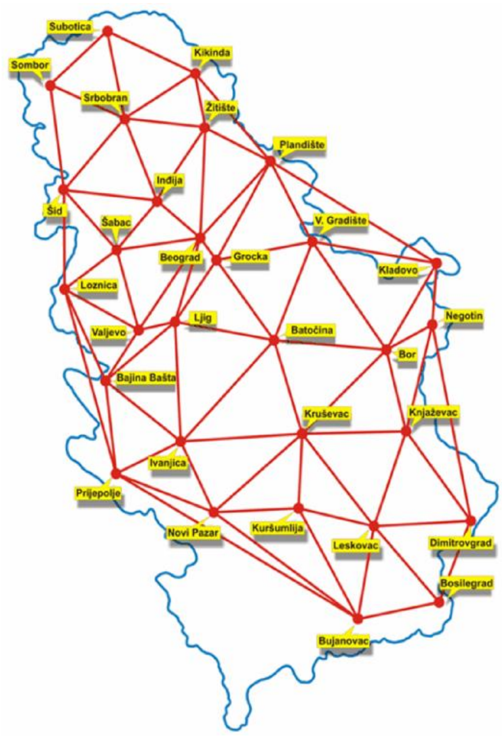

Figure 2 *Active Geodetic Referent Frame of Serbia – AGROS, (http://www.rgz.gov.rs/).*

Their locations were defined in relation with EUREF and SREF points, which means that they are also related to the ITRF96 frame for epoch 1998. This way entire national territory was covered by more than 1,000 points with accurate coordinates in ITRF96.

Their transformation into ETRS89 is easy, because transformation parameters between ITRS and ETRS89 are already defined.

The biggest problem is to create a transformation model which would establish a mathematical connection between the existing and new national reference system. NGB performed the re-calculation, and coordinates from the existing system were transferred into the new ETRS89 – ETRF2000 system and announced them officially in 2011. Necessary transformation parameters are calculated and available on http://www.rgz.gov.rs/.

3 HORIZONTAL (TWO - DIMENSIONAL) REFERENCE SYSTEM

Horizontal reference system is a two – dimensional coordinate subset of spatial reference system, where positions of points are determined by two – dimensional coordinates (geodetic length and width), related to reference two – axial rotary ellipsoid of GRS80, reference system used for determination the mathematical model of the Earth in Serbia.

So, the new horizontal reference system of Serbia is a subset of spatial reference system, which should provide common and accurate description of 2D positions of points and objects. Since it represents a horizontal subset of spatial reference system, it does not need a special definition. Introduction of ETRS89 horizontal positions of points and objects in a system of geographic coordinates is also related to the ellipsoid GRS80. On the other side, horizontal ETRS89 positions of points and objects are determined by the Cartesian planar coordinates. Position of points in the horizontal reference system in Serbia is determined by two-dimensional coordinates in the plane of UTM projection (Universal Transverse Mercator) to adopted GRS80 ellipsoid. According to Paragraph 17 *of Regulation for the Basic Geodetic Works [2], the geodetic survey and processing of results in main reference network are performed in every 5 years, in order to assure integrity and observe time evolution of spatial coordinate reference system.*

Estimation of trigonometric network quality is possible in case when the etalon coordinates are available for the specific number of trigonometric points.

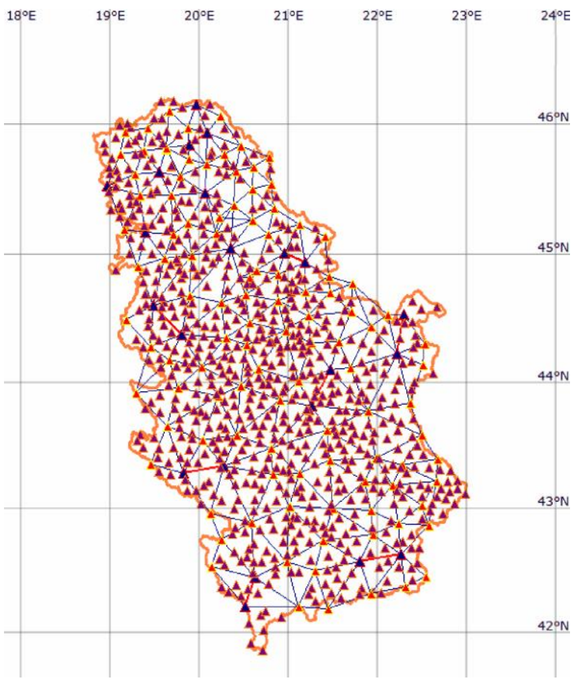

Figure 3 *The first and second class trigonometric network (http://www.rgz.gov.rs/)*

Etalon coordinates are those which are defined with superior accuracy in relation to the used coordinates. In order to determine the quality of existing horizontal base, a group of 3,400 common points on the Serbian territory is used, under the basic assumption than numeric parameters of trigonometric network quality are equal for all parts of the network of the former SFRY.

This group of points is the result of efforts made by NGB in order to provide the common points with average 5 km spacing on the whole territory of Serbia, thus enabling selection of optimal transformation model between the existing and new reference system. The used group of trigonometric points consists of all classes. GPS surveying was performed by NGB in several surveying campaigns in the period between 1997 and 2008, mainly in the following two phases:

- Approximately half of total number of points was defined in the static mode, during surveying campaigns for realization the passive geodetic national reference network (SREF) in the period between 1997 and 2003;
- Other half was determined in the network RTK mode, starting from 2003, when realization of active national geodetic reference frame – AGROS has also started.

The estimated accuracy was 1 cm for horizontal position determined in the static mode and 2 cm for RTK positioning. Reference points during realization were points from SREF and AGROS, which means that all of GNSS positioning results belong to the reference frame ITRF96, epoch 1998.7. Considering the positioning accuracy, it is obvious that coordinates of these points may be used as an etalon in relation to the coordinates from the existing reference system.

Now, for each of 3,400 points, the coordinates are known in the Gauss – Kruger projection (y, x and height H in the national height system), and also the Cartesian coordinates (X, Y, Z) related to the reference frame ITRF96. This situation was used to perform MNK procedure of parameter evaluation in the Helmert transformations. The evaluation results, among other things, represent deviations (residuals) on the common points. During GPS campaign, which had an aim to increase the number of common points, in order to provide a homogenous coverage of the whole territory, two groups of common points were determined:

- Basic group, with 4,484 common points;
- Additional group of 430 common points.

The main group was used in evaluation the transformation model parameters. The additional group was mainly referred to the polygon points concentrated in towns and cities. The basic group points were used to determine the parameters of Helmert transformation, applicable to the whole territory of Serbia. The result was a unique group of seven parameters (3 parameters of translation, 3 parameters of rotation and scale parameter). Any point can be transformed from the new reference system into former one and vice versa. There are two ways of transformation, depending on transformation parameters:

- Transformation with global parameters for the whole territory of Serbia and residual grid;
- Transformation with local parameters of specific finite elements.

Most of the EU countries have adopted the new system in past decade. Transformation model has to provide a connection of national reference system to the European reference system, and more important, a solid base for numerous geodetic activities, such as the national survey, real estate cadastre, engineering and technical works, GIS applications, etc.

4 VERTICAL REFERENCE SYSTEM

Vertical reference system is one - dimensional coordinate subset of spatial reference system, used for defining the reference planes as a base for determination of heights. Vertical reference system, based on ellipsoid reference surface, is considered as geometric.

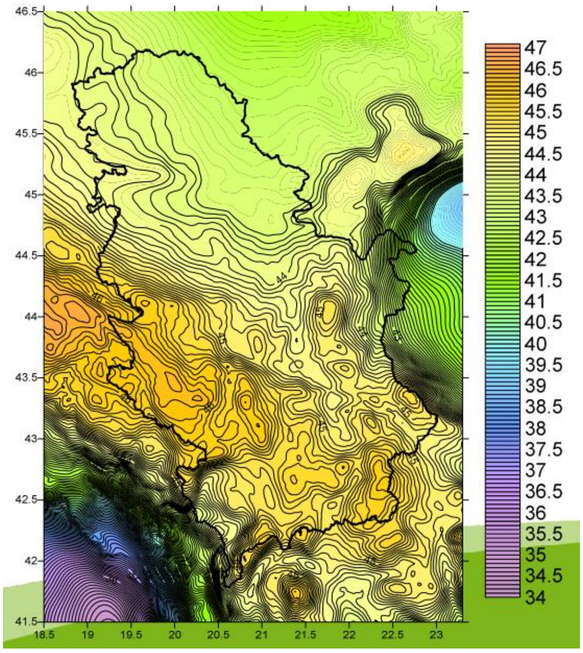

Figure 4 *Illustration of the new gravimetric quasi-geoid model*

Positions of points and objects in the national geometric vertical reference system are determined by one – dimensional coordinates, i.e. geodetic heights related to two – axial rotary ellipsoid of geodetic reference system GRS80.

The Bessel ellipsoid may be also used as the reference plane for geodetic heights. Vertical reference system based on reference plane, defined in the Earth gravity field, is considered as natural. In Serbia, the reference plane of natural vertical reference system is present by quasi-geoid. Quasi-geoid plane is defined as a plane whose points have vertical spacing from the reference two – axial rotary ellipsoid of GRS80, equal to spacing between the points of physical Earth surface and points on same perpendicular line where the real and normal potential of the Earth gravity field have same value.

Positions of points and objects in natural vertical reference system of Serbia are determined by one – dimensional coor-dinates, i.e. normal heights related to quasigeoid plane. In practice, the relation between two systems of heights – ellipsoid and national (which is referred to the Adriatic Sea mean level, determined by surveying the sea level with a single mareograph in only one year) is determined by defining a model of reference height plane, which is, in case of relatively flat planes, practically treated as a plane parallel to ellipsoid.

If the ellipsoid heights of points are determined, the point heights in the na tional system are calculated by interpolation the first degree polynomial (according to the regulation on GPS technology application in the real estate survey by NGB in 2002), as follows:

H = h + A + B•Y + C•X,

where:

H is height in the national system,

h is ellipsoid height,

Y, X – coordinates of points in the national system,

A, B, C - unknown polynomial parameters.

The unknown polynomial parameters are determined based on the known heights in both systems by minimal square method, where minimal number of common points should not be less than four. Layout of known points has to be regular (one point on 2 x 2 km area). Each network is still stabilized as it was the case at the Second High Accuracy Level of the former SFRY (NVT2), applying the fundamental and operational match marks. Leveling network in Serbia is still referred to match marks at mareograph in Trieste, Italy; the second leveling network has never been established, nor included into UELN, and Serbia has never participated in EUVN and EUVN_DA.

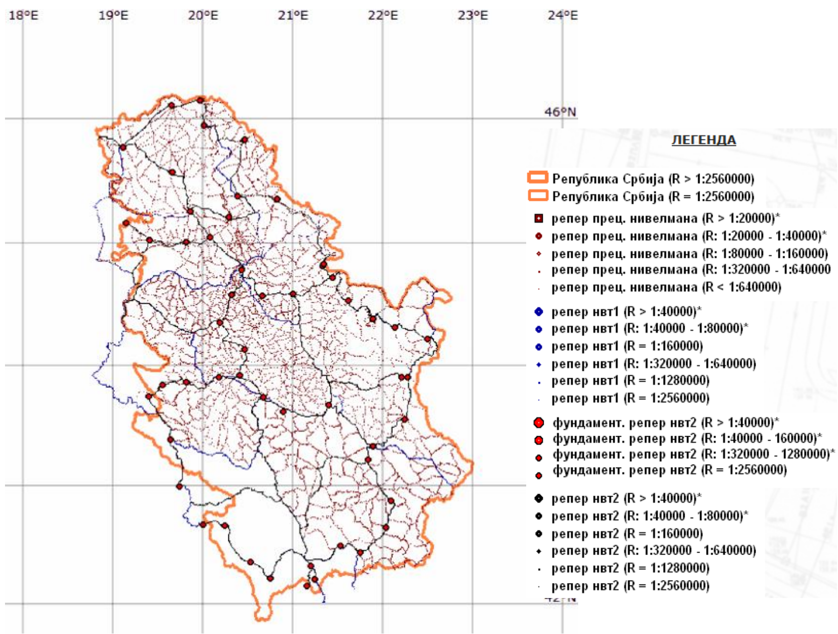

Figure 5 *Accurate Level and High Accuracy Level (NVT1 and NVT2)* (http://www.rgz.gov.rs/)

5 GRAVIMETRIC REFERENCE SYSTEM

Gravimetric survey in geodesy is used for solving problems related to determination of the Earth size and shape, as well as external gravity field. The first gravimetric survey in this area was performed in the 19 century in the Austro - Hungarian territory. In a period between two World Wars, the Military - Geographic Institute (VGI) determined the difference between gravity accelerations of Potsdam and Belgrade. Establishment the first class gravimetric network took place in the period between1952 and 1953. Network consists of 15 points with a shape of central system with 14 closed triangles and the point Belgrade (airport Zemun) as a base. The second class gravimetric network was developed to increase density of the first class network. Network had a shape of closed polygon with node points. In the period between 1964 and 1967, the Federal Geodetic Bureau (FGB) performed forming and survey in the Basic gravimetric Network. Network included the point Belgrade and base Belgrade – Skopje. Along with realization the first and second class gravimetric networks, a detailed gravimetric survey was also in progress, so that today there are surveying data from the period between 1952 and 1980 with more than 80,000 gravimetric points. Point layout is irregular and goes from two points per km^2 in Vojvodina to one point at 3 km^2 in the South and West Serbia. Determinations of relative gravity accelerations were performed with high quality and according to the world standards at that time (1950-1970), while further increases of network density enabled local geophysical explorations. Such situation in a matter of conflict with the existing global standards, as well as lack of organized regional and local gravimetric survey, makes their use difficult for the scientific and technical purposes. Gravimetric reference system enables a gravimetric determination of absolute and relative gravity acceleration and calculation of gravimetric parameters. Gravimetric reference system is defined by the following reference systems:

- Reference system of gravimetric determinations;
- Reference system of normal gravity field.

Reference system of gravimetric determinations is specified by real gravity field of the Earth, as well as each specific value of absolute gravity acceleration. By realization of UNIGRACE project, measuring the absolute values of gravity acceleration was performed in many European countries in the period between 1996 and 2000. Reference system of gravimetric determinations is realized through the national gravimetric reference frame, which represents a group of materialized points and values of absolute gravity acceleration related to the specific epoch. Measurements of absolute gravity acceleration values were performed between 10 and 26 October 2007. Geographic locations of three measured points were monasteries: Grgeteg at Fruska Gora (AG1), Gradac near Raska (AG2) and Sveta Bogorodica in the Sicevac Canyon (AG3). Serbian gravimetric reference frame is present by the Basic Gravimetric Network, harmonized with the International Gravity Standardization Network 1971 (IGSN71).

The basic gravimetric network consists of 60 closed polygons, while total number of connections is Δg=137 (Figure 5). The basic gravimetric network includes 78 points:

- 3 given points with values of absolute gravity acceleration;
- 37 points of the Serbian Reference Network (SREF);
- 37 fundamental match marks of NVT2;
- 1 point (GT251).

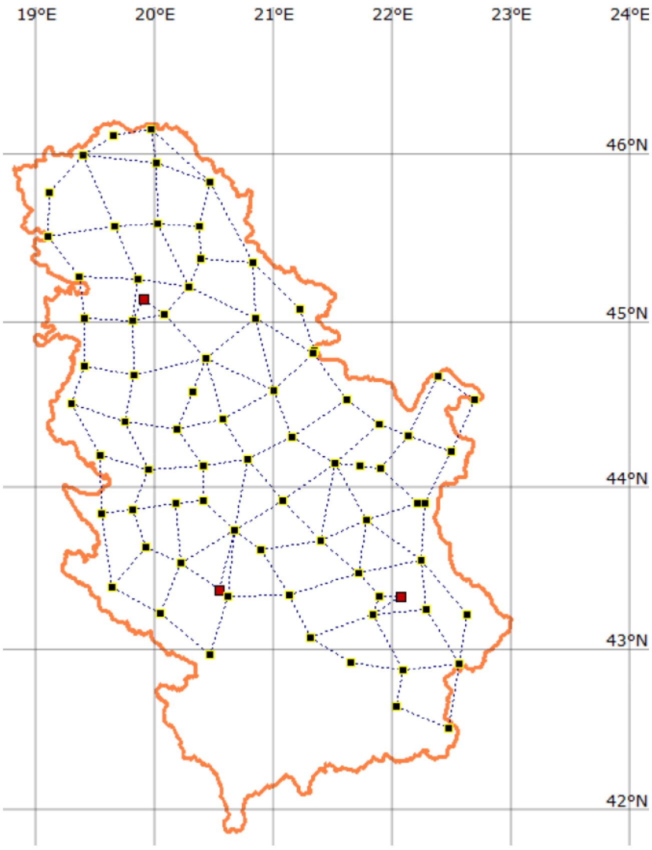

Figure 6 *The basic gravimetric network (http://www.rgz.gov.rs/)*

Basic gravimetric network is connected to the given points through six connection points.

Sum of 2,317 new points with approximate 5 km spacing of regional survey is planned on the territory of the whole Serbian. Survey is also performed at 838 points of national reference network and 42 fundamental match marks, which makes total of 3,196 points. Considering the approach in gravimetric works, which match the standards of the EU countries, it can be concluded that the gravimetric works in Serbia are harmonized with the applied approach in Europe. For gravimetric reference system and its realization, with null and basic gravimetric network and gravimetric survey, it can be said that it will achieve the level of networks in other European countries in a few years.

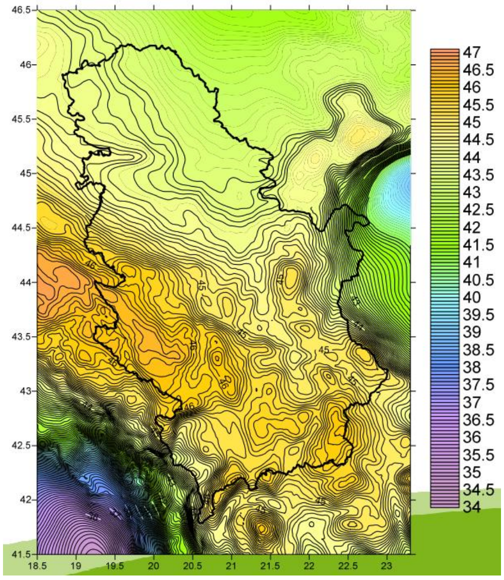

Figure 7 *The Serbian quasi-geoid model 2011*

6 CONCLUSION

The existing national reference system in Serbia is based on the non – geocentric Bessel ellipsoid and Gauss – Kruger projection of meridian zones. Considering the achievements both in geodetic methodology and surveying technology, it is obvious that the existing Serbian reference system does not match actual demands on accuracy and reliability, whether by definition or realization. As for the EU countries, most of them performed the transformation to the new reference system in past ten years. Adopted transformation model should enable connection of our national reference system with the European reference system, and more important, it would provide a solid base for solving problems in national survey, real estate cadastre, engineering and technical operations and GIS applications.

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STATISTIČKA OBRADA REZULTATA MEĐULABORATORIJSKOG ISPITIVANJA GRANULOMETRIJSKOG SASTAVA KAMENOG UGLJA RUDNIKA AVRAMICA***

Izvod

U radu su prikazani rezultati međulaboratorijskog ispitivanja granulometrijskog sastava kamenog uglja iz Rudnika Avramica. Ispitivanja su izvršena na reprezentativnim uzorcima uglja. Rezultati su obrađeni na dva načina i to: numeričkom metodom – Cochran-ov test preciznosti i grafičkom interpretacijom – Računanje z vrednosti u skladu sa standardom SRPS ISO 5725-2 [1]. Izračunate su: varijansa ponovljivosti Sr^2*; međulaboratorijska varijansa* S_L^2 *i varijansa obnovljivosti* S_R^2*.Uzorci su metodom deljenja dostavljeni svim laboratorijama učesnicama.*

Ključne reči: *statistička obrada rezultata, kameni ugalj, granulometrijski sastav*

UVOD

U ovim ispitivanjima učestvovale su tri akreditovane laboratorije. Međulaboratorijsko ispitivanje granulometrijskog sastava kamenog uglja rudnika Avramica, vršeno je u skladu sa standardom *SRPS B.H8.372:1976* [3].

Za svaku laboratoriju pripremljena su po tri reprezentativna uzorka uglja, u količini koju propisuje standard *SRPS B.H8.372:1976.* Uzorci su na adekvatan način spakovani i isporučeni u ostale tri laboratorije [4,5].

Radi davanja uporedne analize ostvarenih rezultata, u obračunu osnovnih i neophodnih parametara međulaboratorijskih ispitivanja, razmatrani su rezultati dobijeni prosejavanjem uzoraka na serijama sita koje poseduje svaka od laboratorija, a u skladu sa standardom.

Takođe su procenjene i varijanse ponovljivosti i obnovljivosti.

Ciljevi sprovođenja ovakvih ispitivanja, su između ostalog i :

- Provera celokupnog rada laboratorije;
- Provera zaposlenih u laboratoriji pri pojedinačnom ispitivanju;

Uspostavljanje efikasnosti metode ispitivanja, sa ciljem davanja tačnosti izlaznih rezultata korisnicima usluga laboratorija [6].

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*** *Ovaj rad je proistekao kao rezultat Projekta br. 34006: Mehanohemijski tretman nedovoljno kvalitetnih mineralnih sirovina, i Projekta br 33023: Razvoj tehnologija flotacijske prerade ruda bakra i plemenitih metala radi postizanja boljih tehnoloških rezultata koje finansira Ministarstvo prosvete, nauke i tehnološkog razvoja Republike Srbije.*

PRIKAZ REZULTATA MEĐULABORATORIJSKOG ISPITIVANJA

Tabela 1. *Rezultati ispitivanja granulometrijskog sastava uglja*

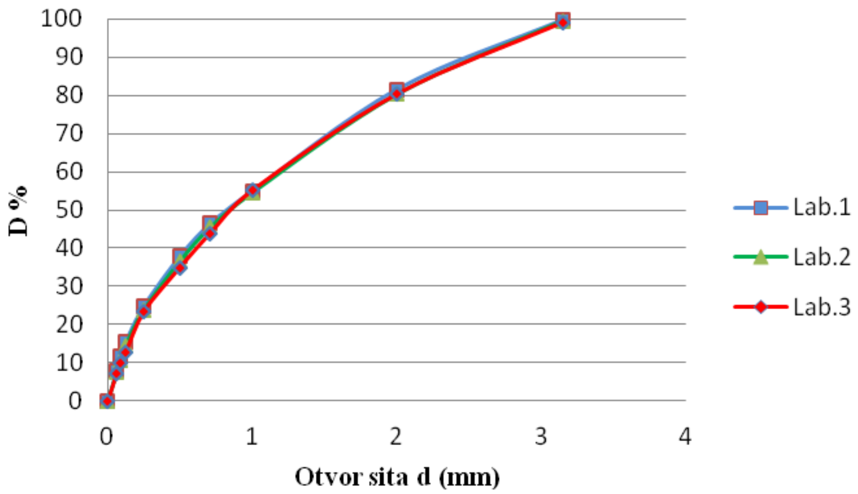
Oznaka lab.	**1**			**2**			**3**		
Oznaka uzorka	Prva proba	Druga proba	Treća proba	Prva proba	Druga proba	Treća proba	Prva proba	Druga proba	Treća proba
Sita (mm)	Prolaz kroz sito D (%)								
0,063	8,43	7,83	7,46	8,91	7,29	6,89	7,30	7,38	7,42
0,090	11,93	11,97	11,53	12,18	9,82	9,55	9,75	9,82	9,91
0,125	15,73	15,76	15,13	16,55	13,41	13,76	12,91	13,21	12,46
0,250	24,95	25,04	24,57	26,39	22,35	22,91	23,94	21,97	24,36
0,500	37,98	38,21	37,51	39,98	35,12	34,66	37,69	34,75	32,53
0,710	46,41	46,77	46,07	48,53	44,57	43,09	47,03	43,74	41,12
1	54,80	55,38	54,60	58,14	54,08	51,15	56,62	53,38	55,30
2	81,48	81,69	81,43	82,58	80,05	78,01	82,45	79,11	79,42
3,15	99,82	99,79	99,77	99,52	99,45	99,30	99,64	98,72	98,96
4	100	100	100	100	100	100	100	100	100

U tabelama 1-3 redom su prikazani rezultati ispitivanja granulometrijskog sastava uglja, srednje vrednosti ćelija i standardne devijacije - mere rasipanja ćelija.

Na slici 1, grafički su prikazane srednje vrednosti granulometrijskog sastava, određene iz rezultata triju prosejavanja, za svaku od tri ispitne laboratorije.

Tabela 2. *Srednje vrednosti ćelija*

Oznaka lab, *i*	**1**	**2**	**3**	***Suma srednjih vrednosti***
Srednje vrednosti	$\bar{x}_{ij}$			$\bar{\bar{x}}_{ij}$
Sita (mm), *j*	$\bar{x}_{1j}$	$\bar{x}_{2j}$	$\bar{x}_{3j}$	$\sum \frac{x_{ij}}{3}$
0,063	7,91	7,70	7,37	7,660
0,090	11,81	10,52	9,83	10,720
0,125	15,54	14,57	12,86	14,323
0,250	24,85	23,88	23,42	24,050
0,500	37,90	36,59	34,99	36,493
0,710	46,42	45,40	43,96	45,260
1	54,93	54,46	55,10	54,830
2	81,53	80,21	80,33	80,690
3,15	99,79	99,42	99,11	99,440
i-oznaka lab.(1-3) ***j-oznaka mreže sita(1-9)***				



Sl. 1. *Srednje vrednosti granulometrijskog sastava*

Tabela 3. *Standardne devijacije - mere rasipanja ćelija*

Oznaka lab. *i*	**1**		**2**		**3**		***Suma kvadrata standardnih devijacija***
Srednje vrednosti	S_{ij}						
Sita (mm) *j*	S_{i1}	S_{i1}^2	S_{i2}	S_{i2}^2	S_{i3}	S_{i3}^2	ΣS_{ij}^2
0,063	0,489	0,239	1,070	1,145	0,061	0,004	1,388
0,090	0,243	0,059	1,447	2,094	0,080	0,006	2,159
0,125	0,355	0,126	1,721	2,962	0,377	0,142	3,230
0,250	0,249	0,062	2,189	4,792	1,276	1,628	6,482
0,500	0,357	0,127	2,948	8,691	2,588	6,698	15,516
0,710	0,350	0,122	2,813	7,913	2,961	8,767	16,802
1	0,405	0,164	3,510	12,320	1,629	2,654	15,138
2	0,138	0,019	2,289	5,240	1,845	3,404	8,663
3,15	0,025	***0,000625≈0,001***	0,112	0,012	0,477	0,227	0,24

Napomena: *Standardna devijacija treba da se izrazi jednom cifrom više, u odnosu na date rezultate u tabelama 1 i 2, te je u skladu sa tom konstatacijom izvršeno i zaokruživanje na tri decimale prikazanih rezultata u tabeli 3, (tačka 7.2.10 -SRPS ISO 5725-2).*

REZULTATI COCHRANOVOG TESTA

Tabela 4. *Rezultati Cochranovog testa*

Sita (mm)	Lab.	Ispitna vrednost Sij^2	C vrednost	Kritične vrednosti		Komentar	Ocena
				1%	5%		
0,063	*2*	*1,145*	*0,825*	*0,942*	*0,871*	*C≤Ctab(5%)*	*Korektan*
0,090	*2*	*2,094*	*0,969***			*C≥Ctab(1%)*	*Usamljena vrednost (outliers)*
0,125	*2*	*2,962*	*0,917**			*C(1%)≥C≥(5%)*	*Zalutala vrednost (stragglers)*
0,250	*2*	*4,792*	*0,739*			*C≤Ctab(5%)*	*Korektan*
0,500	*2*	*8,691*	*0,560*			*C≤Ctab(5%)*	*Korektan*
0,710	*3*	*8,767*	*0,522*			*C≤Ctab(5%)*	*Korektan*
1	*2*	*12,320*	*0,814*			*C≤Ctab(5%)*	*Korektan*
2	*2*	*5,240*	*0,605*			*C≤Ctab(5%)*	*Korektan*
3,15	*3*	*0,227*	*0,946***			*C≥Ctab(1%)*	*Usamljena vrednost (outliers)*

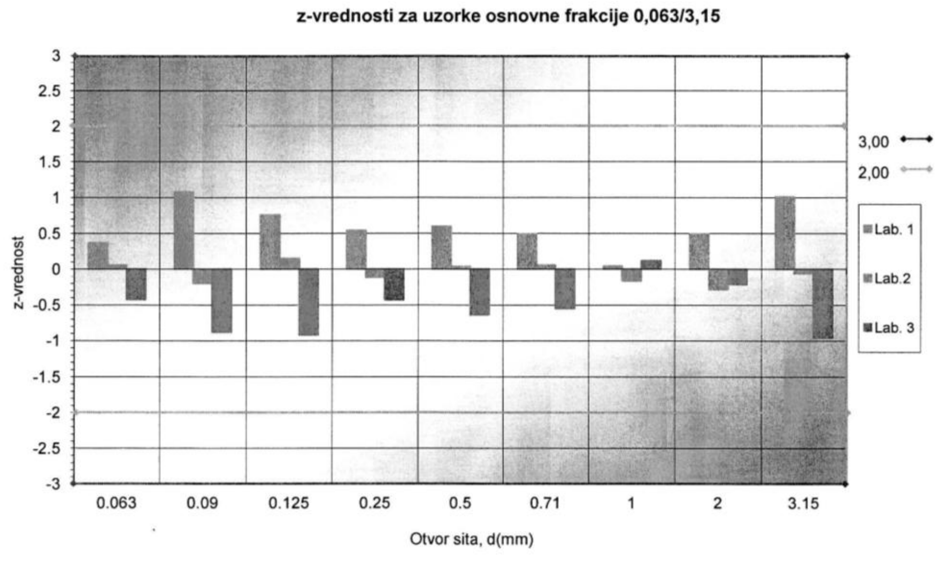
Napomena: *Usamljene vrednosti (outliers) nisu uzete u proračun varijansi ponovljivosti i obnovljivosti, (tačka 7.1.6 -SRPS ISO 5725-1 [2]).*

REZULTATI Z-VREDNOSTI

Izračunate z vrednosti prikazane su u tabeli 5, a grafik z vrednosti na slici 1.

Tabela 5. *Izračunate z vrednosti*

Oznaka lab. *i*	**1**	**2**	**3**
Sita (mm) *j*	**Izračunate z vrednosti**		
0,063	0,3675	0,0588	-0,4263
0,090	1,0783	-0,1979	-0,8805
0,125	0,7630	0,1548	-0,9172
0,250	0,5442	-0,1156	-0,4286
0,500	0,5963	0,0411	-0,6369
0,710	0,4901	0,0591	-0,5493
1	0,0445	-0,1647	0,1202
2	0,4943	-0,2825	-0,2118
3,15	1,0142	-0,0579	-0,9562



Sl. 1. *Grafik z vrednosti*

z-vrednost se izražava jednačinom:

$$z = (\bar{x}_{ij} - \bar{\bar{x}}_{ij})/S_R$$

gde je:

$\bar{x}_{ij}$ - *srednja vrednost ćelije (laboratorije) na datom nivou*

$\bar{\bar{x}}_{ij}$ - *suma srednjih vrednosti laboratorija na datom nivou (dodeljena vrednost)*

S_R - *standardna devijacija obnovljivosti*

Tumačenje rezultata:

Rezultati sa:

- ***Z < 2 smatraju se korektnim;***
- ***2 < Z < 3 smatraju se diskutabilnim;***
- ***Z > 3 smatraju se nezadovoljavajućim.***

U tabeli 6 prikazane su vrednosti varijansi.

Tabela 6. *Izračunate vrednosti varijansi*

Sita (mm) *i*	Sr^2	Sr	S_L^2	S_L	S_R^2	S_R
0,063	0,4627	0,6802	0,0000 (-0,0793)	0	0,4627	0,6802
0,090	0,0325	0,1803	0,9893	0,9946	1,0218	1,0108
0,125	1,0767	1,0376	1,4675	1,2114	2,5442	1,5950
0,25	2,1607	1,4699	0,0000 (-0,1855)	0	2,1607	1,4699
0,5	5,1720	2,2742	0,3960	0,6293	5,5680	2,3597
0,71	5,6010	2,3666	0,0000 (-0,3360)	0	5,6010	2,3667
1	5,0460	2,2463	0,0000 (-1,5564)	0	5,0460	2,2463
2	2,8877	1,6994	0,0000 (-0,4255)	0	2,8877	1,6993
3,15	0,0065	0,0806	0,1126	0,3355	0,1191	0,3451

Sr^2-Varijansa ponovljivosti
S_L^2 - Međulaboratorijska varijansa
S_R^2 - Varijansa obnovljivosti

Napomena: *Usled efekta slučajnosti, dobijene negativne vrednosti za* S_L^2 *smatraju se jednakim nuli (tačka 7.4.5.4- SRPS ISO 5725-2).*

ZAKLJUČAK

Svrha međulaboratorijskog ispitivanja sprovedena između navedenih laboratorija, bila je ocena preciznosti ispitne metode i ocena sposobnosti ispitnih laboratorija.

Nakon statističke obrade rezultata dvema statističkim metodama, može se izvesti sledeći zaključak: Rezultat laboratorije br. 2, na situ otvora 0,090 mm, nakon statističke obrade Cochranovim testom može se smatrati usamljenom vrednošću, kao i laboratorije br. 3 na situ od 3,15 mm. Istim testom konstantovana je vrednost koja se nalazi u intervalu zalutalih zrna na situ od 0,125 mm u laboratoriji broj 2. Ostali rezultati ispitnih laboratorija, po osnovu Cochranovog kriterijuma kritičnih vrednosti, smatraju se korektnim (tabela 4). Statistički obrađeni rezultati laboratorije 1 primenom Cochranovog kriterijuma, smatraju se zadovoljavajućim t.j korektnim.

Z-rezultati svih laboratorija (tabela 5, slika 1), su u zadatim granicama koje propisuje statistička metoda z-vrednosti, što dalje ukazuje na osposobljenost laboratorija za navedenu standardnu metodu određivanja granulometrijskog sastava uglja kao i tačnost izlaznih rezultata.

U obzir treba uzeti i moguće uticajne faktore - efekte na krajnje rezultate ispitivanja:

1. uzorkovanje (homogenost);
2. priprema uzorka (efekat homogenizacije ili izuzimanje dela uzorka);
3. efekat izvršioca;
4. uticaj transporta.

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STATISTICAL PROCESSING THE INTERLABORATORY TESTING RESULTS OF GRAIN-SIZE DISTRIBUTION OF STONE COAL FROM THE COAL MINE AVRAMICA***

Abstract

This work presents the results of interlaboratory testing the grain-size distribution of stone coal from the Coal Mine Avramica. Tests were carried out on representative samples of coal. The results were processed by two ways: numerical method - Cochran's test of accuracy and graphic interpretation - Calculating the z value in accordance with the Standard SRPS ISO 5725-2 [1]. The followings were calculated: variance of repeatability variance Sr^2; interlaboratory variance S_L^2 and reproducibility variance S_R^2. The samples distributed to all participating laboratories using the method of sharing.

Keywords: *statistical processing of the results, stone coal, grain-size distribution*

INTRODUCTION

Three accredited laboratories were involved in these tests. Interlaboratory testing of grain-size distribution of coal from the Coal Mine Avramica was carried out in accordance with the Standard SRPS B.H8.372:1976 [3].

Three representative samples of coal were prepared for each laboratory, in the amount stipulated by the Standard SRPS B.H8.372: 1976. The samples were properly packaged and shipped in three other laboratories [4,5].

In order to give a comparative analysis of the achieved results in calculation the basic and nenecessary parameters of interlaboratory tests, the results obtained by sieving of samples on series of sieves in each laboratory were discussed, and in accordance with the Standard.

The variances of repeatability and reproducibility were also estimated.

The aims of conducting such tests, among other things, are the followings:

- Checking the whole work of laboratory;
- Checking the employed in laboratory at individual test;

Establishing the efficiency of test method, with the aim of giving to the users of laboratory services the accuracy of output results [6].

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REVIEW OF INTERLABORATORY TEST RESULTS

Table 1 *Test results of grain-size distribution of coal*

Lab designa-tion	**1**			**2**			**3**		
Sample designa-tion	First sample	Second sample	Third sample	First sample	Second sample	Third sample	First sample	Second sample	Third sample
Sieves (mm)	Passage through a sieve D (%)								
0.063	8.43	7.83	7.46	8.91	7.29	6.89	7.30	7.38	7.42
0.090	11.93	11.97	11.53	12.18	9.82	9.55	9.75	9.82	9.91
0.125	15.73	15.76	15.13	16.55	13.41	13.76	12.91	13.21	12.46
0.250	24.95	25.04	24.57	26.39	22.35	22.91	23.94	21.97	24.36
0.500	37.98	38.21	37.51	39.98	35.12	34.66	37.69	34.75	32.53
0.710	46.41	46.77	46.07	48.53	44.57	43.09	47.03	43.74	41.12
1	54.80	55.38	54.60	58.14	54.08	51.15	56.62	53.38	55.30
2	81.48	81.69	81.43	82.58	80.05	78.01	82.45	79.11	79.42
3.15	99.82	99.79	99.77	99.52	99.45	99.30	99.64	98.72	98.96
4	100	100	100	100	100	100	100	100	100

Tables 1-3 respectively present the results of grain-size distribution of coal, the mean values of cells standard deviation of cell-cell dispersion measures. In Figure 1, graphically shows the mean particle size composition, determined from the results of three sieving for each of the three testing laboratories.

Table 2 *Mean values of cells*

Lab designation, *i*	**1**	**2**	**3**	***Sum of mean values***
Mean values				
Sieves (mm), *j*				—
0.063	7.91	7.70	7.37	7.660
0.090	11.81	10.52	9.83	10.720
0.125	15.54	14.57	12.86	14.323
0.250	24.85	23.88	23.42	24.050
0.500	37.90	36.59	34.99	36.493
0.710	46.42	45.40	43.96	45.260
1	54.93	54.46	55.10	54.830
2	81.53	80.21	80.33	80.690
3.15	99.79	99.42	99.11	99.440
i-lab designation1-3) ***j-designation of sieve mesh(1-9)***				

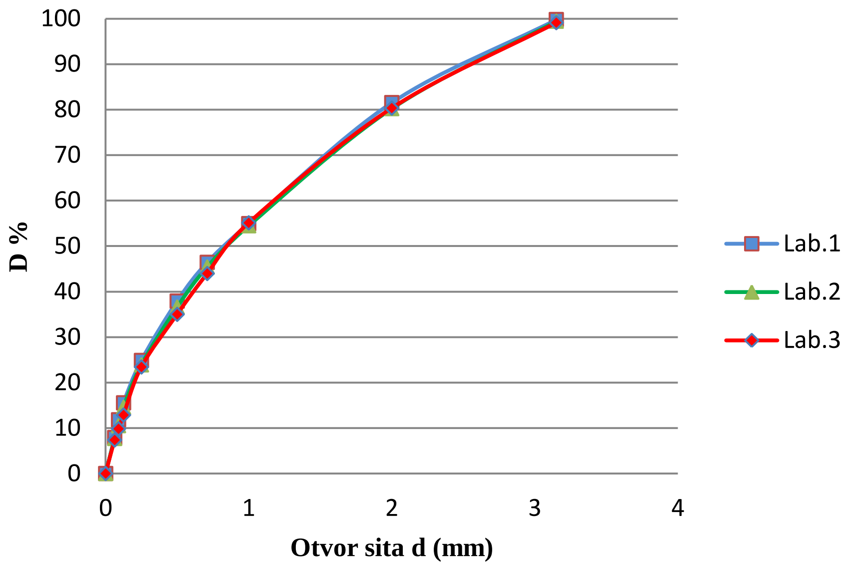

Figure 1 *Mean values of grain-size distribution*

Table 3 *Standard deviations - measures of cell dispersion*

Lab designation *i*	**1**		**2**		**3**		***Sum of squares of standard deviations***
Mean values	*Sij*						
Sieves (mm) *j*	*Si1*	*Si1*^{2}	*Si2*	*Si2*^{2}	*Si3*	*Si3*^{2}	$\Sigma\, S_{ij}^{2}$
0.063	0.489	0.239	1.070	1.145	0.061	0.004	1.388
0.090	0.243	0.059	1.447	2.094	0.080	0.006	2.159
0.125	0.355	0.126	1.721	2.962	0.377	0.142	3.230
0.250	0.249	0.062	2.189	4.792	1.276	1.628	6.482
0.500	0.357	0.127	2.948	8.691	2.588	6.698	15.516
0.710	0.350	0.122	2.813	7.913	2.961	8.767	16.802
1	0.405	0.164	3.510	12.320	1.629	2.654	15.138
2	0.138	0.019	2.289	5.240	1.845	3.404	8.663
3.15	0.025	***0.000625≈ 0.001***	0.112	0.012	0.477	0.227	0.24
Note: Standard deviation is expressed by one digit more, compared to the results in Tables 1 and; so, in accordance with this statement, made and the rounding to three decimal places was made of the results shown in Table 3 (item 7.2.10 -SRPS ISO 5725-2)							

RESULTS OF THE COCHRAN TEST

Table 4 *Results of the Cochran test*

Sieves (mm)	Lab	Test value Sij^2	C value	Critical values 1%	Critical values 5%	Comment	Evaluation
0.063	*2*	*1.145*	*0.825*			*C≤Ctab(5%)*	*Correct*
0.090	*2*	*2.094*	*0.969***			*C≥Ctab(1%)*	*Outliers*
0.125	*2*	*2.962*	*0.917**			*C(1%)≥C≥(5%)*	*Stragglers*
0.250	*2*	*4.792*	*0.739*			*C≤Ctab(5%)*	*Correct*
0.500	*2*	*8.691*	*0.560*	*0.942*	*0.871*	*C≤Ctab(5%)*	*Correct*
0.710	*3*	*8.767*	*0.522*			*C≤Ctab(5%)*	*Correct*
1	*2*	*12.320*	*0.814*			*C≤Ctab(5%)*	*Correct*
2	*2*	*5.240*	*0.605*			*C≤Ctab(5%)*	*Correct*
3.15	*3*	*0.227*	*0.946***			*C≥Ctab(1%)*	*Outliers*

Note : *Outliers are not taken into calculation of repeatability and reproducibility variances (item 7.1.6 -SRPS ISO 5725-1 [2]).*

RESULTS OF Z-VALUE

Calculated z values are shown in Table 5, and graph of z value in Figure 2.

Table 5 *Calculated z values*

Lab designation *i*	1	2	3
Sieves (mm) *j*	**Calculated z values**		
0.063	0.3675	0.0588	-0.4263
0.090	1.0783	-0.1979	-0.8805
0.125	0.7630	0.1548	-0.9172
0.250	0.5442	-0.1156	-0.4286
0.500	0.5963	0.0411	-0.6369
0.710	0.4901	0.0591	-0.5493
1	0.0445	-0.1647	0.1202
2	0.4943	-0.2825	-0.2118
3.15	1.0142	-0.0579	-0.9562

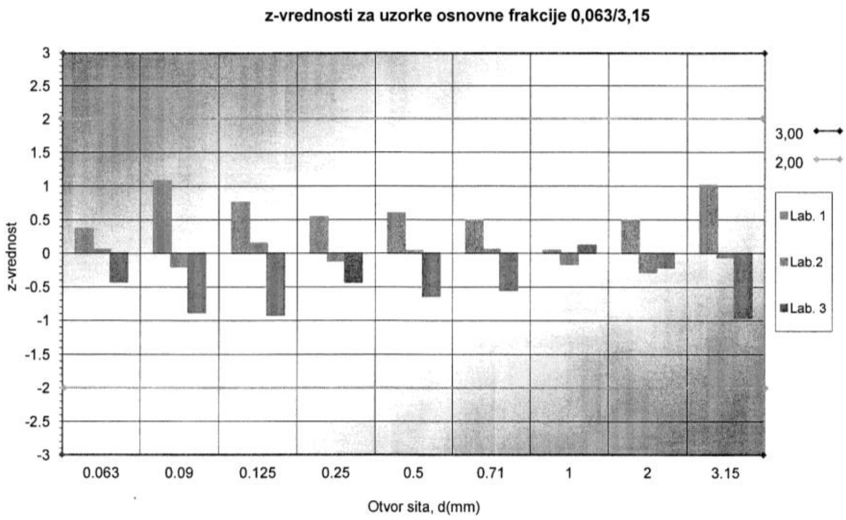

Figure 2 *Graph of z value*

z-value is expressed by equation:

Where:

– medium value of a cell (laboratory) at a given level

– sum of mean values of laboratory at a given level (assigned value)

- standard deviation of reproducibility

Interpretation of the results:
Results with:

- ***Z < 2 considered as correct;***
- ***2 < Z < 3 considered as questionable;***
- ***Z > 3 considered as unsatisfactory.***

Table 6 *Calculated values of variances*

Sieves (mm) *i*	Sr^2	Sr	S_L^2	S_L	S_R^2	S_R
0.063	0.4627	0.6802	0.0000(-0.0793)	0	0.4627	0.6802
0.090	0.0325	0.1803	0.9893	0.9946	1.0218	1.0108
0.125	1.0767	1.0376	1.4675	1.2114	2.5442	1.5950
0.25	2.1607	1.4699	0.0000(-0.1855)	0	2.1607	1.4699
0.5	5.1720	2.2742	0.3960	0.6293	5.5680	2.3597
0.71	5.6010	2.3666	0.0000(-0.3360)	0	5.6010	2.3667
1	5.0460	2.2463	0.0000(-1.5564)	0	5.0460	2.2463
2	2.8877	1.6994	0.0000(-0.4255)	0	2.8877	1.6993
3.15	0.0065	0.0806	0.1126	0.3355	0.1191	0.3451

Sr^2-Repeatibility variance
S_L^2-Interlaboratory variance
S_R^2- Reproducibility variance

Due to the effect randomness, the obtained negative values for S_L^2 *are assumed to be zero (item 7.4.5.4- SRPS ISO 5725-2).*

CONCLUSION

The purpose of interlaboratory testing, conducted between these laboratories, was evaluation the precision of test method and evaluation the capabilities of testing laboratories.

After statistical processing the results using two statistical methods, the following conclusion can be made: The result of laboratory No. 2, on a sieve mesh of 0.090 mm, after statistical processing by the Cochran test, can be considered as an isolated value, as well as the result of laboratory No. 3 on a sieve mesh of 3.15 mm. The same test has confirmed that the value is in the range of strayed grains on a sieve of 0.125 mm in the laboratory No. 2. The other results of testing laboratories, based on the Cochran criteria of critical values are considered to be correct (Table 4). The results of laboratory No. 2, statistically processed using 1 the Cochran criteria, are considered as satisfactory, i.e. correct.

The z-results of all laboratories (Table 5, Figure 2), are in the given limits, imposed by the statistical method of z-values, which further indicates the competence of laboratories for the given standard method of determining the grain-size distribution of coal and the accuracy of output results.

Possible influencing factors-effects on the final results of the test have to be also considered:

1 sample (homogenezity);
2 sample preparation (the effect of homogenization or excluding a part sample);
3 effect of executor;
4 impact of transport.

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ODREDJIVANJE PARAMETARA METODA OTKOPAVANJA LABORATORIJSKIM ISPITIVANJIMA NA FIZIČKIM MODELIMA SLIČNOSTI**

Izvod

Ovaj rad je nastao na osnovu predhodno izvršenih laboratorijskih istraživanja u laboratorijskim uslovima, na fizičkim modelima sličnosti. On predstavlja sintezu teoretskog objašnjenja i praktičnog istraživanja. Pojave koje su razmatrane ne mogu se pratiti u stvarnim, jamskim, uslovima već se moraju ispitivati u laboratoriji. Predložena je nova konstrukcija metode blokovskog zarušavanja kojoj je zbog specifičnog rasporeda otkopnih blokova dat naziv "Metoda poluetažnog prinudnog zarušavanja sa jednostranim bočnim utovarom rude". Za ovu metodu istraživani su i odredjeni optimalni parametri za njenu buduću praktičnu primenu.

***Ključne reči**: podzemna eksploatacija, metode otkopavanja, fizički modeli sličnosti*

UVOD

Za otkopavanje siromašnih rudnih ležišta koja zaležu na sve većim dubinama, neminovno se javlja potreba primene visokoproizvodnih metoda otkopavanja. Povećanjem kapaciteta smanjuju se troškovi eksploatacije i time omogućava ekonomski isplativo otkopavanje ležišta. Metoda poluetažnog prinudnog zarušavanja pripada grupi visokoproduktivnih metoda otkopavanja.

Visoki proizvodni kapaciteti koji se mogu ostvariti ovom metodom uslovljeni su prvenstveno mogućnošću potpune mehanizovanosti svih proizvodnih procesa eksploatacije. Osnovni nedostatak metoda iz ove grupe predstavlja nemogućnost potpunog istakanja rude, što je u direktnoj vezi sa osiromašenjem rude. Veće iskorišćenje rude postiže se pri njenom većem osiromašenju što za sobom povlači i veće troškove transporta, izvoza i prerade. To ukazuje da se osiromašenje može povećati do odredjene granice, kada ukupni troškovi dobijanja i prerade prevazilaze ekonomsku vrednost rude.

Odredjivanjem optimalnih konstruktivnih parametara metode otkopavanja dobijaju se najpovoljnije vrednosti iskori-šćenja i osiromašenja rude.

MODELSKO ISPITIVANJE PARAMETARA METODA OTKOPAVANJA

Modelska ispitivanja predstavljaju jednu od neophodnih etapa pri naučnom priləženju rešavanja različitih problema. Na osnovu modelskih ispitivanja mogu se

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proveriti rešenja dobivena analitičkim putem. Istovremeno modelske metode omogućuju da se prate izvesni procesi za koje bi u slučaju ispitivanja na terenu trebalo mnogo vremena i sredstava, a da se pri tome ne izgubi u kvalitetu.

Izučavanje zakonitosti istakanja rude zahteva razradu osnovne teorije toga procesa i praktične podloge u cilju sniženja gubitaka i osiromašenja rude.

Primena metoda otkopavanja kod kojih se minirana ruda mora predhodno propustiti kroz neki ispusni otvor zahteva dobro poznavanje teorije istakanja (točenja) miniranog materijala. Modelska ispitivanja su u ovim istraživanjima od neprocenjive važnosti s obzirom da u jamskim uslovima ne postoji mogućnost posmatranja promena u rudi koja se istače. Oslanjanje na dobijene rezultate i njihovu primenu u praksi zahteva vrlo precizan i strpljiv rad uz obavezno poštovanje odredjenih zakonitosti. Znači, pri modelskim ispitivanjima moraju se poštovati odredjeni principi koji su zasnovani na sličnosti koja mora postojati izmedju pojava u modelima i onih koje se dešavaju u prirodi.

Ruski akademik L. I. Sedov daje definiciju modeliranja na sledeći način: ″Modeliranje je zamena izučavanja pojava u prirodi koje nas interesuju, izučavanjem analogne pojave na modelu manje ili veće razmere, obično u specijalnim laboratorijskim uslovima. Osnovni smisao modeliranja sastoji se u tome da se rezultatima ogleda, koji su dobijeni na modelima, mogu dati neophodni odgovori o karakteru efekata i o različitim veličinama, vezanim sa pojavom u prirodnim uslovima″ [1]. Za dve pojave može se reći da su slične ako po zadanim karakteristikama jedne može se odrediti karakteristika druge pojave preko razmere sličnosti.

Pri modelskim ispitivanjima moraju se poštovati odredjeni principi. Oni se zasnivaju na sličnosti koja mora postojati izmedju pojava u modelima i onih koje se dešavaju u prirodi.

Uslov sličnosti moguće je postići samo ako se svi parametri, koji karakterišu sistem, mogu dobiti množenjem parametara modela nekim konstantnim množiteljem (razmerom).

U slučaju linearne sličnosti razmera se javlja kao konstanta koja je obično odredjena eksperimentalno ili proračunom. Najjednostavniji primer je geometrijska sličnost dva ili više objekata gde se odnos izmedju odgovarajućih razmera, koje odredjuju geometrijsku formu, javlja konstantnom veličinom [2]. Geometrijska (linearna) sličnost podrazumeva, pre svega, izradu svih delova modela u usvojenoj geometrijskoj razmeri. To znači da su odnosi linearnih dimenzija modela i dimenzija u prirodi konstantni (npr. dimenzije bloka miniranja u modelu i dimenzije bloka miniranja u prirodi nalaze se u istom odnosu).

Geometrijska sličnost podrazumeva i umanjenje krupnoće materijala kojim se vrši eksperiment. Umanjenjem krupnoće materijala vrlo često se menjaju i njegove fizičko - mehaničke karakteristike.

Specijalnim eksperimentom ustanovljeno je:

Najmanje dopuštene geometrijske dimenzije pri modeliranju treba da budu i takve da se sačuva postojanje fizičko - mehaničkih svojstava sipućeg materijala [3].

$$n_{dop} \prec \frac{\tau_n - f \cdot \sigma_n}{C_n} \qquad (1)$$

gde su:

τ_n - glavno tangencijalno naprezanje čestica,

σ_n - glavno normalno naprezanje,

f - koeficijent unutrašnjeg trenja,

C_n - sile adhezije.

Ako se za prihvaćene geometrijske dimenzije modela fizičke osobine sredine (materijala koji se toči) ne menjaju i omogućuju slobodno isticanje materijala, karakterističnog za prirodne uslove, onda je proces modeliranja fizički sličan prirodnom [3].

Modeliranje mehaničkih kretanja bazira se na kinematskoj sličnosti, koja odredjuje sličnost mehaničkih kretanja. Položaj objekata ispitivanja odredjuje se koordinatama njegovih tačaka u funkciji od vremena ili zakonom kretanja. U slučaju kinematske sličnosti, odnos koordinata bilo kojih analognih tačaka prirode i modela, za odgovarajuće momente vremena, javlja se konstantnim.

$$\frac{X_{ip}(tp)}{X_{im}(tm)} = \frac{Y_{ip}(tp)}{Y_{im}(tm)} = \frac{Z_{ip}(tp)}{Z_{im}(tm)} = R_l \qquad (2)$$

gde su:

X_{ip} (tp), Y_{ip} (tp) i Z_{ip} (tp) - koordinate i - te tačke u prirodi u funkciji od vremena,

X_{im}(tm), Y_{im}(tm), Z_{im}(tm) - koordinate analogne tačke modela u funkciji od vremena,

t_p, t_m - skala vremena za prirodu i model,

R_l - koeficijent sličnosti dužine (razmera dužine).

Kinematska sličnost omogućuje odredjivanje (ovih) karakteristika kretanja u prirodi (brzine, ubrzanja) prema rezultatima ispitivanja na modelu. Veličina brzine odredjuje se iz odnosa:

$$\frac{(V_x)_{ip}}{(V_x)_{im}} = \frac{dX_{ip}/dt_p}{dX_{im}/dt_m} \qquad (3)$$

Ako se označi odnos $t_p/t_m = R_t$, a imajući u vidu izraz (2), izraz (3) dobija novi oblik:

$$\frac{(V_x)_{ip}}{(V_x)_{im}} = \frac{R_l}{R_t} = R_v \qquad (4)$$

gde su:

R_t - koeficijent sličnosti vremena (razmera vremena).

R_v - koeficijent sličnosti brzine (razmera brzine).

Koeficijent sličnosti vremena (R_t) se obično zadaje u polaznim predpostavkama ili se odredjuje eksperimentalno.

Po analogiji može se napisati:

$$\frac{(V_y)_{ip}}{(V_y)_{im}} = \frac{(V_z)_{ip}}{(V_z)_{im}} = \frac{R_l}{R_t} = R_v \qquad (5)$$

Razmeru ubrzanja takodje je moguće izraziti kroz polazne koeficijente sličnosti:

$$R_a = \frac{a_{ip}(t_p)}{a_{im}(t_m)} = \frac{dV_{ip}/dt_p}{dV_{im}/dt_m} = \frac{R_v}{R_t} = \frac{R_l}{R_t^2} \qquad (6)$$

U opštem slučaju kinematička sličnost biće ispunjena ako je brzina kretanja komada ugradjenih u modelu proporcionalna brzini kretanja rude u prirodi. Brzina kretanja čestica pri istakanju u kinematskim modelima je $\sqrt{n}$ puta manja nego u prirodi (gde je n - razmera modeliranja) [3].

Medjutim, pri kinematičkoj sličnosti ne može se ništa reći o silama u elementima sistema. Da bi ispitivali karakteristike sile i energije procesa na modelima i primenili rezultate ispitivanja u prirodi, prema uslovima kinematičke sličnosti, neophodno je obezbediti materijalnu sličnost tačaka sistema [1]:

$$\frac{m_{ip}}{m_{im}} = R_m = const \qquad (7)$$

gde su:

m_{ip} - masa i-te tačke u prirodi,

m_{im} - masa analogne tačke na modelu,

R_m - koeficijent sličnosti mase (razmera mase).

U slučaju dinamičke sličnosti veza izmedju sile i rada u prirodi i na modelu izražava se kroz koeficijent sličnosti dužine, mase i vremena:

$$\frac{F_{ip}}{F_{im}} = \frac{m_{ip} \cdot a_{ip}}{m_{im} \cdot a_{im}} = = R_m \cdot R_a = \frac{R_m \cdot R_l}{R_t^2} = R_f \tag{8}$$

$$\frac{A_{ip}}{A_{im}} = \frac{F_{ip} \cdot L_{ip}}{F_{im} \cdot L_{im}} = = R_f \cdot R_l = \frac{R_m \cdot R_l^2}{R_t^2} = R_a \tag{9}$$

gde su:

F_{ip} - veličina sile koja deluje na i-tu tačku u prirodi,

F_{im} - veličina sile koja deluje na i-tu tačku modela,

R_f - koeficijent sličnosti sile (razmera sile),

A_{ip} - rad izvršen pri pomeranju i-te tačke u prirodi,

A_{im} - rad izvršen pri pomeranju analogne tačke modela,

R_a - koeficijent sličnosti rada (razmera rada).

Sveukupnost dinamičke i kinematičke sličnosti nazivamo mehaničkom sličnošću.

Iz ovog razloga, da bi se na modelu mogli proučiti procesi vezani za pojavu istakanja rude, deformacije i pritiska, neophodno je da budu zadovoljeni osnovni zahtevi mehaničke sličnosti. Za zadovoljenje ovih zahteva potrebno je utvrditi odgovarajuće kriterijume. U slučaju modeliranja u rudarstvu, od presudnog uticaja na ponašanje stenskog masiva oko podzemne prostorije su: zapreminska masa i unutrašnje sile (naponi) u masivu. U saglasnosti sa ovim uslovom utvrdjivanje kriterijuma sličnosti svodi se na primenu Njutnovog zakona sličnosti, za slučaj zajedničkog delovanja težinskih sila i unutrašnjih naprezanja, čiji je uticaj na ponašanje stenske mase oko podzemne prostorije i najdominantniji. Ova zavisnost u konačnom obliku, može se prikazati obrascem [11]:

$$\frac{N_p}{l_p \cdot \gamma_p} = \frac{N_m}{l_m \cdot \gamma_m} = K \tag{10}$$

gde su:

N_p - specifična sila u prirodi,

N_m- specifična sila na modelu,

γ_p - zapreminska masa u prirodi,

γ_m - zapreminska masa na modelu,

l_p - dimenzije u prirodi,

l_m - dimenzije na modelu i

K - neimenovani broj na osnovu koga se odredjuje kriterijum sličnosti.

Da bi mehanički procesi, koji su izazvani unutrašnjim naprezanjima i težinom materijala, u prirodi bili slični odgovarajućim procesima na modelu, neophodno je da kriterijum sličnosti (K) - odredjen na osnovu podataka dobijenih sa terena i podataka dobijenih sa modela, medjusobno bude jednak. Ukoliko je ovaj kriterijum zadovoljen tada su i uslovi sličnosti ispunjeni.

Kako predhodni obazac predstavlja osnovni obrazac mehaničke sličnosti kod modeliranja mehaničkih procesa u stenskoj masi, to radi jednostavnijeg (praktičnijeg) njegovog korišćenja, isti se može napisati u obliku [4]:

$$N_p = \frac{\gamma_p}{\gamma_m} \cdot \frac{l_p}{l_m} \cdot N_m \tag{11}$$

Ovaj obrazac predstavlja osnovnu vezu izmedju objekata u prirodi i fizičkih modela kod laboratorijskih istraživanja kinematike izvesnih procesa vezanih za otkopavanje i istraživanja deformaciono - naponskih promena oko podzemne prostorije.

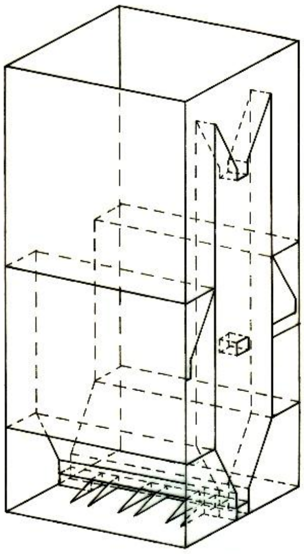
IZRADA MODELA

Istraživanje osnovnih parametara metode poluetažnog zarušavanja izvršeno je eksperimentalnim laboratorijskim metodama na modelima sličnosti od prirodnog materijala.

Predložena metoda razradjena je kroz varijantu sa normalnom širinom bloka i jednostranim bočnim utovarom.

Pri izboru razmere modeliranja nastojalo se da razmera bude što je moguće manja kako bi uslovi i rezultati ispitivanja bili što bliži prirodnim. Za predložene parametre otkopnih blokova i karakteristike rudnog ležišta i rude, usvojena je razmera 1:100.

Model je napravljen od providnog materijala pleksiglasa debljine 8 mm, u razmeri 1:100. Ovakvu razmeru uslovila je pre svega visina blokova od 80 m iz kojih se ruda jednovremeno istače. Model ima oblik prizme sa pravougaonom osnovom dimenzije 320 x 450 mm i visine 1100 mm (sl. 1.). Obzirom da je jedan od promenljivih parametara osno rastojanje izmedju bočnih utovarnih komora, dno bloka na modelu ima oblik tranšeje, a konstruisano je tako da omogućava promenu osnog rastojanja izmedju utovarnih komora. To je ostvareno na taj način što su napravljeni posebni izmenljivi segmenti, koji odgovaraju osnim rastojanjima izmedju bočnih utovarnih komora od 8, 10 i 12 m. Za ove vrednosti osnog rastojanja moćnost pojasa minirane rude iznosi 24, 30 i 36 m. Dimenzije utovarnih komora su 40 x 35 mm (u prirodnim uslovima 4 x 3,5 m). Ispitivanja na modelu vršena su za širinu bloka miniranja od 120, 140 i 160 mm (u prirodnim uslovima 12, 14 i 16 m). Promena širine bloka miniranja ostvarena je ugradnjom dodatnih ploča (sa obe strane) od pleksiglasa, koje se za model učvršćuju zavrtnjima.



Sl. 1. *Aksonometrijski izgled modela M-1*

Da bi se ostvario jasan kontakt izmedju rude i jalovine koja je okružuje, izradjen je šablon od lima, koji se nakon ugradnje rude i jalovine u model vadi iz modela ostavljajući jasan kontakt izmedju rude i jalovine. Aksonometrijski izgled modela M-1 prikazan je na slici br. 1. Da bi se simulirale neravnine na stranicama otkopnih blokova, odnosno trenje izmedju odminirane rude i stranica bokova otkopnih blokova, kao i u samom dnu otkopnog bloka, na stranicama modela (bočnim i čeonim) nalepljeno je brusno platno (šmirgl papir). Konstrukcija predložene metode poluetažnog prinudnog zarušavanja, može se videti sa čeone strane modela. Geometrija metode uradjena je u obliku okvira takodje od pleksiglasa.

Ovako izradjen model (za maksimalne parametre koji će se tokom istraživanja menjati) omogućavaju promenu svih konstruktivnih parametra metode otkopavanja (širinu bloka miniranja B, osno rastojanje izmedju bočnih utovarnih komora l, moćnost pojasa minirane rude m_1, visinu bloka iz koga se ruda istače H). Visina bloka iznosi 80 m. Ona odgovara visini jednog horizonta (etaže) i njena vrednost tokom istraživanja i promene ostalih parametara zadržana je kao konstantna veličina.

PRIPREMA RUDE I JALOVINE

Za ova istraživanja korišćena je ruda iz rudnog tela "Borska Reka". Uzorak rude pripremljen je od kompozita rude od uzoraka jezgara bušotina na dubinskom istražnom bušenju i od rude dobijene sa radilišta rudarsko - istražnih radova na koti -155 m u rudnom telu "Borska Reka". Ovako pripremljen uzorak rude sa zadovoljavajućom tačnošću može da predstavlja reprezentativni uzorak ležišta.

Granulometrijski sastav rude odredjen je na osnovu elemenata pukotinskog sistema u ležištu i stečenih iskustava na otkopavanju rude u borskoj jami. Takodje, na osnovu razradjenih faza tehnološkog procesa dobijanja rude uradjena je prognoza srednjeg prečnika minirane rude.

PROGNOZA GRANULACIJE MINI-RANE RUDE I IZBOR GRANULO-METRIJSKOG SASTAVA RUDE I JALOVINE

Pri primeni metoda otkopavanja sa zarušavanjem rude, značajnu ulogu ima njeno istakanje u procesu utovara, kada se, u zavisnosti od većeg broja faktora, uslovljava odgovarajuće iskorišćenje rude [5]. Jedan od značajnih faktora istakanja rude je i njena granulacija koja je uslovljena bušačko-minerskim radovima. Kod sitnije granulacije minirane rude dolazi do formiranja elipsoida istakanja sa manjom malom poluosom, odnosno većim ekscentricitetom [6]. Sa povećanjem učešća krupnijih klasa krupnoće povećava se širina elipsoida istakanja, a karakteristika elipsoida istakanja odnosno njegov ekscentricitet se smanjuje. Na bazi parametara bušenja i miniranja može se izvršiti prognoza granulacije minirane rude. U osnovi matematičkih modela za prognozu granulacije odminirane stenske mase su zakoni drobljenja koji predstavljaju zavisnost krupnoće od energije eksploziva uz dalje empirijsko odredjivanje i uvodjenje korekcija za najznačajnije faktore drobljenja.

Na osnovu polaznih podataka, a primenom prognoze po Mironovu [7] dobijaju se vrednosti srednjeg prečnika komada minirane rude u granicama 0,308 - 0,426 m. Dobijene vrednosti srednjeg prečnika predstavljaju važan parametar na osnovu koga će se izvršiti priprema rude i odrediti učešće pojedinih klasa krupnoće.

Veliki je značaj pravilne procene srednjeg prečnika minirane rude. Granulometrijski sastav u najvećoj meri odredjuje oblik figure istakanja [8]. Dobro poznavanje efekata bušačko-minerskih radova je važno kao osnova za primenu metoda kod kojih se ruda propušta kroz neki ispusni otvor. Od karakterisitke elipsoida istakanja (njegovog ekscentriciteta) zavisi količina dobijene, odnosno izgubljene rude, kao i količina elipsoidom zahvaćene jalovine [9].

Pripremljena količina rude i jalovine na osnovu dimenzija modela iznosi: Q_r = 75,00 kg; Q_j = 150,00 kg. Srednji prečnik komada može se sračunati po formuli:

$$d_{sr} = \frac{\sum d_i \cdot P_i}{100} \text{ mm} \qquad (12)$$

gde su:

$d_i = \frac{d_1 + d_2}{2}$, mm - srednji prečnik uske klase krupnoće,

P_i - procentualno učešće pojedinih klasa krupnoće.

Srednji prečnik komada za rudu iznosi:

$$d_{sr} = \frac{\sum d_i \cdot P_i}{100} = 0.385 \text{ m}$$

Srednji prečnik komada za jalovinu:

$$d_{sr} = \frac{\sum d_i \cdot P_i}{100} = 0.581 \text{ m}$$

Da bi se dobila željena granulacija mora se najpre obezbediti dovoljna količina rude i jalovine za svaku klasu krupnoće. Količina rude je odredjena za maksimalnu moćnost minirane rude, a količina jalovine za minimalnu moćnost minirane rude. Njihov zbir je veći od zapremine modela. Pripremljene količine potrebnih klasa krupnoće rude sipaju se na gomilu i metodom prstena i kupe vrši se njihovo mešanje. Da bi se dobio ravnomerni raspored svih klasa krupnoće mešanje se ponavlja tri puta. Ovakav postupak mešanja primenjuje se i za jalovinu. Pripremom rude dobijena je ruda sa srednjim prečnikom d_{sr} = 385 mm i jalovina sa d_{sr} = 581 mm. Na ovaj način dobijeni uzorak rude i jalovine spreman ja za ugradnju u model.

IZVODJENJE OGLEDA

Istakanje rude iz utovarnih komora vrši se lopaticama koje simuliraju utovarne kašike utovarno-transportnih mašina, napravljene takodje u usvojenoj razmeri 1:100. Utovar lopaticom vrši se naizmenično iz svakog hodnika u jednakim dozama. Ovako naizmeničan način utovara omogućava da krovinski kontakt izmedju minirane rude i obrušene jalovine ostane horizontalan. Na taj način sprečava se prevremeni silazak jalovine u ispusne otvore.

Racionalno izvodjenje laboratorijskih ispitivanja zahteva odredjivanje potrebnog broja ogleda. Da bi našli empirijske formule neke nezavisno promenljive veličine U_i od više n nezavisno promenljivih veličina X_i ako svaka od njih može da ima p vrednosti, ili varijanti, potrebno je izvršiti p^n različitih opažanja ogleda. Ako je pri tome potrebno i više puta ponoviti opažanje, ogled, na primer q puta onda će ukupan broj N opažanja biti [20]:

$$N = q \cdot p^n \tag{13}$$

gde su:

N - potreban broj ogleda,

p - vrednosti koje ima nezavisno promenljiva veličina,

n - nezavisno promenljive veličine (varijabile)

q - broj ponavljanja ogleda.

U konkretnom slučaju je usvojeno da se eksperimenti izvedu sa dve promenljive veličine (varijabile), od kojih svaka ima tri nivoa vrednosti, pa je puni plan faktorijelnog eksperimenta: 3 x 3^2 = 27. Obzirom da broj ogleda u eksperimentalnom planu nije veliki, a zbog pouzdanosti dobijenih rezultata usvojen je potpuni plan eksperimenata.

STALNI I PROMENLJIVI PARAMETRI PRI ISPITIVANJU

U toku izvodjenja ogleda operiše se sa sledećim usvojenim parametrima i veličinama:

- dimenzije podetažnih hodnika,
- dimenzije hodnika za bušenje,
- njihovo medjusobno rastojanje,
- dimenzije utovarnih komora,
- visina poluetaže (podetaže),
- granulometrijski sastav rude i jalovine,
- zapreminska masa rude i jalovine sa odgovarajućim faktorom rastresitosti,

- nagibni ugao ravni miniranja α,
- ugao krajnjih bušotina β.

Promenljive veličine su:

- Moćnost pojasa minirane rude, koja uslovljava broj utovarnih komora, odnosno njihovo medjusobno rastojanje ($m_1 = n\, W\, K_r$)
- Širina bloka miniranja (B).

Na osnovu izučavanja zakonitosti istakanja rude na modelu i na osnovu preliminarnih istraživanja parametra razmatrane metode uzete su tri vrednosti širine bloka miniranja: B = 12, 14, 16 m. Osna rastojanja izmedju bočnih utovarnih komora iznose: l = 8, 10, 12 m.

Izmenom promenljivih veličina moguće je utvrditi pri kojim se parametrima postiže najveće iskorišćenje i zadovoljavajuće osiromašenje rude.

ISTAKANJE RUDE

Pri interpretaciji rezultata formirani su tabelarni i grafički prikazi. U svakoj tabeli, za svaki izvedeni ogled, prikazan je bilans jednog ogleda iz kojeg se vidi, po dozama istakanja, količina istočene rudne mase (rovne rude) Q_{rm} , čiste rude $Q_{čr}$, i jalovine Q_j u kg. Takodje, u tabeli je data i njihova kumulativna vrednost, kao i iskorišćenje rude I_r (%) i osiromašenje rude O_r (%) u dozi i ukupno [11].

Na osnovu dobijene čiste rude $Q_{čr}$ (kg) iz svake doze deljenjem sa količinom ugradjene rude Q_r (kg) u modelu, za taj ogled dobija se iskorišćenje za svaku dozu tj.

$$I_r = \frac{Q_{čr}}{Q_r} \cdot 100 \text{ , \%} \qquad (14)$$

Ukupno iskorišćenje dobija se iz odnosa čiste rude $Q_{čr}$ i to kumulativno, prema ugradjenoj količini rude Q_r u modelu.

Osiromašenje za svaku dozu predstavlja odnos količine jalovine Q_j za svaku dozu posebno, prema ukupnoj količini rovne rude Q_{rm}, za tu dozu tj.

$$O_r = \frac{Q_j}{Q_{rm}} \cdot 100 \text{ , \%} \qquad (15)$$

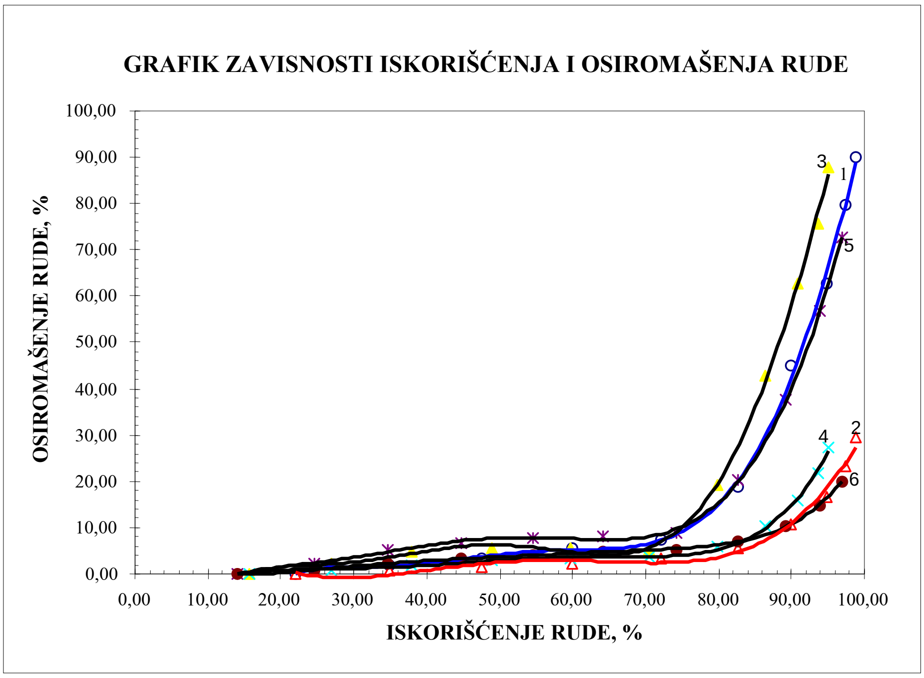
Ukupno osiromašenje dobija se iz odnosa količina jalovine Q_j kumulativno, prema količini rudne mase Q_{rm} kumulativno za tu dozu.

INTERPRETACIJA I ANALIZA DOBIJENIH REZULTATA

Na osnovu izmerenih količina čiste rude i jalovine pri istakanju (u dozama istakanja), za svaki ogled, izračunate su vrednosti iskorišćenja i osiromašenja rude u dozi i ukupno. Sračunate vrednosti su predstavljene grafički i dobijene su funkcionalne zavisnosti.

Na modelu M-1 u prvoj seriji ogleda uradjeno je 27 ogleda. Tri puta su širina bloka miniranja (B = 12, 14, 16 m) i osno rastojanje izmedju bočnih utovarnih komora (l = 8, 10, 12 m) menjale svoju vrednost. Za svaki izabrani par ovih parametara ogled je ponavljan po tri puta.

Najpovoljniji rezultati dobijaju se za širinu bloka B = 12 m i osno rastojanje između utovarnih komora l = 12 m. Pri ovim vrednostima parametara dobija se količina čiste rude od preko 22 %. Za ukupno iskoriščenje od 89,94 % dobija se osiromašenje od 10,68 % [11].



Sl. 2. *Uporedni rezultati istakanja rude iz modela M-1 u I seriji (tri utovarne komore) za odnose parametara H = 80 m, B = 12, 14 i 16 m i l = 12 m*

1, 2. B = 12m; l = 12m (1 u dozi; 2 ukupno)
3, 4. B = 14m; l = 12m (3 u dozi; 4 ukupno)
5, 6. B = 16m; l = 12m (5 u dozi; 6 ukupno)

ZAKLJUČAK

U ovom radu razmatrana je nova konstrukcija metode otkopavanja. Ona se može svrstati u grupu blokovskih metoda, a primenljiva je za masovno otkopavanje rude. Zbog specifičnosti konstrukcije metodi je dat naziv ”Metoda poluetažnog prinudnog zarušavanja”. Obaranje rude se vrši u blokovima velike visine, manje ili velike širine i u pojasima velike moćnosti. Konstrukcijom metode predvidjena je priprema dna bloka sa bočnim utovarnim komorama, što omogućuje istovremeno istakanje rude po celoj širini miniranog pojasa. Ovakvom pripremom omogućeno je protočno provetravanje otkopnih blokova.

Analizom rezultata i uporedjivanjem dobijenih vrednosti došlo se do najboljih odnosa parametara. Za varijantu metode poluetažnog prinudnog zarušavanja sa jednostranim bočnim utovarom, koja je ispitivana na modelu M - 1, optimalni parametri su:

- visina bloka H = 80 m,
- širina otkopnog bloka (širina pojasa miniranja) B = 12 m,
- osno rastojanje izmedju bočnih utovarnih komora l = 12 m.

Pri ovim vrednostima parametara dobija se najveća količina čiste rude od 22 % i iskorišćenje rude od 90 % uz minimalno osiromašenje od 10 %.

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DETERMINATION OF MINING METHOD DESIGN PARAMETERS ON PHYSICAL SIMILARITY MODELS**

Abstract

This paper is based on previous laboratory researches on physical similarity models. It is a synthesis of theoretical and practical researches. The analyzed parameters could not be discusses in the real - time underground conditions, but only in laboratory. As the result, the new mining method is designed, named "Semi – level caving with lateral loading". Researches included method design and optimization of method parameters.

Keywords*: underground mining, mining methods, physical similarity models*

INTRODUCTION

High - productive mining methods are necessary in modern mining, due to a trend of increasing the ore deposit depths and decreasing the ore grades. Increase of output lowers the excavation costs and enables the economically justified underground mining. Semi - level caving belongs to a group of high - productive mining methods.

High productivity of this method is enabled, primarily, through mechanization of each technological process. The main disadvantage of this group of mining methods is ore drawing, since complete ore recovery causes high ore dilution. Ore dilution increases the haulage costs, hoisting and mineral processing. It means that there is a limit in ore dilution, beyond which the mining costs would exceed ore value.

Determination of optimal mine design parameters enables optimal relation between ore recovery and ore dilution.

MODEL TESTING OF MINE DESIGN PARAMETERS

Model testing is a necessary step in scientific approach to solving different problems. Model testing enables evaluation of the results, obtained by theoretical researches. Also, model testing enables monitoring of processes which would demand a lot of time and means in case of in situ testing, while the quality of results is still satisfactory.

Analysis of ore drawing process includes the theoretical considerations, followed by practical testing, resulting in optimal values of ore dilution.

Application of mining methods, which include ore drawing, requires a good understanding of ore drawing process. This is where model testing is crucial, since it is impossible to monitor the ore drawing in the mine during the process. In order to gain the solid and acceptable results from model testing, it is necessary to follow the

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certain procedure and regularities. It means that there are principles based on similarity between natural occurrence and its model, which have to be obeyed in model testing.

By L. I. Sedov, the Russian author, modeling is replacement of studying natural occurrences by studying analog occurrence at a model with certain scale, usually in laboratory environment. Basic concept of modeling is to gain the results on character and parameters of natural occurrence [1]. Two occurrences are considered as similar if by input parameters of first occurrence it is possible to determine parameters of second occurrences using similarity scale.

Model testing needs to follow the certain principles. Principles are based on similarity in natural occurrences and models. Principle of similarity is fulfilled only if each parameter, that describes the system, can be gained by multiplication with constant multiplier, i.e. with scale.

In the case of linear similarity, scale is usually the constant, gained experimentally or by calculation. Most simple example is geometric similarity of two or more objects, where relation between scales which determine geometric form is constant [2]. Geometric or linear similarity means that models are created based on geometric scale. Geometric (linear) similarity means that model dimensions are created according to scale (for instance, blasting block dimensions in the mine and in model are in the same scale).

Geometric similarity is also applied to a grain size. At the certain grain size, material properties are changed. That is why there is a limit in grain size reduction scale, in order to preserve physical and mechanical properties of material [3]:

$$n_{dop} \prec \frac{\tau_n - f \cdot \sigma_n}{C_n} \tag{1}$$

where:

τ_n - main tangential stress of particles,

σ_n – main normal stress,

f – internal friction ratio,

C_n - adhesion.

If a geometric scale, used for model dimensions, can be also applied to a grain size, without changing its properties, than it can be concluded that modeling process is physically similar to the natural process [3].

Modeling of mechanic movements is based on kinematic similarity. Position of analyzed objects is determined by coordinates of its points, in function of time, or by kinematic law. In case of kinematic similarity, relation of coordinates between any of analog points in nature and model, for corresponding moments of time, is constant:

$$\frac{X_{ip}(tp)}{X_{im}(tm)} = \frac{Y_{ip}(tp)}{Y_{im}(tm)} = \frac{Z_{ip}(tp)}{Z_{im}(tm)} = R_l \tag{2}$$

where:

X_{ip} (tp), Y_{ip} (tp) i Z_{ip} (tp) – coordinates of i – point in nature in a function of time;

X_{im}(tm), Y_{im}(tm), Z_{im}(tm) – coordinates of analog point in model in a function of time;

t_p, t_m – time scale for nature and model;

R_l – length similarity coefficient (length scale).

Kinematic similarity enables determination of movement parameters (velocity, acceleration) in nature based on tests made on model. Velocity is determined through the following relation:

$$\frac{(V_x)_{ip}}{(V_x)_{im}} = \frac{dX_{ip}/dt_p}{dX_{im}/dt_m} \tag{3}$$

If the relation $t_p/t_m=R_t$ is added, and considering relation (2), relation (3) becomes:

$$\frac{(V_x)_{ip}}{(V_x)_{im}} = \frac{R_l}{R_t} = R_v \tag{4}$$

Where:

R_t – coefficient of similarity for time (time scale)

R_v – coefficient of similarity for velocity (velocity scale).

Time scale (R_t) is usually part of input presumptions or it is determined experimentally.

Using the analogy, the following is:

$$\frac{(V_y)_{ip}}{(V_y)_{im}} = \frac{(V_z)_{ip}}{(V_z)_{im}} = \frac{R_l}{R_t} = R_v \qquad (5)$$

Acceleration scale can also be calculated using the initial coefficients of similarity:

$$R_a = \frac{a_{ip}(t_p)}{a_{im}(t_m)} = \frac{dV_{ip}/dt_p}{dV_{im}/dt_m} = \frac{R_v}{R_t} = \frac{R_l}{R_t^2} \qquad (6)$$

In general, kinematic similarity will be fulfilled if the velocity of grains included in a model is proportional to velocity of ore in nature. Velocity of grains during drawing in a model testing is $\sqrt{n}$ times lower than velocity of ore in nature (n is modelling scale) [3].

However, kinematic similarity does not provide force and energy similarity. In order to enable the analyses of force and energy on models and apply the results in nature, it is necessary to provide the material similarity of system points [1]:

$$\frac{m_{ip}}{m_{im}} = R_m = const \qquad (7)$$

Where:

m_{ip} – mass of i – point in nature;

m_{im} – mass of analog point in model;

R_m – coefficient of similarity for mass (mass scale).

In case of dynamic similarity, relation between force and work in nature and in model is determined through length, mass and time scale:

$$\frac{F_{ip}}{F_{im}} = \frac{m_{ip} \cdot a_{ip}}{m_{im} \cdot a_{im}} = = R_m \cdot R_a = \frac{R_m \cdot R_l}{R_t^2} = R_f \qquad (8)$$

$$\frac{A_{ip}}{A_{im}} = \frac{F_{ip} \cdot L_{ip}}{F_{im} \cdot L_{im}} = = R_f \cdot R_l = \frac{R_m \cdot R_l^2}{R_t^2} = R_a \qquad (9)$$

Where:

F_{ip} - force acting on i – point in nature;

F_{im} – force acting on i – point in model;

R_f - force scale;

A_{ip} – work done moving i – point in nature;

A_{im} – work done moving analog point in model;

R_a – work scale.

Totality of dynamic and kinematic similarity is called mechanical similarity.

So, for studying the ore drawing, deformations and pressure in models, it is necessary to match the requirements of mechanical similarity. This means that it is necessary to determine certain criteria. In modeling of mining, most important influence factors to stability of underground opening are density and internal forces (stresses) in the ground. Defining the similarity criteria is based on the Newton law of similarity, for the case of joint action of gravity and stress, as the most dominant influence to surrounding rock. Final form of this relation is:

$$\frac{N_p}{l_p \cdot \gamma_p} = \frac{N_m}{l_m \cdot \gamma_m} = K \qquad (10)$$

Where:

N_p – specific force in nature;

N_m- specific force in model;

γ_p – density in nature;

γ_m – density in model;

l_p – dimensions in nature;
l_m – dimensions in model;
K – similarity criterion number.

In order to provide the similarity between mechanical processes caused by stress and gravity in nature and corresponding processes in model, similarity criterion K determined based on field data has to be equal to similarity criterion gained from model data. In that case conditions of similarity are fulfilled.

Previous formula is the basic formula of mechanical similarity in modeling of rock mass mechanical processes, but in order to simplify its application it could also be used in the following form:

$$N_p = \frac{\gamma_p}{\gamma_m} \cdot \frac{l_p}{l_m} \cdot N_m \tag{11}$$

This formula is a basic relation between objects in nature and physical models in laboratory testing of kinematics in the underground mining. It can be also used in research the stress and deformation alterations around underground objects.

CREATION OF MODEL

Research of main design parameters for semi – level caving was carried out by laboratory experimental methods on models. Variant of mining method chosen for analysis has normal block width and single – sided lateral loading.

Criterion for selection of scale was that it should be as low as possible, in order to make model testing closer to natural conditions. For this type of mine design modeling and rock and ore properties, selected scale was 1:100.

Model is made of transparent material (Plexiglas), 8 mm thick, in 1:100 scale. Such scale is mainly defined due to block height, which is 80 m in the field. Model has a shape of prism, with dimensions 320 x 450 x 1100 mm (Figure 1). Since spacing between loading drifts should be changeable, block has trenches in its bottom, and it is created in a way that enables variation of spacing between loading drifts. This variation was enabled by exchangeable sets, because each of them had different spacing, thus matching requirements for variation between 8 m, 10 m and 12 m spacing. With variation of loading drifts spacing, thickness of blasted ore zone also varies, between 24 m, 30 m and 36 m. Loading drift is 40 x 35 mm in model, or 4 x 3.5 m in nature. Blasting zone was 120, 140 and 160 mm wide (12, 14 and 16 m in nature). Variation of model width was done using additional Plexiglas panels on both sides of model.

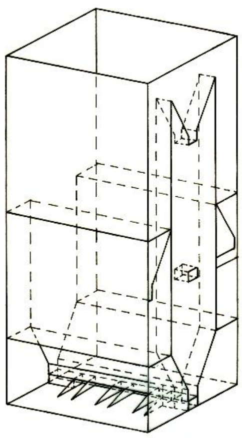

Figure 1 *Model M-1*

In order to provide clear contact between ore and waste, thin metal sheet is inserted during model loading. After model is loaded by ore and waste, metal sheet is removed, thus leaving a clear contact between ore and waste. Axonometric layout of model M-1 is shown in Figure 1.

In order to simulate rough surfaces on block walls and block bottom, i.e. friction between drawing ore and block walls, a sandpaper was applied to model walls that are in contact with ore.

Geometric design of method is visible from model face side. Frames representing method design geometry are also made of Plexiglas.

Such designed model enables a variation of each design parameter through testing process: blasting block width (B), spacing between lateral loading drifts (l), blasted ore thickness (m_1) and block height (H). Block height is 80 m. It matches the height of a level, and it was kept as a constant during the test.

PREPARATION OF ORE AND WASTE

Ore from the Jama Bor underground mine, ore body Borska Reka, is used for model testing. Ore used for model testing is a composite made of ore from core drilling and exploration works at K-155m level in the ore body Borska Reka.

Grain size distribution is determined based on elements of fracture system in the deposit and previous experiences in the Jama Bor. Also, the average grain size is predicted for this technological process.

PREDICTION OF GRAIN SIZE DISTRIBUTION FOR BLASTED ORE AND SELECTION OF GRAIN SIZE FOR ORE AND WASTE

For application the caving methods, one of the key factors is ore drawing, because it is strongly related to ore recovery [5]. Another important factor in ore drawing process is ore grain size distribution, dependent on drilling and blasting technology. If blasted ore has smaller size grains, the drawing ellipsoid has shorter short semi – axis and higher eccentricity. With the increase of larger grain size share in grain distribution, the drawing ellipsoid becomes wider, and its eccentricity decreases.

Grain size distribution can be predicted based on drilling and blasting parameters. Laws of ore crushing are the base for mathematical prediction models for grain size distribution. Size distribution of crushed ore depends on energy of explosive, while other factors of crushing are determined empirically.

Based on the input data for this model, using prediction by Mironov [7], the predicted average grain size should be between 0.308 m and 0.426 m. Value of the average diameter is important parameter, used as a base for preparation of ore and share of specific grain sizes.

Correct prediction of average grain diameter is very important. Grain size distribution is most important influence factor to drawing ellipsoid shape [8]. Good knowledge on effects of drilling and blasting is important for correct application of mining methods which include ore drawing process. Parameters of drawing ellipsoid have a huge impact do ore recovery and ore loss, as well as ore dilution [9].

For this model, a total of 75 kg of ore and 150 kg of waste have been prepared. Average grain diameter can be calculated by following formula:

$$d_{sr} = \frac{\sum d_i \cdot P_i}{100}\text{, mm} \qquad (12)$$

Where:

$d_i = \frac{d_1 + d_2}{2}$, mm – average diameter of narrow grain size class;

P_i – percentage of specific grain size classes.

For ore, the average grain diameter is:

$$d_{sr} = \frac{\sum d_i \cdot P_i}{100} = 0.385 \text{ m}$$

For waste, the average grain diameter is:

$$d_{sr} = \frac{\sum d_i \cdot P_i}{100} = 0.581 \text{ m}$$

In order to achieve wanted grain size distribution, it is necessary to provide a sufficient quantity of ore and waste for each grain size class.

Quantity of ore is determined for maximum thickness of blasted ore, while quantity of waste is determined according to minimum thickness of blasted ore. It means that sum of ore and waste has higher volume than the model. Prepared ore is poured on a bunch and then it is mixed, using the ring or cone mixing method. In order to gain equal distribution of each class, mixing is repeated for three times. Same procedure is applied for waste, too.

Ore prepared for model testing has the average diameter of d_{sr} = 385 mm, while waste is d_{sr} = 581 mm. This way ore and waste is ready to be poured into model.

MODEL TESTING

Ore drawing from loading drifts is performed using small shovels, thus simulating LHD loading, also regarding 1:100 scale. Loading is performed in each loading drift successively. Such successive loading enables draw control and preserves horizontal roof contact between ore and waste. This is important because such draw control prevents premature occurrence of waste in loading drifts.

Rational model testing requires determination of necessary number of tests. In order to establish empiric formula for independent variable (U_i) from several (n) independent variables (X_i), if each of them may have number of values (p), it is necessary to perform p^n tests. If the process needs to be repeated for q times, total number of tests is:

$$N = q \cdot p^n \qquad (13)$$

Where:

N – necessary number of tests;
p – values of independent variable;
n – variables;
q – number of process repetition.

For our case, it was determined that tests would be performed with two variables, with each of them having three levels of values, which means that full test plan will be: $3 \times 3^2 = 27$. Since the full test plan has reasonable number of tests, this plan is considered as suitable in this case.

CONSTANT AND VARIABLE PARAMETERS

During the testing, following parameters were considered as constant:

- Dimensions of sublevel drifts;
- Dimensions of drilling drifts;
- Drift spacing;
- Dimensions of loading drifts;
- Semi – level (sublevel) height;
- Grain size distribution of ore and waste;
- Density of ore and waste, along with looseness factor;
- Angle of blasting plane (α);
- Angle of end blastholes (β).

Variable parameters are following:

- Thickness of blasted ore zone, related to number of loading drifts and their spacing (m_1 = n W K_r);
- Blasting block width (B).

Based on properties of a model and preliminary research on method parameters, blasting block widths are respectively: B = 12, 14, 16 m. Spacing between loading drifts is l = 8, 10, 12 m.

By varying values of variable parameters, it is possible to determine optimal parameters for best ore recovery and satisfying ore dilution.

ORE DRAWING

Tables and graphs are used for the interpretation of results. Each test has its own table, with ore drawing dosage, drawn bulk ore (Q_{rm}), clean ore (Q_{cr}) and waste (Q_j), in kilograms. Also, tables provide cumulative values, ore recovery (I_r, %) and ore dilution (O_r), in a dosage and in total [11].

Ore recovery for each dosage is calculated by dividing of clean ore with total ore in model (Q_r, kg):

$$I_r = \frac{Q_{\check{c}r}}{Q_r} \cdot 100 \text{ , \%} \qquad (14)$$

Total ore recovery is gained as division of cumulative clean ore and total ore in model.

Ore dilution for each dosage is a relation between waste in each dosage and total of bulk ore for that dosage (Q_{rm}):

$$O_r = \frac{Q_j}{Q_{rm}} \cdot 100 \text{ , \%} \qquad (15)$$

Total dilution is calculated from cumulative waste and cumulative bulk ore for each dosage.

ANALYSIS OF THE RESULTS

Ore recovery and ore dilution were calculated based on measured clean ore and waste that were drawn in each test, for a single dosage and in total. Calculated values are presented in a graph and functional relations were established.

Total of 27 tests were performed on M-1 model. Block width varied three times (B = 12, 14, 16 m), as well as loading drifts spacing (l = 8, 10, 12 m). For each pair of values, the test was repeated three times.

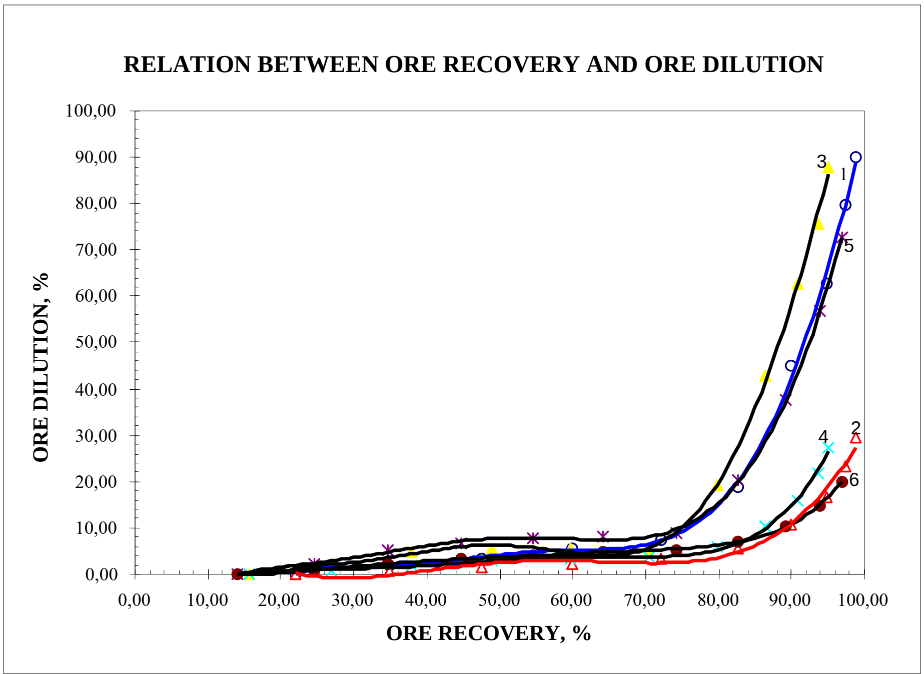

Figure 2 *Results of ore drawing from M-1 model in first series of tests (with three loading drifts), for H = 80 m, B = 12, 14 and 16 m and l = 12 m;*
Curves 1, 2: B = 12 m; l = 12 m (curve 1 – in dosage, curve 2 – total);
Curves 3, 4: B = 14 m; l = 12 m (curve 3 – in dosage, curve 4 – total);
Curves 5, 6: B = 16 m; l = 12 m (curve 5 – in dosage, curve 6 – total).

As it is seen from the graph, in first series, the best results are provided with l = 12 m spacing between loading drifts and B = 12 m block width. In this case share of clean ore is 22%. For total ore recovery of 89.94%, ore dilution is 10.68% [11].

CONCLUSION

New mining method was analyzed in this paper. This method belongs to a group of block methods and it is suitable for high capacity mining.

Due to its properties, the method is called "Semi - level caving". Ore is excavated in blocks width significant height, smaller or larger width and in thick blasting zones. Mine design includes block development with lateral loading drifts, thus providing simultaneous ore drawing from entire blasted zone. Such block development also provides good ventilation and air flow in blocks.

Analyses of the results and comparison of gained values provided optimal mine design parameters. Optimal parameters for Semi – level caving with single sided lateral loading, tested in model M-1, are as follows:

- Block height, H = 80 m;
- Block width (blasted zone width), B = 12 m;
- Spacing between loading drifts, l = 12 m.

For these parameters, share of clean ore is 22%, ore recovery is 90% with minimum ore dilution of 10%.

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MODEL UPRAVLJANJA INVESTICIONIM PROJEKTIMA PRIMJENOM METODE OSTVARENE VRIJEDNOSTI

Izvod

Metoda ostvarene vrijednosti (engl. Earned Value Method) je noviji alat projektnog menadžmenta, koji koristi informacije o troškovima, vremenskom rasporedu i radnom učinku kako bi se utvrdio trenutni status projekta. Ona omogućava menadžeru da predvidi konačan ishod projekta na osnovu aktuelnih poznatih pojedinačnih vrijednosti i predstavlja metod za mjerenje napretka projekta ili efikasnosti performansi. Rad opisuje osnovne principe ove metode, sa osnovnim ciljem da se upozna šira stručna javnosti o mogućnosti primjene ovog korisnog alata za upravljanje rudarskim projektima, posebno sa aspekta mogućnost njene primjene kod upravljanja velikim investicionim projektima poput projekata u površinskoj eksploataciji ležišta mineralnih sirovina.

Ključne riječi: *Metoda ostvarene vrijednosti, projektni menadžment, perfomanse projekta*

UVOD

Nauka vezana za upravljanje projektima razvijala se tokom 19. i 20. vijeka, u skladu sa talasom inovacija u društvu, koje su prethodile ili su se paralelno razvijale sa industrijskim napretkom tako da moderno upravljanje projektima koristi mnoge ideje i tehnike koje su razvijene kroz opšte upravljačke koncepte i iskustva. [1] Metoda ostvarene vrijednosti (MOV), za analizu projektnog menadžmenta, svoj osnovni oblik poprima pojavom industrijskih inženjera, krajem 1800-te godine. [2] Institut za projektni menadžment objavljuje knjigu “Vodič kroz projektni menadžment” (engl. A Guide to the Project Management Body of Knowledge, PMBOK Guide, Project Management, 2000) sa kojom prikazuju pojednostavljenu MOV terminologiju i metodologiju. [3]

METODA OSTVARENE VREDNOSTI - MOV

Za kvalitetno upravljanje projektima potrebna su znanja koja se mogu podijeliti u devet područja upravljanja projektom, a to su upravljanje integracijom projekta, dužinom, vremenom, troškovima, kvalitetom, ljudskim resursima, komunikacijama, rizikom i nabavkom. Baš Metoda ostvarene vrijednosti pokriva područje znanja o upravljanju troškovima projekta,

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sadrži procese koji su uključeni u procjenjivanje, budžetiranje i kontrolisanje troškova, na način da se projekat završi u okviru budžeta i u predviđenom vremenu. [3] Ovo isto važi o za procese vezane za kontrolu troškova na projektu. Kao najbolja tehnika kontrole troškova u praksi se pokazala metoda pod nazivom Metoda ostvarene vrednosti (eng. Earned Value Method - EVM). Metoda ostvarene vrijednosti je korisan alat za predviđanje ishoda projekta u smislu vremenskog izvršenja, troškovnog izvršenja i očekivanih finalnih troškova, poznata je zbog mjerenja učinka, upravljanja prema ciljevima, obračunu troškova obavljenog posla i sistema za kontrolu planiranih troškova.

Osnovne postavke implementacije MOV su:

1. Projektni plan, koji identifikuje rad koji se treba ostvariti
2. Vrednovanje planiranih radova, pod nazivom Planirana vrijednost (engl. Planned Value - PV) ili Planirani troškovi planiranog rada (engl. Budgeted Cost of Work Scheduled - BCWS) i
3. Predefinisana pravila „zarađivanja“ (koja se nazivaju metrike) da bi se mogao izmjeriti ostvareni rad, pod nazivom Ostvarena vrednost (engl. Earned Value - EV) ili Planirani troškovi izvršenog rada (engl. Budgetetd Cost of Work Performed - BCWP).

Implementacija MOV za velike ili složene projekte uključuje mnogo više funkcija, kao što su pokazatelji i prognoze troškova izvođenja (preko i ispod budžeta) i raspored izvršavanja (da li kasne ili se izvršavaju prije utvrđenog roka). Kako god bilo, većina osnovnih zahtjeva za jedan MOV sistem je da izmjeri napredak koristeći Planiranu vrednost i Ostvarenu vrednost.

Pratiti projekat bez metode ostvarene vrijednosti u današnje vrijeme je vrlo teško, jer često dolazi do prekoračenja budžeta ili kašnjenja projekta, i ne pruža zaključke o trenutnoj realizaciji projekta. Potrebno je koristiti metod koji može da izmjeri objektivno i kvantitativno tehničke performanse, a to je ono što se dobija Metodom Ostvarene Vrijednosti.

Tokom planiranja MOV zahteva postavljanje mera performansi osnovnog plana. Projektni rad treba da se dekom-ponuje (koristeći engl. Work Brakedown Structure - WBS) u zadatke koji će se izvršavati i biti laki za rukovanje, što se često naziva i centar kontrole. Nevažno je da li će individua ili tim morati da upravljaju pojedinačnim radim elementom, čitav posao se mora dodijeliti radnoj snazi na izvršenje koristeći organizaciono rasčlanjivanje (engl. Organizational Brakedown Structure - OBS). Kada se projekat treba vremenski i resursno rasčlaniti u radni plan, obim, vremenski okvir i troškove treba integrisati i snimiti (vrijeme - faza - budžet) kao osnovni plan za mjerenje performansi (engl. Performance measurement baseline - PMB). Time dobijamo hipotetički radni plan, tj gantogram kome se dodaju MOV tehnike.

OPIS I TERMINOLOGIJA METODE OSTVARENE VRIJEDNOSTI

Tri veličine čine osnovu za mjerenje troškovnih performansi Metodom ostvarene vrijednosti. Osnovni princip MOV je isti nezavisno od toga kog je tipa i veličine projekat na koji se ona primjenjuje. Slijedi prikaz vrijednosti potrebnih da bi se primijenila MOV:

1. *Planirana Vrijednosti (engl. Planed Value - PV), ili* Planirani troškovi planiranog rada (engl. Budgeted Cost of Work Scheduled-BCWS), opisuje koliko je rada potrebno u bilo kom momentu u vremenu projekta. To je numerička refleksija planiranog rada koji je određen za planirano vrijeme, i ona

je određena planom (poznatim kao engl. PMB - Performance Measurement Baseline) na osnovu koga se mjeri stvarni napredak projekta. Jednom utvrđen plan se može mijenjati samo da bi se izrazile troškovne i vremenske promjene koje (iskazuju) prate promjene obima posla.

2. *Ostvarena vrijednosti (engl. Earned Value - EV)* predstavlja trenutno stanje progresa u određenom vremenu (presjeku stanja) progresa. Prikazuje količinu rada koji je stvarno izvršen do određenog datuma (u određenom vremenskom periodu), izražen kao planirana vrijednost rada. Ovaj parametar je u literaturi poznat i kao Planiranu troškovi izvršenog rada (engl. Budgeted Cost of Work Performed-BCWP).
3. *Stvarni troškovi (engl. Actual Value - AC)*, poznat je još i kao Stvarni troškovi izvršenog rada (engl. Actual Cost of Work Performed - ACWP), predstavlja nivo utrošenih resursa da bi se izveo stvarno izvršen rad do nekog datuma (u određenom periodu). [2]

Ove tri veličine mogu odrediti ukupan budžet projekta kao i odrediti raspored i troškove performansi i procijeniti troškove do završetka projekta. Dodatni uslovi su definisani za snimanje troška i rasporeda performansi i programskog budžeta:

- Osnova za mjerenje performansi, (engl. Performance Measurement Baseline - PMB) - zbir svih planiranih troškova planiranog rada za svaku fazu za svaki vremenski period, izračunat za ukupno trajanje projekta . PMB formira vremenski fazno-budžetski plan na osnovu koga se mjeri učinak projekta.
- Planirani troškovi projekta (engl. Budget At Completion - BAC) su suma svih budžeta dodijeljenih projektu. U dodatku PMB, postoji iznos upravljačkih rezervi, koje su dio ukupnog budžeta projekta i koji se ne dodeljuje određenim fazama i čuva se za kontrolu upravljačkog procesa.

ANALIZA PERFORMANSI I PROGNOZE

Kao što je već napomenuto vrijednosti kao što su PV, EV, AC mogu biti iskorišćene za analizu trenutnog statusa projekta i kako bi se predvidjela moguća budućnost projekta. MOV sagledava performanse projekta za tekući period i kumulativne performanse do određenog datuma. Ovdje ćemo se upoznati sa četvrtim glavnim podatkom, Planirani budžet projekta (engl. Budget at Completion-BAC) koji predstavlja završni podatak plana za mjerenje performansi, odnosno predstavlja ukupnu planiranu vrijednost projekta. Ovaj rad ima za cilj da predstavi i opiše sledeće:

- VARIJANSE: Vremenska (SV) i Troškovna varijansa (CV), Varijansa za cjelokupan projekat (VAC)
- INDEKSE: Troškovni (CPI) i Vremenski (SPI) indeks efikasnosti i Indeks realizacije do završetka (TCPI)
- PREDSKAZIVAČE: Realna vremenska procjena radova na projektu (EACt), Procenjeni budžet projekta (EAC) i Procjena preostalih troškova projekta (ETC)

Tabela 1. *EVM i osnovna pitanja za projektno upravljanje[4]*

Pitanja projektnog menadžmenta	**MOV mere performansi**	**Objašnjenje**
Kako koristimo projektno vrijeme?	**Vremenska analiza i predviđanje**	
Da li smo ispred ili iza rasporeda?	Vremenska varijansa (SV)	Negativno- radovi kasne Pozitivno- radovi se izvršavaju prije utvrđenog roka
Koliko efikasno koristimo vrijeme?	Vremenski indeks efikasnosti (SPI)	Efikasnost izvedenog rada %
Kada ćemo najverovatnije završiti projekat?	Realna vremenska procjena radova na projektu (EACt)	Kada ce se projekat završiti ako se sadašnji trend nastavi
Kako trošimo budžet projekta?	**Troškovna analiza i predviđanje**	
Da li smo izvan ili u okviru budžeta?	Troškovna varijansa (CV)	Negativno- prekoračenje budžeta Pozitivno- utrošeno je manje od planiranog budžeta
Koliko efikasno koristimo naše resurse?	Troškovni indeks efikasnosti (CPI)	Za svaku uloženu n.j, dobija se _ n.j.
Koliko efikasno moramo da koristimo naše preostale resurse?	Indeks realizacije do završetka (TCPI)	Do te mjere se mora unaprediti BAC da bi se plan ostvario
Koliko će projekat najverovatnije da košta?	Procenjeni budžet projekta (EAC)	Finalni budžet projekta ukoliko se trenutni trendovi nastave
Da li ćemo biti ispod ili izvan budžeta?	Varijansa za cjelokupan projekat (VAC)	Koliko ce se prekoračiti budžet na kraju projekta?
Koliko će preostali rad da košta?	Procena preostalih troškova projekta (ETC)	Koliko ce koštati preostali rad na projektu?

Predviđanje uključuje pravljenje procjena ili predskazivanja okolnosti u budućnosti projekta, koje su zasnovane na informacijama i saznanjima dostupnim za vrijeme predviđanja. Prognoze su proizvedene, ažurirane i ponovno izdate na osnovu informacija radnih performansi koje su dobijene , bilo da je u pitanju projekat koji je izvršen ili se nalazi u procesu. Informacije o performansama rada govore o prošlim performansama i bilo kojoj informaciji koja može uticati na projekat u budućnosti, npr. EAC i ETC.

Vremenska analiza i predviđanje

Vremenska varijansa (engl. Schedule Variance - SV), izračunava se oduzimanjem Planirane vrednosti (PV) od Ostvarene vrednosti (EV). Pozitivna vrijednost ovog parametra ukazuje na povoljne uslove, dok negativna ukazuje na napovoljne.

$SV = EV - PV \qquad SV\% = SV/PV$

Vremenski indeks efikasnosti (engl. Schedule Performance Index - SPI) prikazuje koliko efikasno projektni tim koristi svoje vrijeme. Računa se tako što se EV podijeli sa PV:

$SPI = EV / PV$

Realna vremenska procjena radova na projektu (engl. Time Estimate at Completion - EACt), koristeći indeks SPI i prosječnu PV po jedinici vremena, projektni tim može da generiše grubu procjenu kada će projekat biti završen, ako se trenutni trend nastavi, poredeći ga sa planiranim pretpostavljenim krajem.

EACt = (BAC / SPI) / (BAC / mjeseci)

Važno je napomenuti da ovaj metod generiše potpuno grube procjene i uvijek se mora porediti sa statusnim prikazom po metodi vremensko zasnovanog rasporeda kao što je metod kritičnog puta. Može da se desi da analiza ostvarene vrijednosti pokaže da nema vremenske varijanse ali da se projekat ipak nalazi izvan rasporeda, kao na primjer kada se izvrše zadaci koji su planirani u budućnosti prije zadataka koji se nalaze na kritičnom putu. [5,6,7]

Troškovna analiza i predviđanje

Troškovna varijansa (engl. Cost Variance - CV) pokazuje da li je projekat u okviru ili izvan budžeta. Ova mjera se dobija tako što se Stvarna vrijednost oduzme od Očekivane vrijednosti:

CV = EV - AC CV%=CV / EV

Troškovni indeks efikasnosti (engl. Cost Performance Index - CPI). Ostvarena vrijednost i Stvarna vrijednost mogu biti iskorišćene da bi se izračunao CPI, koji je najefikasniji indikator kumulativne troškovne efikasnosti projekta. CPI mjeri koliko efikasno tim koristi svoje resurse:

CPI = EV / AC

Kada je kumulativni CPI u prihvatljivom okviru, ali ima opadajući trend u različitim mjernim periodima, već tada treba da daje naznake za brigu i preispitivanje silaznog trenda.

Indeks realizacije do završetka (engl. To-Compete Performance Index-TCPI). Još jedan veoma koristan indeks TCPI, koji pomaže timu da odredi efikasnost koja mora biti postignuta za preostali dio rada projekta da bi došao do kraja, kao što su planirani troškovi projekta (BAC) ili revidiranje procijenjenog budžeta projekta (EAC). TCPI za dostizanje BAC se izražava tako što se preostali rad dijeli sa preostalim budžetom.

TCPI = (BAC - EV) / (BAC - AC)

Procijenjeni budžet projekta (engl. Estimate at Completion - EAC), ovaj pokazatelj za projektni tim predstavlja finalni trošak projekta (budžet) ukoliko se trenutni trendovi nastave. Jedan opšti metod kalkulacije EAC je da se BAC podeli sa kumulativnom vrijednošću CPI:

EAC = BAC / CPI

Varijansa za cjelokupan projekat (engl. Variance at Completion - VAC). Kada posedujemo podatak o EAC sada možemo izračunati VAC, koji pokazuje da li će se projekat završiti u okviru ili izvan budžeta, tako sto ćemo BAC oduzeti od EAC:

VAC = BAC - EAC

VAC% = VAC / BAC

Procena preostalih troškova projekta (engl. Estimate To Completion - ETC). Postoje dva načina da se izračuna vrednost ETC, koja prikazuje koliko će koštati preostali rad. Jedan način je Upravljački ETC koji se razvija od strane radnika i menadžera, baziran na analizama preostalog rada. Upravljački ETC se dodaje na AC da bi se dobio Upravljački EAC ukupnih troškova na kraju projekta.

EAC = AC + ETC

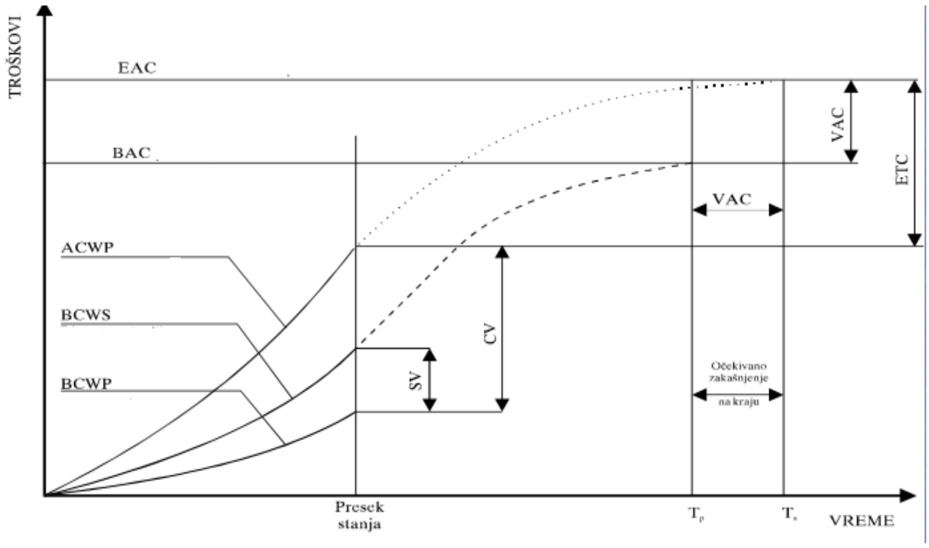
Da bi došle do ovih procena, organizacije mogu da koriste procenat ETC zasnovan na efikasnosti do određenog datuma koji se meri pomoću CPI:

ETC = (BAC - EV) / CPI

EAC = AC + ETC

EAC=AC+[(BAC–EV)/CPI]=BAC/CPI

Prekoračenja troškova mogu biti unapređeni, ali obično se ne mogu u potpunosti oporaviti. EVM pomaže efikasnosti i efektivnosti projektnog upravljanja, omogućava menadžerima i drugima da se fokusiraju na izvršenje projekta i da aktiviraju kontrolne akcije samo kada i gde je to potrebno. Koristeći ovu metodu organizacije mogu da utvrde prihvatljive nivoe performansi za projekat i njegove radne zadatke. Postoji mogućnost da se dozvoli kretanje varijanse od ±10% od planiranih, i na osnovu ovoga kada dođe do odstupanja neće se preduzimati nikakve akcije sve dok ovo odstupanje ne pređe dozvoljene granice. Kada varijanse budu negativne to će predstavljati problem, a kada su pozitivne to znači da postoji prilika za projekat. [5,6,7]. Na slici ispod dat je grafički prikaz veličina MOV za mjerenje perfomansi na projektu.



Sl. 1. *Prikaz veličina Metode ostvarene vrednosti*

Primjer

Nakon 12 mjeseci od početka realizacije projekta otvaranja površinskog kopa uglja, projektni tim odlučuje da razmotri tok realizacije projekta čija je ukupna vrednosti budžeta 100 miliona € (BAC) i planiranog trajanja 36 mjeseci. Od projektnog tima se očekuje da napravi prognozu (trend) kretanja troškova do kraja projekta, procjenu ukupnih troškova do kraja projekta, procjenu ukupnih troškova (EAC) i koeficijent porasta ukupnih troškova. U narednoj tabeli dat je pojednostavljeni prikaz: [8]

Tabela 2. *Prikaz vrijednosti na presječnom datumu*

Aktivnosti	Datum ispostavljanja situacija (Presječni datum)	Planska cijena za planirani obim realizacije do presječnog datuma	Ostvarena realizacija (%)	Stvarni troškovi realizacije do presječnog datuma	Planska cijena za ostvareni obim realizacije do presječnog datuma
		PV		AC	EV
A	nakon 6 mj.	4 mil.€	100%	5 mil. €	4 mil. €
B	nakon 9 mj.	6 mil. €	100%	8 mil. €	6 mil. €
C	nakon 12 mj.	10 mil. €	80%	12 mil. €	8 mil. €
∑(A+B+C)		20 mil. €		25 mil. €	18 mil. €

SV = EV – PV = 18 – 20 = - 2 mil. €

SV% = SV / PV = -10%

- 10% projekta se nalazi iza planiranog vremenskog rasporeda, tačnije 10% planiranog rada nije izvršeno.

SPI = EV / PV = 18mil.€ / 20mil.€ = 0.90

- Od 8 planiranih radnih sati u danu, samo 7 sati i 20 minuta se izvodi rad na projektu, tačnije posao se obavlja sa efikasnošću od 90%.

EACt = (BAC/SPI) / (BAC / mjeseci)=
=(100 mil.€/0.90)/(100 mil.€/36) =
= 3.999

- Ukoliko je planirano da ce projekat trajati 36 meseci, projektni menadžer zna da ako se nastavi sadašnji trend kretanja, projekat ce trajati 3.9 meseci duže od planiranog.

CV = EV – AC = 18 – 25 = - 7 mil.€

CV% = CV / EV= -28%

- Za dosadašnji izvršeni rad, 28% troškova projekta nalazi se izvan budžeta.

CPI = EV/AC=18 mil.€/25 mil.€=0.72

- Na svaki uložen 1€ u projekat, vraća se 72 centa.

TCPI = (BAC - EV) / (BAC - AC) =
= 82 mil.€ / 75 mil.€= 1.093

- Da bi se dostiglo planirano BAC, performanse za preostali rad se moraju sa CPI (0.72) unaprediti do TCPI (1.093).

EAC = BAC / CPI = 100 mil. €/0.72=
= 138.89 mil. €

- Trenutna procjena ukupnog koštanja projekta je 138.89 mil. €.

VAC = BAC – EAC =
100 mil.€–138.89 mil.€ = -38.89 mil.€.

- Ukoliko se nastavi sadašnji trend, projekat ce koštati dodatnih 38.89 mil. €.

ETC = EAC – AC=
= 138.89 mil.€ – 25 mil.€ =
= 113.89 mil.€

- Procjenjuje se da će preostali rad koštati 113,89 mil €.

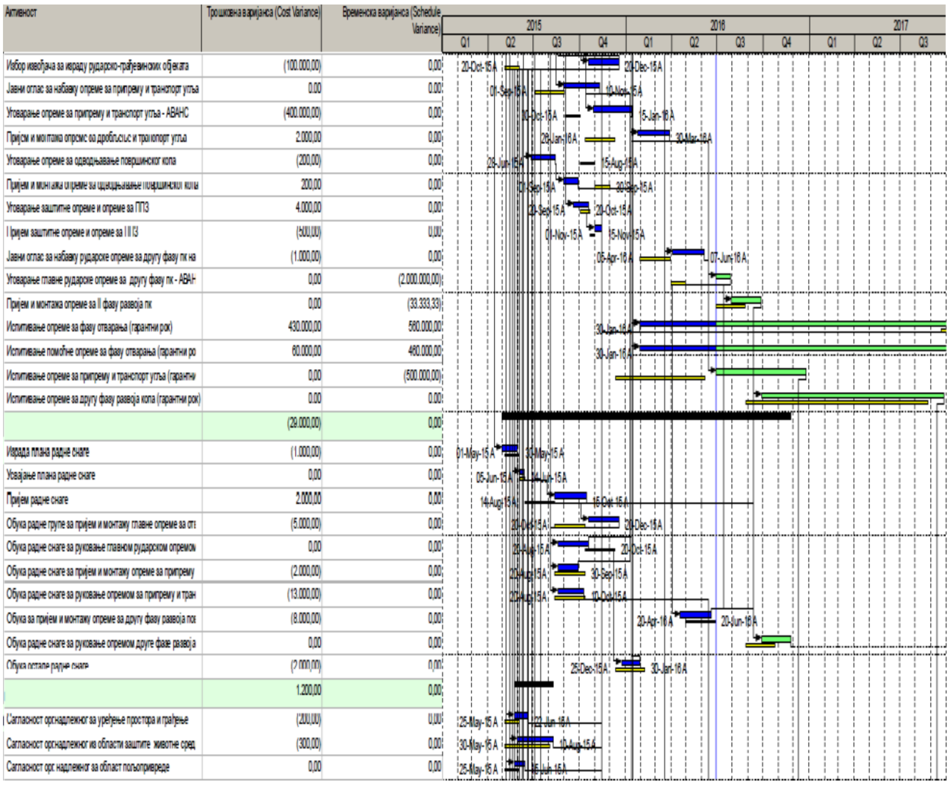
Naveden praktičan primjer poslužio je samo radi boljeg razumijevanja primjene ove metode na projektu. Postoji pet koraka za uspostavljanje MOV, i četri koraka za njeno korišćenje. Koraci su uopšteno opisani, ali su oni isti za sve projekte. Da bi se postavila Metoda ostvarene vrijednosti treba uraditi sledeće:

1. Uspostaviti strukturni dijagram, raščlaniti poslove i podijeliti projekat po upravljačkim etapama
2. Identifikovati aktivnosti koje treba realizovati, a koje predstavljaju sveukupan projekat
3. Rasporediti troškove koji će biti napravljeni za svaku aktivnost
4. Rasporediti aktivnosti tokom vremena
5. Podatke staviti u tabele, dobro isplanirati, analizirati kako bi plan postao prihvatljiv

Da bi se koristile informacije koje se dobijaju kalkulacijom Metodom ostvarene vrijednosti potrebno je uraditi sledeće:

1. Ažurirati vremenski napredak, na osnovu izvještaja o napretku pojedinih aktivnosti
2. Unijeti stvarne troškove realizovanih aktivnosti
3. Na osnovu postojećih podataka program daje grafički prikaz plana i realizacije, koji praktično predstavlja izvještaj o statusu projekta.

Na slici ispod dat je primjer za "Površinski kop Ugljevik Istok", uz napomenu da se radi o simulaciji, a ne o stvarnim vrijednostima.



Sl. 2. *Simulirani primjer u softverskom program Primavera Oracle*

PREDNOSTI METODE OSTVARENE VRIJEDNOSTI

Ovdje ćemo navesti neke od prednosti Metode ostvarene vrijednosti koje su opisali u svojim radovima Fleming i Koppelman. [2]

1. U pitanju je poseban sistem kontrole upravljanja, koji pruža pouzdane podatke
2. Integriše rad, vremenski raspored i troškove koristeći radnu strukturu projekta (WBS)
3. Pripadajuća baza podataka o završenim projektima se može koristiti za komparativnu analizu
4. Kumulativni troškovni indeks efikasnosti projekta (CPI) daje signal upozorenja u ranoj fazi projekta
5. Vremenski indeks efikasnosti (SPI) daje signal upozorenja u ranoj fazi projekta
6. CPI je predskazatelj konačne cijene projekta
7. Koristi metod zasnovan na indeksima za predviđanje konačne cijene projekta
8. Indeks performansi „do završetka" omogućava procjenu projektovane konačne cijene
9. Referentnu tačku predstavlja periodični (npr. sedmični, mjesečni) CPI
10. Upravljanje po principu izuzetka može smanjiti opterećenje prevelike količine informacija

ZAKLJUČAK

Metoda ostvarene vrijednosti danas se upotrebljava na svim vrstama projekata, bez obzira na njihovu veličinu. Može se slobodno reći da ne postoji područje ljudskog djelovanja gdje se ne može primijeniti ili gdje se ne primjenjuje, a posebno je pogodna za upravljanje kompleksnim projektima poput investicionih projekata u oblasti površinske eksploatacije ležišta mineralnih sirovina. Ako se postavlja pitanje zašto baš MOV metoda, odgovor treba tražiti u praktičnim iskustvima jer se pokazala kao najbolja metoda za praćenje napretka većine projekata, integrišući trajanje, troškove, i vremenski raspored. Mnoge organizacije u svijetu su usvojile Ostvarenu vrijednost kao standardizovan alat za upravljanje (npr. US Department of Defence, Australian Standard). Međutim, kada se vrši realizacija, metod treba koristiti u skladu sa ciljem, a ne kao sredstvo za prognoziranje jer on, ipak, samo olakšava praćenje napretka projekta, odnosno određuje status projekta.

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MANAGEMENT MODEL OF INVESTMENT PROJECTS USING THE EARNED VALUE METHOD

Abstract

The Earned Value Method represents a relatively new project management tool, which uses the information on costs, time schedule and operating performance in order to determine the current status of the project. It allows the project manager to predict the final outcome of the project, based on current known individual values, and represents a method for estimating the project performance or performance efficiency. The paper describes the basic principles of this method, with the aim to introduce the potential application of this useful tool for management of mining projects to wider professional community, especially with regards to the possibility of its application in the management of large investment projects, such as the surface mining projects of mineral deposits.

Keywords: *Earned Value Method, Project Management, Project Performance*

INTRODUCTION

A field of science related to the Project Management was developed during the 19th and 20th century, along with the innovation trends in the society, which preceded or were developed in parallel with the industrial progress, resulting that the modern project management today utilises numerous ideas and techniques, developed through the general management concepts and experiences [1]. The Earned Value Method (EVM) for the Project Management analysis, was established in its basic form by the industrial engineers at the end 1800 [2]. In order to encourage broader use of EVM in the private sector, the U.S. federal government decided to utilise much more flexible the Earned Value Management System (EVMS) in 1996. The Project Management Institute released the book "A Guide to the Project Management Body of Knowledge" (PMBOK) in which the simplified EVM terminology and methodology was present [3].

THE EARNED VALUE METHOD (EVM)

High-quality Project Management requires skills which could be divided into nine project management segments, such as the management of project integration, length, time, cost, quality, human resources, communications, risk and procurement. EVM covers the area of know-how regarding to the management of project costs, and contains the processes involved in estimating, budgeting and cost control so that the project is completed within the budget and scheduled time [3]. This is also true for the processes related

* *Mixed Holding "Power Utility of the Republic of Srpska", Parent Joint Stock Company Trebinje, Subsidiary Company "Mine and Thermal Power Plant Ugljevik", Joint Stock Company, Ugljevik,*

to the project cost control. The method which has proved in practice as the best cost control technique is called the Earned Value Method (EVM). The Earned Value Method is a useful tool able to predict the outcome of the project in terms of execution time, execution costs and expected final costs. The method is well known on account of performance measurement, management by the objectives, costs of the performed work and control system for the budgeted costs.

The basic grounds of EVM implementation are:

1. Project Plan, which identifies the required work to be performed
2. Evaluation the planned work, better known as the Planned Value (PV) or Budgeted Cost of Work Scheduled (BCWS) and
3. Predefined rules of "earning" (called metrics) in order to measure the amount of work accomplished, named Earned Value (EV) or Budgeted Cost of Work Performed (BCWP).

Implementation of EVM for large or complex projects, includes many more functions, such as indicators and forecasts of performance cost (over or under budget) and schedule performance (whether they are executed prior to or after the deadline). Nonetheless, most of the basic requirements for an EVM system are required in order to measure the system progress using the Planned Value and Earned Value.

Today, monitoring the project without EVM is very difficult, due to often exceeding of the project budget or delays in the project itself, and it does not provide the conclusions on the current project realisation. It is necessary to use a method that can measure the technical performance in an objective and quantitative manner, which is exactly what EVM provides.

During the planning process, EVM requires establishing the performance measurement of the basic plan. The project work should be divided (using the Work Brakedown Structure - WBS) into tasks which should be carried out and easy to handle, what is often caleled the control center. It is irrelevant whether an individual or team will have to manage an individual work element, but the entire operation must be assigned to be performed by the workforce using the Organizational Brakedown Structure (OBS). When a project has to be divided into a work plan on the account of time and resources, it is required to integrate and record its scope, time framework and costs (time-phase-budget) as the basic plan for performance measurement (Performance Measurement Baseline-PMB). Therefore, the final result is a hypothetical work plan, i.e. the Gantt chart with the addition of EVM techniques.

DESCRIPTION AND TERMINOLOGY OF THE EARNED VALUE METHOD

Three items represent the basis for measuring the cost performance using the Earned Value Method. The basic principle of EVM remains the same regardless to the type and size of the project it is applied. A general description of the required items to implement EVM is as follows:

1. *Planned Value (PV)*, or Budgeted Cost of Work Scheduled (BCWS), describes the extent of work required at any time within the project. It represents a numeric reflection of scheduled work planned for a certain time period, and it is defined by the Performance Measurement Baseline (PMB) by which the actual progress of the project is evaluated. Once established plan can be altered only to mark the changes in the project cost and time, which follow (indicate) the changes in the scope of work.
2. *Earned Value (EV)* represents the current state of progress at a specified time period (overview). It displays the amount of work that has actually been performed to a cer

tain date (within a certain time period), expressed as a Budgeted Cost of Work Performed (BCWP).

3. *Actual Cost (AC)* is also known as the Actual Cost of Work Performed (ACWP), and it represents the level of resources used to perform actual work to a certain date (within a certain time period) [2].

These three items can determine the total budget of the project, as well as the performance cost, performance schedule and the estimated cost to the finalisation of the project. The additional requirements are defined to register the performance cost, performance schedule and program budget:

- Performance Measurement Baseline (PMB) - the sum of all planned costs for each phase of work for each time period, calculated for the total duration of the project. PMB establishes a time-phased-budget plan by which the performance of the project is measured.
- Budget At Completion (BAC) - the sum of all budgets allocated to the project. In addition to PMB, there is the amount of control provisions, which represents a component of the total budget of the project and which is not assigned to the certain stages but it is kept for the management process control.

Performance Analysis and Forecasts

As previously mentioned, the items such as PV, EV, AC might be utilised to analyze the current status of the project and to predict a possible future status of the project. EVM overviews the project performance for the current period and cumulative performance to a certain date. Here, the fourth key item wqill be introduced – the Budget at Completion (BAC), which represents the final data of the Performance Measurement Baseline (PMB) or total planned value of the project. This paper aims to present and describe the following aspects:

- VARIANCES: Schedule (SV) and Cost Variance (CV), Variance at Completion (VAC)
- INDICES: Schedule Performance Index (SPI), Cost Performance Index (CPI) and To-Complete Performance Index (TCPI)
- ESTIMATES: Time Estimate at Completion (EACt), Estimate at Completion (EAC) and the Estimate to Completion (ETC)

Table 1 *EVM and Basic Project Management Questions [4]*

Project Management Questions	**EVM Performance Measures**	**Explanation**
How are we doing time-wise?	**Schedule Analysis & Forecasting**	
Are we ahead or behind schedule?	Schedule Variance (SV)	Negative- work behind schedule Positive-work performed ahead of schedule
How effectively do we use the time?	Schedule Performance Index (SPI)	Efficiency of the performed work %
When will we finish the project the most likely?	Time Estimate at Completion (EACt)	Estimated time of project completion if the current tendencies continue
How are we doing cost-wise?	**Cost Analysis & Forecasting**	
Are we under or over our budget?	Cost Variance (CV)	Negative – budget overrun Positive- spending less than the planned budget
How efficiently do we use our resources?	Cost Performance Index (CPI)	For each monetary unit invested, _ of the unit is refunded

How efficiently must we use our remaining resources?	To-Complete Performance Index (TCPI)	The level BAC has to be improved to, in order to accomplish the plan
How much will the project cost the most likely?	Estimate at Completion (EAC)	Final budget of the Project if the current tendencies continue
Will we be under or over budget?	Variance at Completion (VAC)	The amount of over budget?
What will the remaining work cost?	Estimate to Completion (ETC)	What will the remaining work cost?

Forecasting includes making estimates or predictions of circumstances in the project future, based on information and findings available during the making of the forecast. Forecasts are made, updated and re-issued on the basis of obtained information regarding job performance, whether it is a completed project or a project which is still in the process of implementation. The information about the operational performance refers to performance in the past as well, and about any information that may affect the project in the future, such as EAC and ETC.

Schedule Analysis and Forecasting (How are we doing time-wise?)

Schedule Variance (SV) is calculated by subtracting the Planned value from Earned Value. A positive value of this parameter indicates favourable conditions, while negative indicates unfavourable conditions.

$$SV = EV - PV$$

$$SV\% = SV / PV$$

Schedule Performance Index (SPI) demonstrates how efficiently the time is used by the Project team. It is calculated by dividing EV with PV:

$$SPI = EV / PV$$

Time Estimate at Completion (EACt), using SPI index and average PV per unit of time, the Project team can generate a rough estimate of when the project will be completed, if the current tendencies continue, by comparison of it with the estimated finalization date.

$$EACt = (BAC / SPI) / (BAC / months)$$

It is important to note that this method generates entirely rough estimates and should always be compared to the status display using a time based layout method, such as the critical path method. It is possible that the Earned Value analysis shows that there is no temporal variance, but that the project is still outstanding from the schedule, for example, when the tasks which are planned to be performed in the future, are accomplished prior to the tasks that are on the critical path. [5,6,7]

Cost Analysis and Forecasting (How are we doing costwise?)

Cost Variance (CV) indicates whether the project is within or over the budget funding. This item is calculated by deducting the Actual Value from Earned Value:

$$CV = EV – AC$$

$$CV\% = CV / EV$$

Cost Performance Index (CPI). Both the Earned Value and Actual Cost can be utilized to calculate the CPI, which is the most effective indicator of cumulative cost-effectiveness of the project. CPI evaluates how efficiently the team uses its resources:

$$CPI = EV / AC$$

When the cumulative CPI is within acceptable limits, but has a downward trend in the different measurement periods, it should be considered as a troublesome factor, demanding the review of decreasing trend.

To-Complete Performance Index (TCPI). Another very useful TCPI index, helping the team to determine the effectiveness which must be obtained for the remainder of the work in order to finalise the project, such as the Budget at Completion (BAC) or revision of Estimate at Completion (EAC). TCPI for achieving the BAC is expressed by dividing the remaining amount of work with the remaining budget.

TCPI = (BAC - EV) / (BAC - AC)

Estimate at Completion (EAC). This indicator represents the final cost of the project (budget) for the project team, if the current trends continue. A general method of calculation of the EAC is to divide BAC with the cumulative value of CPI:

EAC = BAC / CPI

Variance at Completion (VAC). Once the information are gor on the EAC, it is possible to calculate the VAC, which indicates whether the project will be completed under or over the budget. It can be done by subtracting BAC frin EAC:

VAC = BAC – EAC

VAC% = VAC / BAC

Estimate to Completion (ETC). There are two ways to calculate the value of ETC, which shows the cost of the work remaining. On of them is Management ETC which is developed by the workers and managers, based on the analyses of the remaining amount of work. AC is added to Management ETC in order to obtain Management EAC of total cost at the end of the project.

EAC = AC + ETC

To reach these estimates, the organizations can use the ETC percentage based on the efficiency to a certain date, measured by CPI:

ETC = (BAC - EV) / CPI

EAC = AC + ETC

EAC = AC + [(BAC – EV) / CPI] =
= BAC / CPI

Cost overruns can be improved, but usually not fully recovered. EVM improves the efficiency and effectiveness of project management, allows managers and others to focus on project execution and to utilise control actions only when and where necessary. Using this method, the organizations can establish acceptable levels of performance for the project and its tasks. There is a possibility to allow the variance deviation ± 10% of the planned values, and on that basis, when such deviations occur, no action shall be taken until the deviation exceeds the predefined limit. When the variances are negative it shall indicate a problem, but when they are positive it indicates that there is a viable opportunity for the project implementation [5,6,7].

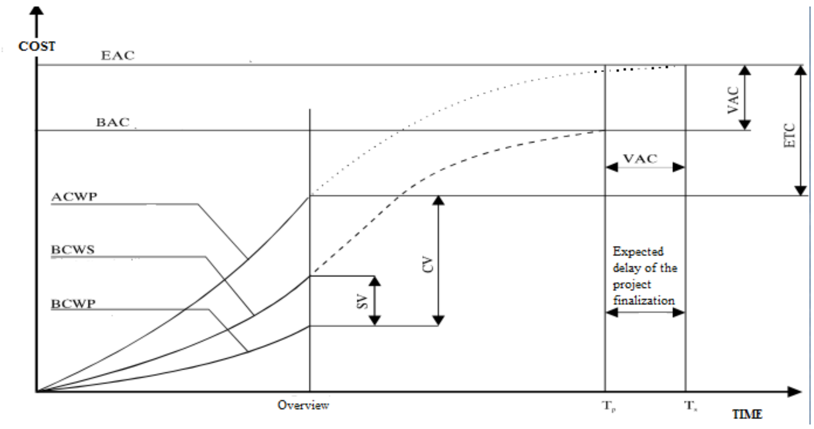

Figure 1 *Display of the EVM values*

Example

12 months after beginning the realisation of the Open Pit Coal Mine Exploitation Project, the project team decided to consider the course of the project implementation, with the project Budget at Completion (BAC) amounting up to 100 million € and the planned duration of 36 months. The project team is expected to create a trend of cost distribution throughout the project to its finalisation, estimate the total cost by the end of the project, to make an estimate of total costs (EAC - Estimate to Completion) and to calculate the coefficient of increase in total costs. The following Table provides a simplified overview: [8]

Table 2 *Overview of the value at the date of situation report*

Activities	Date of situation report.	Planned cost for the planned scope of realization to the date of situation report	Accomplished realization (%)	Actual realization costs to the date of situation report	Planned costs for the accomplished scope of realization to the date of situation report
		PV		AC	EV
A	after 6 months	4 million €	100%	5 million €	4 million €
B	after 9 months	6 million €	100%	8 million €	6 million €
C	after 12 months	10 million €	80%	12 million €	8 million €
∑(A+B+C)		20 million €		25 million €	18 million €

SV= EV – PV = 18 – 20 = - 2 mil. €

SV% = SV / PV= -10%

- 10% of the Project is behind the planned schedule, i.e. 10% of planned work has not been completed.

SPI = EV / PV =
= 18 million € / 20 million € =0.90

- Out of 8 planned working hours per day, only 7 hours and 20 minutes are spent working on the project, i.e. the work is performed with the efficiency percentage of 90%.

EACt = (BAC / SPI) / (BAC / months)
= (100 million € / 0.90)/(100 million € / 36) = 3.999

- If it was scheduled that the project would last 36 months, the project manager knows that if the current project progress is continued, it will take 3.9 months longer than the planned.

CV = EV – AC = 18 – 25 = - 7 million €

CV% = CV / EV= -28%

- For the work currently performed, 28% of the project is over the budget.

CPI = EV / AC
= 18 million € / 25 million €= 0.72

- For every € 1 invested in the project, 72 cent return is obtained.

TCPI = (BAC - EV) / (BAC - AC) =
= 82 million € / 75 million € =
= 1.093

- In order to meet the planned BAC, the performance for the remaining work must be increased from CPI (0.72) to TCPI (1.093).

EAC = BAC / CPI=
= 100 million € / 0.72=
= 138.89 million €

- Current estimation of the total project cost is €138.89 million.

VAC = BAC – EAC =
=100 million € – 138.89 million €
= - 39.89 million €

- If the current trends continue, the project will cost an additional €39.89 million.

ETC = EAC – AC =
= 138.89 million € – 25 million €
= 113.89 million €

- It is estimated that the remaining work will cost 113.89 million €.

The above practical example is provided only for the purpose of better understanding the application of this method to the project. There are five stages for the implementation of EVM, and four stages for its use. The stages are described in general, but they remain the same for all projects. In order to implement EVM, the following actions should be taken:

1. To establish a structural diagram, break down the operations (Work Breakdown Structure - WBS) and split the project onto its management stages
2. To identify the activities to be accomplished, and which represent the entire project
3. To distribute the expected costs onto each activity
4. To distribute the activities, timewise
5. To put the data into the tables, create a well organized, solid plan, and analyse it to obtain an acceptable plan.

In order to utilise the information obtained by calculation the EVM, it is required to do the following:

1. To update the time progress, based on the Report on the progress of individual activities,
2. To enter the actual cost of the completed activities
3. Based on the available data, the program provides a graphical representation of the plan and realization, which practically represents a report on the project status.

The following diagram provides an example of the "Open Pit Mine – Ugljevik East“. Please note that the diagram represents a simulation, not the actual values.

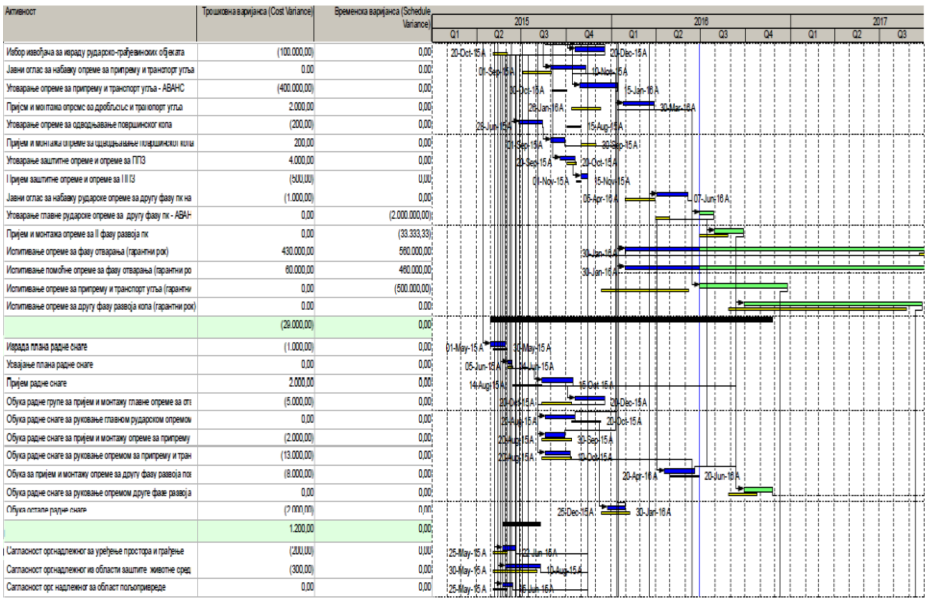

Figure 2 *A sample simulation using the Oracel Primavera software*

ADVANTAGES OF THE EARNED VALUE METHOD

Several benefits of the Earned Value Methods, described by Fleming and Koppelman in their works, are listed hereby [2]:

1. It is a single management control system that provides reliable data
2. It integrates work, schedule and costs using a work breakdown structure (WBS)
3. The associated database of completed projects is useful for comparative analysis
4. The cumulative cost performance index (CPI) provides an early warning signal
5. The schedule performance index (SPI) provides an early warning signal
6. The CPI is a predictor for the final costs of the project
7. It uses an index-based method to forecast the final costs of the project
8. The "to-compete" performance index allows evaluation of the forecasted final costs
9. The periodic (e.g. weekly or monthly) CPI is a benchmark
10. The management by exception principle can reduce information overload

CONCLUSION

The Earned Value Method is used today for all types of projects, regardless of their size. It can be stated that there is no area of human activity where it could not be applied or where it has not been applied yet. It is particularly suited for managing complex projects such as the investment projects in the field of surface mining of mineral deposits. If the question is why EVM method should be used, the answer is to be sought at the actual, practical experiences, since it has proven itself as the most reliable method for monitoring the progress of the majority of projects integrating their duration, costs, and time schedule. Many organizations worldwide have acquired the EVM as a standardized management tool (eg. The U.S. Department of Defence, the Australian Standard). However, when the project realization is performed, the method should be used according to the goal, not as a forecast tool, since it only makes easier monitoring the project progress and helps establishing the project status.

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DINAMIČKI PRITISAK TLA NA POTPORNI ZID PRI NJEGOVOM POMERANJU**

Izvod

U radu se istražuje uticaj kako linearne, tako i nelinearne zavisnosti između horizontalne reakcije F po osnovi i pomeranja zida D. Tlo se usvaja kao materijal samo sa uglom unutrašnjeg trenja i bez kohezije.

Ključne reči: *dinamičko opterećenje, dinamički efekat sila inercije, masa zida, reakcija pritiska tla, dinamička horizontalna reakcija, reaktivna sila*

UVOD

Pri analizi datog problema, osnovna pretpostavka je da se zid pomera samo u vidu smicanja **D** po horizontalnoj osnovi, pri čemu se ne uzima u obzir obrtanje zida i njegovo vertikalno pomeranje. Na ovaj način, zid se razmatra kao sistem sa jednim stepenom slobode. Navedena jednostavna računska šema omogućava rešenje problema kao bočnog dinamičkog pritiska tla za različite slučajeve delujućeg dinamičkog opterećenja. Ovde se istražuje uticaj kako linearne, tako i nelinearne zavisnosti između horizontalne reakcije F po osnovi i pomeranja zida **D**. Dinamičko opterećenje na tlo izaziva u tlu smanjenje kohezione veze i kao takvo, tlo se usvaja kao materijal samo sa uglom unutrašnjeg trenja i bez kohezije.

1. OSNOVNE POSTAVKE

Polazeći od graničkog stanja Kulona pri datom dinamičkom opterećenju, pri čemu se pomeranje odvija po površini klizanja. Pretpostavka je, da je sila pritiska normalna na stranice zida. Redukcija dinamičkog sistema na statički je preko sile inercije klina širine potpornog zida. Ugao nagiba dinamičke linije širenja, kao i u teoriji Kulona, rešava se iz uslova maksimuma pritiska kao funkcija ugla nagiba linije širenja.

Reakcija od strane nepomičnog dela rastresite mase tla, slika 1, je pod uglom unutrašnjeg trenja ρ, otklonjena od normale na liniju BC određena uzimanjem u obzir dinamičkog efekta.

Pri početnom rasporedu dinamičkog opterećenja $q_t = f(t)$ na površinu terena na zid deluju sledeće sile, slika 1:

* *Institut za rudarstvo i metalurgiju Bor*

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- Q, težina zida,
- I_m, sila inercije mase zida pri smicanju po površini osnove tla, I_m = -m·**D"**
- m, masa zida,
- **D",** ubrzanje horizontalnog pomeranja zida,
- E_b, reakcija pritiska tla po prednjoj strani A_1B_1 zida
- F, dinamička horizontalna reakcija smicanja po kontaktu zid-osnova tla

Sumama sila F_{sum} suprotstavljena pomeranju zida po njegovoj osnovi i ako se uvodi i statička sila E_a, tada se uključuje i statička sila trenja po Kulonu.

Na osnovu eksperimentalnih istraživanja za prvi početni period pomeranja zida je linearna zavisnost dinamičke reakcije F po osnovi zida i pomeranja **D**

$F = f_t \cdot D..$ (1)

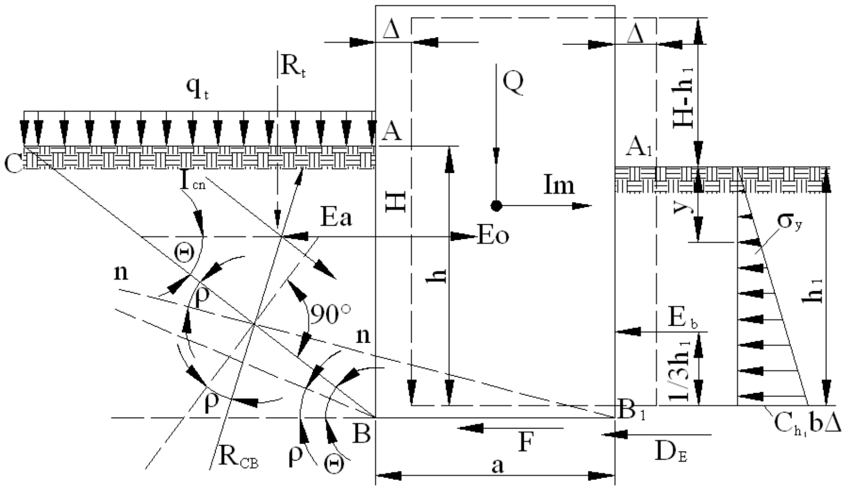
- f_t, koeficijent smicanja, koji uzima u obzir moguću pojavu plastičnih deformacija,

=

≈

) =

- $\psi = 0,5$
- C_{st}, statički koeficijent elastičnog pritiska tla osnove zida



Sl. 1.

Proizvod $\psi \cdot C_{st}$ predstavlja svojevrsni koeficijent krutosti na smicanje zida po osnovi tla, sa uzimanjem u obzir uticaj dinamičkog efekta.

Konačno, sila F određuje se u zavisnosti od pomeranja **D** i mora biti ograničena veličina maksimalne dinamičke sile trenja, tj.

$F \leq 1,4 \cdot f_{os} \cdot Q$

- f_{os} = (0,6 do 0,7), koeficijent trenja osnove temelja sa temeljnim tlom.

Eksperimenti potvrđuju da sila F pri malim vrednostima **D** može dostići značajnu vrednost, kao što je:

1.1. Veza između reaktivne sile Eb i smičućeg pomeranja D

Primena hipoteze Vinklera i usvajanje da je intenzitet σ_y reaktivni otpor tla po bočnoj površi zida upravo proporcionalan smičućem pomeranju **D.**

(3)

- C_y, koeficijent elastičnog pritiska tla na u horizontalnom pravcu,

(4)

- β, konstanta za dato tlo,
- y, dubina.

Uvrštavanjem izraza (4) u (3) dobija se:

(5)

za $y = 0$, $\sigma_y = 0$,

za $y = h1$, $\sigma_y = \beta \cdot h_1 \cdot D = C_{h1}\, D$ (6)

- C_{h1}, koeficijent elastičnog pritiska tla u bočnom pravcu niz zid.

Izraz (4) predstavlja dijagram u obliku trougla iz kojeg se može proračunati reaktivna sila E_b, slika 1:

(7)

Za slučaj pomeranja samo smicanjem po osnovi zida:

(8)

Izraz (8) uvodi dinamički koeficijent elastičnog pritiska osnove tla i jednak je:

što odgovara krtom stanju tla. Konačno, umesto izraza (8) dobija se:

(9)

$h_2 = 0{,}4 \cdot h_1$

- C_b, prosečni koeficijent sleganja po celom temelju

$C_b = 0{,}4 \cdot C_{st} = 0{,}5 \cdot C_{h1}$.

Tačka dejstva pritiska E_b nalazi se na 1/3 h_1, slika 1.

2. DINAMIČKO SMICANJE ZIDA I PRITISAK TLA

Izvođenje izraza za dinamički pritisak, analogan je rešavanju zadatka statičkog pritiska sa uzimanjem u obzir pomeranja zida. Razmatrajući dejstvo ravnomerno raspoređenog opterećenja intenziteta q_t, čija je masa zanemarljiva, slika 1, raspoređenog po površini tla i menjajući se u vremenu po potencijalnoj funkciji, imaće sledeći oblik:

(10)

gde su:

početne vrednosti intenziteta opterećenja i njihov prvi, drugi ... n-ti izvod po vremenu, tj. pri t = 0.

Označavajući sa R_t ravnomerno raspoređeno opterećenje na površini dužine AC, slika 1, i analizirajući deo zida od klina širenja, dobije se dinamički uslov ravnoteže zida, slika 1.

(11)

Ovde je sila F ograničena veličinom $n{\cdot}f_t{\cdot}Q$

Iz izraza (11) dobije se:

(12)

2.1. Uslov dinamičke ravnoteže klina klizanja ABC

Sa slike 1 jasno se vidi da na klin klizanja deluju sledeće sile:

1. Dinamička reakcija od strane zida, jednaka i suprotno usmerena po pravcu sile bočnog pritiska E_a;
2. Sila reakcije od strane površi klizanja R_{CB} pod uglom ρ sa pravcem normale na površ klizanja;
3. Jednako delujuće R_t zadano vertikalno dinamičko opterećenje na površini tla

(13)

- q_t, opterećenje na površini tla,
- θ, ugao nagiba površi klizanja;

4. Sila inercije I_{in} , koja je u slučaju smicanja, po pravcu paralelno sa površi klizanja

(b)

- m_{in}, masa prizme klizanja

(14)

- , ubrzanje pomeranja prizme klizanja

(15)

- h, visina prizme.

Očigledno je da pri θ = 0, ubrzanja moraju biti jednaka. Suma projekcija svih sila na osu n-n koje deluju na prizmu ABC, slika 1, izbegava se nepoznata sila R_{CB}, koja je normalna na osu n-n

(16)

Uvrštavanjem u izraz (16) R_t po (13), I_{in} po (b) i (15)

(17)

Jasno se vidi da dinamički pritisak zavisi od zadatog dinamičkog opterećenja i od ubrzanja pomeranja prizme klizanja.

Izjednačujući izraz za E_a po (12) sa izrazom (17) i sa objedinjavajućim izrazom za **D** dobije se diferencijalna jednačina pomeranja zida.

(18)

Sređivanjem, dobija se:

(19)

Kvadrat kružne učestalosti je:

(20)

a odgovarajuća masa tla je:

(21)

Iz potencijalnog zakona promene q_t po (10) lako je dobiti integral diferencijalne jednačine metodom početnih parametara

...

(22)

Pri trenutno početnom impulsu iskoristi se integraljenjem zavisnost u vremenu između impulsa i opterećenja

(23)

U tom slučaju je početna vrednost brzine:

Na ovaj način, izrazom (22) dobije se potpuno dinamičko pomeranje pri početnom trenutnom impulsu S_0 i opterećenju q_t .

Pri $\theta = 45^{\circ}+\rho/2$, tada je pomeranje najveće pri impulsu $\omega_t = \pi/2$

(24)

Pri početnom naprasnom smicanju zida po osnovi tla (zemljotres)

Na ovaj način je dobijen opšti izraz dinamičkog pomeranja zida pri dejstvu samo dinamičkog raspoređenog opterećenja na tlo, čija je masa zanemarljiva.

Pri dejstvu brzo nanošenog konstantnog opterećenja q_0 , tada veličina pomeranja zida dobija vrednost:

(26)

Pomeranje zida u funkciji vremena dobije se dinamički pritisak tla na zid, uvrštavanjem jednačine (22) u (17)

(27)

Izraz (27) daje opšte rešenje dinamičkog pritiska rastresitog tla pri početnom raspo-ređenom stepenu opterećenja q_t i trenutnom impulsu S_0.

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DYNAMIC PRESSURE OF SOIL ON A SUPPORTING WALL IN ITS DISPLACEMENT[**]

Abstract

*This work studies the effect of both linear and non-linear dependence between the horizontal reaction F on the basis of displacement the wall **D**. The soil is adopted only as a material with an angle of internal friction and without cohesion.*

Keywords: *dynamic loading, dynamic effect of inertia forces, wall mass, soil pressure reaction, dynamic horizontal reaction, reaction force*

INTRODUCTION

In the analysis of this problem, the basic assumption is that the wall moves only in the form of shear **D** on the horizontal basis, where the rotation of wall and its vertical displacement are not taken into account. In this way, the wall is considered as a system with one degree of freedom. The above simple computational scheme provides the problem solution of dynamic lateral soil pressure acting for different cases of dynamic loading. Here, the effect of both linear and non-linear dependence is studied between the horizontal reaction F on the basis of displacement the wall **D**. Dynamic load on the soil causes reduction the cohesion link in the soil and as such, the soil is adopted only as a material with an angle of internal friction and without cohesion.

1 BASIC SETTING

Starting from the boundary condition of Coulomb at a given dynamic loading, where the displacement takes place on the surface of sliding, the assumption is that the pressure force is perpendicular to the wall side. Reduction of dynamic system on a static is over inertia forces of a wedge of supporting wall width. The inclination angle of dynamic expansion line, as well as in the theory of Coulomb, is solved from the condition of maximum pressure as a function of inclination angle of expansion line.

Reaction by the stationary part of loose soil mass, Figure 1, is at angle of internal friction ρ, removed from the normal to the line BC, determined by taking into account the dynamic effect.

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At the initial schedule of dynamic loading $q_t = f(t)$ on the ground surface on the wall, the following forces act, Figure 1:

- Q, wall weight,
- I_m, inertia force of wall mass in shearing on the surface of soil base, $I_m = -m \cdot \mathbf{D''}$,
- m, wall mass,
- **D"**, acceleration of horizontal wall displacement,
- E_b, reaction of soil pressure on the front side of A_1B_1 wall,
- F, horizontal dynamic shearing reaction per contact wall – soil base.

Sums of forces F_{sum} is opposing to the wall displacement along its base, and if the static force E_a is introduced, then the static friction force per Coulomb is included.

Base on the experimental research for the first initial period of wall displacement is a linear dependence of dynamic reaction of F on the basis of the wall and displacement **D**.

$$F = f_t \cdot D \qquad (1)$$

- f_t, shearing coefficient, which takes into account the possible occurrence of plastic deformations,

=

≈

) =

(2)

- $\psi = 0.5$

- C_{st}, static coefficient of elastic soil pressure of the wall base.

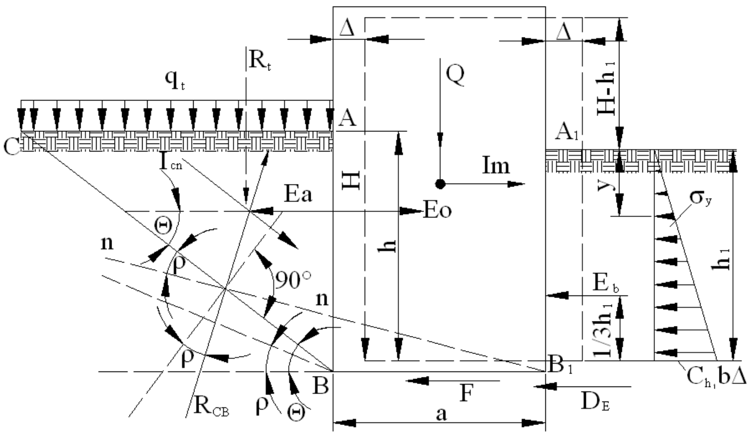

Figure 1

Product $\psi \cdot C_{st}$ represents a stiffness coefficient of shear wall on the basis of soil, taking into account the influence of dynamic effect.

Finally, the force F is determined depending on displacement **D** and it must be a limited value of maximum dynamic friction force, i.e.

$$F \leq 1.4 \cdot f_{os} \cdot Q$$

- f_{os} = (0.6 to 0.7), friction coefficient of foundation base with foundation

Experiments confirm that the force F at low values of D may reach the significant value, such as:

In the period between 15 and 21 August 2010, the Serbian Geodetic Bureau, supported by the Serbian Army, performed the survey included in the EUREF2010 campaign. This campaign has been implemented with the aim of:

1.1 Connection between reaction force E_b and shear displacement D

The use of Winkler hypothesis and adoption that the intensity σ_y is the reactive soil resistance at the side wall surface exactly proportional to shear displacement D.

(3)

- C_y, elastic coefficient of elastic soil pressure in the horizontal direction,

(4)

- β, constant for a given soil,
- y, depth.

Substituting the equation (4) in (3), the following is obtained:

(5)

for $y = 0$, $\sigma_y = 0$,

for $y = h1$, $\sigma_y = \beta \cdot h_1 \cdot D = C_{h1} \cdot D$ (6)

- C_{h1}, elastic coefficient of elastic soil pressure in the lateral direction down the wall.

Expression (4) is a diagram in a form of triangle from which the reaction force E_b, Figure 1, can be calculated:

(7)

For the case of displacement only by shearing on the basis of wall:

(8)

Expression (8) introduces a dynamic coefficient of elastic pressure of soil base and it is equal to:

which corresponds to the brittle state of the soil. Finally, instead of equation (8), the following is obtained:

(9)

$h_2 = 0.4 \cdot h_1$

- C_b, average subsidence coefficient along whole foundation

$C_b = 0.4 \cdot C_{st} = 0.5 \cdot C_{h1}$.

Point of pressure effect E_b is at 1/3 h_1, Figure 1.

2 DYNAMIC SHEAR OF WALL AND SOIL PRESURE

Derivation the expression for dynamic pressure is analogous to the problem solution of static pressure taking into account displacement of the wall. Considering distribution of equal load intensity q_t, whose mass is negligible, Figure 1, distributed on the soil and changing in time at a potential function, will have the following form:

(10)

where:

- the initial values of loading intensities and their first, second ... nth derivative per time, i.e. at t = 0.

Marking with R_t the uniformly distributed load on the surface of length AC,

Figure 1, and analyzing a part of the wall from the wedge of expansion, the dynamic equilibrium condition of the wall is obtained, Figure 1.

(11)

Here, the force F is the limited by the size $n{\cdot}f_t{\cdot}Q$

From equation (11), the following is obtained:

(12)

2.1 Condition of dynamic equilibrium of sliding wedge ABC

Figure 1 clearly shows that the following forces act on a sliding wedge:

1. Dynamic reaction of the wall is equal and opposite directed per direction of lateral pressure force E_a;
2. Reaction force of the sliding surface R_{CB} at angle ρ with direction of perpendicular to the sliding surface;
3. Equally acting R_t default vertical dynamic load on the soil surface

(13)

- q_t, load on the soil surface,
- θ, inclination angle of sliding surface.

4. Inertial force I_{in}, which is, in the case of shear, parallel in the direction with sliding surface

(b)

- m_{in}, mass of sliding prism

(14)

- , acceleration of sliding prism displacement

(15)

- h, height of prism.

It is obvious that at θ = 0, the accelerations must be equal. Sum of projections of all forces on the axis n-n acting on the prism ABC, Figure 1, avoiding the unknown force R_{CB}, which is perpendicular to the axis n-n

(16)

Including into expression (16) R_t by (13), I_{in} by (b) and (15)

(17)

It is clear that the dynamic pressure depends on the given dynamic load and acceleration of movement the prism of sliding.

Equating the expression for E_a by (12) with the expression (17) and integrating expression for D, the differential equation of wall displacement is obtained.

(18)

The following is obtained by rearrangement:

(19)

Square of a circular frequency is:

(20)

and the corresponding soil mass is:

(21)

From the potential law of change q_t by (10), it is easy to obtain an integral differential equations using the method of initial parameters

...

(22)

At the currently initial impulse, the integral dependence is used in the time between pulses and load

(23)

In this case, the initial value of speed is:

In this way, by expression (22), the full dynamic displacement is obtained at the currently initial impulse S_0 and load q_t.

At $\theta = 45^{\circ}+\rho/2$, then the largest displacementis at impulse $\omega_t = \pi/2$

(24)

At the initial sudden shearing of wall on the soil basis (earthquake)

(25)

In this way, a general expression of dynamic displacement of the wall is obtained only at the effect of dynamic distributed load on soil with negligible mass.

At the applied quickly constant load q_0, then the size of wall displacement gets the value:

(26)

By displacement of the wall as a function of time, the dynamic soil pressure on the wall is obtained, inserting equation (22) into (17)

(27)

Expression (27) gives the general solution of dynamic pressure of loose soil at the initial distributed degree of the load q_t and current impulse S_0.

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KOMPLEKSNA DINAMIKA MODELA NASTANKA RUDARSKI GENERISANIH POTRESA DUŽ REAKTIVIRANIH RASEDA**

Izvod

U ovom radu vrši se analiza dinamike Baridž-Knopof modela bloka sa oprugom, za koji se pretpostavlja da predstavlja model nastanka rudarski generisanih potresa duž transkurentnog raseda na maloj dubini. Analiza se vrši putem numeričke simulacije dva modela sa dva različita zakon trenja, modifikovanih uvođenjem vremenskog kašnjenja τ u izraz za trenje, kojim se uzima u obzir odloženi efekat napredovanja rudarskih radova na generisanje potresa duž postojećih raseda. U prvom modelu, usvaja se da je zakon trenja zavisan samo od brzine kretanja bloka. Uvođenjem vremenskog kašnjenja, dinamika modela bloka sa oprugom pokazuje prelaz od ravnotežnog stanja preko periodičnog kretanja do determinističnog haosa, kao tranzijentnu (prolaznu) pojavu. U drugom modelu, usvaja se da važi Diterih-Ruina zakon trenja zavisan od brzine kretanja bloka i stanja kontaktne površi. U ovom slučaju, povećanjem vrednosti parametra τ, model pokazuje prelaz od ravnotežnog stanja, preko periodičnog i kvaziperiodičnog kretanja do determinističkog haosa, za određenu vrednost kontrolnih parametara. Dobijeni rezultati ukazuju na to da dinamika modela nastanka potresa u velikoj meri zavisi od prirode odabranog zakona trenja u stenskoj masi. Rezultati takođe ukazuju na činjenicu da je determinističko modelovanje moguće u slučaju izučavanja mehanizma nastanka rudarski generisanih potresa duž raseda, pošto se, u ovom slučaju, stohastičko ponašanje generiše iz polaznog determinsitičkog sistema.

Ključne reči: *rudarski generisani potres, bifurkaciona analiza, zakon trenja, deterministički haos*

UVOD

Povećanje seizmičke aktivnosti u seizmički aktivnim oblastima, kao i pojava potresa u aseizmičkim područjima najčešće nastaje kao rezultat podzemnih rudarskih radova na velikim dubinama [1]. Ovakav tip seizmičnosti pripada velikoj grupi tzv. indukovanih ili pobuđenih potresa, koji nastaju onda kada inženjerska aktivnost uzrokuje oslobađanje akumuliranog tektonskog napona. Seizmičnost izazvana rudarskom aktivnošću obično se definiše kao pojava seizmičkih događaja uzrokovana prekoračenjem čvrstoće na smicanje stenske mase, u naponskom polju stenskog masiva u blizini čela iskopa [2]. Pri tome, obično se registruju dva tipa rudarski generisanih potresa – potresi direktno izazvani napredovanjem iskopa, i potresi povezani sa reak-

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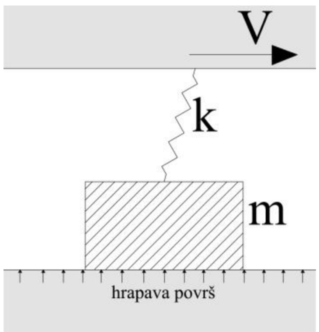
tiviranjem kretanja duž postojećih geoloških diskontinuiteta [3,4]. Nešto detaljniju podelu rudarski izazvanih potresa predložili su Horner i Hasegava [5] u vidu šest osnovnih modela nastanka potresa indukovanih podzemnom eksploatacijom: potresi izazvani provaljivanjem tavanica podzemnih prostorija, lomom zaštitnih stubova, prekoračenjem čvrstoće na zatezanje povlatne stenske mase, kao i reaktiviranjem kretanja duž normalnog, reversnog i transkurentnog raseda. Ovi modeli se obično razmatraju pri opštoj analizi rudarski izazvane seizmičnosti [1]. Pri tome, pojava prva tri tipa potresa može biti izbegnuta, ili njihova veličina može biti u značajnoj meri redukovana, primenom odgovarajućeg načina eksploatacije, pravilnim odabirom vrste podgrade, pre svega u zavisnosti od vrste i fizičko-mehaničkih svojstava stenske mase. S druge strane, potresi izazvani reaktiviranjem kretanja duž raseda ne mogu se kontrolisati, što ih čini jednim od najznačajnijih geoloških hazarda u područjima sa podzemnom eksploatacijom mineralnih sirovina. Ovakva kompleksnost rudarski generisanih potresa duž postojećih raseda proizilazi i iz njihove generički „haotične'' dinamike mehanizma nastanka potresa, kao i kretanja (oscilovanja) tla za vreme potresa.

Kortas [6] je istraživao nelinearno dinamičko ponašanje rudarski generisanih potresa na primeru pet seizmograma registrovanih potresa u Poljskoj i Južnoj Africi, i u svim slučajevima utvrdio deterministički haotično ponašanje. S druge strane, Huang, Yin i Dai [7], na osnovu ideje Brejsa i Bajerlija [8] o trzanju kao mogućem fenomenološkom modelu nastanka potresa, vršili su istraživanje modela dva bloka sa oprugom, kojim su simulirali nastanak potresa. Njihova analiza je pokazala da nastanak rudarski generisanih potresa duž postojećih raseda može biti opisan trzanjem u modelu dva bloka, ukazujući na determinističku prirodu modela, za razliku od uobičajenog poimanja mehanizma nastanka potresa kao stohastičke pojave. Slično tome, u ovom radu takođe se pristupa analizi Baridž-Knopof modela (u daljem tekstu za Baridž-Knopof model koristićemo skraćenicu BK model) bloka sa oprugom (Slika 1), koji se sastoji od jednog bloka (dela stenske mase određenog sastava), koji je preko opruge povezan sa pokretnom gornjom pločom, koja uzrokuje kretanje celog sistema preko hrapave podloge. Raspored nestabilnog klizanja u BK modelu može biti opisan Gutenberg-Rihter i Omori-Ucu zakonom [9].



Sl. 1. *BK model sa jednim blokom, povezanim preko opruge sa gornjom pokretnom pločom, koja uzorkuje pomeranje bloka duž donje nepokretne podloge; m predstavlja masu bloka, k predstavlja krutost opruge, a v predstavlja brzinu gornje ploče (bloka).*

U ovom radu, vrši se analiza BK modela sa jednim blokom i dva različita zakona trenja. Kod prvog zakona trenja, originalno predloženog od strane Karlsona i Langera [10], trenje između bloka i donje podloge predstavlja funkciju samo brzine bloka. Drugi, Diterih-Ruina zakon trenja, predstavlja zakon trenja zavisan od brzine bloka i stanja kontaktne površi, i eksplicitno uključuje u razmatranje promenljivu stanja θ, kao prosečno vreme kontakta između bloka i hrapave podloge. Oba modela se izučavaju, uvodeći vremensko kašnjenje τ u izraz za trenje, kojim se opisuje ,,zakasneli okidački" (trigerring effect) uticaj napredovanja podzemnih rudarskih radova a pojavu potresa duž postojećih raseda.

Naglašavamo, takođe, da BK model, sa samo jednim blokom, i sa zakonom trenja zavisnim samo od brzine, ili i od brzine i od stanja, bez uvedenog vremenskog kašnjenja τ, ne pokazuje deterministički haotično ponašanje, koje je već utvrđeno u sistemima sa više blokova. Koliko je nama poznato, složeni uticaj trenja na nastanak zemljotresa do sada nije razmatran uvođenjem vremenskog kašnjenja. Cilj ovog rada predstavlja ispitivanje dinamike predloženih modela, sa uključenim vremenskim kašnjenjem u izraz za trenje. Drugim rečima, hoćemo da procenimo uticaj svojstava kontaktne površi duž raseda na nastanak rudarski generisanih potresa.

KARLSON-LANGER MODEL

U prvom slučaju, polazimo od modela prvobitno predloženog od strane Vieire [11], u sledećem obliku:

$$\ddot{U} = -U - \frac{1}{1+\frac{\dot{U}}{v^c}} + vt \qquad (1)$$

gde

U - predstavlja pomeranje bloka,

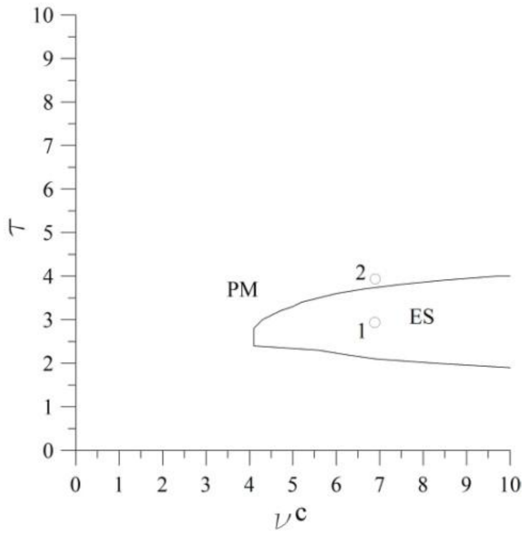
v - bezdimenzionalnu brzinu bloka, kao odnos između vremena klizanja i vremena mirovanja (vremena koje je potrebno da sila u opruzi prevaziđe vrednost statičkog koeficijenta trenja),

a - v^c predstavlja bedimenzionalnu karakterističnu (referentnu) brzinu.

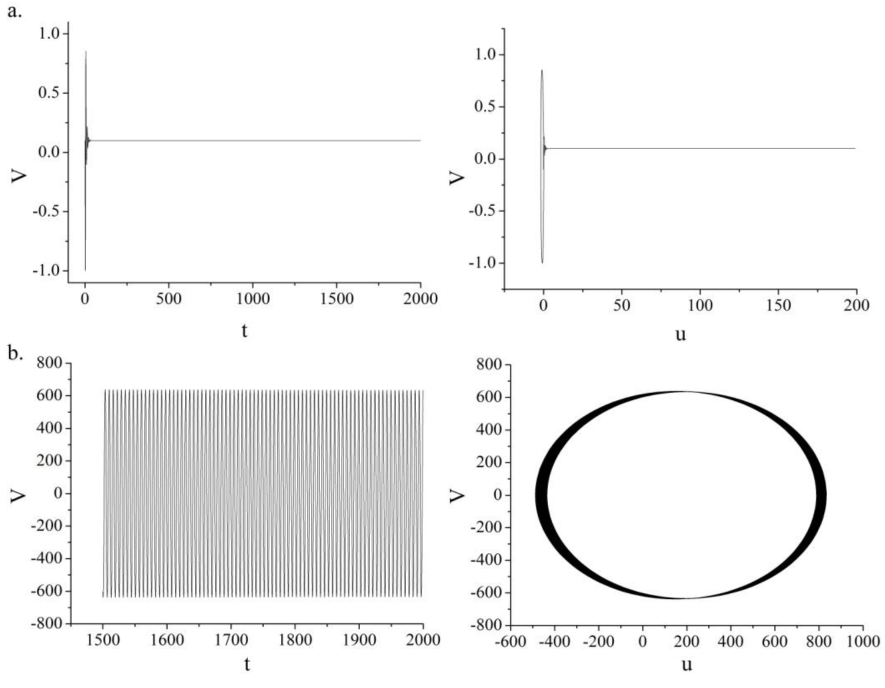
U ovom radu, za razliku od Vieire [11], dozvoljavamo kretanje bloka unazad. Polazeći od modela sa jednim blokom (1) uvodimo vremensko kašnjenje τ u izraz za trenje na sledeći način:

$$\ddot{U} = -U - \frac{1}{1+\frac{\dot{U}(t-\tau)}{v^c}} + vt \qquad (2)$$

Parametri modela su isti kao i u jednačini (1). Rezultati numeričke analize sistema (2) pokazuju da sa promenom parametra τ, ponašanje posmatranog modela sa jednim blokom menja se od ravnotežnog stanja ka periodičnom kretanju, i obrnuto. Na slici 2 prikazan je bifurkacioni dijagram sistema (2) za različite vrednosti parametara τ i v^c. Primeri ravnotežnog stanja (tačka 1 za $\tau = 3$ i $v^c = 7$) i periodičnog ponašanja (tačka 2 za $\tau = 4$, $v^c = 7$) sa slike 2 prikazani su kao vremenske serije i odgovarajući fazni portreti na slici 3.

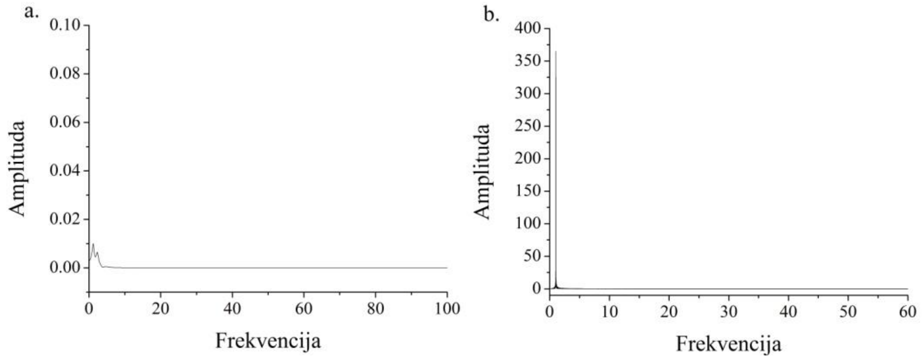


Sl. 2. *Bifurkacioni dijagram BK modela sa jednim blokom, u parametarskoj ravni (τ,v^c), za v=0.1. ES i PM predstavljaju oznake za ravnotežno stanje i periodično kretanje, redom. Odgovarajuće vremenske serije i fazni portreti za tačku 1 i 2 prikazani su na slici 3.*



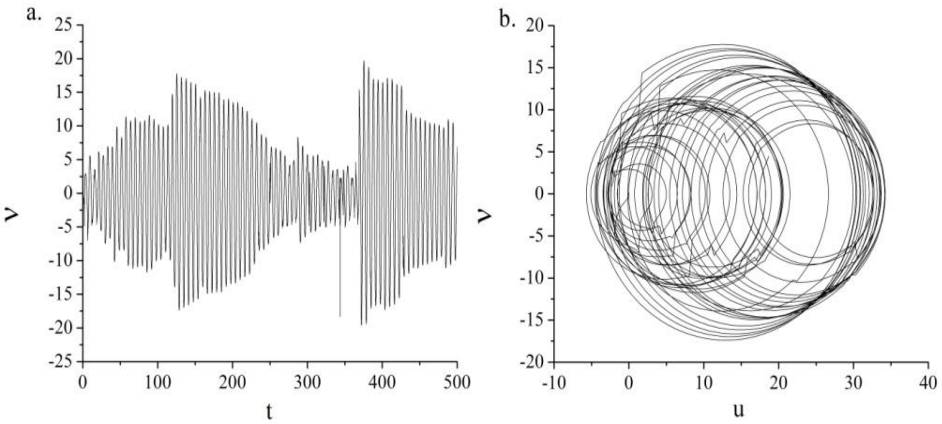
Sl. 3. *Vremenska serije promenljive v (brzina) i odgovarajući fazni portret za:*
a. *ravnotežno stanje (tačka 1 sa slike 2; τ=3, v^c=7, v=0.1).*
b. *periodično kretanje (tačka 2 sa slike 2; τ=4, v^c=7, v=0.1).*
Promenljive su date kao bezdimenzionalne veličine.

Ravna linija (Slika 4a) i usamljeni pik (Slika 4b) u Furijeovom spektru snage potvrđuju pojavu ravnotežnog stanja i periodičnog ponašanja, redom, za tačke 1 i 2 sa slike 2.

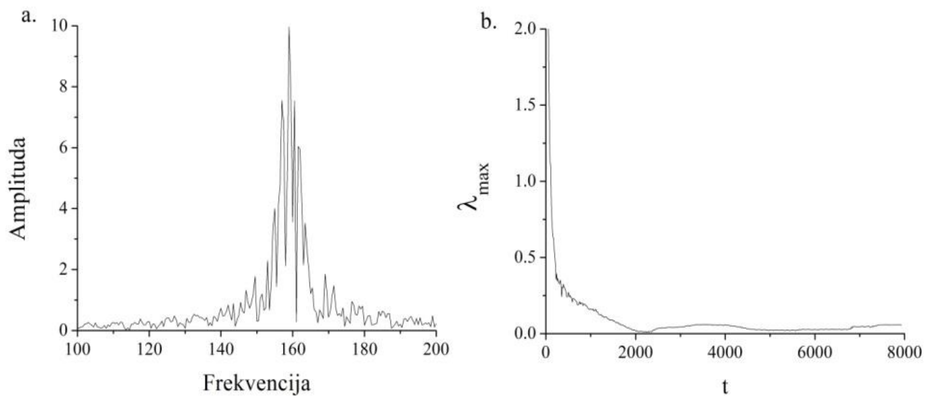


Sl. 4. a. *Ravna linija u Furijeovom spektru snage ukazuje na ravnotežno stanje sistema (tačka 1 sa slike 2).* **b.** *Usamljeni pik u Furijeovom spektru snage ukazuje na periodično ponašanje (tačka 2 sa slike 2). Vrednosti parametara su iste kao na slici 3.*

Međutim, izuzev ova dva moguća stanja sistema, dolazi do pojave i relativno slabog determinističkog haosa, koji se u ovom sistemu javlja samo kao tranzijentni (prolazni) fenomen. Ovakav vid haotičnog ponašanja je očekivan, s obzirom na to da rudarski generisani potresi predstavljaju kratkotrajne pojave (najčešće ispod 5s). Odgovarajuća vremenska serija i fazni portret za tranzijentno haotično ponašanje sistema (2) prikazani su na slici 5, za vrednosti parametara τ = 0.7 and v^c = 1.0. Širokopojasni, kontinualni šum u Furijeovom spektru snage (slika 6a) i pozitivna vrednost najvećeg Ljapunovljevog eksponenta (slika 6b) potvrđuju deterministički haotično kretanje izučavanog modela (2).



Sl. 5. *Vremenska serija promenljive v (a) i odgovarajućeg faznog portreta (b) za vrednosti parametara τ=0.7 i v^c=1.0 (deterministički haos).*



Sl. 6. a. *Širokopojasni kontinualni šum u Furijeovom spektru snage ukazuje na relativno slabo izraženo deterministički haotično ponašanje sistema.* **b.** *Najveći Ljapunovljev eksponent konvergira ka pozitivnoj vrednosti λ=0,08.*

MADARIAGA MODEL

Drugi model koji opisuje ,,trzajuće" kretanje duž reaktiviranog raseda zasniva se na sistemu jednačina predloženom od strane Madariage [12]:

(3)

gde su bezdimenzionalne veličine:

$\varepsilon=(B\text{-}A)/A$ kao mera promene brzine kretanja bloka,

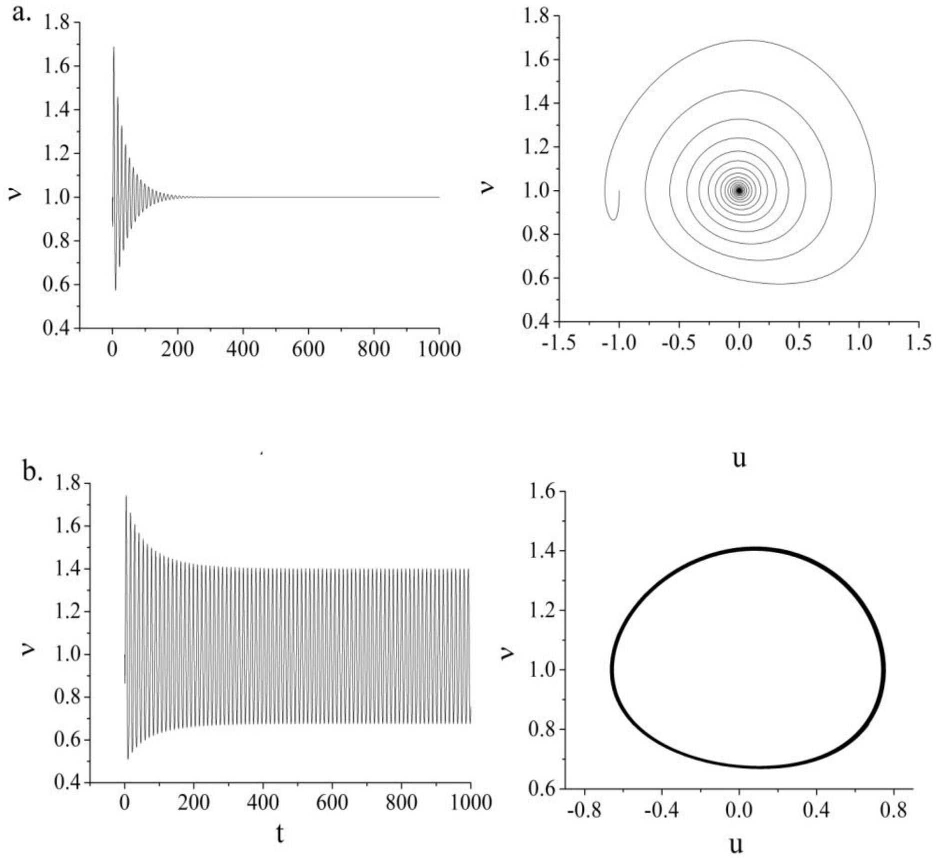
$\xi=(kL)/A$ konstanta opruge, i

$\gamma=(k/M)^{1/2}(L/v_0)$ frekvencija ,,trzanja''.

Za razliku od prethodnog modela, gde je trenje bilo u funkciji samo brzine kretanja bloka, u ovom modelu se pretpostavlja da važi Diterih - Ruina zakon trenja, koji obuhvata i promenljivu stanja θ, i na taj način omogućava da model kvalitativno opiše gotovo sve važnije seizmičke pojave poput trzanja, ,,regenerisanja'' rasedne zone memorijskih efekata [13]. Ovo je u potpunosti u saglasnoti sa istraživanjima trenja u stenskoj masi koja su ukazala na to da trenje ne može biti funkcija samo brzine kretanja bloka [14]. U ovom radu, proširujemo model (3) uvodeći vremensko kašnjenje τ u izraz za trenje, čime dobijamo sledeći sistem:

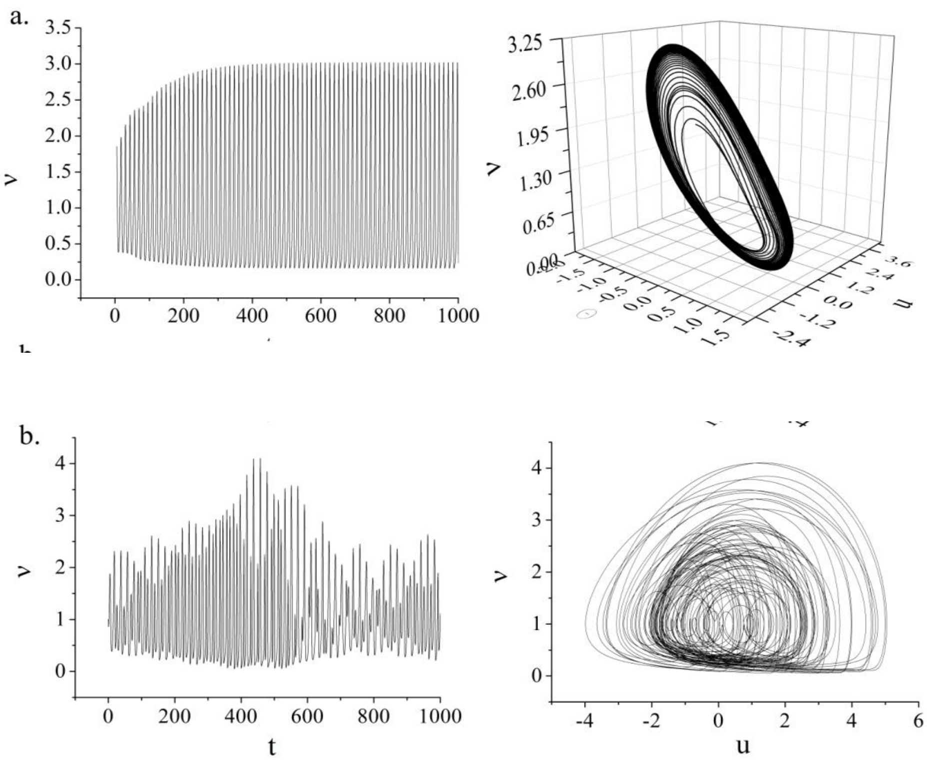
(4)

Numerička analiza modela pokazuje da model iz ravnotežnog stanja, u kojem se nalazi za vrednosti parametara ε, ξ and γ: 0,2, 0,8 i 0,8, redom, i bez vremenskog kašnjenja (slika 7a) prelazi u periodično oscilatorno) ponašanje predstavljeno u vidu graničnog ciklusa u faznom portretu (slika 7b), za sledeće vrednosti parametara: τ =10, ε = 0,4, ξ = 0,8 i γ = 0,8. Daljom promenom parametara, model pokazuje kvazi-periodično (slika 8a) i deterministički haotično ponašanje (slika 8b).

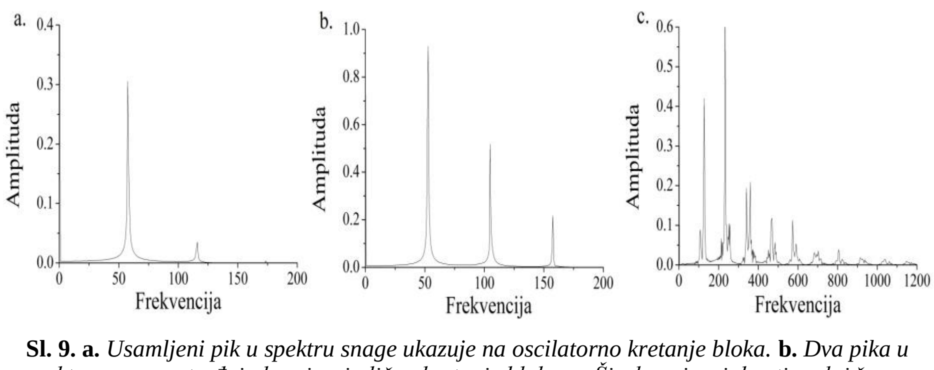


Sl. 7. *Vremenska serija promenljive v i odgovarajući fazni portret za sledeće vrednosti parametara:* **a.** *τ=0, ε = 0,2 , ξ= 0,8 i γ = 0,8 (ravnotežno stanje);* **b.** *τ=10, ε = 0,4, ξ = 0,8 i γ = 0,8 (periodično ponašanje, zanemarujući tranzijente). Promenljive su date kao bezdimenzionalne veličine.*

Raznovrsna dinamika modela bloka sa oprugom može se potvrditi izračunavanjem Furijeovog spektra snage, kao što je prikazano na slici 9. Usamljeni pik u spektru snage (slika 9a) ukazuje na oscilatorno ponašanje modela, dok dva pika na slici 9b potvrđuju kvaziperiodično kretanje. Širokopojasni, kontinualni šum na slici 9c predstavlja potvrdu determinističkog haotičnog ponašanja.



Sl. 8. *Vremenska serija promenljive v i odgovarajući fazni portret za sledeće vrednosti parametara: a. τ=12, ε = 0,5, ξ = 0,8 i γ = 0,8 (kvaziperiodično kretanje); b. τ=16, ε = 0,8 ξ=0,8 i γ = 0,8 (deterministički haos). Promenljive su date kao bezdimenzionalne veličine.*

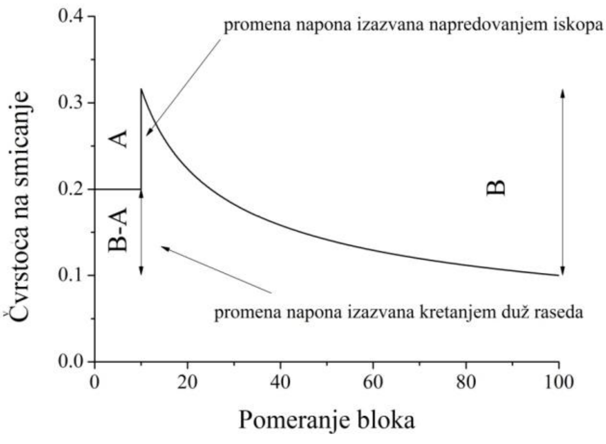


Sl. 9. a. *Usamljeni pik u spektru snage ukazuje na oscilatorno kretanje bloka.* **b.** *Dva pika u spektru snage potvrđuju kvaziperiodično kretanje bloka.* **c.** *Širokopojasni, kontinualni šum u spektru snage predstavlja potvrdu deterministički haotičnog ponašanja.*

DISKUSIJA I ZAKLJUČAK

U ovom radu, izvršena je analiza dva različita modela nastanka rudarski generisanih potresa duž postojećih raseda. U oba slučaja, pristupilo se izučavanju BK modela sa samo jednim blokom, sa dva različita zakon trenja između bloka i hrapave podloge. Ovi originalni modeli, bez uvedenog vremenskog kašnjenja, pokazuju samo periodično ponašanje, što ih čini neodgovarajućim modelima nastanka rudarski generisanih potresa duž postojećih raseda, pa čak i modelima tekontkih zemljotresa. Glavni razlog tome predstavlja činjenica da dinamika modela mora biti nestabilna kako bi na odgovarajući način opisala trzanje bloka, i, samim tim, simulirala nastanak potresa. Međutim, sa uvedenim vremenskim kašnjenjem τ, kojim se modeluje odloženi uticaj napredovanja rudarskih radova na generisanje potresa duž postojećih raseda, oba modela pokazuju znatno kompleksnije ponašanje. U prvom modelu, ova kompleksnost je slabije izražena, s obzirom na to da se ,,haotično" ponašanje javlja samo za jako uske oblasti parametarskog prostora. U drugom modelu, potpuna kompleksnost modela ogleda se u prelazu od ravnotežnog stanja, preko periodičnog i kvaziperiodičnog kretanja do pojave determinističkog haosa.

Na osnovu dobijenih rezultata, drugi model se prirodno nameće kao pogodniji za opis nastanka rudarski generisanih potresa. Razlog tome leži pre svega u kompleksnosti Diterih-Ruina zakona trenja, koji u obzir uzima različite parametre sistema, za razliku od relativno jednostavnog zakona trenja u prvom slučaju. Štaviše, Madariaga model uzima u obzir promene napona pre i za vreme kretanja bloka, što se može dovesti u vezu sa promenama naponskog stanja izazvanih napredovanjem rudarskih radova. Ove promene su, pre svega, opisane promenom vrednosti parametra ε (Slika 10), kojim je predstavljen odnos između opadanja napona za vreme kretanja bloka i povećanja napona kada je blok u stanju mirovanja izložen dejstvu sile gornje ploče. Što je veća vrednost parametra ε, to je veći i koeficijent trenja duž postojećeg raseda. U ovom slučaju, kompleksno nestabilno deterministički haotično ponašanje modela uočava se za vrednost parametra $\varepsilon < 1$, ukazujući na mogućnost kretanja duž postojeće oslabljene rasedne zone, koje je uzrokovano promenama naponskog stanja indukovanim dejstvom nekog spoljašnjeg faktora (napredovanjem rudarskih radova u ovom slučaju).



Sl. 10. *Shematski prikaz promene napona u modelu bloka sa oprugom, prikazanom na slici 1.*

Ova promena je jako idealizovana i, u opštem slučaju, zavisi od vrste stenske mase. Međutim, prethodna istraživanja su pokazala da se Diterih-Ruina zakon trenja približno podudara sa eksperimentalno dobijenim rezultatima.

Takođe, Diterih-Ruina zakonom trenja obuhvaćena je i promenljiva stanja θ, koja opisuje stanje kontaktne površi između bloka i donje hrapave podloge. S obzirom na to da kretanje duž raseda uzorkuje mnoge različite pojave (frikciono zagrevanje i topljenje, termalne pritiske, efekte podmazivanja silikagelom, kao i efekte granularnog trenja), svojstva kontaktne zone su jako kompleksna, i ova zona odlučujući uticaj na kretanje duž raseda. Uticaj ovih efekata na kretanje bloka je u ovom radu pojačan uvođenjem vremenskog kašnjenja τ. Da bismo dalje proučavali uticaj trenja na kretanje bloka, sledeća faza istraživanja će biti proširena i na model sa dva bloka. Štaviše, naša ideja je da uvedemo parametar jačine trenja C, potom da istovremeno menjamo i parametar τ i parametar C, na osnovu čega možemo dalje oceniti moguće promene dinamike bloka.

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COMPLEX DYNAMICS OF THE FAULT-SLIP ROCKBURST NUCLEATION MODELS**

Abstract

This paper gives the study of dynamics the Burridge-Knopoff spring-block model, assumed to represent a rockburst nucleation model along a shallow (near horizontal) thrust fault. The analysis is performed through numerical simulations of two models with different friction laws, modified by introduction the time delay τ in friction terms, which takes into account the delayed triggering effect of the mining excavation works. In the first model, a velocity dependent friction force is assumed. By introduction the time delay, the dynamics of one-block model shows a transition from equilibrium state to the periodic motion, with deterministic chaos as transient feature. In the second case, the model with the Dieterich-Ruina rate-and state- dependent friction law are examined. Increasing the time delay τ, the model exhibits a transition from equilibrium state, to periodic, quasiperiodic motion and chaos, for the certain parameter range. The obtained results indicate that the dynamics of rockburst nucleation model strongly depends on the nature of chosen friction law. It also confirms the fact that deterministic modeling is possible in the case of rockburst nucleation, since "stochastic" motion is generated from the starting deterministic system.

Keywords: *rockburst, bifurcation analysis, friction law, deterministic chaos*

INTRODUCTION

An increase in seismicity in seismic and aseismic areas was observed as the result of deep underground mining [1]. This type of seismicity belongs to a large group of so called ''induced seismicity'' phenomena, indicating triggering nature of engineering activities in release the preexisting stresses of tectonic origin. Seismicity induced by mining is usually defined as the appearance of seismic events caused by rock failures, which is the result of changes in the stress field in the rockmass near mining excavations [2]. Two broad types of mine tremors are usually observed – those directly connected with mining operations and those associated with movement along the major geologic discontinuities [3,4]. A more detailed division of mine tremors was proposed by Horner and Hasegawa [5], who suggested six models of induced seismicity in the underground mines in Canada: cavity collapse, pillar burst, tensional fault, normal fault, thrust fault and shallow (near-horizontal) thrust fault. These models are commonly used for analyzing mine seismicity in general [1]. The first three types of rockbursts could be reduced or even prevented using the appropriate excavation method and tunnel support, concerning the quality of rock masses. However, rockbursts

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induced by movement along the preexisting rock discontinuities are difficult, or even impossible to control, what makes them the most severe geological hazards in mining areas (the latter three models). This complexity in controlling, predicting and, finally, preventing this kind of fault-induced rockbursts reveals itself also in the possible ''chaotic'' dynamics of rockburts nucleation and corresponding ground motion. Kortas [6] investigated the nonlinear dynamics of five data sets (seismograms) referring to seismicity induced by mining and observed deterministic chaos in all the examined data sets. As for the rockburst nucleation, Huang, Yin and Dai [7], following the suggestion of Brace and Byerlee [8], that stick-slip motion may be analogous to the mechanism of crustal earthquakes, studied a spring-and-two-slider model, in order to simulate the behavior of rockbursts. Their analysis demonstrates that the fault-slip rockbursts could be well explained by stick-slip motion, indicating the chaotic behavior, which implies that dynamics of a rockburst model is deterministic instead of stochastic. Similarly, in this paper, the dynamics of the spring-block Burridge-Knopoff model (Abbreviation BK model is used for Burridge-Knopoff model) (Figure 1) is also analyzed, which consists of one block of the certain rock type, connected through harmonic spring to a moving plate and driven along the rough surface. Distribution of unstable slipping events in the BK model follows the Gutenberg-Richter and Omori-Utsu law [9].

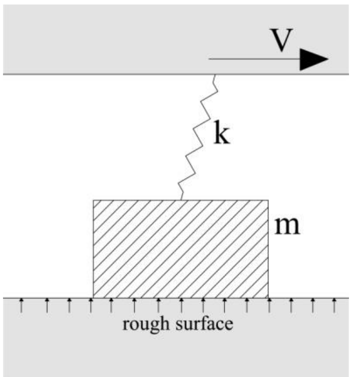

Figure 1 *The Burridge-Knopoff spring-block model, represented by a block, coupled through a spring to a loader plate, moving along the rough surface of lower plate; m is mass of block; k is spring stiffness and v represents slip velocity*

In present paper, the BK model with one-block and two different friction laws is analyzed. The first law, originally proposed by Carlson and Langer [10], assumes velocity dependent friction between the block and lower plate. The second, the Dieterich-Ruina friction law, represents rate-and state-dependent friction law, and explicitly incorporates the time-dependent state variable θ, as the average contact time along the rough surface of fault. Both of these models are studied by introducetion the time delay τ in friction term, which strengthens the role of friction in the motion along the fault. BK model, with only one block, coupled either with velocity-dependent or the Dieterich-Ruina friction law, without the introduced time-delay τ, does not exhibit a deterministic chaotic motion, which is already observed in a multi-block system. As it is known, the complex friction effect has not been considered so far by introduction the time delay in equations governing the motion of spring-block model. The aim of this paper is to investigate the dynamics of these suggested models, with time delay included in friction term. In other words, estimation of influence the contact surface character and corresponding friction on dynamics of rockburst nucleation model is required.

CARLSON-LANGER MODEL

In the first case, the mode,l originally proposed by Vieira [11], is used in the following form:

$$\ddot{U} = -U - \frac{1}{1+\frac{\dot{U}}{v^c}} + vt \qquad (1)$$

where

- U - represents block displacement,
- v – dimensionless pulling speed, as the ratio of slipping time to the loading time (time it takes for a pulling spring to be stretched enough to overcome static friction), and
- v^c - represents dimensionless characteristic velocity.

In present paper, in contrast to Vieira [11], a backwards motion is allowed. Starting from model (1) for one-block system, the time delay τ is introduced in the following way:

$$\ddot{U} = -U - \frac{1}{1+\frac{\dot{U}(t-\tau)}{v^c}} + vt \qquad (2)$$

Parameters of model are the same as in the equation (1). The performed numerical analysis shows that, as the parameter τ is changed, system exhibits a transition from equilibrium state to periodic motion and vice versa. Figure 2 shows bifurcation diagrams of different dynamical behavior (equilibrium state and periodic motion) in two parameter plane (τ,v^c). Examples of equilibrium state and oscillations for point 1(τ=3, v^c=7**)** and point 2 (τ=4, v^c=7) from Figure 2, shown as time series and phase portraits in Figure 3.

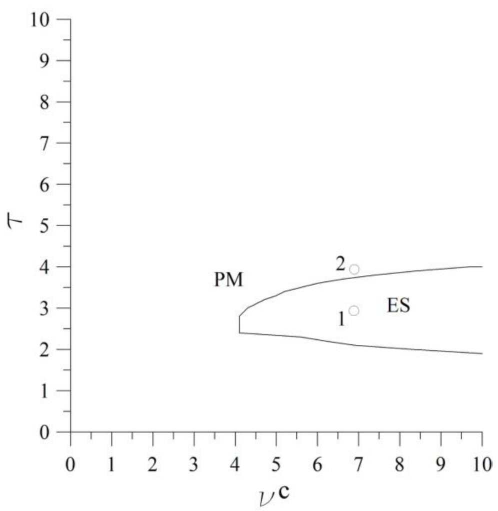

Figure 2 *Bifurcation diagram of one-block BK model in the parameter plane (τ,v^c), for v=0.1. ES and PM are abbreviations for equilibrium state and periodic motion, respectively. Time series and phase portraits for point 1 and 2 are shown in Figure 3.*

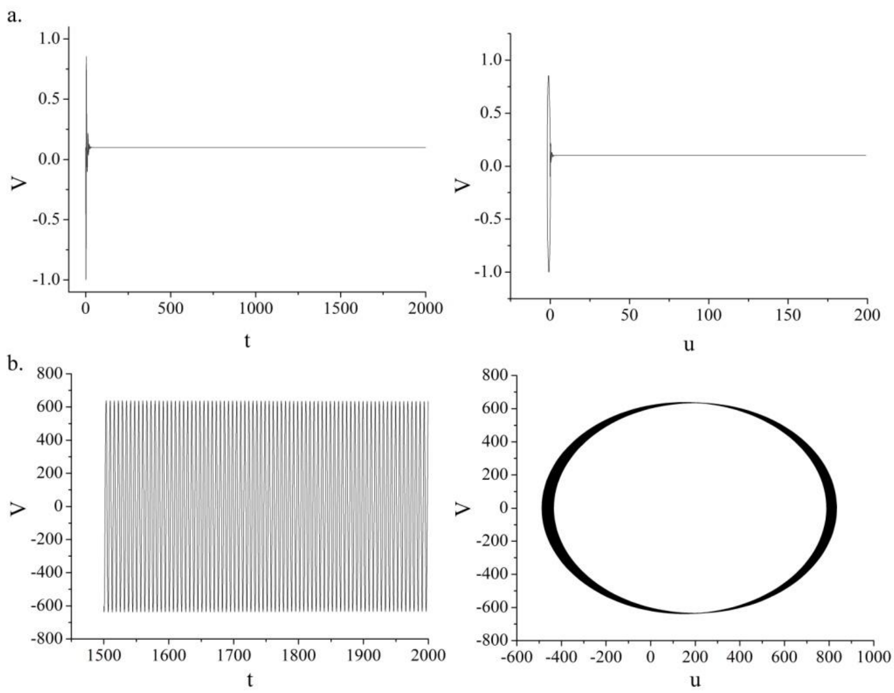

Figure 3 *Temporal behavior of variable v (velocity) and corresponding phase portrait for:* **a.** *equilibrium state (point 1 from Figure 2; $\tau=3$, $v^c=7$, $v=0.1$).* **b.** *periodic motion (point 2 from Figure 2; $\tau=4$, $v^c=7$, $v=0.1$). Variables are given as dimensionless quantities.*

Flat line (Figure 4a) and single peak (Figure 4b) in the Fourier power spectrum confirm equilibrium state and periodic-motion, respectively, for points 1 and 2 from Figure 2.

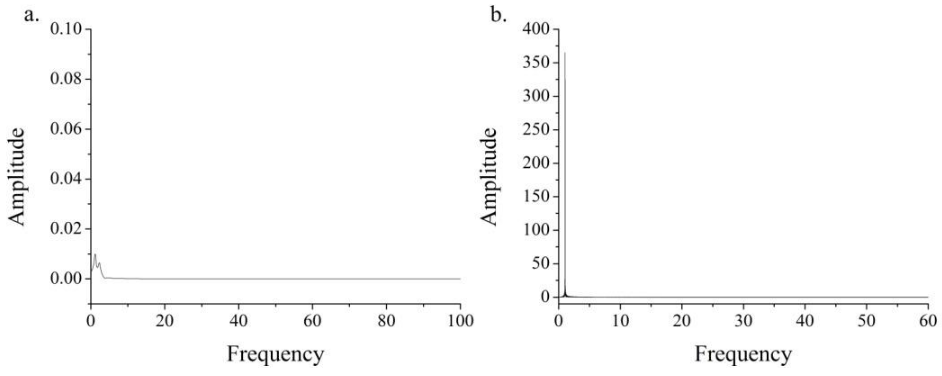

Figure 4 a. *Flat line in the Fourier power spectrum indicates equilibrium state (point 1 from Figure 2).* **b.** *Single peak in the Fourier power spectrum indicates periodic motion (point 2 from Figure 2). Parameter values are the same as in Figure 3.*

However, except for these two distinct states of studied system, relatively weak chaotic behavior is captured, but only as a transient feature. This kind of chaotic behavior is expected, since rockbursts are short-term occurrences. The corresponding time series and phase portraits for this, often seen but nongeneric phenomenon are shown in Figure 5, for the following parameter values: τ=0.7 and v^c=1.0. The Broadband noise in the Fourier power spectrum (Fig. 6a) and calculated positive maximal Lyapunov exponent (Fig. 6b) confirm the chaotic motion of studied model

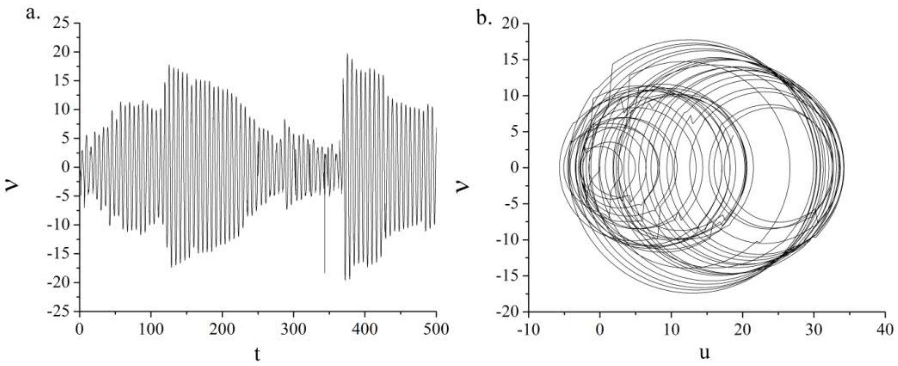

Figure 5 *Temporal behavior of variable v (a) and corresponding phase portrait (b) for the following parameter values: τ=0.7 and v^c=1.0 (chaos).*

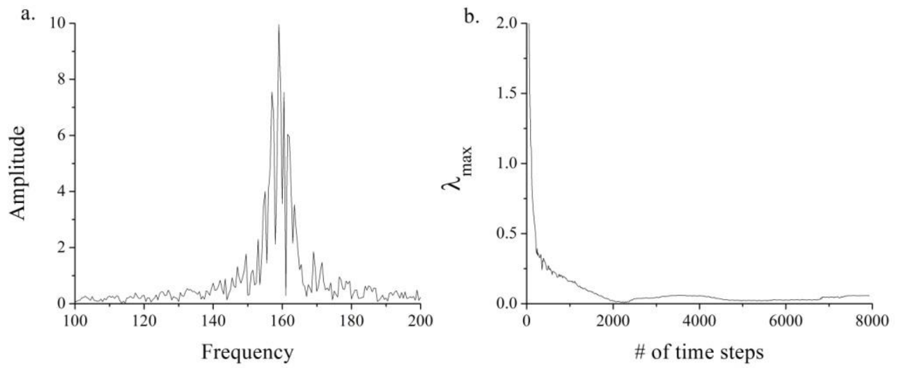

Figure 6 a. *The continuous broadband noise in the Fourier power spectrum indicates relatively weak chaotic behavior of the system.* **b.** *The maximal Lyapunov exponent converges well to λ=0.08.*

THE MADARIAGA MODEL

The second model, describing the stick-slip behavior of reactivated motion along the preexisting fault is based on the system of equations proposed by Madariaga [12]:

(3)

where

ε=(B-A)/A measures the sensitivity of velocity relaxation,

$\xi=(kL)/A$ is nondimensional spring constant, and

$\gamma=(k/M)^{1/2}(L/v_0)$ is nondimensional slip frequency.

Contrary to the previous model, where friction was dependent only on the block velocity, this model is coupled with the Dieterich-Ruina empirical law, which includes a state variable θ, enabling the model to exhibit almost entirely observed seismic behavior such as the stick-slip phenomena, fault healing and memory effects [13]. This is fully in compliance with subsequent studies which indicated that the friction term could not be a single valued function of velocity [14]. Now, the model (3) will be expanded adding the time delay term τ in the friction term. In this way, the following system of delay differential equations is obtained:

(4)

Numerical analysis shows that the model is in an equilibrium state, illustrated as fixed point in the phase portrait, without time delay and with the following values of parameters ε, ξ and γ: 0.2, 0.8 and 0.8, respectively (Figure 7a). Figure 7b indicates a periodic (oscillatory) behavior of model, presented as a limit cycle in the phase portrait, for the following values of parameters: τ =10, ε = 0.4, ξ = 0.8 and γ = 0.8. Quasiperiodic and deterministic chaotic motion of the model, for the certain parameter values, are presented in Figure 8.

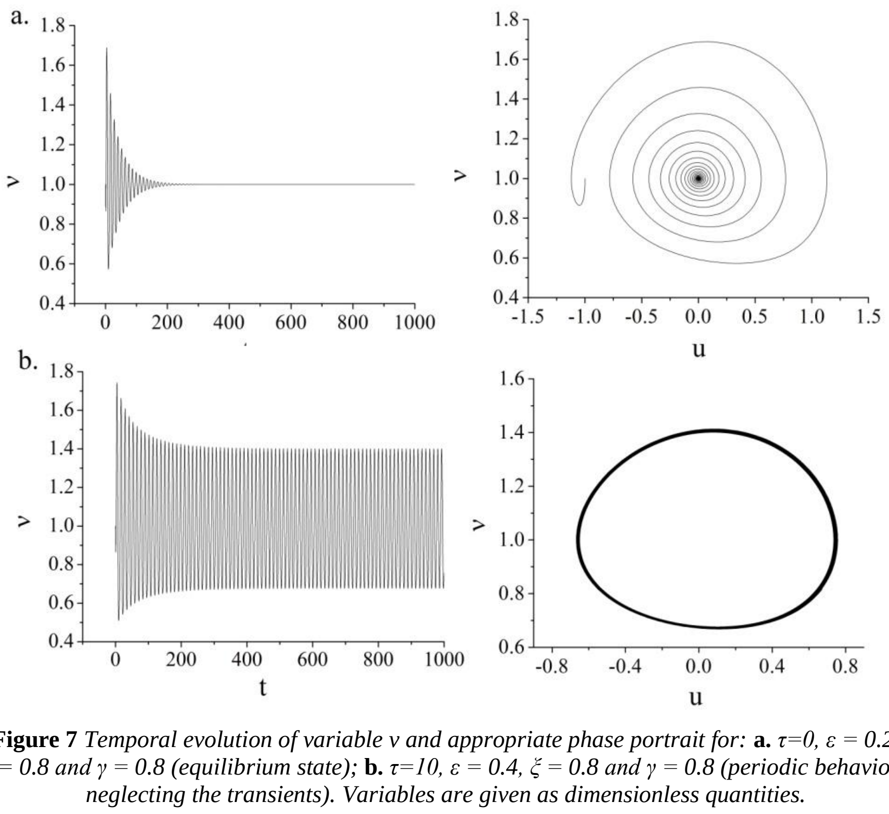

Figure 7 *Temporal evolution of variable v and appropriate phase portrait for:* **a.** *τ=0, ε = 0.2, ξ= 0.8 and γ = 0.8 (equilibrium state);* **b.** *τ=10, ε = 0.4, ξ = 0.8 and γ = 0.8 (periodic behavior, neglecting the transients). Variables are given as dimensionless quantities.*

Various dynamics of the block motion could be confirmed calculating the Fourier power spectrum for oscillations, quasiperiodic motion and chaotic orbits, shown in Figure 9. The single peak in power spectrum in Figure 9a indicates the oscillatory behavior of the system under study, while the second peak in Figure 9b indicates a presence of quasiperiodic motion. The broadband noise in Figure 9c indicates the deterministic chaotic dynamics.

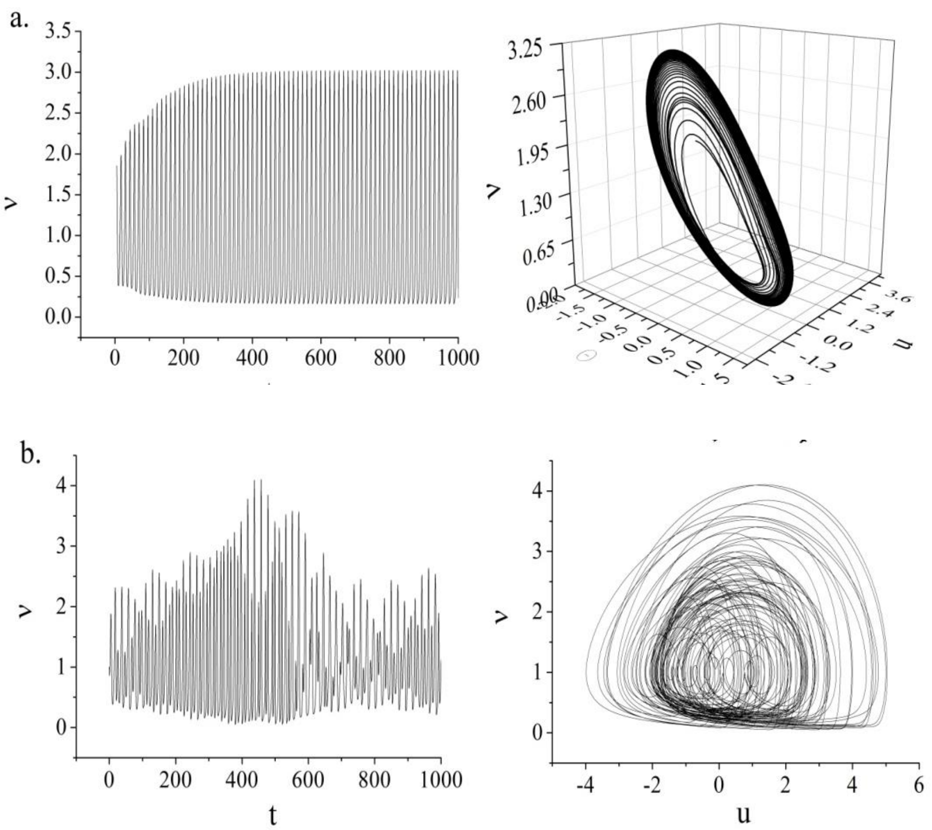

Figure 8 *Temporal evolution of variable v and appropriate phase portrait for:* **a.** *τ=12, ε = 0.5, ξ = 0.8 and γ = 0.8 (quasiperiodic motion);* **b.** *τ=16, ε = 0.8 ξ = 0.8 and γ = 0.8 (deterministic chaos). Variables are given as dimensionless quantities.*

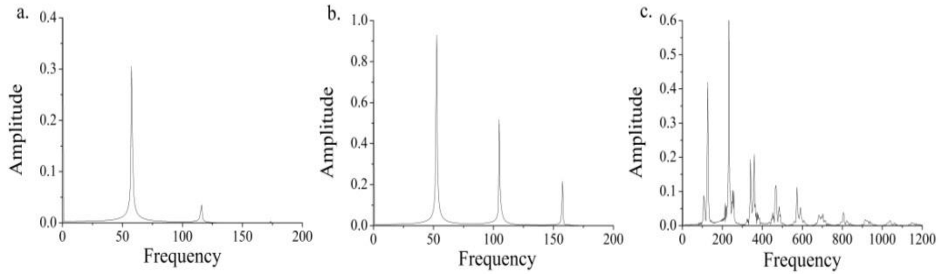

Figure 9 a. *Single peak in power spectrum indicates the oscillatory behavior of model*
b. *Two peaks in power spectrum indicate the appearance of quasiperiodic motion.*
c. *The broadband noise in the Fourier power spectrum indicates the chaotic behavior of the system.*

DISCUSSION AND CONCLUSION

In present paper, two different models of fault-slip rockburst nucleation are analyzed. In both cases, the motion of the BK model with one block is studied, coupled with different type of friction force between the block and rough surface. These original models with one block, without the introduced time delay, exhibit only the periodic motion, which makes them incompatible as models for rockburst or even tectonic earthquake nucleation. The main reason for this is that the dynamics of system must become unstable in order to generate stick-slip motion, and, conse-quently, simulate seismic event.

However, with the introduced time delay τ, which accounts the delay triggering effect of the mining excavation work, both models exhibit highly complex behavior. In the first model, this complexity is weak, since the chaotic motion appears only in the narrow regions of parameter values. On the other side, in the second model, full complexity reveals in the transition from equilibrium state, across the periodic and quasiperiodic motion to deterministic chaos. This kind of motion is a natural consequence of more complex friction law, which is assumed in the second model.

Based on the obtained results, a model was chosea as more convenient for describing the rockburst nucleation. The main reason for this is the complexity of the Dieterich-Ruina friction law, which takes into account various parameters of system, in contrast to the simple velocity dependent friction law in the first case. Moreover, the Madariaga model takes into account the stress changes before and during the block motion, which could be related to the stress changes induced by mining excavations. This stress changes are described by parameter ε (Figure 10), which represents the relation between the stress decrease during the block motion and the stress increase during the stick phase (when the upper plate starts to act on the block). The higher the parameter ε, the higher the value of friction coefficient along the preexisting fault. In this case, highly complex, unstable, deterministic chaotic dynamics of the model is obtained for $\varepsilon < 1$, indicating the possibility of motion along the weak preexisting fault, initiated by a stress increase, induced by some external factor (mining excavation in this case).

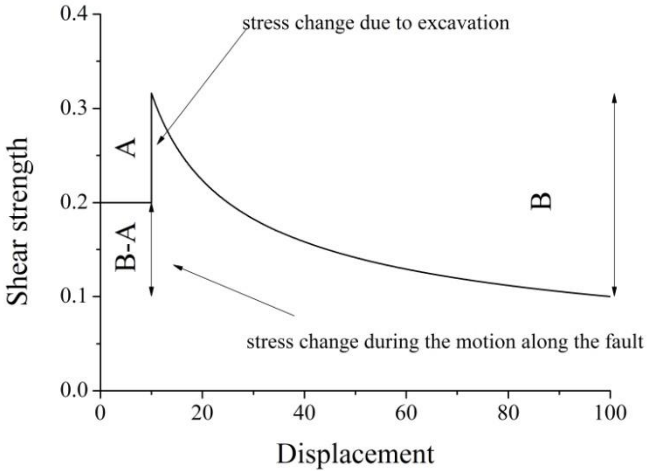

Figure 10 *A schematic illustration of step change in stress of the spring-block model, illustrated in Figure 1. The stress change during the motion is highly idealized and it generally differs for various rock types. However, the previous studies have shown that the Dieterich-Ruina friction law corresponds well with the experimentally obtained results.*

Also, the Dieterich-Ruina friction law incorporates the state variable θ, which describes the state of contact surface between the block and lower plate. Since the movement along the fault commonly induces many different mechanisms (flash heating, frictional melting and thermal pressurization, lubrication by silica-gel production, and effects of granular friction), the contact surface is highly complex, and it has a crucial effect on the motion along the fault. These effects are emphasized in this paper introducing the time delay τ. In the next phase of our work, research will be expanded by the use of analyzing model with two blocks. Moreover, this idea is to include the strength parameter C in the friction term, and then, by simultaneously varying both parameters, C and τ, to estimate the dynamics of studied BK model.

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GRANULOMETRIJSKI SASTAV POLAZNOG UZORKA KLASE KRUPNOĆE -3,35 mm – FAKTOR POUZDANOSTI BOND-OVOG RADNOG INDEKSA MELJIVOSTI[***]

Izvod

Istraživanja Bond-ovog radnog indeksa meljivosti na siromašnoj i bogatoj rudi bakra RB Bor dala su dva, za teoriju i praksu procesa mlevenja, značajna rezultata. Jedan potvrđuje prethodna teorijska i praktična iskustva na ovim sirovinama, a to je, nešto veća otpornost usitnjavanja siromašne u odnosu na bogatu rudu bakra W_i^s *= 14,11 kWh/t, odnosno* W_i^{bs} *= 13,35 kWh/t. Drugi rezultat ukazuje na uticaj granulometrijskog sastava polaznog uzorka za određivanje Bond-ovog radnog indeksa klase krupnoće -3,35 mm, na vrednost ovog pokazatelja,* W_i^b *= 16,28 kWh/t tj.* W_i^{bs} *= 13,35 kWh/t. Mala razlika u otpornosti prema usitnjavanju ispitivanih ruda bakra daje mogućnost zajedničke prerade ovih sirovina. Konstatovani uticaj granulometrijskog sastava polaznog uzorka na vrednost Bond-ovog radnog indeksa, pored teorijskog ima i veliki praktičan značaj pri projektovanju i izboru procesne opreme u procesu mlevenja. Istraživanja kinetike mlevenja siromašne i bogate rude bakra, kao i različita vremena potrebna za dobijanje proizvoda mlevenja određene finoće potvrđuju prethodnu konstataciju.*

Ključne reči: *ruda bakra, kinetika, meljivost, Bond, prerada.*

1. UVOD

Jama rudnika bakra Bor raspolaže sa značajnim rezervama siromašne rude bakra, sa sadržajem bakra od oko 0,95 - 1 %, i manjim rezervama, nekoliko stotina hiljada tona koje su u fazi eksploatacije, bogate rude sa sadržajem bakra od 2 – 5 %, zlata 1- 3 g/t u pojedinim delovima ležišta i znatno više, i srebra od 2,7 - 7,23 g/t.

Ideja o homogenizaciji navedenih sirovina u određenim masenim odnosima radi zajedničke prerade, tehnički je prihvatljiva, međutim, tehnološku opravdanost zajedničke prerade navedenih sirovina neophodno je detaljno istražiti i verifikovati. Tehnološku opravdanost zajedničke prerade siromašne i bogate rude potrebno je sagledati sa dva aspekta. Prvi se odnosi na mogućnost i opravdanost zajedničke pripreme, koja se prevashodno odnosi na mlevenje i klasiranje, dok je drugi aspekt, sagledavanje opravdanosti zajedničkog flotiranja.

U ovom radu su prezentovani rezultati istraživanja otpornosti prema usitnjavanju i kinetika procesa mlevenja siromašne i

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[***] *U ovom radu su prikazani rezultati projekata TR 33007 „Implementacija savremenijih tehničko-tehnoloških i ekoloških rešenja u postojećim proizvodnim sistemima Rudnika bakra Bor i Rudnika bakra Majdanpek“ i TR 33038 „Usavršavanje tehnologija eksploatacije i prerade rude bakra sa monitoringom životne i radne sredine u RTB Bor Grupa“ finansiranih od strane Ministarstva prosvete, nauke i tehnološkog razvoja Republike Srbije.*

bogate rude, sa ciljem sagledavanja tehnološke opravdanosti zajedničke pripreme, odnosno zajedničkog mlevenja i klasiranja.

2. EKSPERIMENTALNI DEO

2.1. Materijal

Snimanjem industrijskog procesa drobljenja u pogonu Rudnika bakra Bor, izuzeti su reprezentativni uzorci definitivnog proizvoda drobljenja siromašne i bogate rude, gornje granične krupnoće 35 mm.

2.2. Oprema i postupci korišćeni u eksperimentima

Granulometrijski sastav svih uzoraka koji su bili predmet ispitivanja određivan je sitovnom analizom mokrim ili suvim postupkom na sitima odabrane veličine otvora, serije Tyler. Opiti mokrog prosejavanja izvođeni su primenom mehaničkog vibracionog uređaja određene frekvence. Suvo prosejavanje uzoraka vršeno je takođe mehaničkim vibracionim uređajem primenom za suvo prosejavanje [Magdalinović, 1985].

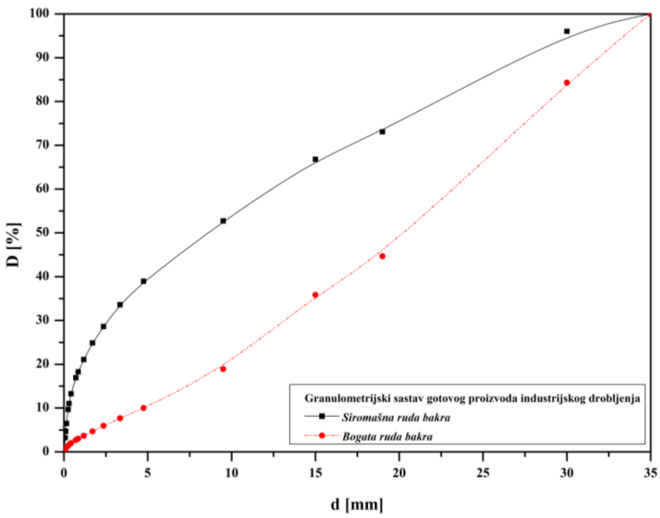
Određivanje Bond-ovog radnog indeksa meljivosti vršeno je u Bond-ovom mlinu sa kuglama postupkom suvog mlevenja [Bond, 1949, 1952, 1961]. Kao metod za određivanje Bond-ovog radnog indeksa korišćen je skraćeni postupak, prof. N. Magdalinovića [Magdalinović, 1989].

Ispitivanja kinetika mlevenja vršena su u cilindričnom laboratorijskom mlinu sa kuglama dimenzija (DxL) = (400x125 mm) i brojem obrtaja n = 60 min^{-1}. Svi opiti mlevenja su vršeni na mokro, sa istom masom i granulometrijskim sastavom šarže, istim masama uzoraka i sadržajem čvrstog u pulpi.

3. REZULTATI I DISKUSIJA

3.1. Granulometrijski sastavi siromašne i bogate rude bakra

Uzorci definitivnog proizvoda drobljenja siromašne i bogate rude su prosejani suvim postupkom na odabranoj seriji sita, a rezultati ispitivanja prezentovani dijagramima na slici 1.



Sl. 1. *Granulometrijski sastav gotovog proizvoda industrijskog drobljenja siromašne i bogate rude bakra*

Rezultati ispitivanja pokazuju veliku razliku u granulometrijskim sastavima definitivnih proizvoda drobljenja siromašne i bogate rude bakra. Definitivan proizvod drobljenja siromašne rude bakra je znatno sitnozrniji, što se jasno zapaža kako na prikazanim dijagramima, tako i preko karakteristika krupnoće, srednjeg prečnika širokog raspona krupnoće, D_{sr} (jednačina 1).

$$D_{sr} = \frac{\sum_{i=1}^{n} W_i}{\sum_{i=1}^{n} \frac{W_i}{d_{si}}}, \text{ mm} \qquad (1)$$

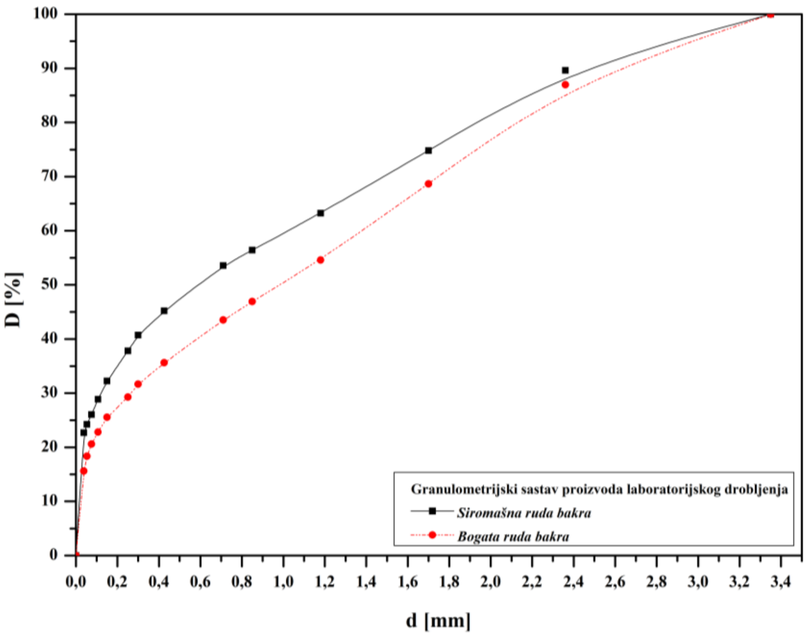
gde su:

D_{sr} – srednji prečnik smeše zrna, (mm)
W_i – učešće uske klase krupnoće, (%)
d_{si} – srednji prečnik uske klase krupnoće, (mm)

Vrednosti ovih značajnih pokazatelja su, za siromašnu rudu, D^s_{sr} = 0,602 mm, a za bogatu D^b_{sr} = 3,125 mm.

Konstatovana, velika razlika, u granulometrijskim sastavima siromašne i bogate rude, može, ali i ne mora biti posledica različite otpornosti prema usitnjavanju pojedinih sirovina. Razlog tome je mogućnost da su pojedine rudne sirovine u ležištu ili u fazi eksploatacije, miniranju i otkopavanju, veoma različitih granulometrijskih karaktersitika, tako, da i relativno selektivno usitnjavanje u procesu drobljenja nije dovelo do ujednačavanja granulometrijskih karakteristika definitivnih proizvoda drobljenja ispitivanih sirovina. Dalja priprema siromašne i bogate rude za definisanje Bond-ovog radnog indeksa i kinetika mlevenja vršena je laboratorijskim usitnjavanjem sirovine u čeljusnoj drobilici do GGK 3,35 mm.

Proizvodi drobljenja siromašne i bogate rude u laboratorijskoj čeljusnoj drobilici prosejani su na odabranoj seriji sita, a granulometrijski sastavi prikazani dijagramima na slici 2.



Sl. 2. *Granulometrijski sastavi proizvoda laboratorijskog drobljenja siromašne i bogate rude, odnosno polaznih uzoraka za određivanje Bond-ovog indeksa meljivosti*

Definisanjem karakteristika krupnoće proizvoda drobljenja u laboratorijskoj čeljusnoj drobilici, siromašne i bogate rude, preko istih pokazatelja, D^s_{sr} = 0,071 mm, D^b_{sr} = 0,095 mm može se konstatovati razlika u granulometrijskim sastavima.

Smanjenja razlike u granulometrijskim sastavima proizvoda drobljenja laboratorijske čeljusne drobilice siromašne i bogate rude u odnosu na iste karakteristike ulaznih sirovina, dijagrami na slici 2, ne mogu se eksplicitno pripisati različitim otpornostima usitnjavanja siromašne i bogate rude. Ova pojava je u manjoj ili većoj meri uslovljena dominantno selektivnim usitnjavanjem ispitivanih sirovina u laboratorijskoj čeljusnoj drobilici.

Sagledavanje opravdanosti zajedničke pripreme, mlevenja i klasiranja, siromašne i bogate rude bakra sa stanovišta obezbeđivanja optimalne finoće gotovog proizvoda mlevenja, bez opasnosti od preusitnjavanja jedne od zastupljenih sirovina, moguće je pouzdanije sagledati određivanjem Bond-ovog radnog indeksa i kinetike procesa mlevenja ispitivanih sirovina.

3.2. Bond-ov radni indeks meljivosti siromašne i bogate rude bakra

Bond-ova teorija usitnjavanja je široko prihvaćena u teoriji i praksi procesa usitnjavanja prirodnih sirovina. Prema istoj, energija usitnjavanja se definiše relacijom:

$$W = W_i \cdot \left(\frac{10}{\sqrt{P}} - \frac{10}{\sqrt{F}} \right), \quad \text{(kWh/Sht)} \tag{2}$$

gde su:

W - specifična potrošnja energije, (kWh/Sht)

W_i - Bond-ov radni indeks koji karakteriše meljivost (drobljivost) sirovine, (kWh/Sht)

F – veličina otvora sita kroz koje prolazi 80 % sirovine pre usitnjavanja, (μm)

P – veličina otvora sita kroz koje prolazi 80 % sirovine posle usitnjavanja, (μm).

Bond-ov radni indeks (W_i), je materijalna konstanta koja se utvrđuje laboratorijskim ispitivanjima po proceduri i u uređaju koji je definisao F.C. Bond [Bond, 1949, 1952, 1961].

Kao metod za određivanje Bond-ovog radnog indeksa meljivosti korišćen je skraćeni postupak, prof. N. Magdalinovića [Magdalinović, 1985; 1989].

Rezultati ispitivanja meljivosti siromašne i bogate rude bakra dati su u tabeli 1.

Tabela 1. *Rezultati ispitivanja meljivosti siromašne i bogate rude bakra*

Sirovina	Opit	Bond-ov radni indeks meljivosti W_i (kWh/t)	W_{isr} (kWh/t)
Siromašna ruda bakra	1	14,21	14,11
	2	14,15	
	3	13,98	
Bogata ruda bakra	1	16,20	16,28
	2	16,34	
	3	16,31	

Rezultati istraživanja pokazuju da bogata ruda bakra poseduje veću otpornost prema usitnjavanju. Bond-ov radni indeks meljivosti bogate rude, W_i^b = 16,28 kWh/t u odnosu na isti pokazatelj za siromašnu rudu bakra, W_i^s = 14,11 kWh/t, ima za oko 13,33 %, veću vrednost.

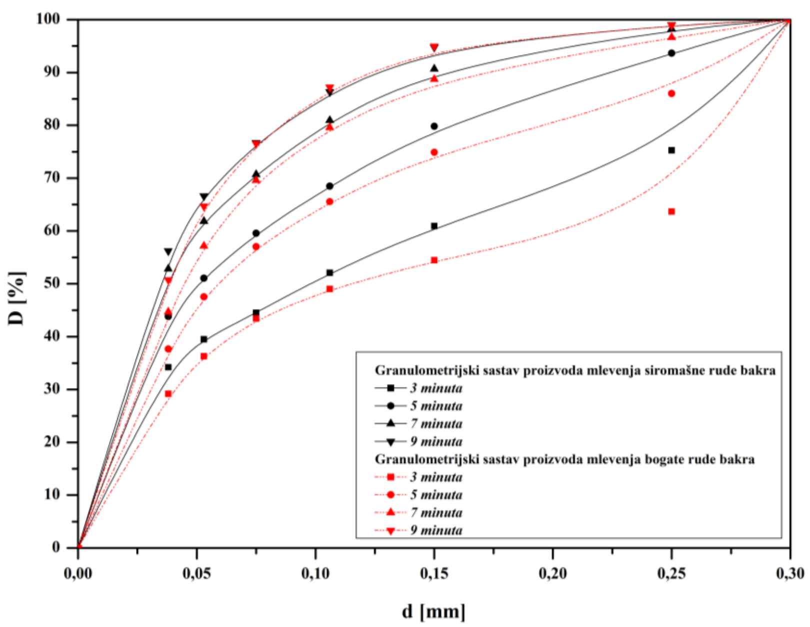
Dobijeni rezultati ispitivanja su u suprotnosti sa dosadašnjim naučnim istraživanjima i praktičnim iskustvima na ovim tipovima sirovina i shodno tome upućuju na potrebu daljih istraživanja u cilju razjašnjenja ove pojave.

3.3. Kinetika mlevenja siromašne i bogate rude bakra

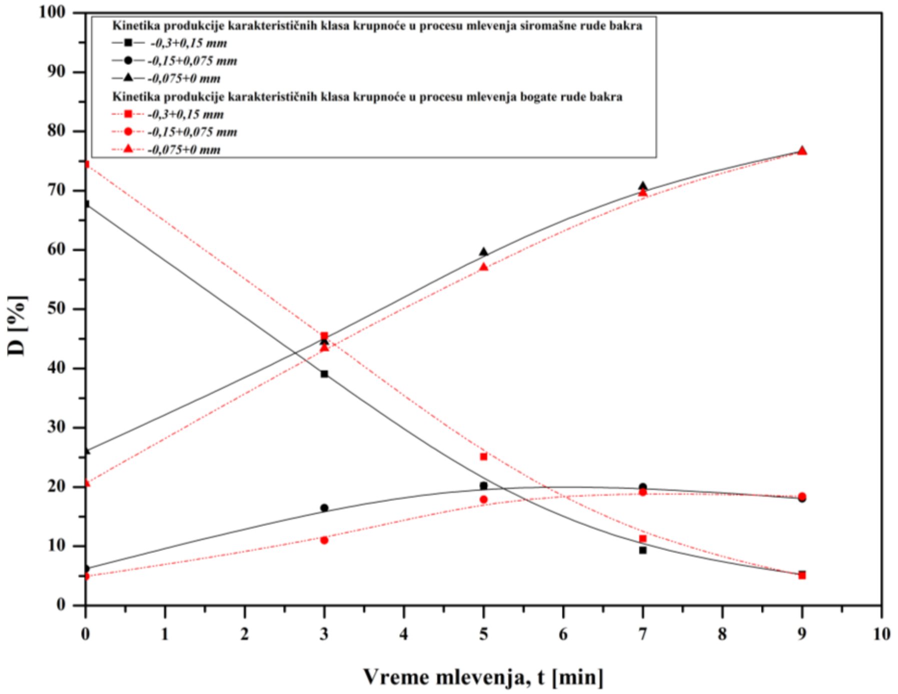
Mlevenje siromašne i bogate rude bakra vršeno je mokrim postupkom u laboratorijskom mlinu sa kuglama pri identičnim tehničko-tehnološkim parametrima. Opiti mlevenja su izvođeni u vremenskim trajanjima od 3; 5; 7 i 9 minuta. Proizvodi mlevenja svakog opita na siromašnoj i bogatoj rudi prosejavani su na odabranoj seriji sita, definišući učešća, za naša istraživanja, karakterističnih klasa krupnoće. Na slici 3, dijagramima su prikazane uporedne vrednosti granulometrijskih sastava proizvoda mlevenja siromašne i bogate rude bakra nakon mlevenja u trajanju od 3; 5; 7 i 9 minuta, a na slici 4, kinetike produkcije karakterističnih klasa krupnoće u opitima mlevenja istih sirovina.

Veća otpornost prema usitnjavanju bogate u odnosu na isti pokazatelj za siromašnu rudu bakra, definisana Bond-ovim radnim indeksom meljivosti, W_i^b = 16,28 kWh/t, odnosno W_i^s = 14,11 kWh/t, koja nije u saglasnosti sa dosa-dašnjim iskustvima na ovim sirovinama, upućuje na potrebu dodatnih istraživanja ove pojave. Potrebu za istraživanjem ove pojave potvrđuju rezultati kinetika mlevenja siro-mašne i bogate rude, dijagrami na slikama 3 i 4.

Uporednom analizom dijagrama granulometrijskih sastava proizvoda mlevenja siromašne i bogate rude, nakon mlevenja u istim vremenskim intervalima, zapaža se nekoliko karakterističnih pojava. Svi proizvodi mlevenja siromašne rude bakra su finozrniji od istih dobijenim mlevenjem bogate rude, što može ukazivati na manju otpornost prema usitnjavanju siromašne rude bakra. Međutim, smanjenje razlika u granulometrijskim sastavima u funkciji povećanja vremena mlevenja indiciraju suprotnu tvrdnju.



Sl. 3. *Dijagrami granulometrijskih sastava proizvoda mlevenja siromašne i bogate rude bakra*



Sl. 4. *Dijagrami kinetike produkcije karakterističnih klasa krupnoće u procesu mlevenja siromašne i bogate rude*

Različito ponašanje siromašne i bogate rude bakra u procesu mlevenja potvrđuju i različite brzine smanjenja učešća najkrupnijih, +0,15 mm, i različite brzine nastajanja najfinijih klasa krupnoće, -0,075 mm, u funkciji vremena mlevenja, dijagrami na slici 4. Brzine smanjenja učešća najkrupnije klase i brzina nastajanja najfinije klase krupnoće su izraženije pri mlevenju bogate u odnosu na mlevenje siromašne rude bakra. Ova konstatacija nedvosmisleno ukazuje da bogata ruda bakra ima manju otpornost prema usitnjavanju u odnosu na siromašnu rudu, što je u suprotnosti sa rezultatima ispitivanja meljivosti preko definisanja vrednosti Bond-ovog radnog indeksa. Razjašnjenje ove pojave potražićemo u pravcu sagledavanja uticaja granulometrijskog sastava polaznog uzorka klase krupnoće -3,35+0 mm na vrednost Bond-ovog radnog indeksa meljivosti.

3.4. Uticaj granulometrijskog sastava polaznog uzorka klase krupnoće -3,35+0 mm, na vrednost Bond-ovog radnog indeksa meljivosti

Suprotstavljene pokazatelje meljivosti siromašne i bogate rude bakra definisane Bond-ovim radnim indeksom meljivosti i kinetikama procesa mlevenja istih sirovina istražićemo sagledavanjem uticaja granulometrijskog sastava polaznog uzorka klase krupnoće -3,35+0 mm. Za ova istraživanja formiran je novi, sintetički uzorak bogate rude bakra GGK -3,35 mm, indentičnog granulometrijskog sastava, granulometrijskom sastavu siromašne rude bakra koja je bila predmet predhodnih ispitivanja.

Na novom, sintetičkom uzorku bogate rude bakra određen je Bond-ov radni indeks meljivosti i definisane kinetike mlevenja, sa ciljem upoređivanja dobijenih rezultata sa rezultatima prethodnih istraživanja.

3.5. Bond-ov radni indeks meljivosti sintetičkog uzorka bogate rude bakra

Primenom istog metoda za određivanje Bond-ovog radnog indeksa meljivosti, po skraćenom postupku prof. N. Magdalinovića, na sintetičkom uzorku bogate rude bakra određene su vrednosti ovog pokazatelja.

U tabeli 2, date su uporedne vrednosti Bond-ovog radnog indeksa za siromašnu i bogatu rudu bakra, rezultati predhodnih ispitivanja, i vrednosti istog pokazatelja za sintetički uzorak bogate rude bakra.

Uporednom analizom rezultata istraživanja može se zaključiti da bogata ruda bakra istih granulometrijskih karakteristika polaznog uzorka ima manju otpornost prema usitnjavanju u odnosu na siromašnu rudu. Vrednost Bond-ovog radnog indeksa meljivosti bogate rude je W_i^{bs} = 13,35 kWh/t, što je u odnosu na isti pokazatelj za siromašnu rudu, W_i^{s} = 14,11 kWh/t, manja vrednost za 0,76 kWh/t, odnosno oko 5,38 %.

Tabela 2. *Rezultati ispitivanja meljivosti siromašne, bogate i sintetičkog uzorka bogate rude bakra.*

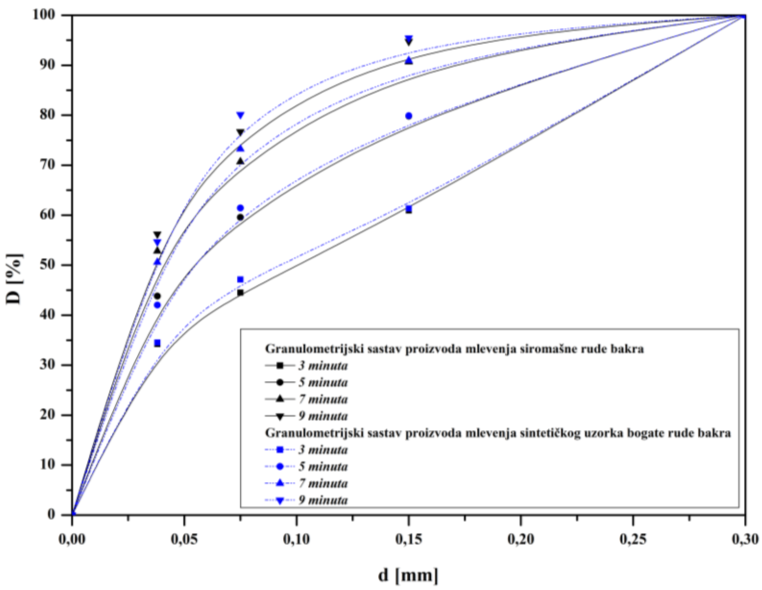
Sirovina	Opit	Bond-ov radni indeks meljivosti W_i (kWh/t)	$W_{i\ sr}$ (kWh/t)
Siromašna ruda bakra	1	14,21	14,11
	2	14,15	
	3	13,98	
Bogata ruda bakra	1	16,20	16,28
	2	16,34	
	3	16,31	
Sintetički uzorak bogate rude	1	13,42	13,35
	2	13,26	
	3	13,37	

Dobijena, manja vrednost Bond-ovog radnog indeksa meljivosti za bogatu rudu bakra u odnosu na siromašnu rudu je u skladu sa dosadašnjim naučnim rezultatima i praktičnim iskustvima ostvarenim na ovim sirovinama.

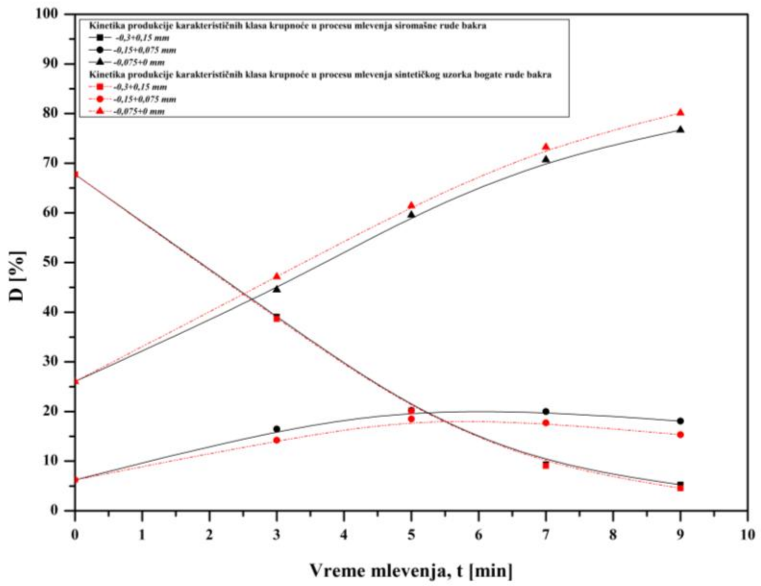
Razlika između vrednosti Bond-ovog radnog indeksa meljivosti bogate rude bakra u svom primarnom, industrijskom obliku pojavljivanja W_i^{b} = 16,28 kWh/t i sintetičkom uzorku iste sirovine W_i^{bs} = 13,35 kWh/t, je posledica različitog granulometrijskog sastava polaznog uzorka. Na ovom primeru razlika u vrednosti Bond-ovog radnog indeksa meljivosti na istoj sirovini je za 2,93 kWh/t, odnosno 18 %, što može dovesti do niza nepouzdanih zaključaka i negativnih inplikacija u praktičnoj primeni.

3.6. Kinetike mlevenja siromašne i bogate rude bakra istih granulometrijskih karakteristika

Istim postupkom i na indentičan način, kao u predhodnoj fazi istraživanja, vršeno je mlevenje uzoraka siromašne i bogate rude istih granulometrijskih karakteristika. Uporedne vrednosti granulometrijskih sastava proizvoda mlevenja uzoraka siromašne rude i sintetičkih uzoraka bogate rude bakra dobijenim pri različitim vremenima mlevenja prikazane su dijagramima na slici 5, a kinetike smanjenja učešća najkrupnije i nastajanja finijih klasa krupnoće u procesu mlevenja istih sirovina u funkciji vremena, date su dijagramima na slici 6.



Sl. 5. *Dijagrami granulometrijskih sastav proizvoda mlevenja siromašne i sintetičkog uzorka bogate rude*



Sl. 6. *Dijagrami kinetike produkcije karakterističnih klasa krupnoće u procesu mlevenja siromašne i sintetičkog uzorka bogate rude*

Za ostvarivanje proizvoda mlevenja zahtevane finoće, 60 % učešća klase – 0,075mm, potrebno vreme mlevenja siromašne rude je 5,15 minuta, a bogate 4,85 minuta, slika 6.

Nešto finiji granulometrijski sastav proizvoda mlevenja i nešto kraće vreme potrebno za ostvarivanje zahtevane finoće gotovog proizvoda mlevenja bogate rude bakra, za oko 0,30 minuta, potvrđuju rezultate ispitivanja otpornosti usitnjavanja definisane Bond-ovim radnim indeksom na sintetičkom uzorku iste sirovine.

4. ZAKLJUČAK

Razlike u granulometrijskim sastavima definitivnih industrijskih proizvoda drobljenja, definisanih srednjim prečnicima širokog raspona krupnoće, D^s_{sr} = 0,602 mm, za siromašnu i D^b_{sr} = 3,125 mm, za bogatu rudu bakra, slika 1, uslovile su razlike u istim karakteristikama i polaznih uzoraka za određivanje Bond-ovog radnog indeksa meljivosti GGK 3,35 mm, D^s_{sr} = 0,071 mm, odnosno D^b_{sr} = 0,095 mm.

Naknadna istraživanja su pokazala da naznačena razlika u granulometrijskim sastavima polaznih uzoraka GGK 3,35 mm utiče na eksperimentalne vrednosti Bond-ovog radnog indeksa meljivosti.

Vrednosti Bond-ovog radnog indeksa uzorka bogate rude bakra definitivnog proizvoda industrijskog drobljenja, pripremljenog standardnim postupkom sa srednjim prečnikom D^b_{sr} = 0,095 mm, iznosi W_i^b = 16,28 kWh/t, dok je za istu sirovinu, srednjeg prečnika polaznog uzorka D^{bs}_{sr} = 0,071 mm, W_i^{bs} = 13,35 kWh/t. Razlika u vrednosti Bond-ovog radnog indeksa meljivosti od 2,93 kWh/t, odnosno oko 18 %, je sa aspekta praktične primene, u projektovanju i izboru opreme u procesu mlevenja i klasiranja ispitivanih sirovina od velikog, kako tehničko-tehnološkog, tako i ekonomskog značaja. Pored praktičnog značaja, rezultati istraživanja koji pokazuju uticaj granulometrijskog sastava polaznog uzorka za određivanje Bond-ovog radnog indeksa meljivosti, GGK 3,35 mm, na eksperimentalnu vrednost ovog pokazatelja, doprinose i teoriji procesa usitnjavanja, kako sa stanovišta boljeg razumevanja, tako i pouzdanije praktične primene.

Određivanjem vrednosti Bond-ovog radnog indeksa meljivosti siromašne i bogate rude bakra jednakih granulometrijskih karakteristika polaznih uzoraka, GGK 3,35 mm, D_s = 0,071 mm, dobijene su vrednosti W_i^s = 14,11 kWh/t, za siromašnu i W_i^{bs} = 13,35 kWh/t za bogatu rudu bakra.

Razlika u vrednostima Bond-ovih radnih indekasa meljivosti od 0,76 kWh/t, odnosno nekih 5,38 %, u korist siromašne rude, potvrđuje nešto veću otpornost prema usitnjavanju ove sirovine u odnosu na bogatu rudu bakra, što je u skladu sa dosadašnjim rezultatima istraživanja na ovim sirovinama.

Nešto veća otpornost prema usitnjavanju definisanog Bond-ovim radnim indeksom, potvrđena je eksperimentima kinetika mlevenja istih sirovina, slika 6. Za ostvarivanje gotovog proizvoda mlevenja finoće 60 % učešća klase – 0,075 mm, za siromašnu rudu bakra potrebno je duže vreme mlevenja za oko 0,30 minuta. Relativno mala razlika u otpornosti prema usitnjavanju, kinetici mlevenja, kao i činjenici nejednakih i promenljivih granulometrijskih sastava definitivnih industrijskih proizvoda drobljenja ispitivanih sirovina, siromašne i bogate rude bakra, upućuju na mogućnost zajedničke pripreme, mlevenja i klasiranja, bez bojazni preusitnjavanja ili nedovoljnog usitnjavanja bilo koje od njih. Konačna potvrda opravdanosti zajedničke prerade, pripreme i flotacijske koncentracije siromašne i bogate rude bakra, moguća je nakon detaljnih sagledavanja flotabilnosti i drugih karakteristika značajnih za proces flotiranja, svake od ispitivanih sirovina.

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GRAIN-SIZE DISTRIBUTION OF STARTING SAMPLE OF SIZE CLASS -3.35 mm - RELIABILITY FACTOR OF THE BOND WORK INDEX OF GRINDABILITY[***]

Abstract

The investigation of the Bond' work index of grindability of low-grade and high-grade copper ore from the Copper Mine Bor has given two, for the theory and practice of comminution processes, significant results. The first confirms the previous theoretical and practical experiences on these raw materials, which is slightly higher fragmentation resistance of low-grade copper ore, compared to high-grade copper ore W_i^p=14.11 kWh/t and W_i^{rs}=13.35 kWh/t, respectively. The second result indicates the effect of grain-size distribution of starting sample, size class -3.35 mm, for determination the Bond' work index -3.35 mm size class, on the values of Bond work index, W_i^r=14.11 kWh/t and W_i^{rs}=13.35 kWh/t. The slight difference in resistance to fragmentation of tested copper ore samples gave the possibility of common processing of these raw materials. The stated effect of grain-size distribution of starting sample on the value of Bond work index, has a theoretical as well as a practical significance in designing and selection of process equipment in the grinding process. The grinding kinetics of low-grade and high-grade copper ore, as well as different times, required to obtain the grinding products of certain fineness confirm the previous statement.

Keywords: *copper ore, kinetics, grinding, Bond, processing*

1 INTRODUCTION

The Jama of the Copper Mine in Bor has significant reserves of low-grade copper ore in ore body "Brezonik", with the average copper content of about 0.95 to 1%, and small reserves with 239,000 tons in the orebody T, with the average copper content of 5.095 % and high gold content of 2.621 g / t of ore and silver from 2.7 to 7.23 g / t, which are in the process of exploitation.

Homogenization of these materials in certain mass ratios for common processing of low-grade and high-grade copper ore in the Flotation Plant in Bor is technically acceptable. However, the technological justifications for common processing the both copper ores, it is necessary carefully investigate, verified and consider thesame from two aspects. The first is related to the

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[***] *This paper presents the results of the Projects TR 33007 "Implementation of Modern Technological and Environmental solutions in the Existing Production Systems of the Copper Mine Bor and Copper Mine Majdanpek" and TR 33038 "Improvement the Technology of Mining and Processing of Copper Ore with Monitoring the Environmental and Working in RTB Bor Group", funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia. The authors acknowledge the mentioned Ministry for the financial support.*

possibility of common preparation and justification, which is primarily related to the grinding and classification, while the second aspect, the common perception justification flotation.

This paper presents the research results of grindability and kinetics of grinding for low-grade and high-grade copper ore, with the aim to consider the technological feasibility of common preparation and processing as well as grinding and classification.

2 EXPERIMENTAL PART

2.1 Material

Two different copper ore samples, taken as the final products of industrial crushing of low-grade and high-grade copper ore in the Flotation Plant Bor were used as the experimental materials.

2.2 Equipment and Methods

Grain-size of samples was determined by the wet and dry sieve method, using the standard laboratory sieves of Tyler series. The wet and dry sieving was performed using a mechanical vibratory device with specific frequency [Magdalinović, 1985].

The standard Bond work index of grindability test was carried out in a closed-cycle dry grinding and screening process, which is carried out until steady state condition is obtained [Bond, 1949, 1952, 1961]. As a method for determination the Bond work index, the account procedure by prof. N. Magdalinović [Magdalinović, 1989] was used. The Bond grindability test for determining the Bond work index, W_i, is conducted in the Bond ball mill, size D×L= 305×305 mm, and number of revolution of 70 min^{-1}. The mill is loaded with balls from 15.5 up to 30.6 mm in diameter, having thus the total mass of 20.125 kg.

Testing the kinetics of grinding were conducted in a cylindrical laboratory ball mill size (DXL) = (400x125 mm) and the number of revolutions n = 60 min^{-1}. All tests were carried out on wet, with equal the ball charge in the mill and the mass distribution of the ball sizes fractions as well as the ore mass and tsolid content in the pulp.

3 RESULT AND DISCUSSION

3.1 Grain size distribution of low-grade and high-grade copper ore

The samples of final product were sieved by dry procedure on a series of standard sieves down to 35 mm. The obtained results are presented in Table 1.

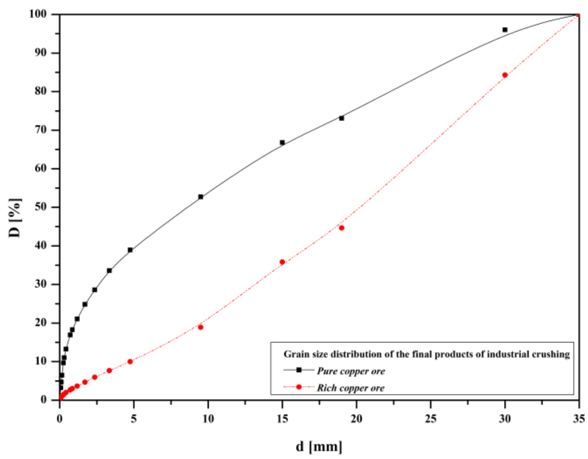

Figure 1 *Grain-size distribution of the final product of industrial crushing the low-grade and high-grade copper ore*

Test results showed a great difference in the grain-size distribution of final products of crushing low-grade and high-grade copper ore. The final crushing product of low-grade copper ore is much finer that it is observed in present diagrams (Figure 1), as well as the mean diameter over a wide size range, D_{av} (equation 1).

$$D_{av} = \frac{\Sigma_{i=1}^{n} W_i}{\Sigma_{i=1}^{n} \frac{W_i}{d_{avi}}}, \text{ mm} \qquad (1)$$

where:

- D_{av} - mean diameter of grain mixture, (mm)
- W_i - participation of narrow grain-size fraction (%)
- D_{avi} - mean diameter of narrow grain-size fraction(mm)

Values of tgrain mean diameter are 0.602 mm and 3.125 mm for low-grade and high-grade copper ore, respectively. It was concluded that a great difference in the grain-size distribution of low-grade and high-grade copper ore, may or may not be due to the different grindability of raw materials. The reason for this is a very different granulometric characteristic of raw materials, in the ore body and in the exploitation phase, blasting and excavation. Therefore, a relatively selective comminution in the crushing process did not lead to homogenization of granulometric characteristics of the final product of crushing the tested materials. Further preparation of low-grade and high-grade copper ore, for determination of the Bond work index and kinetics of grinding, was performed in the closed-cycle of dry crushing and screening process, in the laboratory jaw crusher to the upper limit of size 3.35 mm.

The obtained results of the grain-size distribution the final crushing product of low-grade and high-grade copper ore, in the laboratory jaw crusher, are shown in Figure 2.

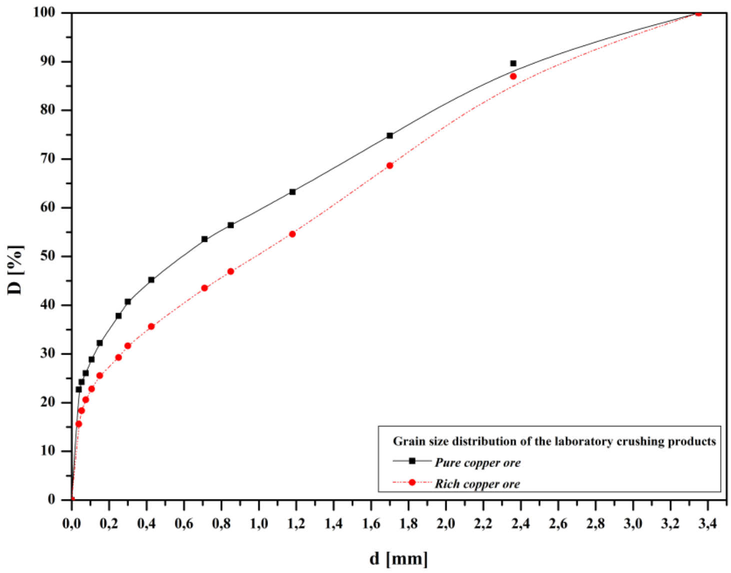

Figure 2 *Grain size distribution of the laboratory crushing product of low-grade and high-grade copper ore*

By defining the characteristics of grain-size of the crushing products in the laboratory jaw crusher, for low-grade and high-grade copper ore, over the grain mean diameter, 0.071 mm and 0.095 mm respectively, the difference in the particle size distribution can be stated.

Small differences in the grain-size distribution of crushing product in the laboratory jaw crusher, compared to the same characteristics of low-grade and high-grade copper ore, diagrams in Figure 2, cannot be explicitly attributed to different grindability of low-grade and high-grade copper ore. This phenomenon is more or less determined by dominant selective comminution of tested materials in the laboratory jaw crusher.

The justification of common preparation the both copper ores in the process of grinding and classification, from the viewpoint of providing the optimum grain size of final grinding product, without the risk of comminution; it is possible to observe the test aimed to determination the Bond' work index and kinetics of grinding of investigated materials.

3.2 The Bond work index of low-grade and high-grade copper ore

The Bond theory of comminution is widely accepted in the theory and practice of comminution process of raw materials. According to this, Bond proposed an empirical equation that relates power consumption in crushing and grinding to the feed and product size distribution [Bond, 1960]. The formula is as follows:

$$W = W_i \cdot \left(\frac{10}{\sqrt{P}} - \frac{10}{\sqrt{F}} \right), \text{ (kWh/Sht)} \tag{2}$$

where:

W - specific energy consumption (kWh/Sht)

Wi – the Bond work index, (kWh/Sht)

F - feed 80 % passing size, (μm)

P - product 80 % passing size, (μm).

The Bond work index (Wi), is a material constant which is determined by laboratory testing procedure and in the Bond ball mill, which was defined by Bond [Bond, 1949, 1952, 1961]. For determination the Bond work index, the account procedure by prof. N. Magdalinović [Magdalinović, 1985, 1989] is used.

The grindability test results of low-grade and high-grade copper ore, are given in Table 1.

Table 1 *Results of the Bond work index of low-grade and high-grade copper ore*

Sample	Test	The Bond work index W_i (kWh/t)	Average value of the Bond work index W_{iav} (kWh/t)
Low-grade copper ore	1	14.21	14.11
	2	14.15	
	3	13.98	
High-grade copper ore	1	16.20	16.28
	2	16.34	
	3	16.31	

Study results show that high-grade copper ore has higher resistance to comminution. The Bond work index of high-grade copper ore, W_i^r=16.28 kWh/t, compared with the value of Bond work index of low-grade copper ore, W_i^p=14.11 kWh/t, has a higher value for about 13.33%.

The results obtained are oposite tothe current scientific research and practical experience in these types of raw materials and therefore suggest the need for further research, in order to clarify this phenomenon.

3.3 Grinding of kinetics of low-grade and high-grade copper ore

Grinding tests of low-grade and high-grade copper ore, was carried out using the wet procedure in the laboratory ball mill with identical technical and technological parameters. All kinetics tests were conducted at the following times: from 3, 5, 7 and 9 minutes. The grinding products of low-grade and high-grade copper ore were sieved on wet using a series of standard sieves, defining the mass distribution of characteristic size fraction.

Figure 3 shows the comparative values of grain-size distribution of grinding products of low-grade and high-grade copper ore, after grinding of 3, 5, 7 and 9 minutes, and Figure 4, the production kinetics of characteristic size fractions in the grinding process of testing samples.

Higher resistance to comminution of high-grade copper ore W_i^r=16.28 kWh/t, compared to low-grade copper ore W_i^p=14.11 kWh/t, defined by the Bond work index, which is inconsistent with the results of previous experience on these raw materials, indicates the need for additional research on this phenomenon. The results of grinding kinetics of both copper ores are shown in diagrams in Figures 3 and 4. Comparative analysis of particle size distribution of grinding products of low-grade and high-grade copper ore, after grinding at the same time intervals, can observe a few characteristic phenomena. All grinding products of low-grade copper ore are finer than the same of high-grade copper ore, which can indicate on the less resistance to comminution of low-grade copper ore. But, decreasing the difference in grain-size distribution at increasing grinding time indicates the opposite claim.

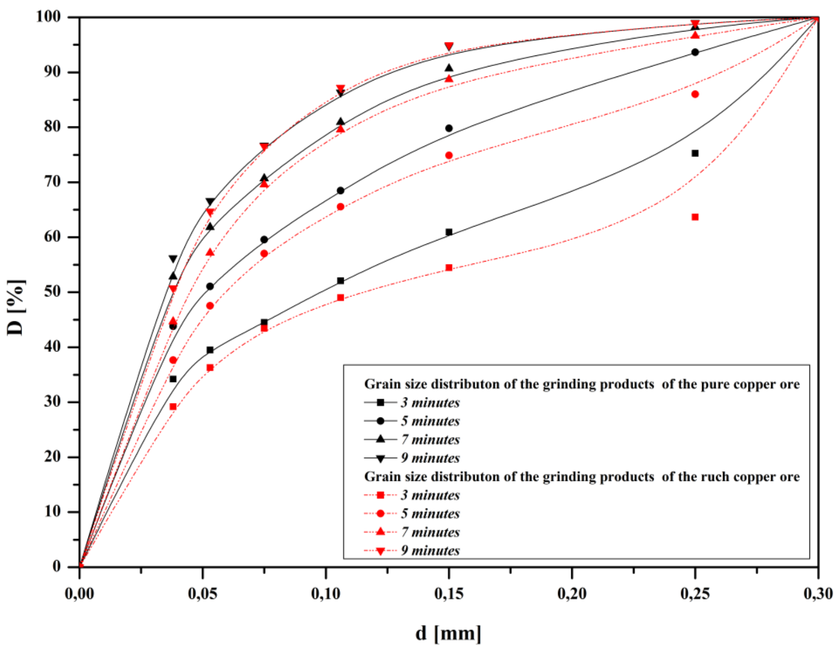

Figure 3 *Grain-size distributon of grinding products of low-grade and high-grade copper ore*

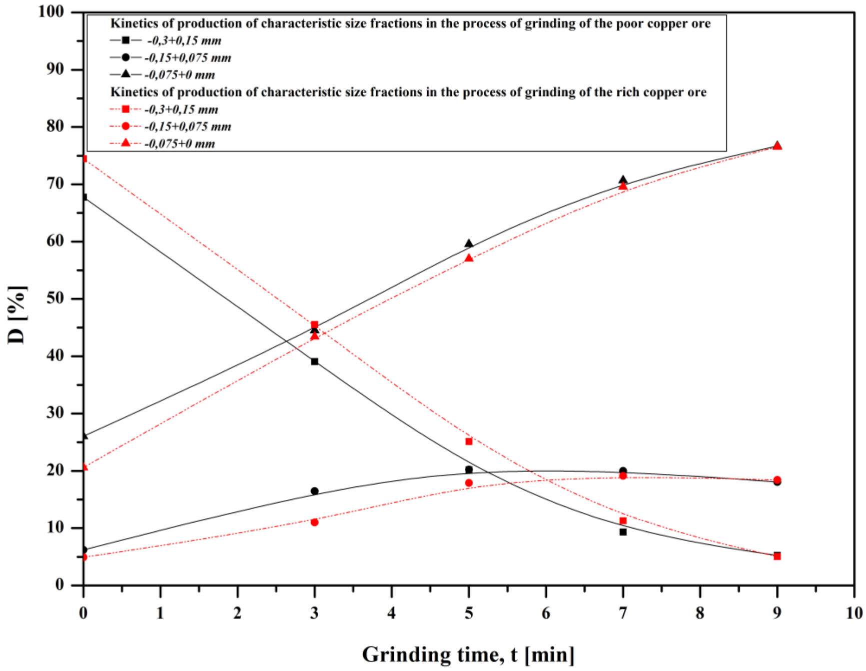

Figure 4 *Diagrams of production kinetics of characteristic size fractions in the grinding process of low-grade and high-grade copper ore*

The different behavior of low-grade and high-grade copper ore in grinding process confirms different kinetics reduction of the coarsest particle size fraction and kinetics of production of the finest size, as a function of grinding time, which is shown in Figure 4. The kinetic reduction of the coarsest particle size fraction +0.15 mm, and the kinetics of production of the finest size, -0.075 mm were evident in grinding of high-grade ore compared to low-grade ore. This conclusion strongly suggests that high-grade copper ore has less resistance to comminution compared with low-gradecopper ore, which is in contrast with the results of the Bond grindability tests. The clarification of this phenomenon is found in considering the effect of grain-size distribution of the starting sample, size class -3.35+0 mm, on the value of Bond work index.

3.4 The effect of particle size distribution of the starting sample size class - 3.35 +0 mm, on the value of Bond work index

For this study, a new synthetic sample of rich copper ore down to 3.35 mm was formed with identical particle size distribution of grain-size distribution of low-grade copper ore, which was the subject of previous tests.

On the new, synthetic sample of high-grade copper ore, the Bond work index was determined by the account procedure of prof. N. Magdalinović [Magdalinović, 1985, 1989] and grinding kinetics in order to compare the obtained results with the results of previous research.

The comparative grindability test results of low-grade, high-grade and synthetic sample of high-grade copper ore are given in Table 2.

Table 2 *Compared values of the Bond work index of low-grade, high-grade and synthetic sample of high-grade copper ore*

Sample	**Test**	**The Bond work index W_i (kWh/t)**	**Average value of the Bond work index W_{iav} (kWh/t)**
Low-grade copper ore	1 2 3	14.21 14.15 13.98	14.11
High-grade copper ore	1 2 3	16.20 16.34 16.31	16.28
Synthetic sample of high-grade copper ore	1 2 3	13.42 13.26 13.37	13.35

Comparable values of Wi were determined by the Bond test on samples. It can be concluded that high-grade copper ore with the same grain size characteristics has a lower resistance to fragmentation than low-grade copper ore. In Table 2, it can be seen that the Wi values of high-grade copper ore W_i^{rs} = 13.35 kWh/t, determined by the Bond test on syntetic samples of identical grain size at −3.35+0 mm were lower by 0.76 kWh/t or 5,38 % than the Wi values W_i^p = 14.11 kWh/t determined for the samples of high-grade copper ore.

Value of the Bond work index of grindability of high-grade copper ore over low-grade copper ore is in the correlation with the previous research results and practical experiences obtained on these raw materials.

The difference between the Bond work index grindability of primary high-grade copper ore W_i^r=16.28 kWh/t and synthetic samples of the same raw material Wi^{bs}=13.35 kWh/t, is the result of different grain-size distribution of starting sample. For this example, the difference in value of the Bond work index on the same ore sample is 2.93 kWh/t or 18 %, which may lead to unreliable conclusions and negative implications in practice of comminution.

3.5 Grinding kinetics of low-grade and high-grade copper ore of the same grain size characteristics

The grinding kinetics tests of synthetic sample of high-grade copper ore with same grain size characteristics of low-grade copper ore were conducted in the laboratory ball mill with identical technical and technological parameters.

Comparable values of grain-size distronution of grinding products of both copper ores, obtained at different grinding time, are shown in Figure 5, and the kinetics of production of characteristic narrow size fractions in the grinding process of testing samples are shown in Figure 6.

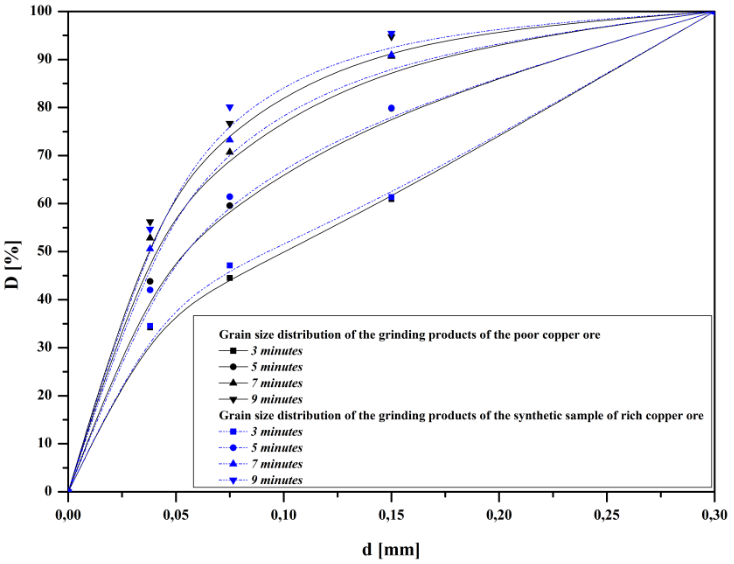

Figure 5 *Grain-size distribution of grinding products of low-grade and synthetic sample of high-grade copper ores*

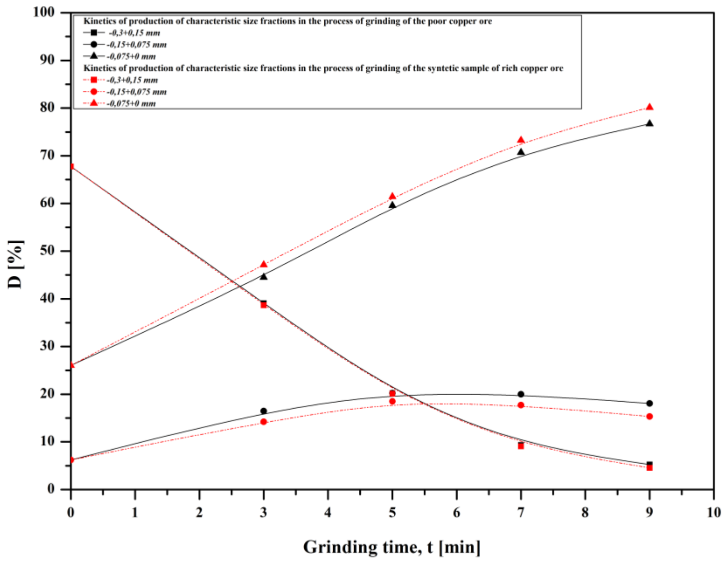

Figure 6 *Kinetics of production of characteristic size fractions in the grinding process of low-grade and synthetic sample of high-grade copper ores*

On diagrams of grain size-distribution of grinding products of testing copper ore samples, which are shown in Figure 5, it can be seen a slightly finer grain size of grinding product of high-grade copper ore.

For achievement the fineness of grinding product, 60% of class - 0,075 mm, the grinding time of low-grade and high-grade copper ore were 5.15 minutes and 4.85 minutes, respectively, Figure 6.

Slightly finer grain size distribution of finished product and shorter grinding time of high-grade copper ore, for about 0.30 minutes, confirm the test results of resistance to the fragmentation defined by the Bond work index of the same material synthetic sample.

4 CONCLUSION

The differences in grain-size distribution the final products of industrial crushing process, define with grain mean diameter of wide size range, D_{av}^{p} = 0.602 mm and D_{av}^{r} = 3.125 mm, for low-grade and high-grade copper ore, respectively, Figure 1, caused the differences in characteristics of starting samples for determination the Bond working index of grindability, D_{av}^{p} = 0.071 mm and D_{av}^{r} = 0.095 mm.

Subsequent studies have shown that marked differences in the grain size composition of these samples with GGK 3.35 mm effect on the experimental value of the Bond work index of grindability.

The values of Bond work index of low-grade and high-grade copper ore, determined on the final product sample of industrial crushing process, prepared using standard procedure with average the diameter D_{av}^{r} = 0.095 mm and D_{av}^{p} = 0.071 mm, were W_{i}^{r} = 16.28 kWh/t and W_{i}^{p} = 14.11 kWh/t, respectively. Difference in value of the Bond work index grindability of 2.93 kWh/t, about 18%, from the viewpoint of practical application in designing and selection the equipment in the process of grinding and sieving of tested raw materials, have both technological, as well as economic impor-tance. The results indicated the effect of grain-size distribution of starting sample, size class -3.35 mm, for determination the Bond work index, -3.35 mm size class, on values of the Bond work index. These results contribute to the theory and practice of comminution process, both in terms of better understanding and reliable practical applications.

Comparable values of the Bond work index of low-grade and high-grade copper ore, determined by the Bond test on the samples with identical grain size (D_{av} = 0.071 mm and GGK 3.35 mm) are W_{i}^{p} = 14.11 kWh/t and W_{i}^{rs} = 13.35 kWh/t, respectively. The difference in value of the Bond work index of grindability (about 0.76 kWh/t or 5,38 %), as the results of higher resistance to fragmentation of low-grade copper ore, is in the correlation with the previous research results and practical experiences, obtained on these raw materials.

Slightly higher resistance to fragmentation, defined by the Bond work index of grindability, was confirmed with grinding kinetics experiments on tested copper ore material, Figure 6. For achieving the fineness of finished product (60% of class - 0.075 mm), longer grinding time for high-grade copper ore of about 0.30 minutes is required. The slight difference in the resistance to fragmentation and grinding kinetics and the fact of unequal and variable grain size composition of the final industrial products of tested copper ore samples gave the possibility of common processing of these raw materials. The final confirmation of justification the common processing, preparation and flotation concentration of low-grade and high-grade copper ore is possible after detailed investigation of floatability and other characteristics of both copper ore samples, which are important for the flotation process.

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UTICAJ UPRAVLJAČKIH MERA NA DOBITAK U RUDARSKIM PREDUZEĆIMA

Izvod

Dobitak (   ) se pojavljuje kao pozitivna razlika između prihoda ( ) kao rezultata reprodukcije i troškova poslovanja (T) kao oblika ulaganja potrebnih za ostvarenje tih rezultata. U sukcesiji perioda menja se prihod, menjaju se i troškovi, pa je moguće da se prati promena veličine dobitka. U iskazivanju uticaja promene prihoda na promenu dobitaka treba posebno izraziti efekte uticaja obima ( ) i cena proizvoda (   ). Troškovi poslovanja su drugi element koji utiče na promenu dobitka i to preko promene utrošaka ( ) i cena po jedinicama utrošaka (   ).

U radu su sagledani uticajni elementi formiranja dobitka u rudarskoj proizvodnji, specifičnosti elemenata ulaganja koji utiču na ostvareni fizički obim proizvodnje kao i na veličinu ostvarenih utrošaka za taj obim proizvodnje. Uticaj dinamike cena na dobitak u rudnicima je sagledan kroz uticaj prodajnih cena metala na visinu ukupnog prihoda i kroz uticaj nabavnih cena elemenata proizvodnje na visinu ostvarenih troškova.

Na povećanje dobitka u rudarskim preduzećima se može uticati upravljačkim aktivnostima sadržanim u različitim merama za otklanjanje subjektivnih slabosti u poslovanju bez dodatnog ulaganja, korišćenjem postojećih unutrašnjih rezervi.

Ključne reči: *dobitak, promena dobitka, ukupan prihod, troškovi, rudarska preduzeća, faktori dobitka, upravljačke mere*

UVOD

U sistemu robne privrede i u uslovima kada subjekti privređivanja imaju naglašeniju ulogu samostalnih robnih proizvođača, dobitak kao poseban pojavni oblik rezultata ima veliki značaj. Jer, ako preduzeća egzistiraju u uslovima tržišne privrede i naglašene primene ekonomskih zakonitosti, postoji imanentna nužnost tržišnog valorizevanja kako ostvarenih rezultata, tako i svih izvršenih ulaganja u reprodukciji.

Polazeći od uloge rudarskih preduzeća koja snabdevaju raznovrsnim mineralnim sirovinama mnoge oblasti i grane delatnosti što je važno s aspekta celokupne društvene reprodukcije, to je od značaja da se pogodnim merama bilo organizacione prirode u kratkom roku (na šta je u radu ukazano) bilo dugoročnim merama poslovne politike utiče na povećanje dobitka.

1. DOBITAK

Polazeći od toga da se vrednost proizvodnje realizuje kroz ukupan prihod ( ), a ukupna vrednost elemenata proizvodnje iskazuje ostvarenim troškovima poslovanja ( ) ostvareni dobitak (   ) dobije se

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kao razlika između prihoda i troškova poslovanja:

S obzirom na to da se prihod pojavljuje kao pojavni oblik rezultata proizvodnje i realizacije, te da su troškovi reprodukcije oblik ulaganja po osnovu ostvarivanja procesa proizvodnje, sledi da se dobitak ostvaruje u svojoj ekonomskoj suštini kroz i putem ostvarivanja samog procesa reprodukcije.

Utvrđivanje dobitka svodi se na identifikovanje elemenata i faktora ukupnog prihoda ( ) i elemenata i faktora troškova poslovanja (T). Veličina ukupnog prihoda je funkcija obima i realizacije i cena po kojim se ona obavlja ( ). Veličina troškova poslovanja je u funkciji utrošaka materijalnih činilaca proizvodnje (materijala i sredstava za rad) i njihovih nabavnih cena, kao i utrošaka radne snage i zarada po jedinicama rada ( ). Tako se dobitak može iskazati:

gde je:

- realizovani fizički obim proizvodnje
- prodajna cena proizvoda
- utrošci elemenata proizvodnje
- nabavne cene po jedinici utrošaka

Dobitak preduzeća je značajan faktor reprodukcije. To dejstvo se manifestuje u trojakom vidu: putem veličine, putem raspodele i putem upotrebe dobitka.

Od veličine dobitka zavisi mogućnost podmirenja razvojnih, zajedničkih i određenih ličnih potreba. Time se istovremeno određuju mogućnosti razvoja u narednom periodu.

Iako je sistem raspodele bitan faktor ekonomije poslovanja preduzeća od ne manjeg značaja je i alokacija odnosno upotreba pojedinih namenskih kvota dobitka. Od primenjene politike i posebno od korišćenih kriterijuma u toj alokaciji u značajnoj meri zavise efekti koji se mogu očekivati.

Sa aspekta mogućnosti kontrolisanja njihovog dejstva na veličinu dobitaka utiču objektivni (društveni, tehnički i prirodni) i subjektivni odnosno organizacioni faktori.

2. UTICAJ ELEMENATA NA PROMENU DOBITKA

Kao što je istaknuto veličina dobitka uslovljena je prihodom i troškovima poslovanja. U sukcesiji perioda menja se i prihod, menjaju se i troškovi, pa je moguće da se prati promena veličine dobitka.

2.1. Promena prihoda

Promena prihoda u dva sukcesivna perioda uslovljava promenu dobitka. Efekti promene dobitka pod tim uticajem mogu se kvantitativno izraziti:

gde je:

promena dobitka pod uticajem dinamike prihoda

koeficijent promene dobitka uslovljen promenama prihoda

—

Kako je prihod umnožak proizvoda i cena, to je potrebno meriti, odnosno utvrditi dejstvo promene prihoda na dobitak i po osnovu promene obima (čiji se efekti manifestuju i promenom troškova) i po osnovu promene cena proizvoda. Ukupna promena dobitka po osnovu dinamike obima proizvoda i cene proizvoda se iskazuje:

gde je:

promena dobitka uslovljena uticajem dinamike obima proizvodnje

promena dobitka uslovljena dinamikom cena proizvoda

koeficijent promene dobitka pod uticajem dinamike obima

koeficijent promene dobitka uslovljen dinamikom cena proizvoda

2.2. Promena troškova

Troškovi poslovanja su drugi element koji utiče na formiranje dobitka. Dobitak se menja u obrnutoj srazmeri sa promenama troškova.

Promena dobitka uslovljena promenom troškova iznosi:

gde je:

promena dobitka uslovljena dinamikom troškova (rashoda)

— koeficijent promene dobitka uslovljen promenom troškova

Pošto su troškovi funkcija utrošaka i cena utrošenih elemenata, to se promena dobitka prati preko promene troškova koja je uslovljena dinamikom utrošaka i dinamikom cena utrošenih elemenata.

Ukupna promena dobitka po osnovu dinamike utrošaka i dinamike cena utrošenih elemenata se iskazuje:

gde je:

promena dobitka uslovljena promenom utrošaka

promena dobitka uslovljena promenom cena utrošenih elemenata proizvodnje

koeficijent promene dobitka zbog promene utrošaka elemenata proizvodnje

koeficijent promene dobitka uslovljen promenom cena utrošenih elemenata proizvodnje

3. ELEMENTI I FAKTORI DOBITKA U RUDARSKOJ PROIZVODNJI

Ekonomska stvarnost rudarskih preduzeća ispoljava se u vidu određenih specifičnosti koje se odnose na elemente ulaganja (ležište mineralne sirovine i karakter ležišta mineralne sirovine), celinu proizvodnog procesa i njegove faze (istraživanje, eksploatacija i priprema mineralnih sirovina) i uticaj prirodnih faktora na ulaganje (geološke karakteristike rude, sadržaj metala u rudi i drugo).

Veličinu dobitka u rudarskom preduzeću određuju prihodi i troškovi koji su značajno uslovljeni uticajem raznih faktora različitog intenziteta delovanja i različitog kvaliteta koji se mogu grupisati na objektivne i organizacione odnosno subjektivne.

Objektivno uslovljeni faktori u rudnicima čiji se uticaj ne može menjati u toku datog ciklusa reprodukcije potiču iz same sredine koja se eksploatiše (prirodni uslovi ležišta mineralne sirovine) kao i tehničkih uslova u kojima se proizvodnja odvija (tehnička opremljenost rada, primena metoda otkopavanja, ulaganja u kapacitet i drugo) ili se njihov uticaj ispoljava kao dejstvo društvenih faktora kao eksterni uslovi značajni za rad preduzeća i tržišni uticaji na cene proizvoda i cene proizvodnih faktora.

Zbog značajnog učešća ljudskog rada u rudarskoj proizvodnji dobitak je uslovljen i organizacionim faktorima kako u sferi proizvodnje kao određene subjektivne slabosti neposrednih izvršilaca i organizatora procesa proizvodnje tako i u režijskoj sferi kao subjektivne slabosti radnika u pratećim službama na poslovima prodaje i nabavke.

Kako se objektivnim faktorima tretiraju faktori koji su u osnovi neizmenjeni u posmatranom periodu, mogućnosti za smanjenje troškova i povećanje dobitka najvećim delom su u različitim merama za uticaj na subjektivne faktore. U dužem vremenskom periodu može se uticati na izmenu objektivnih faktora vodeći računa o efektima izvršenih ulaganja.

3.1. Ukupan prihod

Najveći deo ukupnog prihoda[1] rudnika kroz učešće u raspoređivanju ukupno ostvarenog prihoda na nivou složenog poslovnog sistema[2] utvrđuje se na osnovu količine isporučenog koncentrata i prosečno ostvarene cene koncentrata. Ostvareni prihod rudnika se može kvantitativno izraziti:

gde je:

- realizovana količina koncentrata olova (t)
- realizovana količina koncentrata cinka (t)
- prodajna cena koncentrata olova (din/t)
- prodajna cena koncentrata cinka (din/t)

[1] *U strukturi stvarnog ukupnog prihoda rudarskih preduzeća osim prihoda od prodaje javljaju se i prihodi od subvencija, revalorizacioni prihodi*

[2] *Rudnici u sastavu RMHK Trepča dd.*

3.1.1. Obim proizvodnje

Fizički obim proizvodnje u rudarskim preduzećima determinisan je sa više faktora u prvom redu:

- veličinom rudnog ležišta i njegovim prirodnim karakteristikama
- kapacitetom rudnika od otvaranja, razrade i pripreme ležišta
- primenjenom tehnikom i tehnologijom otkopavanja koja sobom povlači i primenu tehnike i tehnologije rada, izbor opreme
- kadrovskom strukturom i slično

Fizički obim proizvodnje u flotacijama rudnika kao proizvedena količina koncentrata olova i koncentrata cinka uslovljena je dejstvom više faktora:

- količinom pripremljene rude u ležištu sa postojećim sadržajem metala u rudi (različitim od rudnika do rudnika)
- koeficijentom razblaženja ili iskorišćenja rude u ležištu, koji je usko zavistan od primenjenih otkopnih metoda s jedne strane i prirodnih uslova s druge strane
- flotacijskim iskorišćenjima koja zavise od flotabilnosti rude s jedne strane ali i stanjem tehnike i tehnologije u flotacijama s druge strane i primenjenih flotacijskih reagenasa
- sadržajem metala u koncentratu koji je uslovljen optimalnošću procesa flotiranja

3.1.2. Cena proizvoda

Prosečno ostvarena cena koncentrata formira se u zavisnosti od kvaliteta (sadržaja korisnih, plativih komponenti metala u koncentratu), ugovorenih troškova prerade i ostvarenih prosečnih prodajnih cena metala na tržištu. Kretanje berzanskih cena metala nastaje pod uticajem eksternih faktora (uticaj velikih kompanija koje veštački diriguju ponudu i potražnju metala).

3.2. Troškovi

Ukupni troškovi materijalne reprodukcije (   ) ostvareni u rudnicima predstavljaju zbir različitih troškova kao što su: troškovi normiranog materijala, troškovi energije, troškovi režijskog materijala (pogonske i upravno prodajne režije) i troškovi različitih vrsta sredstava za rad.

3.2.1. Troškovi materijala (   )

Najveći deo ostvarenih troškova materijala u rudnicima i njihovim flotacijama odnosi se na troškove normiranog materijala (vezano za troškove izrade čiji se utrošci mogu vezati za jedinicu proizvoda). U rudnicima su takvi troškovi uslovljeni utrošcima sledećih materijala: jamske građe, eksploziva, štapina, burgija, energije, nafte, različitih reagenasa za flotacijsku preradu. Uzroci većih utrošaka od planiranih normativa mogu biti loš kvalitet materijala ali i uticaj subjektivnog faktora odnosno radnika kao neposrednih izvršilaca u proizvodnji.

Na povećanje ostvarenih troškova materijala utiče i povećanje njihovih nabavnih cena posebno cena onih materijala čija se nabavka vrši na suženom tržištu (gde nema tržišne konkurencije) od dobavljača sa monopolskim cenama.

Visoko učešće troškova materijala u ukupnim troškovima ukazuje na značaj kontrole normiranih utrošaka i njihovog svođenja u planirane okvire kao i otklanjanje organizacionih slabosti u funkcionisanju nabavne službe.

Kao izvor sniženja troškova materijala u rudnicima mogu se iskazati kontrola kvaliteta materijala kod preuzimanja, ispravno skladištenje, izdavanje materijala prema podacima tehničkih normativa, tačna knjigovodstvena evidencija, sprovođenje ušteda materijala i dr.

3.2.2. Troškovi sredstava za rad

U rudarskoj proizvodnji javljaju se troškovi više vrsta i sredstava za rad.[3] Reprodukovanje utrošenih sredstava za rad ostvaruje se realizacijom proizvoda dobijenih pomoću njih, jer je u strukturi proizvedene vrednosti i deo prenesene vrednosti ovog elementa proizvodnje, izražen u obliku amortizacije:

Propisani načini za obračun amortizacije u rudnicima su imanentni procesu reprodukcije (vremenska i funkcionalna amortizacija) ali je potrebno istaći da su sistemski zakoni često omogućavali iskazivanje niže amortizacije kao neadekvatnog izraza trošenja sredstava za rad. Zato dolazi do neadekvatnog tekućeg i investicionog održavanja i nedostatka novčanih sredstava za zamenu dotrajalih sredstava za rad, što dovodi do diskontinuiteta proizvodnje i pojave uskih grla u proizvodnji.

Sistemska rešenja koja predviđaju izmenu u samom pristupu amortizacije kao obavezi stvarnog izdvajanja u fondove je neophodan uslov za uključivanje u tržišnu privredu. Struktura osnovnih sredstava,

[3] *Najvažnije grupe osnovnih sredstava u rudnicima su: rudarski radovi i rudarski objekti, gradjevinski objekti, oprema, novčana sredstva i ostalo*

stepen otpisanosti osnovnih sredstava su značajni pokazatelji analize osnovnih sredstava.

Sniženje troškova amortizacije sprovodi se boljim korišćenjem kapaciteta (s obzirom da je amortizacija delimično fiksni trošak). Ispravan odnos prema osnovnim sredstvima u rudniku, ispravno rukovanje sredstvima, stručnom radnom snagom uz optimalno usklađeno korišćenje kapaciteta predstavlja izvor sniženja troškova amortizacije u rudnicima.

3.2.3. Troškovi rada

Troškovi rada kao reprodukciona vrednost utrošaka radne snage u ekonomskoj teoriji se razmatraju kao proizvod utrošaka radne snage i zarade po jedinici rada .

U cilju racionalnog korišćenja radnog fonda u rudnicima je sprovedena tehnička podela rada prema fazama procesa rada (istraživanje, eksploatacija, priprema mineralnih sirovina) sprovođenjem specijalizacije sredstava i osoblja. Diferenciranje poslova u preduzeću je izvršeno prema službama (geološka, investicije i razvoj, planska, računovodstvena i drugo) sve do radnih mesta vesanih za pojedince iz preduzeća.

U cilju dobijanja dobijanja adekvatnog ekvivalenta svoga rada izvršena je kategorizacija svih poslova i radnih mesta u zavisnosti od vrste težine poslova i odgovornosti primenjujući sistem bodovanja.

Za pojedina radna mesta u rudnicima u neposrednoj proizvodnji ustanovljene su radne norme kao ekvivalent za određenu količinu i kvalitet koji se postiže u normalnim uslovima racionalnog korišćenja sredstava za proizvodnju (uslovljavajući direktne troškove rada). Kontrolu utrošaka radne snage na ovim poslovima moguće je sprovesti kontrolom tehničkih normativa, utvrđivanja odstupanja u odnosu na objektivno potrebne utroške rada.

Na pojedinim radnim mestima u okviru pogonske i upravno prodajne režije (uslovljavajući indirektne troškove rada) kao utrošak rada evidentira se vreme provedeno na radu. Kontrola ovih utro-šaka sprovodi se kontrolom prisustva rad-nika na poslu i kontrolom izvršenih zadataka.

Primereno evidentiranju utrošaka rada u rudnicima se primenjuje isplaćivanje zarada po jedinici rada, plaćanje po učinku, plaćanje po vremenu i dopunski (stimulativni sistem nagrađivanja). Zarada radnika treba da bude usklađena sa postignutim rezultatima poslovanja rudnika.

Kao izvori sniženja troškova rada u rudnicima mogu se istaći:

- uvođenje tehničkih normativa gde god je to moguće,
- ustaljenje radne snage (smanjenje fluktacije radnika),
- povećanje kvalifikacije radnika (sprovođenje načela da se radnik odgovarajuće stručnosti i kvalifikacije nalazi na odgovarajućem radnom mestu),
- ispravno nagrađivanje (stimulacije),
- povezivanje ličnih efekata pojedinaca za uspeh organizacione jedinice,
- smanjivanje prekovremenog rada kao skupljeg i neproduktivnijeg,
- efikasna evidencija rada i drugo.

4. UPRAVLJAČKE MERE ZA POVEĆANJE DOBITKA

Tekuće poslovanje moguće je organizovati uspešno ili manje uspešno, što će se direktno odraziti na krajnji poslovni rezultat – dobitak. Konkretni proizvođači, rudarska preduzeća imaju različite prirodne i tehničke uslove poslovanja kao i različite uticaje društvenog okruženja u odnosu na prosečnog proizvođača iz te grane, grupacije radnika. Pojava tih razlika ima za posledicu odstupanje dobitka konkretnog rudarskog preduzeća u odnosu na dobitak prosečnog proizvođača. Ovaj uticaj se ne može menjati u toku procesa reprodukcije i ne organizacionim naporima radnika i upravljača.

Mere za otklanjanje subjektivnih slabosti u funkcionisanju rudnika iscrpljuju se u iskorišćenju unutrašnjih rezervi. Na povećanje dobitka se može uticati različitim upravljačkim aktivnostima sadržanim u različitim merama:

1. Merama tekućeg organizovanja i izvršavanja procesa proizvodnje u rudarskim predizećima kako bi utroške sveli na objektivno uslovljene (standardne, optimalne veličine).
2. Preduzimanjem mera čija primena obezbeđuje potpunije korišćenje kapaciteta rudarskih preduzeća zbog značajnijih efekata kako na povećanje obima proizvodnje tako i uticaja na smanjenje organizacione komponente fiksnih troškova koja optercuje ukupan prihod.
3. Mera za unapređenje procesa razmene u realizaciji proizvoda i u nabavci elemenata proizvodnje. U realizaciji mineralnih sirovina javljaju se određene specifičnosti. Tako se moraju uzimati u obzir uticaj stanja na strateškim rezervama, uticaj odgovarajućih međunarodnih udruženja, spekulativna kretanja i drugo pa su efekti mera vezanih za realizaciju proizvoda donekle ograničeni. Od interesa je ostvariti racionalizacije u nabavci elemenata proizvodnje.
4. Mere koje utiču na kruženje sredstava u reprodukciji po osnovu i putem obima i brzine kruženja sredstava. Najneposredniji efekti se postižu uštedama u angažovanim sredstvima (nabavka po nižim cenama, supstituti), optimalnošću zaliha u rudnicima, skraćenje vremena realizacije proizvoda.
5. Ostale mere identifikovanja povećanja izdataka režijskih troškova i sprovođenje aktivnosti na njihovom smanjivanju.

ZAKLJUČAK

Dobitak u rudarskim preduzećima je uslovljen ostvarenim prihodom preko ostvarenog fizičkog obima proizvodnje i preko ostvarenih berzanskih cena metala. Fizički obim proizvodnje rude značajno je uslovljen prirodnim karakteristikama ležišta mineralnih sirovina i dejstvom tehničkih faktora, primenjenim metodama otkopavanja. Osim uticaja prirodnih faktora, sadržaja metala u rudi, proizvodnja je u višim fazama prerade značajno uslovljena dejstvom tehničkih faktora u procesu prerade rude i prerade koncentrata.

U rudarskim preduzećima dobitak je uslovljen troškovima poslovanja preko ostvarenih utrošaka i cena utrošaka elemenata proizvodnje. Na ovaj način se omogućava efikasno utvrđivanje dejstva faktora trošenja i dejstva faktora cena na veličinu dobitka.

Proizvodnju u rudarskim preduzećima karakteriše značajno učešće ljudskog rada (kao direktnog izvršioca rada i nosioca upravljačkih aktivnosti) pa je neophodno sprovoditi konkretne mere za otklanjanje subjektivnih (organizacionoh faktora). Realizovani napori upravljačkih aktivnosti sprovođenjem raznovrsnih mera (potpunije korišćenje kapaciteta, smanjenje utrošaka, unapredjenje procesa razmene i dr.) imaju za rezultat povećanje dobitka u rudarskim preduzećima.

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THE IMPACT OF MANAGEMENT MEASURES ON PROFIT IN MINING COMPANIES

Abstract

Profit ( ) appears as a positive difference between revenues ( ), as the result of reproduction and operating costs (T), as a form of investment required to achieve these results. In the succession of period, both income and costs are changed, so it is possible to observe a change in the amount of profit. In giving the effect of income change on profit, the volume ( ) and price( ) should be specially expressed. Operating costs are another element that modify the income through changes in consumptions ( ) and price per unit of consumption ( ).

In this paper the influential elements forming earnings in the mining production, specific investment elements that influence on realized production volume and size of actual consumption volume, are considered. The influence of dynamics of prices on profit in the mines was observed through the effect of sale price of metals to total amount of income and the impact of purchase price of elements of production to the amount of costs.

The increasing profits at mining companies may be affected by management actions contained in the various measures eliminating the subjective weakness in a business without additional investment using the existing internal reserves.

Keywords: *profit, changes in income, total income, expenses, mining companies, profit factors, management measures.*

INTRODUCTION

In system of commodity economy when business subjects have the emphasized role of independent commodity producers, the income as a special form is of great importance. Starting from the role of mining companies that supply a variety of mineral deposits and branches of many areas of activity that is important in terms of overall social reproduction, it is essential to influence on increase in profit by appropriate measures, either organizational in nature in the short term (what is examined in this paper) or long-term measures of business policies.

1 PROFIT

Starting from the fact that the production value is realized through the total revenue ( ), and total value of production elements is shown by operating costs ( ), the realized profit ( ) is obtained as the difference between revenues and operating expenses:

Regarding the fact that income appears as a manifestation the results of production and realization, and that the costs of reproduction are the form of investment on the basis of achieving the production

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process, it follows that the profit is achieved in its economic essence through the exercise of reproduction process.

Determining the profit is reduced to identifying the elements and factors of total revenue ( ) and the elements and factors of operating expenses (T). The amount of total revenue is a function of volume and realization the prices at which they are carried out ( ). The amount of business costs is a function of consumption the material factors of production (materials and capital equipment) and their purchase price, and the utilization of labor force and income per unit of labor ( ). Thus, the revenue can be expressed:

where:

- realized production volume
- sale price of the product
- consumption elements of production
- purchase price per unit of consumption

The company profit is a significant factor of reproduction. That effect is manifested in the form of three types: by size, distribution and income.

The possibility of satisfaction of developing, mutual and certain personal needs depends on profit. This also provides the possibility of development in the future.

Although the distribution system is an important factor in the business management, the allocation and use of certain conditional odds of winning is of no less importance. Since the policies and especially the criteria used in the allocation and depends largely on the effects that can be expected.

From the aspect of possibility to control their actions, the profit is influenced by the objective (social, technical and natural) and subjective and organizational factors.

2 THE EFFECT OF ELEMENTS ON CHANGE IN PROFIT

As it is indicated the revenue is conditioned by the income and expenses of business. In the succession of period, the revenue and costs are changed, so it is possible to check the change in profit.

2.1 Change of income

The income change in two successive periods causes the change of profit. Effects of changes in income under that influence can be quantified:

where

change in income under the influence of income dynamics

coefficient of profit changes, caused by changes in income

—

As income is given by the multiplication of products and prices, it is necessary to measure and determine the effect of income changes to profit and change in volume whose effects manifest changes in costs and change in product prices. Total changes in profit based on the dynamics of the volume and prices of products are recognized:

where:

change in income, caused by the effect of dynamics of production volume

change in income, caused by dynamic of product price

coefficient of income changes under the effect of volume dynamics

coefficient of income changes, caused by dynamic changes in product prices

2.2 Change of costs

Operating costs are another element that affects the formation of profit. The profit varies in inverse proportion to changes in costs.

Changing the profit caused by costs change is determined by:

where:

change in earnings, caused by dynamics of operating costs

— coefficient of income changes, caused by changes in the cost

Since the costs are function of consumption and price of consumed elements, the profit change is observed through changes in income of the cost, caused by dynamics of consumption and dynamics of price of spent elements.

Total changes in profit, based on the dynamics of consumption and price dynamics of spent elements, are present:

where:

change in profit, caused by change in consumption

change in profit, caused by change in prices of consumed elements of production

coefficient of profit changes due to a change in consumption elements of production

coefficient of profit changes, caused by price change of used production elements

3 ELEMENTS AND FACTORS OF PROFIT IN MINING PRODUCTION

The economic reality of mining companies is evident in certain specificities elated to the elements of investment (deposit of mineral resources and character of mineral deposit), a whole of production process and its stages (exploration, exploitation and mineral processing) and the effect of natural factors on investment (geological characteristics of ore, metal content in the ore, etc.).

Profit in mining companies is determined by revenues and costs that are significantly conditioned by the effect of various factors and effects of different intensities of different quality which can be classified into objective or subjective.

Objectively conditioned factors in the mines, whose influence cannot be changed during a given cycle of reproduction, originate from the mined environment (natural conditions of mineral resources deposit) and technical conditions in which production takes place (technical equipment operation, application of mining method, investments in capacity, etc.) or their effect manifests itself as the effect of external factors such as social conditions essential for the operation of enterprises and market influences on product price and prices of production factors.

Due to a considerable contribution of human work in the mining production, the profit is conditioned by organizational factors, both in the sphere of production as certain subjective weakness of the direct operators, and organizers of production process, and in the supporting services as subjective weakness of employees in sales and procurement.

As the objective factors are basically unchanged in the observed period, for opportunities for reducing costs and increasing profits are largely in different measures of influence on subjective factors. In a longer period of time it can be influenced on the change of objective factors, taking into account the effects of investments.

3.1 Total Revenue

The most part of total revenue[1] of the mine through participation in the allocation of total income at the level of complex business system[2] is determined by the amount of supplied concentrate supplied and average realized price of concentrate. The achieved revenues of mine can be quantified:

where:

- realized amount of lead concentrate (t)
- realized amount of zinc concentrate (t)
- lead concentrate sale price (din/t)
- zinc concentrate sale price (din/t)

3.1.1 Volume of production

Physical volume of production in the mining enterprises is determined by several factors:

- dimension of ore deposit and its natural features,
- capacity of the mine from opening, development and preparation of deposit,
- the applied technique and technology of mining, which entail the application of techniques and technology, equipment selection,
- personnel structure and so on.

Physical volume of production in the mine flotation plants, as the produced quantity of lead and zinc concentrate, is caused by several factors:

- quantity of prepared ore in deposit with the existing metal content in the ore (different from mine to mine),
- dilution coefficient or ore recovery in deposit, which is closely dependent on the applied method of excavation on one side, and the natural conditions on the other side
- flotation recoveries which depend on the ore floatability and condition of technique and technology in the flotation plants, as well as the applied flotation reagents
- metal content in concentrate which is determined by optimization of flotation process.

3.1.2 Product price

The average realized concentrate price is formed depending on the quality (content of useful, payable metal components in concentrate), contracted processing costs and achieved average sale prices of metals on the market. The movement of stock prices of metals occurs under the influence of external factors (the effect of large companies, artificially directed by supply and demand of metals).

[1] *Revenues from grants, revalued revenues, also occur in the structure of actual total income of mining companies other than revenues from sales.*

[2] *Mines within RMHK Trepca dd.*

3.2 Costs

Total cost of material reproduction ( ), achieved in the mines, represent the sum of various costs such as: standardized material costs, energy costs, overhead material costs (operating and administrative consumption costs) and costs of different assets

3.2.1 Costs of materials ( )

Most of the actual costs of materials in the mines and their flotation plants are related to the standardized materials (related to the production costs whose consumptions can be connected to a unit of product). In the mines such costs are determined by consumptions of the following materials: underground material, explosives, fuses, drill bits, power, petroleum, various flotation reagents for processing. Causes of the larger costs than planned consumption norms can be poor quality materials and the influence of subjective factors and direct operators or workers in production.

Increasing the actual cost of materials is caused by increase of purchase prices especially those materials whose prices are purchasing is done on a narrow market (where there is no market competition) from supplier with monopoly prices.

Higher material costs as a share of total costs points to the importance of control of standardized consumption and their reduction in the planned frames and removing structural weaknesses in a function of supply service.

As the source of material cost reductions in the mines it can be stated by the quality of material control in receiving, proper storage, material according technical standards, accurate accounting records, conducting material saving, etc.

3.2.2 Cost of funds for work

There are many types of costs and funds for work[3] in the mining production. Reproduction of spent funds for work is performed by realization of products obtained by them, because in the structure of produced value there is a part of the transferred value of this element of production, expressed in the form of amortization:

Prescribed method for calculating the amortization in the mines are immanent reproduction process (time and functional amortization) but it is worth emphasizing that the system laws often makes it possible for expression of lower amortization as an inadequate term for spending of funds for work. Therefore, there is an inadequate current and investment maintenance and lack of money to replace worn-out capital equipment, which leads to discontinuation of production and bottlenecks in production.

System solutions that predict changes in the approach to amortization, as an obligation of real distribution to the funds, are a necessary condition for inclusion in a market economy. The structure of fixed assets, write-off of fixed assets degree, are important indicators of analysis the fixed assets.

Lowering the costs of amortization is implemented by better use of capacity (as the amortization is partially fixed cost).

[3] *The most important group of fixed assets in the mines is: mining operations and mining facilities, building structures, equipment, funds and other.*

The correct attitude to fixed assets in the mine, correctly handling the funds, skilled work force with optimum use of capacity is a source of amortization cost reduction in the mines.

3.2.3 Labor costs

Costs of labor, as a reproduction value of labor consumption in economic theory s considered as a product of consumption and labor income per unit of labor

.

In the aim of rational use of funds in the mines, a technical division of labor according to the phases of the work process (exploration, mining, mineral processing) was carried out by implementation the specialized equipment and personnel. Differentiation in enterprise was one by services (geological, investment and development, planning, accounting, etc.) up to working places related to the individuals from the company.

In order to obtain an adequate equivalent of their work the categorization of jobs and all tasks is carried out depending on difficulty of the job and responsibility, applying the scoring system.

For certain jobs in the mines in the immediate production, the labor standards are established as equivalent to the certain amount and quality, achieved in the normal rational use of means of production (causing a direct labor costs). Control of utilization the labor force in these activities is carried out by control of technical standards, determining deviations from objectively necessary costs of labor.

At some workplaces within production and administrative overheads (causing indirect labor costs), the time spent at work is shown as costs of work. Control of these costs is carried out by control the presence of workers at job and control of completed tasks.

Depending on records of costs of labor in the mines, payment of income per unit of labor is applied, performance-related pay, time related payment, and additional (incentive reward system). Salaries of workers should be harmonized with the results of operations of the mine.

As the sources of labor cost reduction in mines, the following can be pointed out:

- introduction of technical standards wherever possible,
- stabilize the workforce (reducing labor turnover),
- increasing the skills of workers (to implement the principle of worker qualifications and relevant expertise is in an adequate position),
- properly reward (incentive),
- connecting the personal effects of individuals for success of organizational units,
- reducing overtime as expensive and unproductive,
- efficient work records and other.

4 MANAGEMENT MEASURES TO INCREASE REVENUE

It is possible to organize the current business successfully or less successfully, which will directly affect the final business outcome-profit. Specific manufacturers, mining companies have different natural and technical conditions for business and different effects of social environment compared to the average producer in that industry, group of workers. The occurrence of these differences has resulted in a deviation of profit of specific mining company in relation to the income of average producers. This impact cannot be changed during the process of reproduction and organizational efforts of workers and control.

Measures for elimination the subjective weaknesses in the operation of the mine is exhausted in their use of internal reserves. The increasing of revenue can be affected by various management activities in its various measures:

1. Measures of the current organization and execution of the production process in mining companies to reduce the costs to objectively conditioned (standard, optimal size).
2. Taking measures whose implementation provides a fuller use of the capacity of mining companies due to the significant effects of increasing volume production and reducing the impact on the organizational component of fixed costs that burden the total income.
3. Measures for improvement in the implementation process of the exchange of products and procurement elements of production. The certain specifics occur in the realization of mineral resources. So it must take into account the impact of strategic reserves state, the impact of relevant international associations, and other speculative movements and the effects of measures related to the implementation of the product somewhat limited. Achieving the rationalization in procurement of production elements is of interest.
4. Measures affecting the circulation of resources in reproduction under and through the volume and rapidity of assets turnover. The most immediate effect is achieved by savings in appropriations funds (buying at lower prices, substitutes), stocks optimality in the mines, shortening product realization time.
5. Other measures to identify the increase of overhead costs and implementation of activities to reduce them.

CONCLUSION

Profit in mining companies is determined by income generated through the physical volume of production and stock prices over the actual metal. The physical volume of ore production is significantly determined by the natural characteristics of mineral deposits and the influence of technical factors, applied mining method. Apart from the influence of natural factors, the metal content in the ore, the production is in the higher stages of processing significantly conditioned by the influence of technical factors in the process of refining and processing ore concentrates.

In mining companies, the profit is conditioned by operating costs through realized costs and prices of production elements. This is a way to effectively determine the influence of costs factors and the effects of prices to profit.

Production in the mining enterprises is characterized by significant involvement of human work (as a direct operator and holder of management activities) and it is necessary to take specific measures to eliminate subjective (organizational factors). Completed efforts of management activities by implementation the various measures (better use of capacity, reducing consumption, improving the process of exchange, etc..) have resulted in an increase in profit in the mining companies.

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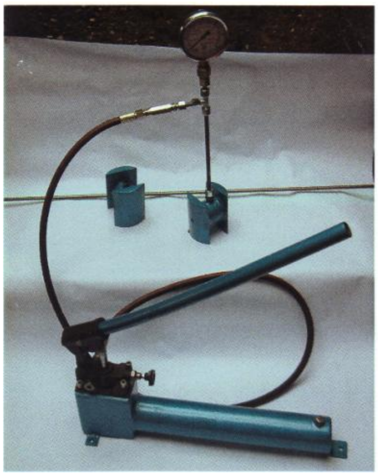

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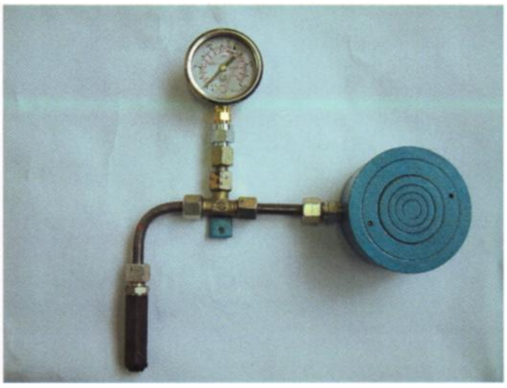

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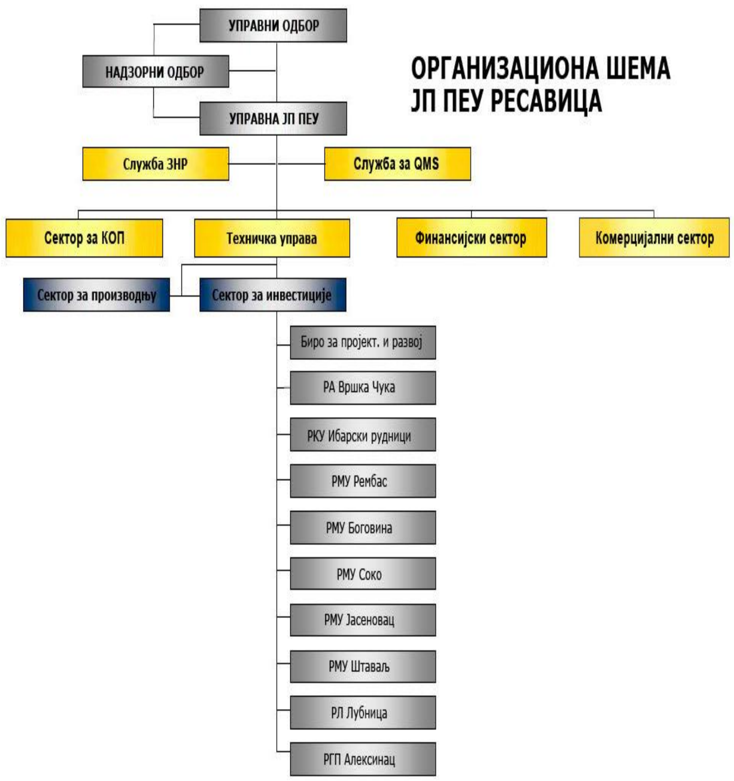

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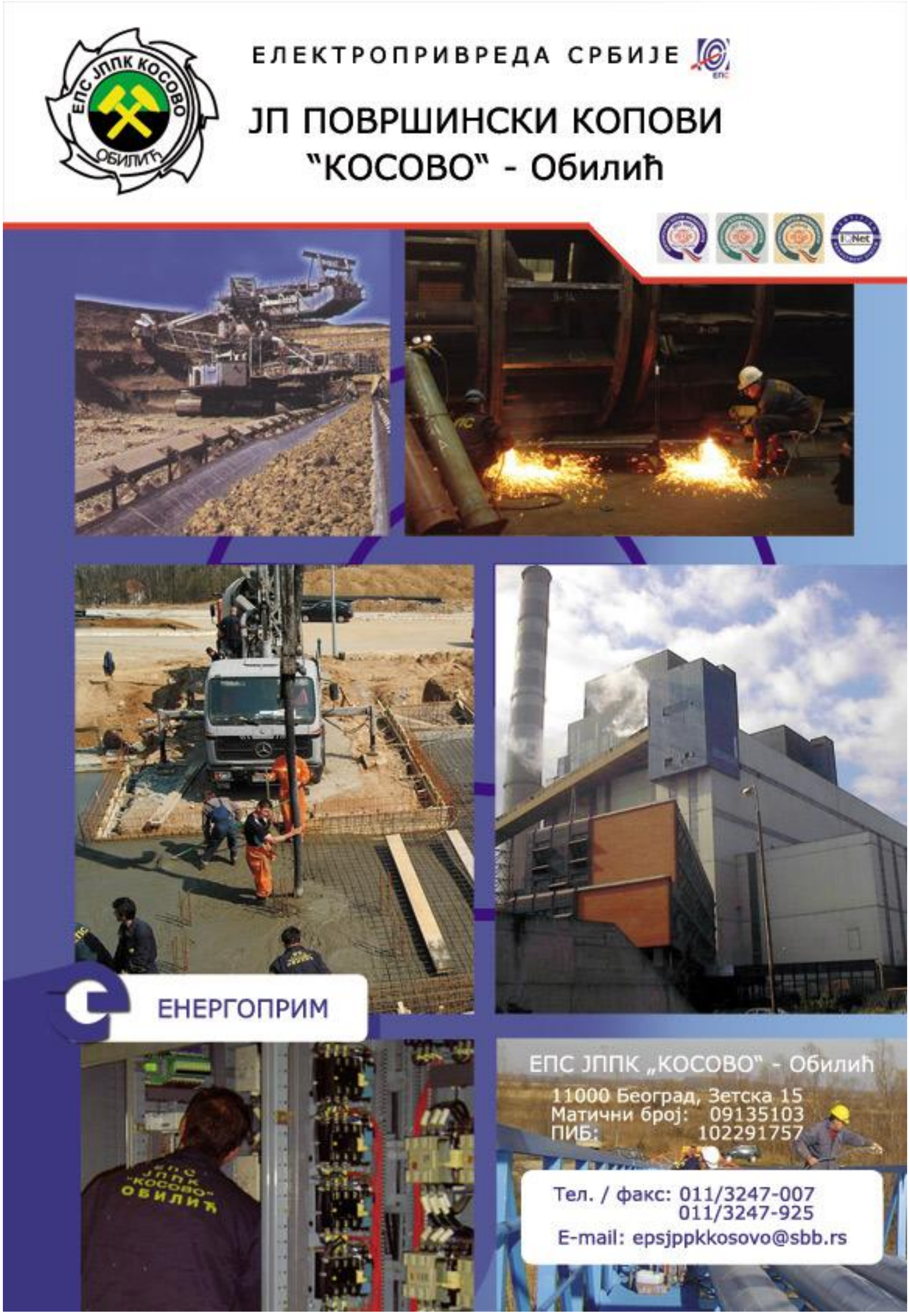
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