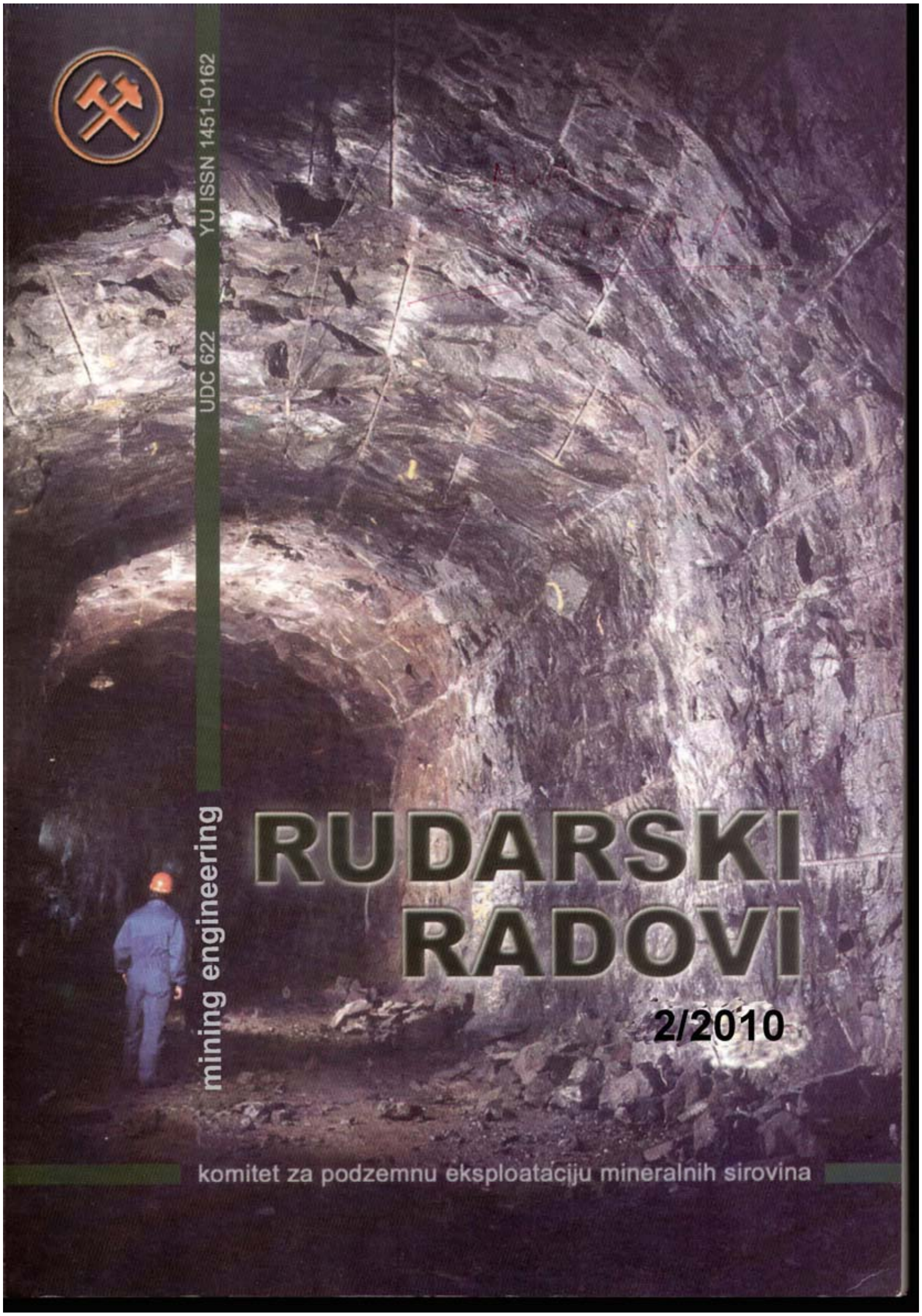
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Vladan Marinković, Miroslava Maksimović*, Milenko Jovanović*, Daniel Kržanović**

IZRADA GEOMODELA LEŽIŠTA UGLJA (POTRLICA, CEMENTARA I DEO KALUŠIĆA) SA PRORAČUNOM REZERVI PROGRAMOM ZA MODELOVANJE LEŽIŠTA I PROJEKTOVANJE POVRŠINSKIH KOPOVA MINEX 5.2.3.

Izvod

U ovom radu je opisan način izrade 3D geološkog modela ležišta uglja Potrlica, Cementara i deo Kalušića Pljevaljskog ugljonosnog basena.

Ležište uglja Potrlica, Cementara i deo Kalušića je istraživano vertikalnim istražnim bušotinama sa površine terena, čime su utvrđeni geološka građa, oblik ležišta i moćnost ugljenih slojeva.

Za izradu geološkog modela izabran je programski paket Minex 5.2.3. koji je posebno dizajniran za modelovanje slojevitih ležišta i projektovanje površinskih kopova.

Cilj izrade geološkog modela je bio dobijanje digitalnog 3D modela koji bi verno i precizno reprezentovao ležište u celini.

Prednost modela izrađenog na ovakav način se ogleda pre svega u mogućnosti sagledavanja prostorne pozicije ležišta, brzog proračuna geoloških rezervi, kao i dobijanje podataka o kvalitativnim karakteristikama uglja kako za celo ležište tako i za pojedine njegove delove.

Ovako izrađen digitalni 3D model predstavlja osnovu za projektovanje rudarskih radova.

Ključne reči: *3D model, geološki model, sloj, proračun rezervi, Minex 5.2.3.*

UVOD

Pljevaljski ugljonosni basen se nalazi na krajnjem severu Crne Gore, neposredno uz grad Pljevlju sa njegove južne strane, u kotlini u kojoj se dolina reke Ćehotine u svom središnjem toku najviše širi. Ukupan neogeni kompleks u pljevaljskoj kotlini zauzima površinu od oko 18 km^2, od čega Pljevaljski basen zahvata oko 12 km^2.

Ležište "Potrlica" zahvata severne, severozapadne i istočne, centralne i južne delove basena a lokalitet "Cementara" vezan je za to ležište sa severozapadne strane. Lokalitet "Kalušić" je vezan za lokalitet "Potrlicu" sa zapadne strane.

Pljevaljska kotlina, u morfološkom smislu, predstavlja paleokarstnu depresiju u srednjem toku rijeke Ćehotine sa prosečnom nadmorskom visinom od 750 m. Depresija je ispunjena ugljonosnim miocenskim sedimentima jezerskog tipa taloženja.

** Institut za rudarstvo i metalurgiju Bor, Srbija*

Obodni krečnjački tereni strmo se izdižu iznad kotline.

Tok izrade 3D geološkog modela

Obrada ležišta započeta je unosom podataka iz nekoliko datoteka (Excel) o istražnim bušotinama.

Datoteke sadrže za svaku bušotinu: ime bušotine, podatke o koti, koordinatama, podatke o litološkim članovima u geološkim stubovima bušotina (koji su relevantni za procenu pozicije slojeva u izdvojenim geološkim sredinama), kao i podatke o rezultatima hemijskih analiza pojedinačnih i kompozitnih proba. U tabeli 1 su prikazani parametri kvaliteta koji su uzeti u obzir kao i imena i sufiksi pod koima su uneti u program.

Izvedeno je devet (9) istražnih bušotina, dubine 8,0 – 12,0 m, na kojima su provedeni opiti SPT-a, uzeti poremećeni i neporemećeni uzorci tla, registrovani nivoi podzemnih voda i ugrađeni piezometri za praćenje oscilacija tokom vremena. Prostorni položaj istražnih bušotina je po profilima upravnim na riječni tok, slika 1.

Tabela 1. *Osnovni podaci o parametrima kvaliteta*

Parametar kvaliteta	Ime	Grid sufix
Vlaga	VLAGA	WU
Sumpor ispariv	SUMPOR-P	SP
Sumor sagoriv	SUMPOR-S	SS
Sumpor ukupan	SUMPOR-U	SU
Pepeo	PEPEO	P
Koks	KOKS	KO
Ugljenik	C-FIX	CF
Gornja toplotna moć	GTE	GTE
Donja toplotna moć	DTE	DTE

Pre početka izrade 3D modela ležišta uglja (Potrlica, Cementara i deo Kalušića), bilo je potrebno formirati bazu podataka na osnovu koje bi se pristupilo izradi modela. Do svih potrebnih podataka se došlo u procesu istražnog bušenja, kao i izvršenih laboratorijskih analiza (prostorni položaj svake bušotine definisan X, Y, Z koordinatom, konačna dubina svake bušotine, litološki članovi određeni u procesu kartiranja jezgra bušotine i podaci o kvalitetu dobijeni laboratorijskim analizama).

Baza podataka se sastoji iz 4 osnovna faila:

- Collars cls. Fail – sadrži sve podatke o prostornom položaju bušotina;
- Quality cls. Fail – sadrži sve podatke vezane za kvalitet;
- Lithology cls. Fail – sadrži sve podatke vezane za litologiju;
- Seam prn. Fail – sadrži podatke o položaju slojeva uglja i jalovih stena, u stubu svake od bušotina.

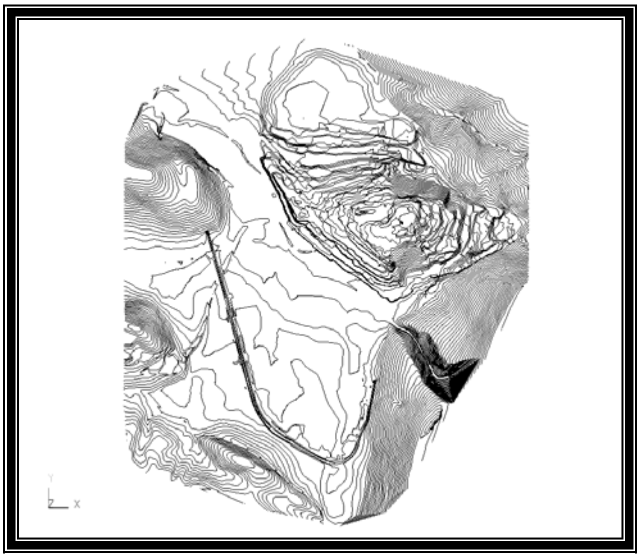
Za zapreminsku masu uglja usvojena je srednja vrednost, koja iznosi 1,36 t/m³ (podatak preuzet iz Elaborata o rudnim rezervama za ležišta Potrlica i Cementara).

Ležište uglja (Potrlica, Cementara i deo Kalušića) je predstavljeno slojevima nepravilnog oblika. Ležište je izgrađeno od četiri ugljena sloja između kojih senalaze slojevi i proslojci jalovih stena, tako da je zbog toga svaki od ovih slojeva i proslojaka, bilo uglja ili jalovine modelovan kao zaseban sloj (tabela 2.)

Takođe su uneti podaci o topografiji terena. Podaci o topografiji preuzeti su od Geodetske službe Rudnika uglja Pljevlja. Digitalizacija je izvršena programskim paketom *AutoCAD (*slika 1).

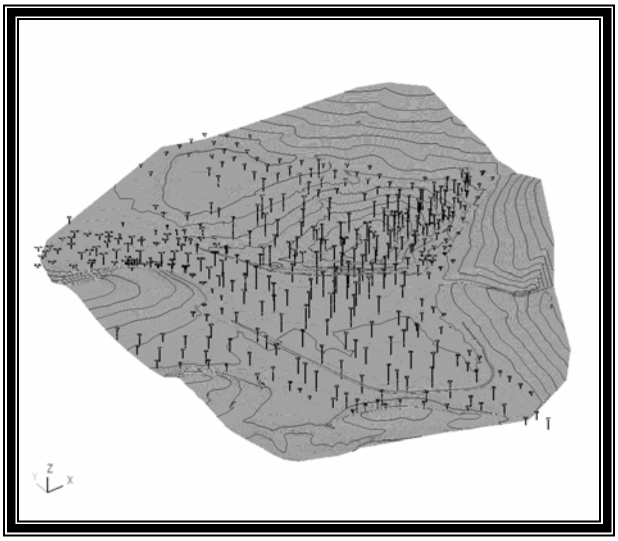
Tabela 2. *Osnovni podaci o slojevima*

Ime sloja	Minex seam name
Površinski pokrivač	PP
Krovinski laporci (različiti varieteti)	KRO1
Krovinski ugljeni sloj	U1
Krovinski laporci (različiti varieteti)	KRO2
Glavni ugljeni sloj	U2a
Međuslojna jalovina (gline)	MJ
Glavni ugljeni sloj	U2b
Podinske gline (različiti varieteti)	POD1
Prvi podinski ugljeni sloj	U3
Podinske gline (različiti varieteti)	POD2
Drugi podinski ugljeni sloj	U4
Podinske gline (različiti varieteti)	POD3
Paleoreljef (krečnjačka osnova)	KR



Slika 1. *3D prikaz topografije (programskim paketom MINEX 5.2.3.).*

Po unosu osnovnih podataka o bušotinama i topografiji u 3D vrši se vizualni pregled odnosa bušotina i površine terena (slika 2.).



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

U program su pored topografije unete i konture ugljenih slojeva odnosno njihove geološke granice, u vidu poligonih linija digitalizovanih programskim paketom *AutoCAD* (tabela 3.)

Tabela 3. *Osnovni podaci o poligonim linijama u modelu*

GRUP	MAP	Objašnjenje
TOPO	MAPA	Topografija
KROVINSKI	CEMENTARA	Kontura krovinskog ugljenog sloja na prostoru Cementare
KROVINSKI	KALUŠIĆ	Kontura krovinskog ugljenog sloja na prostoru Kalušića
GLAVNI	KOMPLET	Objedinjene granice za ležišta Cementara, Potrlica i deo Kalušića
PRVI POD	1	Konture prvog podinskog ugljenog sloja
PRVI POD	2	Konture prvog podinskog ugljenog sloja
PRVI POD	3	Konture prvog podinskog ugljenog sloja
DRUGI POD	DI	Kontura drugog podinskog ugljenog sloja
DRUGI POD	DII	Kontura drugog podinskog ugljenog sloja
DRUGI POD	DIII	Kontura drugog podinskog ugljenog sloja

Potrebno je napomenuti da je glavni ugljeni sloj zbog prisustva jalovih proslojaka u sebi, modelovan metodom deobe sloja. Pri čemu je ovaj sloj podeljen na pod slojeve U2a i U2b.

Svi ostali slojevi su modelovani primenom opšteg metoda modelovanja.

U procesu interpolacije nedostajućih slojeva korišćeni su podaci iz minimalno 3 a maksimalno 4 susedne bušotine, dok je radius pretrage ograničen na 700 m.

Nakon kreiranja ovih slojeva, pristupilo se njihovoj međusobnoj prostornoj korelaciji i izradi 3D modela ležišta. Na tako kreiranom modelu ležišta bilo je moguće proračunati geološke rezerve, kako za svaki sloj ponaosob, tako i za ležište u celosti.

Proračun rezervi programskim paketom *MINEX 5.2.3.*, vrši se metodom trouglova na osnovu poznatih formula.

Površina trouglova je:

$$P_x = \frac{a \times h}{2}$$

a - osnovica trougla (m^2),

h - visina trougla (m).

Srednja debljina sloja:

$$l_{sr} = \frac{(l_1 + l_2 + ... + l_n)}{n}$$

$l_1, l_2, ..l_n$ - debljina ugljenog sloja u istražnom radu (m).

Količina uglja unutar trougla:

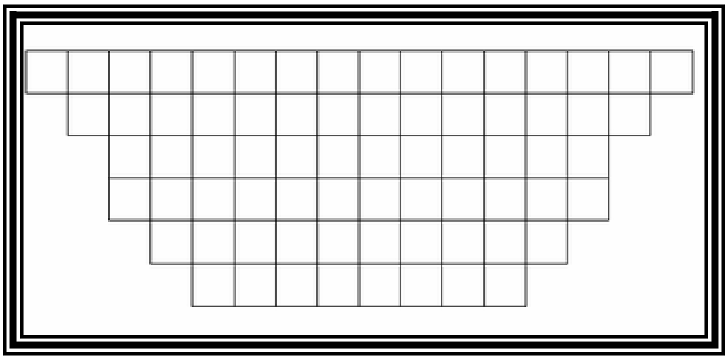
$$Q = P_x \times l_{sr} \times d$$

P_x - površina trouglova (m^2),

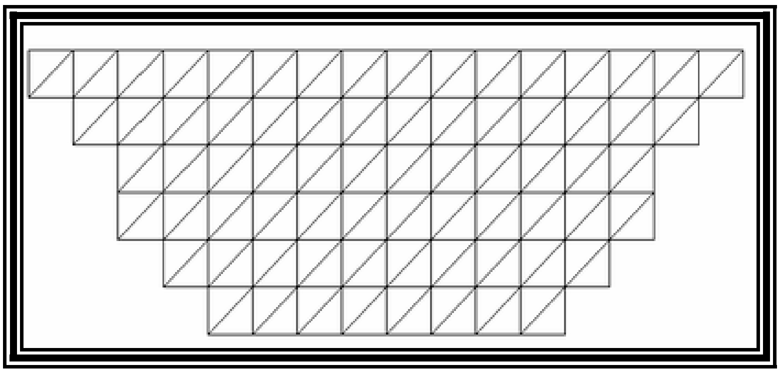
l_{sr} - srednja debljina ugljenog sloja u istražnom radu (m),

d - zapreminska masa uglja (t/m^3).

Trouglovi potrebni za proračun rezervi, dobijaju se na osnovu gridova (mreža) predhodno modeliranih slojeva, pri čemu program svakoj ćeliji kvadratne mreže (sl. 3), dodeljuje dijagonalu tako da od ćelije kvadratnog oblika nastaju dva pravougla trougla (sl. 4).



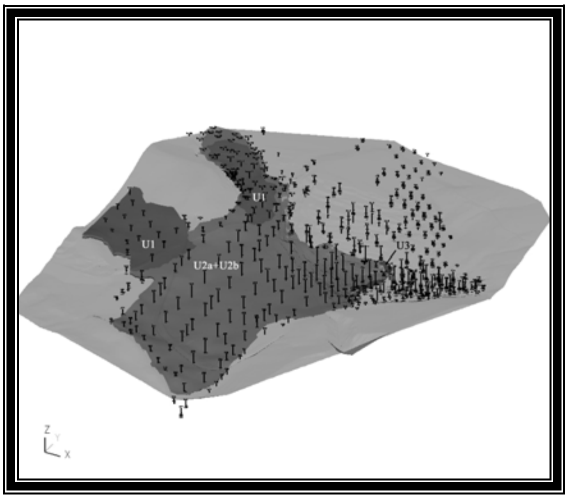
Slika 3. *Grid (mreža) predhodno modeliranog sloja*



Slika 4. *Grid (mreža) predhodno modeliranog sloja sa dijagonalama*

Sve ostale podatke potrebne za proračun rezervi program preuzima iz prethodno kreiranih baza podataka.

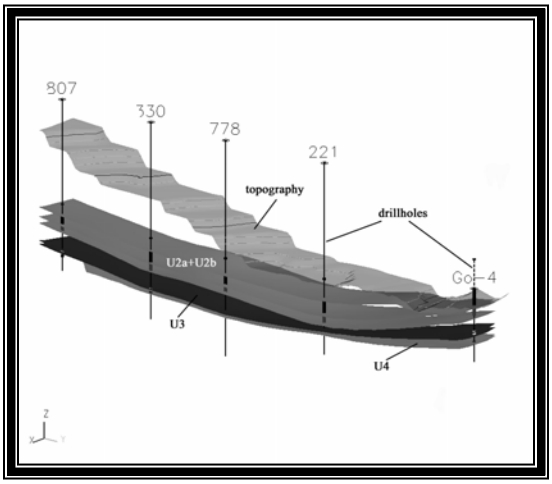
Izgled slojeva u 3D modelovanih programskim paketom Minex 5.2.3. je prikazan slikama 5 i 6.



Slika 5. *3D prikaz slojeva uglja sa topografijom programskim paketom MINEX 5.2.3*

Legenda:

(U1-prvi ugljeni sloj, U2a+U2b-glavni ugljeni sloj i U3-prvi podinski ugljeni sloj).



Slika 6. *3D prikaz slojeva uglja sa topografijom programskim paketom MINEX 5.2.3. (presek).*

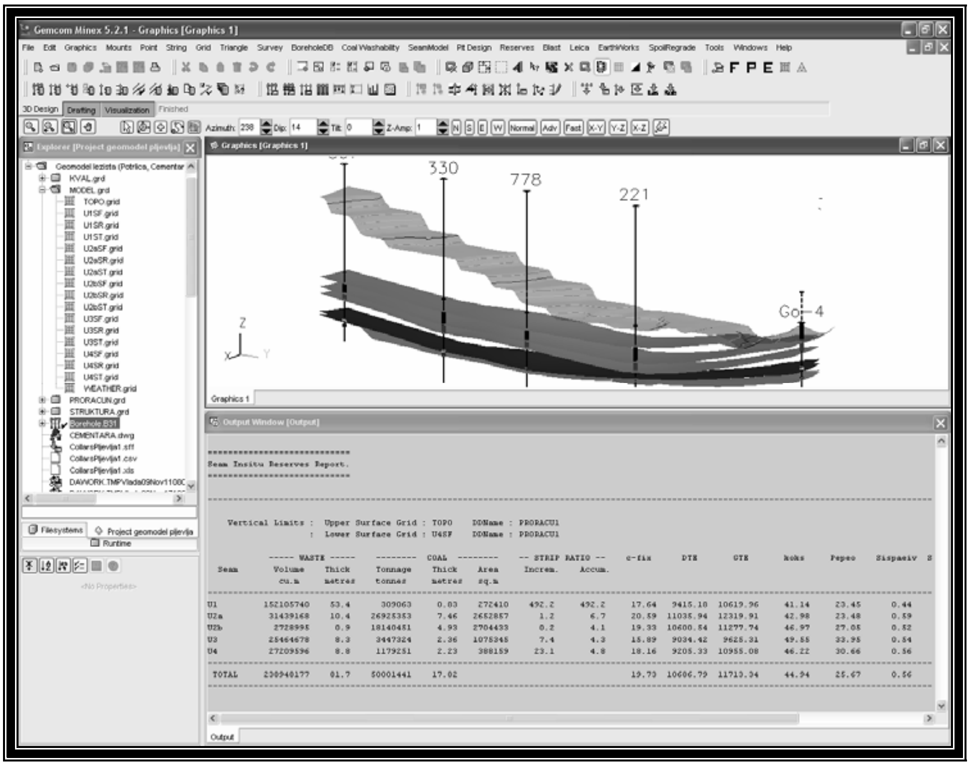
Legenda:

(U2a+U2b-glavni ugljeni sloj, U3-prvi podinski ugljeni sloj i U4-drugi podinski ugljeni sloj).

Rezultati proračuna rezervi, prikazani su u tabeli 4, kao i na slici 7. (izvorni izveštaj tabelarnog prikaza proračuna rezervi programskim paketom *MINEX 5.2.3.*).

Tabela 4: *Rezultati proračuna rezervi uglja programskim paketom Minex 5.2.3.*

ZAPREMINA JALOVINE (m^3)	MOĆNOST JALOVIH SLOJEVA (m)	KOLIĆINA UGLJA (t)	MOĆNOST UGLJENIH SLOJEVA (m)
287.735.443,00	96,9	54.402.280,00	18,37



Slika 7: *Prikaz izvornog izveštaja proračuna geoloških rezervi programskim paketom MINEX 5.2.3*

ZAKLJUČAK

Prednost modela izrađenog na ovakav način se ogleda pre svega u mogućnosti sagledavanja prostorne pozicije ležišta, brzog proračuna geoloških rezervi, kao i dobijanje podataka o kvalitativnim karakteristikama uglja kako za celo ležište tako i za pojedine njegove delove. Ovako izrađen digitalni 3D model predstavlja osnovu za projektovanje rudarskih radova.

LITERATURA

[1] Gomilanović J., Damjanović B., i Damjanović M. 2009.: Elaborat o klasifikaciji, kategorizaciji i proračunu rezervi uglja u ležištu „Potrlica“, lokalitet „Cementara“, Crna Gora.

[2] Gomilanović J. i Damjanović B. 2005.: Elaborat o klasifikaciji, kategorizaciji i proračunu rezervi uglja u ležištu „Potrlica“, Crna Gora.

[3] Dopunski rudarski projekat PK „Potrlica“-Pljevlja od 1989 do 2000 god., Crna Gora.

[4] Nikolić P. i Dimitrijević D. 1990.: Ugalj Jugoslavije, Srbija.

[5] Bugarin M. 2006.: Geologija Ugljeva, Srbija.

[6] Stajević B. 2000.: Projektovanje ležišta mineralnih sirovina, Srbija.

[7] Marinković V., Rajković R., Kržanović D., Pačkovski G., Mitić D., 2D and 3D models, similarity and diferences, časopis Bakar br. 1, 2009 god., str. 1-9

[8] Bošković Z., Cebasek V., Mitrović V., Stanić S., Cement sheath integrity control during well life, Technics Technologies Education Management, Vol. 5, br.3 2010, 450-454

[9] Cebasek V., Bošković Z., Gojković N., Mitrović V., Tangential stress in the in the casing – cement stone – formation system, Technics Technologies Education Management, Vol. 5, br.3 2010, 495-501

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Vladan Marinković, Miroslava Maksimović*, Milenko Jovanović*, Daniel Kržanović**

GEOMODEL DEVELOPMENT OF COAL DEPOSITS (POTRLICA, CEMENTARA AND A PART OF KALUSIC) WITH THE CALCULATION OF RESERVES USING THE PROGRAM OF DEPOSIT MODELLING AND DESIGN THE OPEN PITS MINEX 5.2.3.

Abstract

This paper gives a development method of 3D geological model of the coal deposits Potrlica, Cementara and a part of Kalusic within the Pljevlja Coal Basin.

The coal deposits Potrlica, Cementara and a part of Kalusic were explored by the vertical prospecting drill holes from the terrain surface, what defined the geological structure, deposit form and thickness of coal layers.

The program package Minex 5.2.3 was chosen for development of geological model that is specially designed for modeling of layered deposits and design of open pits.

The aim of development the geological model was obtaining the digital 3D model that would credibly and accurately represent the deposit as a whole.

The advantage of developed model by this way is primarily reflected in a possibility of recognizing the spatial position of deposits, fast calculation of geological reserves as well as obtaining the data on qualitative characteristics of coal both for the whole deposit and some parts of it.

Such developed 3D model presents the base for design the mining works.

Key words: *3D model, geological model, layer, calculation of reserves, Minex 5.2.3.*

INTRODUCTION

The Pljevlja Coal Basin is located in the far north of Montenegro, near Pljevlja town on its southern side, in the ravine where the valley of the Cehotina River is the the most spreads in its middle course. Total Neogeni complex in the Pljevlja ravine covers an area of about 18 km^2, out of which the Pljevlja Basin spreads at about 12 km^2.

The Potrlica deposit overtakes the northern, northwestern and eastern, central and southern parts of the Basin, and the Cementara locality is bound to this deposit on the northwest side. The Kalusic locality is bound to the Potrlica locality on the west side.

The Pljevlja ravine, in the morphological sense, presents the Paleokarst depression in the middle course of the Cehotina River with an average altitude of 750 m. Depression is filled with carbonaceous Miocene sediments of lake-type sedimentation. Peripheral calcareous grounds are steeply raised above the ravine.

* *Mining and Metallurgy Institute Bor, Serbia*

The course of development the 3D geological model

Processing of deposits started by entering the data from some files (Excel) on prospecting drillholes.

The files contain for each drillhole: drillhole name, data on level, coordinates, data on lithological members in geological columns of drillholes (which are relevant to the evaluation of position the geological layers in isolated areas) as well as data on the results of chemical analyses of individual and composite test. Table 1 shows the quality parameters taken into consideration as well as the names and suffixes under which they are included in the program.

Table 1. *Basic data on quality parameters*

Quality parameters	Name	Grid suffix
Humidity	HUMIDITY	WU
Sulfur evaporable	SULFUR-P	SP
Sulfur combustible	SULFUR-S	SS
Sulfur total	SULFUR-U	SU
Ash	ASH	P
Coke	COKE	KO
Carbon	C-FIX	CF
Upper thermal power	GTE	GTE
Lower thermal power	DTE	DTE

Before doing the 3D model of coal deposits (Potrlica, Cementara and a part of Kalusic), it was necessary to establish a data base from which would be the base for model development. The all necessary data were found in the process of prospecting drilling as well as performed laboratory analyses (spatial position of each drillhole defined by X, Y, Z coordinate, the final depth of each drillhole, lithological members determined in the mapping process of drillhole core and data on quality obtained by laboratory analyses).

The database consists of 4 basic files:

- Collars cls. File – contains all data about the spatial position of drillholes;
- Quality cls. File – contains all data on quality;
- Lithology cls. File – contains all data on lithology;
- Seam prn. File - contains data on position of coal layers and dead rocks in a pillar of each drillhole.

For mass volume of coal, the mean value of 1.36 t/m³ was adopted (data taken from the Project Study on ore reserves for the deposits Potrlica and Cementara).

The coal deposits (Potrlica, Cement and a part of Kalušić) is presented in layers of irregular shape. Deposit is made of four coal layers between which are layers and interlayers of dead rocks, so that is why each of these layers and interlayers, either coal or overburden is modeled as a separate layer (Table 2).

Table 2. *Basic data on layers*

Layer name	Minex seam name
Surface caprock	PP
Overlying marls (different varieties)	KRO1
Overlaying coal layer	U1
Overlying marls (different varieties)	KRO2
Main coal layer	U2a
Interlayer waste (clay)	MJ
Main coal layer	U2b
Underlying clays (different varieties)	POD1
First underlying coal layer	U3
Underlying clays (different varieties)	POD2
Second underlying coal layer	U4
Underlying clays (different varieties)	POD3
Paleorelief (limestone base)	KR

Data on terrain topography were also entered. Data on topography were taken from the Geodetic Services of the Coal Mine Pljevlja. Digitization was carried out using the AutoCAD software package (Figure 1).

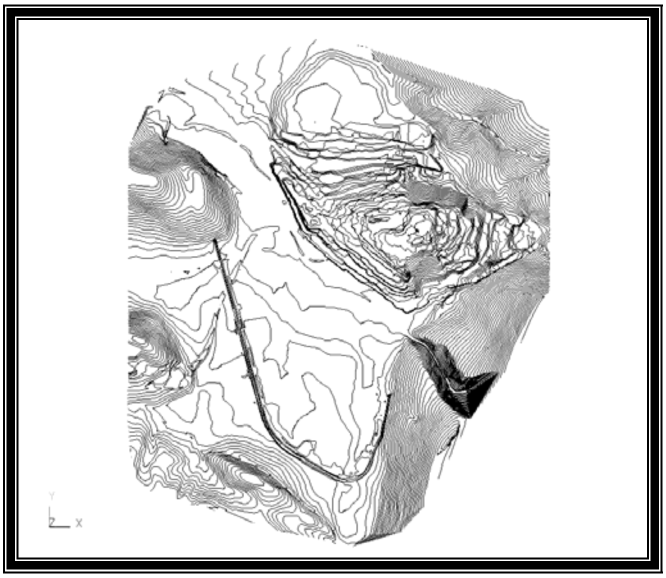

Figure 1. *3D review of topography (program package MINEX 5.2.3).*

By entering basic data on drillholes and topography in 3D, the visual examina tion is done of relation between drillhole and surface ground (Figure 2).

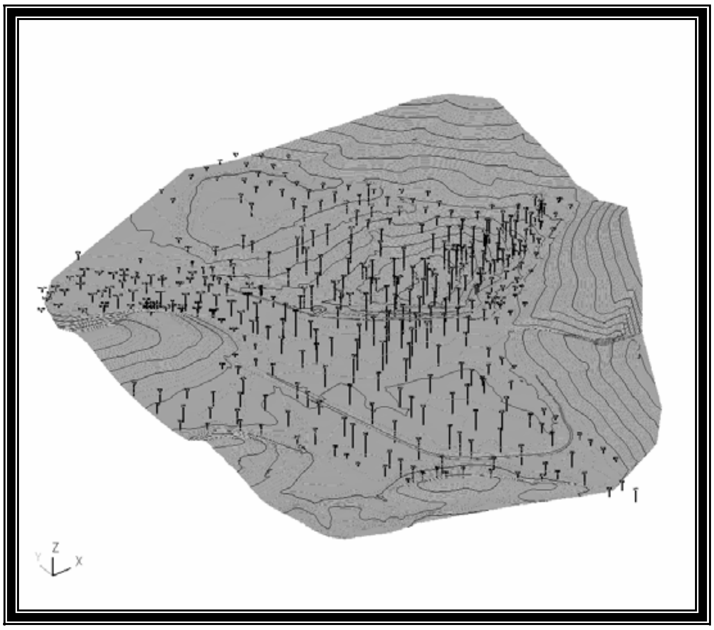

Figure 2. *3D review of relation between topography and drillholes (program package MINEX 5.2.3).*

Beside topography, the contours of coal layers and their geological boundaries were also entered into program in a form of polygonal lines digitalized by the AutoCAD software package (Table 3).

Table 3. *Basic data on polygonal lines in a model*

GROUP	MAP	Explanation
TOPO	MAP	Topography
OVERLYING	CEMENTARA	Contours of overlaying coal layer on Cementara
OVERLYING	KALUSIC	Contours of overlaying coal layer on part of Kalusic
MAIN	COMPLETE	Geological borders for coal deposits Cementara, Potrlica and part of Kalusic
FIRST UNDERLAYING	1	Contours of first underlying coal layer
FIRST UNDERLAYING	2	Contours of first underplaying coal layer
FIRST UNDERLAYING	3	Contours of first underlying coal layer
SECOND UNDERLAYING	DI	Contour of second underlying coal layer
SECOND UNDERLAYING	DII	Contour of second underlying coal layer
SECOND UNDERLAYING	DIII	Contour of second underlying coal layer

It should be noted that the main coal layer due to the presence of dead interlayers in itself, is modeled by the method of layer division, where this layer is divided into the U2a and U2b and layers.

All other layers are modeled using the

general method of modeling.

In the process of interpolation of missing layers, the data were used in at least 3 characters and maximum of 4 adjacent drill holes, the radius of search is limited to 700 m.

After creating of these layers, their spatial correlation between them and creating 3D model of deposit was carried out. On the created model of deposit, it was possible to calculate the geological reserves, both for each layer separately, and for the entire deposit.

Calculation of reserves using the *MINEX 5.2.3* software package is done using the triangles on the basis of known formulae.

Surface of triangles is:

$$P_x = \frac{a \times h}{2}$$

a – triangle base (m^2),
h – triangle height (m).

Middle layer thickness:

$$l_{sr} = \frac{(l_1 + l_2 + ... + l_n)}{n}$$

$l_1, l_2, .. l_n$ - coal layer thickness in exploratory work (m).

Coal quantity inside triangle:

$$Q = P_x \times l_{sr} \times d$$

P_x - surface of triangles (m^2),
l_{sr} - coal layer thickness in exploratory work (m),
d - volume mass of coal(t/m^3).

The required triangles for calculation of reserves are obtained based on the previously modeled layers, in which program on each cell of square network (Figure 3), assign a diagonal such as two right-angled triangles (Figure 4) are formed from a square shaped cell.

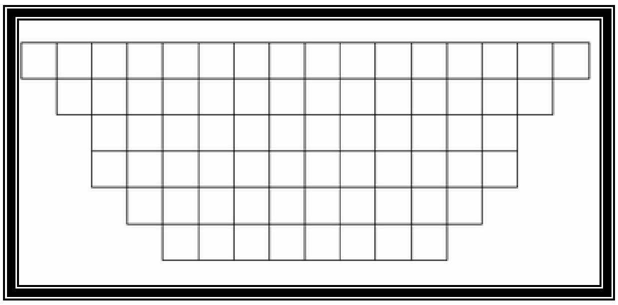

Figure 3. *Grid of pre-modeled layer*

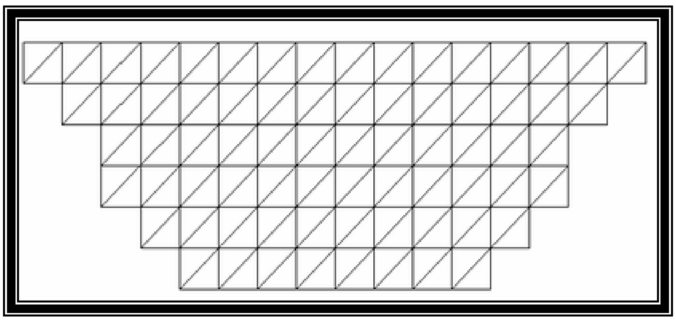

Figure 4. *Grid of pre-modeled layer with diagonals.*

All other necessary data for calculation the reserves, the program takes from pre-created databases.

View of layers in 3D modeled using the software package Minex 5.2.3 is shown in Figures 5 and 6

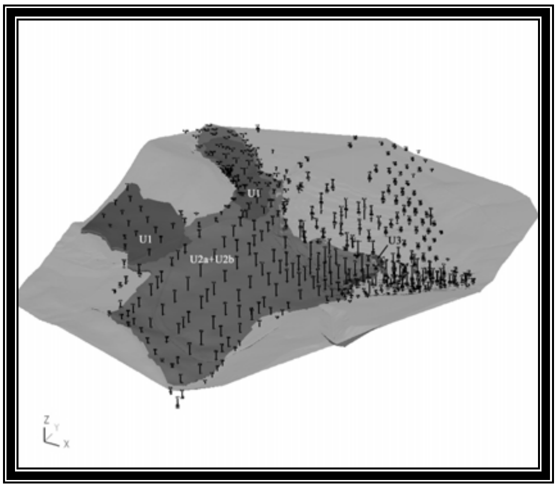

Figure 5. *3D view of coal layers with topography using the MINEX 5. 2 .3 software package*

Legend:

(U1-first coal layer, U2a + U2b – main coal layer and U3-first underlaying coal layer).

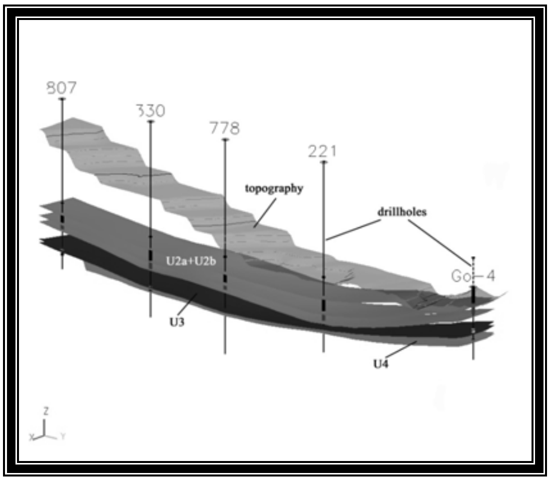

Figure 6. *3D view of coal layers with topography using the MINEX 5. 2. 3 software package. (Vertical section).*

Legend:

(U2a + U2b- main coal layer, U3-first underlying coal layer and U4 - second underlying coal layer).

The results of calculation the reserves are shown in Table 4, as in Figure 7 (original report on calculation of reserves using the MINEX 5.2.3 software package).

Table 4. *Results of calculation the reserves of coal using the Minex 5.2.3 software package.*

WASTE VOLUME (m^3)	**THICKNESS OF WASTE LAYERS (m)**	**COAL QUANTITY (t)**	**THICKNESS OF COAL LAYERS (m)**
287,735,443.00	96.9	54,402,280.00	18.37

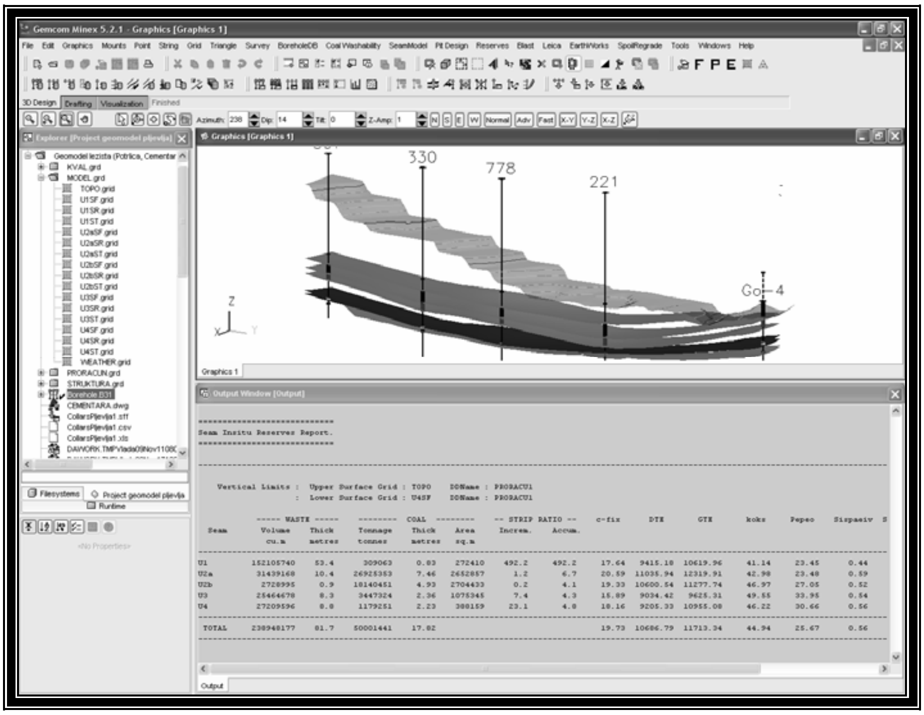

Figure 7. *View of original report on calculation the geological reserves using the software package MINEX 5. 2. 3.*

CONCLUSION

The advantage of model produced in this way is primarily reflected in a possibility of viewing the spatial position of deposit, fast calculation of geological reserves, as well as obtaining the data on qualitative characteristics of coal to the whole deposit and some of its parts. Thus developed the digital 3D model is the base for designing the mining works.

REFERENCES

[1] Gomilanović J., Damjanović B., and Damjanović M. 2009: Study on Classification, Categorization and Calculation of the Ore Reserves in the Deposit “Potrlica”, Locality “Cementara”, Montenegro (in Serbian)

[2] Gomilanović J. and Damjanović B. 2005: Study on Classification, Categorization and Calculation of the Ore Reserves in the Deposit “Potrlica”, Montenegro (in Serbian)

[3] Additional Mining Project of the Open Pit “Potrlica“-Pljevlja from 1989 to 2000, Montenegro (in Serbian)

[4] Nikolić P. and Dimitrijević D. 1990: Coal of Yugoslavia, Serbia (in Serbian)

[5] Bugarin M. 2006: Coal Geology, Serbia (in Serbian)

[6] Stajević B. 2000: Designing of Mineral Deposits, Serbia (in Serbian)

[7] Marinković V., Rajković R., Kržanović D., Pačkovski G., Mitić D., 2D and 3D models, similarity and diferences, časopis Bakar br. 1, 2009 god., str. 1-9

[8] Bošković Z., Cebasek V., Mitrović V., Stanić S., Cement sheath integrity control during well life, Technics Technologies Education Management, Vol. 5, No.3 2010, 450-454

[9] Cebasek V., Bošković Z., Gojković N., Mitrović V., Tangential stress in the in the casing – cement stone – formation system, Technics Technologies Education Management, Vol. 5, No.3 2010, 495-501

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KOMITET ZA PODZEMNU EKSPLOATACIJU MINERALNIH SIROVINA UDK: 622

UDK: 622.3:330.1(045)=861

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VREDNOVANJE KORISNE SIROVINE ČOKA MARINA

Izvod

Ovaj rad pokazuje određivanje vrednosti korisne sirovine ležišta Čoka Marin kao bitnog dela geološko-ekonomske ocene koja može biti:

1) Sa uzimanjem u obzir vremenskog faktora-dinamičko ocenjivanje,

2) Bez uzimanja u obzir vremenskog faktora –sintetički pokazatelji.

Dakle, u ovom radu se pre svega utvrđuje vrednost korisne sirovine ležišta Čoka Marin na osnovu varijante geološkog –rudarskog projektovanja i takva vrednost mineralne sirovine je jednom utvrđena za oba načina ekonomskog vrednovanja ležišta.

Ključne reči: *vrednost, mineralna sirovina, prihod metala, ocena*

UVOD

Osnovna razlika između statičkog i dinamičkog pristupa je u tome što se kod statičkog pristupa izračunavaju sintetičkih pokazatelji tj. koriste se podaci koji se odnose na prosečnu godinu poslovanja, dok se kod izračunavanja dinamičkih pokazatelja koriste podaci za više godina, pa i za celi vek, a koji se svode na godinu ocene (svođenje budućih efekata na današnji dan pomoću određene diskontne stope). Utvrđuje vrednost korisne sirovine ležišta Čoka Marin na osnovu varijante geološkog – rudarskog projektovanja je vrednost mineralne sirovine utveđena za oba načina ekonomskog vrednovanja ležišta.

1. Obračun vrednosti mineralne sirovine

Cena mineralne sirovine

Trenutni uslovi privređivanja u zemlji su veoma složeni i opterećeni su mnogobrojnim problemima: tranzicija i svetska ekonomska kriza.Na svetskom tržištu cena bakra je visoka od 7.400 USD po toni, 35.200 USD po kilogramu zlata i 547 USD po kilogramu srebra (mart 2010.)

Perspektiva prerade, odnosno dobijanja bakra, zavisi od tržišnih uslova, odnosno ponude i potražnje. Na potražnju bakra a i zlata posebno deluju velike kupovine iz Azije (Kina i Indija). Svetska banka svojom najnovijom prognozom predviđa cene ovih metala od 2011- 2020god. i to:

- bakar 4.250 USD/t
- zlato 25.000 USD/kg
- srebro 400 USD/kg

Troškovi metalurške prerade iznose :

a) za bakar:

- topljenje i rafinacija: ukupno 850 USD/t katode za početne dve godine, od treće godine (2013.god.) - 600 USD/t katode do kraja veka (nova topionica).

b) za zlato i srebro troškovi rafinacije po kg:

* *Institut za rudarstvo i metalurgiju*

- zlato:1075 USD
- srebro: 24 USD

Metalurška iskorišenja iznose:

- na bakru 93%(prve dve godine) i 97,5% od treće godine do kraja veka,
- na zlatu 91%,
- na srebru 85%

Vrednost proizvodnje obračunata je na bazi projektovanog kapaciteta proizvodnje i prognoziranih cena za bakar, zlato i srebro i varijante geološko rudarskih parametara. Obračun količina metala za vrednovanje-formiranje prihoda prikazan je u tabelama:

Tabela 1. *Obračun količine katodnog bakra*

Godina	Cu u rud.	flot.iskor.	Cu t	met. isk.	Cu u t
	kg	%	koncentrat	%	za vrednovanje
1	309	98.0	303	93.0	281,51
2	309	98.0	303	93.0	281,51
3	309	98.0	303	97.5	295
4	309	98.0	303	97.5	295
5	309	98.0	303	97.5	295
6	309	98.0	303	97.5	295
7	309	98.0	303	97.5	295
8	309	98.0	303	97.5	295
9	309	98.0	303	97.5	295
10	309	98.0	303	97.5	295
	3090		3030		2923

Tabela 2. *Obračun količine zlata za vrednovanje*

Godina	Au u rud.	flot.iskor.	Au kg	met. isk.	Au u kg
	kg	%	koncentrat	%	za vrednovanje
1	90,4990	94.0	85	91	77,44
2	90,4990	94.0	85	91.0	77,44
3	90,4990	94.0	85	91.0	77,44
4	90,4990	94.0	85	91.0	77,44
5	90,4990	94.0	85	91.0	77,44
6	90,4990	94.0	85	91.0	77,44
7	90,4990	94.0	85	91.0	77,44
8	90,4990	94.0	85	91.0	77,44
9	90,4990	94.0	85	91.0	77,44
10	90,4990	94.0	85	91.0	77,44
	904,9900		850		774,40

Tabela 3. Obračun količine srebra za vrednovanje

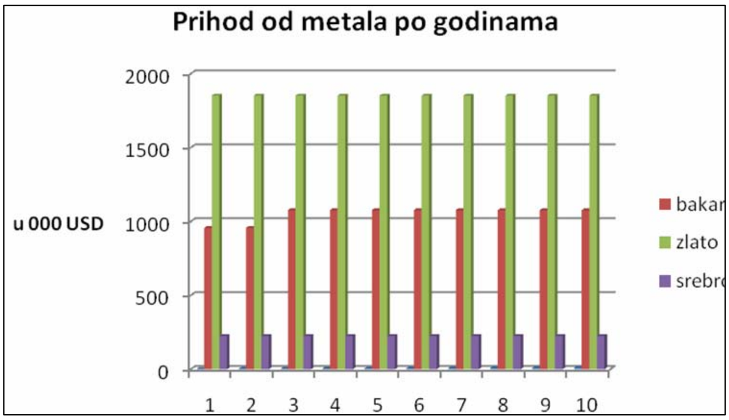
Godina	Ag u rud.	flot.iskor.	Ag kg	met.isk.	Ag u kg
	kg	%	koncentrat	%	za vrednovanje
1	785	90.0	707	85.0	600,68
2	785	90.0	707	85.0	600,68
3	785	90.0	707	85.0	600,68
4	785	90.0	707	85.0	600,68
5	785	90.0	707	85.0	600,68
6	785	90.0	707	85.0	600,68
7	785	90.0	707	85.0	600,68
8	785	90.0	707	85.0	600,68
9	785	90.0	707	85.0	600,68
10	785	90.0	707	85.0	600,68
	7.850		7070		6006,78

Tabela 4. Obračun vrednosti proizvodnje –prihoda po godinama

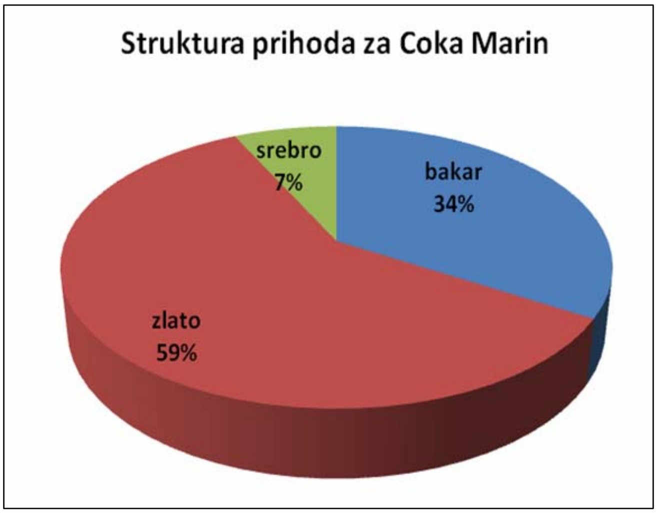
	Količina	cena	prihod	met.prerada	neto prihod
** GODINA:	1				
1 Cu	281.5132	4.2500	1,196.43	239.29	957.14
2 Au	77.4128	23.9250	1,852.10	0.00	1,852.10
3 Ag	600.6780	0.3760	225.85	0.00	225.85
ukupno			3,274.39	239.29	3,035.10
** GODINA:	2				
1 Cu	281.5132	4.2500	1,196.43	239.29	957.14
2 Au	77.4128	23.9250	1,852.10	0.00	1,852.10
3 Ag	600.6780	0.3760	225.85	0.00	225.85
ukupno			3,274.39	239.29	3,035.10
** GODINA:	3				
1 CU	295.1348	4.2500	1,254.32	177.08	1,077.24
2 Au	77.4128	23.9250	1,852.10	0.00	1,852.10
3 Ag	600.6780	0.3760	225.85	0.00	225.85
ukupno			3,332.28	177.08	3,155.20
** GODINA:	4				
1 CU	295.1348	4.2500	1,254.32	177.08	1,077.24
2 Au	77.4128	23.9250	1,852.10	0.00	1,852.10
3 Ag	600.6780	0.3760	225.85	0.00	225.85
ukupno			3,332.28	177.08	3,155.20
** GODINA:	5				
1 CU	295.1348	4.2500	1,254.32	177.08	1,077.24
2 Au	77.4128	23.9250	1,852.10	0.00	1,852.10
3 Ag	600.6780	0.3760	225.85	0.00	225.85
ukupno			3,332.28	177.08	3,155.20

** GODINA: 6					
1 CU	295.1348	4.2500	1,254.32	177.08	1,077.24
2 Au	77.4128	23.9250	1,852.10	0.00	1,852.10
3 Ag	600.6780	0.3760	225.85	0.00	225.85
ukupno			3,332.28	177.08	3,155.20
** GODINA: 7					
1 Cu	295.1348	4.2500	1,254.32	177.08	1,077.24
2 Au	77.4128	23.9250	1,852.10	0.00	1,852.10
3 Ag	600.6780	0.3760	225.85	0.00	225.85
ukupno			3,332.28	177.08	3,155.20
** GODINA: 8					
1 Cu	295.1348	4.2500	1,254.32	177.08	1,077.24
2 Au	77.4128	23.9250	1,852.10	0.00	1,852.10
3 Ag	600.6780	0.3760	225.85	0.00	225.85
ukupno			3,332.28	177.08	3,155.20
** GODINA: 9					
1 Cu	295.1348	4.2500	1,254.32	177.08	1,077.24
2 Au	77.4128	23.9250	1,852.10	0.00	1,852.10
3 Ag	600.6780	0.3760	225.85	0.00	225.85
ukupno			3,332.28	177.08	3,155.20
** GODINA: 10					
1 Cu	295.1348	4.2500	1,254.32	177.08	1,077.24
2 Au	77.4128	23.9250	1,852.10	0.00	1,852.10
3 Ag	600.6780	0.3760	225.85	0.00	225.85
ukupno			3,332.28	177.08	3,155.20
UKUPNI PRIHOD			33,207.01	1,895.22	31,311.79

**Troškovi rafinacije za zlato i srebro obuhvaćeni su umanjenjem prodajnih cena za Au i Ag.*



Grafik 1. *Struktura prihoda po godinama*



Grafik 2. *Udeo prihoda od metala u ukupnom vrednovanju*

Primenjeno na:

Vrednost ležišta bez uzimanja u obzir vremenskog faktora –sintetički pokazatelji

Vu = (Vi – Ti) · (R - G)

gde je:

Vu – vrednost ležišta bez uzimanja vremenskog faktora u USD.

Vi – vrednost korisne sirovine, (umanjenja za gubitke prerade)-156,5 6USD/t

Cu: gubici isk. prerade (flotacijske +metalurške) =2%+3,4%=5,4%

Au: gubici isk. prerade (flotacijske +metalurške) =6%+9%= 15%

Ag: gubici isk. prerade (flotacijske +metalurške) =10%+15%=25%

Ti – troškovi potrebni za dobijanje sirovine, -101,9 USD/t

(R – G) bilansne rezerve umanjene za eksploatacione gubitke.(5%)

Vu = (156,56 – 101,9) · (519872t - G)

Vu=54,7 · 493878,4

Vu=27.015.148 USD

ZAKLJUČAK

Određivanje vrednosti mineralne sirovine je polazni deo ekonomskog vrednovanja ležišta i jedinstveno je za oba na~ina geološkog vrednovanja ležišta: bez uzimanja u obzir vremenskog faktora i uzimanjem u obzir vremenskog faktora.

Vrednovanje je izrazito osetljivo na promenu berzanskih cena metala, ali je to izbegnuto usvajanjem prognoziranih cena Svetske banke (koje su za oko 30-40% nize od tekućih berzanskih cena), što daje garanciju da je vrednost mineralne sirovine određena sa veoma niskim rizikom.

LITERATURA:

[1] B. Cavender, Mineral Production Costs - Analyses and Management, SME, (1999).

[2] N. Dondur, Ekonomska analiza projekata, Mašinski fakultet, Beograd (2002).

[3] G.Mankju, Principi ekonomije, Ekonomski fakultet Beograd, (2005).

[4] M. Bugarin, G. Slavković "Tehnoeko-nomska ocena " Institut za bakar, Bor (2006).

[5] T. Kuronen: Capital Budgeting In A Capital-Intensive Industry, Helsinki University Of Technology, Mat-2.108 Independent research projects in applied mathematics, (2007).

[6] G. Slavković, „Prihod u finansijskoj analizi investicija u rudarstvu“, Inovacije i razvoj, br. 2, 2010. god. str. 25-32

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VALUATION OF RAW MINERAL FOR THE COKA MARIN DEPOSIT

Abstract

This paper shows the determination of raw mineral for the Coka Marin deposit as an important part of geological-economical evaluation that could be:

1. *with taking into account the time factor-the dynamic evaluation,*
2. *without taking into account the time factor-synthetic indicators.*

Therefore, in this paper, the raw mineral of the Coka Marin deposit is primarily determined based on the variation of geological-mining design and such value of raw mineral was once determined for both methods of economic valuation of deposit.

Key words: *value, mineral, income of metals, evaluation*

INTRODUCTION

The basic difference between the static and dynamic approach is that the static approach calculates the synthetic indicators, i.e. the data relating to the average business year are used, while the data for several years and for the whole century are used in calculating the dynamic indicators and they are reduced to the year of evaluation (reducing the future effects on today's date using the certain discount rate). Determination the mineral value of the Coka Marin deposit, based on the variations of geological-mining design of the mineral value, was determined for both methods of economic evaluation of deposit.

1. Calculation of the mineral value

Price of mineral raw

Current economic conditions in the country are very complex and burdened with numerous problems: the transition and world economic crisis. On the world market, the price of copper is high of 7,400 USD per ton, gold is 35,200 USD per kilogram and silver 547 USD per kilogram (March 2010).

Perspective of copper treatment, that is copper production, depends on the market conditions or supply and demand. The demand for copper and gold are particularly under the influence of large purchases from Asia (China and India). The World Bank predicts, in its latest forecast, the prices of these metals from 2011-2020 as follows:

- copper 4.250 USD/t
- gold 25.000 USD/kg
- silver 400 USD/kg

Metallurgical treatment costs are:

a) for copper

* *Mining and Metallurgy Institute Bor*

- smelting and refining:
  Total of 850 USD / t of cathode for the initial two years, and from the third year (2013) - 600 USD / t cathode by the end of the century (The New Smelter).
- b) refining costs for gold and silver per kg are:
- gold: 1075 USD
- silver: 24 USD

Metallurgical recoveries are:

- on gold 93% (the first two years) and 97.5% from the third year by the end of century,
- on gold 91%,
- on silver 85%

The value of production was calculated based on the projected production capacity and the forecasted prices for copper, gold and silver, and geological variant of geological-mining parameters. Calculation of the metal amount for evaluation - the income forming, is shown in tables:

Table 1. *Calculation of cathode copper quantity for valuation*

year	Cu in ore	flot.used	Cu t	met.used	Cu t
	kg	%	concentrate	%	For valuation
1	309	98.0	303	93.0	281,51
2	309	98.0	303	93.0	281,51
3	309	98.0	303	97.5	295
4	309	98.0	303	97.5	295
5	309	98.0	303	97.5	295
6	309	98.0	303	97.5	295
7	309	98.0	303	97.5	295
8	309	98.0	303	97.5	295
9	309	98.0	303	97.5	295
10	309	98.0	303	97.5	295
	3090		3030		2923

Table 2. *Calculation of gold quantity for valuation*

year	Au in ore	flot.used	Au kg	met.used	Au kg
	kg	%	concentrate	%	For valuation
1	90,4990	94.0	85	91	77,44
2	90,4990	94.0	85	91.0	77,44
3	90,4990	94.0	85	91.0	77,44
4	90,4990	94.0	85	91.0	77,44
5	90,4990	94.0	85	91.0	77,44
6	90,4990	94.0	85	91.0	77,44
7	90,4990	94.0	85	91.0	77,44
8	90,4990	94.0	85	91.0	77,44
9	90,4990	94.0	85	91.0	77,44
10	90,4990	94.0	85	91.0	77,44
	904,9900		850		774,40

Table 3. Claculation of silver quantity for valuation

year	Ag in ore	flot.used	Ag kg	metal. used	Ag kg
	kg	%	concentrate	%	For valuation
1	785	90.0	707	85.0	600,68
2	785	90.0	707	85.0	600,68
3	785	90.0	707	85.0	600,68
4	785	90.0	707	85.0	600,68
5	785	90.0	707	85.0	600,68
6	785	90.0	707	85.0	600,68
7	785	90.0	707	85.0	600,68
8	785	90.0	707	85.0	600,68
9	785	90.0	707	85.0	600,68
10	785	90.0	707	85.0	600,68
	7.850		7070		6006,78

Table 4. Calculation of incomes per years

	Quantity	price	income	met.treatment	net income
** year:	1				
1 CU	281.5132	4.2500	1,196.43	239.29	957.14
2 Au	77.4128	23.9250	1,852.10	0.00	1,852.10
3 Ag	600.6780	0.3760	225.85	0.00	225.85
Total			3,274.39	239.29	3,035.10
** year:	2				
1 CU	281.5132	4.2500	1,196.43	239.29	957.14
2 Au	77.4128	23.9250	1,852.10	0.00	1,852.10
3 Ag	600.6780	0.3760	225.85	0.00	225.85
Total			3,274.39	239.29	3,035.10
** year:	3				
1 CU	295.1348	4.2500	1,254.32	177.08	1,077.24
2 Au	77.4128	23.9250	1,852.10	0.00	1,852.10
3 Ag	600.6780	0.3760	225.85	0.00	225.85
Total			3,332.28	177.08	3,155.20
** year:	4				
1 CU	295.1348	4.2500	1,254.32	177.08	1,077.24
2 Au	77.4128	23.9250	1,852.10	0.00	1,852.10
3 Ag	600.6780	0.3760	225.85	0.00	225.85
Total			3,332.28	177.08	3,155.20
** year:	5				
1 CU	295.1348	4.2500	1,254.32	177.08	1,077.24
2 Au	77.4128	23.9250	1,852.10	0.00	1,852.10
3 Ag	600.6780	0.3760	225.85	0.00	225.85
Total			3,332.28	177.08	3,155.20
** year:	6				
1 CU	295.1348	4.2500	1,254.32	177.08	1,077.24
2 Au	77.4128	23.9250	1,852.10	0.00	1,852.10
3 Ag	600.6780	0.3760	225.85	0.00	225.85
Total			3,332.28	177.08	3,155.20

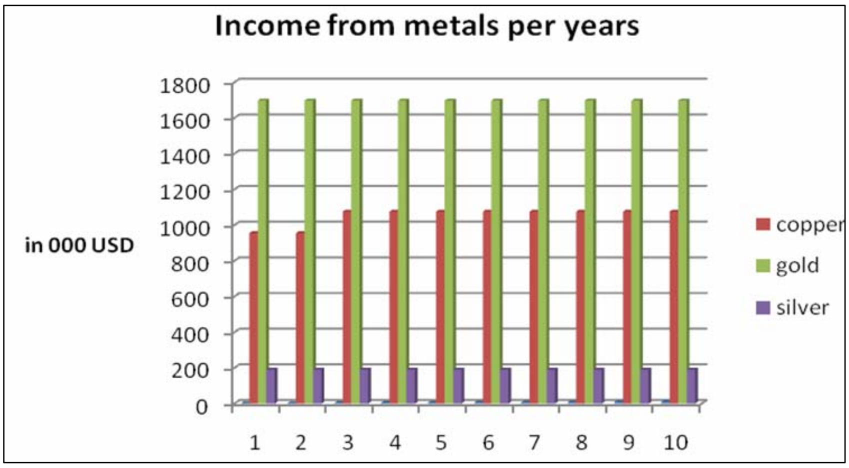
** year:	7				
1 CU	295.1348	4.2500	1,254.32	177.08	1,077.24
2 Au	77.4128	23.9250	1,852.10	0.00	1,852.10
3 Ag	600.6780	0.3760	225.85	0.00	225.85
Total			3,332.28	177.08	3,155.20
** year:	8				
1 CU	295.1348	4.2500	1,254.32	177.08	1,077.24
2 Au	77.4128	23.9250	1,852.10	0.00	1,852.10
3 Ag	600.6780	0.3760	225.85	0.00	225.85
Total			3,332.28	177.08	3,155.20
** year:	9				
1 CU	295.1348	4.2500	1,254.32	177.08	1,077.24
2 Au	77.4128	23.9250	1,852.10	0.00	1,852.10
3 Ag	600.6780	0.3760	225.85	0.00	225.85
Total			3,332.28	177.08	3,155.20
** year:	10				
1 CU	295.1348	4.2500	1,254.32	177.08	1,077.24
2 Au	77.4128	23.9250	1,852.10	0.00	1,852.10
3 Ag	600.6780	0.3760	225.85	0.00	225.85
Total			3,332.28	177.08	3,155.20
Total income			33,207.01	1,895.22	31,311.79

**Costs of refining for gold and silver are included by reduction the seling prices for Au and Ag.*

As the average annual capacity of mining was determined at 20.000 t, in the first variant, and the analyzing period is ten year, it follows that:

Value of production per ton of ore is: 156.56 USD.

The following graphs present graphically the results of this valuation as well as the largest share of income from gold (59%) in total income-valuation of raw mineral.



Graph 1. *Structure of income per years*

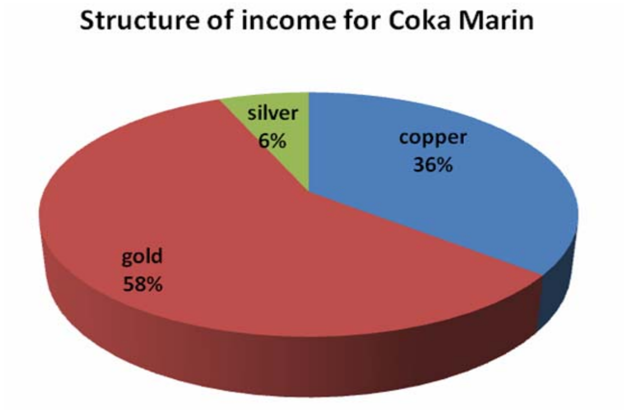


Figure 2. *Share of metal incomes in total valuation*

Applied on:

Value of deposit without taking into account the time factor - synthetic indicators

Vu = (Vi – Ti) · (R - G)

Where:

Vu – Value of deposit without taking into account the time factor in USD

Vi – Value of useful raw mineral,(reduced for treatment loss) – 156.56USD/t

Cu: loss of processing (flotation + metallurgy) = 2% + 3.4% = 5.4%

Au: loss of processing (flotation + metallurgy) = 6% + 9% = 15%

Ag: loss of processing (flotation + metallurgy) =10% +15% = 25%

Ti – production costs of raw mineral - 101.9 USD/t

R – G balance of reserves reduced for mining losses (5%)

Vu = (156.56 – 101.9) · (519872t - G)

Vu=54.7 · 493878.4

Vu=27,015.148 USD

CONCLUSION

Determination the value of raw mineral is the initial part of economic valuation for deposit and that is unique for both models of geological valuation: without taking into account the time factor and with taking into account the time factor.

Valuation is specially sensitive on changing the stock prices of metal, but that was avoid with accepting the World Bank forecast prices (which are about 30-40% lower than the current stock prices), what gives a warranty that the value of raw mineral was determined raw with very low risk.

REFERENCES

[1] B. Cavender, Mineral Production Costs - Analyses and Management, SME, (1999).

[2] N. Dondur, Economical Analyses of Projects, Faculty of Mechanical Engineering, Belgrade (2002).

[3] G.Mankju, Principles of Economics, Faculty of Economics, Belgrade (2005).

[4] M. Bugarin, G. Slavković, "Techno-economical Evaluation", Copper Institute, Bor (2006).

[5] T. Kuronen: Capital Budgeting in a Capital-Intensive Industry, Helsinki University of Technology, Mat-2.108 Independent Research Projects in the Applied Mathematics, (2007).

[6] G. Slavković, „The income in financial analiysis of investments in mining“, Innovation and development, No. 2, 2010. g. pp. 25-32

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KOMITET ZA PODZEMNU EKSPLOATACIJU MINERALNIH SIROVINA UDK: 622

UDK: 622:681.51(045)=861

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PRIMENA MODERNIH RAČUNARSKIH UREĐAJA I ALATA ZA SMANJENJE AKCIDENTNIH SITUACIJA U RUDARSKIM SISTEMIMA

Izvod

Veliki rudarski sistemi zahtevaju obimno održavanje za koje je potrebno izdvojiti dosta velika novčana sredstva kojima se opterećuje poslovanje preduzeća. Ako se tome doda da većina sistema nije adekvatno održavana godinama, naša reč je zapuštenost, onda uvek postoji dilema kojim putem. U ovom radu dat je prikaz primene termovizije u industriji kao efikasnognačina praćenja stanja sistema. Termovizijskom analizom mogu se brzo i precino pronaći kritični delovi u sistemu koji mogu dovesti do otkaza istog. Kao primer uzet je rotorni bager SchRs 800. Analizom termograma konstrukcije bagera locirana su mesta na kojima su povećane temperature na konstrukciji rotornog bagera usled dinamičkih naprezanja tokom rada sistema. Kombinovanjem tehnika termovizijske analize sa merenjima napona koristeći merne trake, informacionih tehnologija i primenom FTA i FMECA metoda za identifikaciju, analizu tipova u efekata kritičnih otkaza sa analizom rizika moze dati veliki doprinos poboljšanju održavanja rudarskih sistema.

Ključne reči: *termovizija, termovizijska kamera, analiza rizika, napon, rotorni bager*

UVOD

Razvoj tehnologije u rudarsrvu doveo je do stvaranja složenih tehničkih sistema koji se teško mogu sagledati bez sistemskog pristupa, analitičkih i metodoloških načina. Tehnički sistemi u rudarstvu predstavljaju katakteristična stanja pojedinih tehnologija u kontekstu funkcionalnih karakteristika, od jednostavnih do najsloženijih radnih aktivnosti. Osnovni procesi rudarstva u toku svog rada su destruktivnim uticajem različitih aktivnosti koje mogu značajno umanjiti njihov kvalitet.

O TERMOVIZIJI

Termovizija predstavlja snimanje temperature tela. Poznato je da sva tela emituju određenu količinu toplote (čal i led). Praćenje emitovanja ovog vida zračenja našlo je široku primenu u praćenju različitih pojava u raznim granama industrije. Merenja termovizijskom kamerom spadaju u grupu nedestruktivnih metoda ispitivanja i omogućuji kontinualno, precizno i brzo određivanje raspodela temperatura sistema koji se analizira u realnim uslovima. Dakle, ona omogućava da se vrši bez kontaktno merenje tempera-

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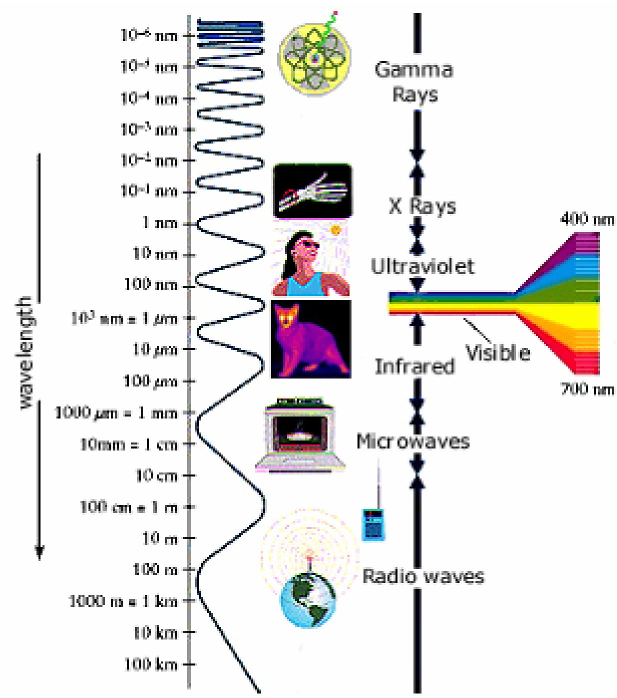
ture objekta. IC kamera je po konstrukciji slična digitalnoj video kameri. Određene IC kamer imaju ugrađen softver koji omogućava korisniku da se fokusira na specifične oblasti OMS i izračuna temperaturu. Drugi sistemi koriste računar ili sistem podataka sa spacijalizovanim softverom koji omogućava temperaturnu analizu.

Analizom dobijenih termovizijskoh informacija omogućava se višeznačna uporedna komparacija termograma i ostalih izmerenih veličina, čime se omogućava sveobuhvatna analiza problema i preventivno delovanje.

Termalne kamere, koje se nekada nazivaju i infracrvene kamere, sposobne su da registruju minimalne razlike u temperaturi i da njih konvertuju u jasnu termalnu sliku na kojoj se mogu uočiti i najsitniji detalji. Za razliku od drugih tehnologija kao što su pojačivači osvetljena, kojima je potrebna barem mala količina svetlosti da bi dali sliku, temalna tehnologija može da vidi u totalnom mraku. Njoj svetlost uopšte nije potrebna.

Termovizijsko snimanje objekata odvija se u infracrvenoj oblasti od 7.5-13 μm, sa spektralnom rezolucijom od 1.3 mrad. Infracrveni spektar u ovoj oblasti daje informacije o raspodeli temperaura na površini posmatranog objekta ili procesa, [1].

Za razliku od ostalih infracrvenih analiza objekata, rezultat ovih analiza je slika, vizuelna infromacija, pri čemu su intenziteti, izmerenih inracrvenih zračenja, predstavljeni bojom. Treba napomenuti da dobijene termovizijske slike predstavljaju pseudo slike, dobijene korišćenjem odgovarajućih LUT tabela, odnosno programskim vezivanjem temperature, za boje ili valere boja. Na taj način korisnik dobija trenutnu informaciju o raspodeli temperatura na posmatranom objektu u vidu vizuelnih informacija.



Slika 1. *Elektromagnetni spektar sa IC delom spektra koji koristi termovizija*

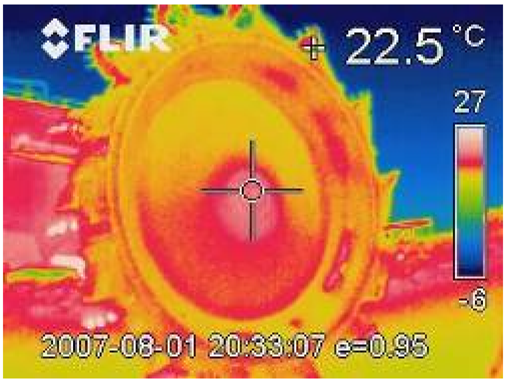
Temovizija je našla vema veliku primenu u svim sverama društva: mašinskoj i elektro industriji, građevinarstvu, rudarstvu, procesnoj industriji, industriji prerade drveta, auto industriji, medicini, policiji, spasilaćkim i vatrogasnim službama...

TERMOVIZIJA U RUDARSTVU

Mogućnost primene termovizijskih kamera u rudarstvu je jako velika, iz prostog razloga što su procesi pri eksploataciji i preradi korisne mineralne sirovine jako složeni uz upotrebu kompleksne mehanizacije i opreme. Samim tim proizvodnja je praćena brojnim zastojima zbog kvarova na opremi i mehanizaciji. Upravo je to pravo mesto delovanja i primene tremovizije u rudarstvu, na praćenju i ranom otkrivanju kritičnih elemenata sistema i preventivnom delovanju.

Praćenje temparaturnih promena termovizijskom kamerom na opremi i objektima, kao posledice pojave napona primenljivo je u gotovo svim fazama podzemne i površinske eksploatacije, kao što je:

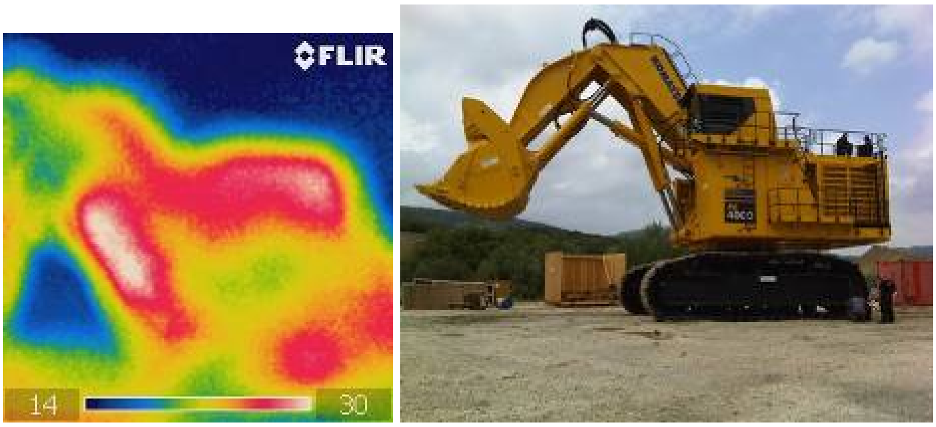
- otkrivanje i praćenje promene napona na delovima bagera (streli, nosaču kašike i samoj kašici, uređaju za kretanje)
- kontrola temperature pojedinih delova elektromotora kod kamiona;
- praćenje temperature uređaja za kočenje na kamionima;
- merenje temperature elektromotora, spojnice, ležajeva, osovina i konstrukcija pogonskih i povratnih stanica trakastih transportera;
- merenje i provera napona na konstrukcijama pretovarnih mostova i odlagača trakastih transportera;
- merenje temperature ležajeva i elektromotora mlinova za mlevenje rude, pumpnih agregata, drobiličnih postrojenja, izvoznih mašina;
- određivanje debljine obloga u mlinovima i napona u istim;
- određivanje mesta na šasijama jamskih kamiona gde se javljaju najveći naponi;
- merenje temperature delova motora, uređaja za hlađenje i izduvnog sistema jamskih kamiona;
- analiza stanja pneumatika kamiona;
- u trafostanicama za otkrivanje preopterećenih osigurača, elektro vodova, sklopki, uklopnika . . .
- Na sledećoj slici može se videti jedan od mnogih primera primene termovizijske kamere, za merenje temperature na radnom organu rotornog bagera.



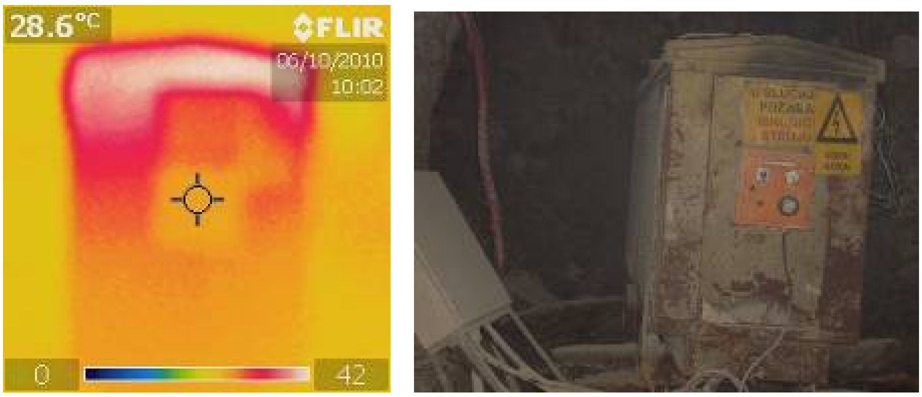
Slika 2. *Termovizijski snimak i standardna fotografija radnog organa rotornog bagera [3]*

Takođe može se primeniti za :

- otkrivanje i praćenje pukotina u bokovima kopa;
- otkrivanje pukotina na objektima koji se nalaze u blizini kopa (postolja drobiličnih postrojenja, radionice, postolja trakastih transportera);
- otkrivanje delova rudnika u kojima se javljaju oksidacioni procesi kao predfaze požara;
- prećenje oksidacionih procesa na deponijama korisne mineralne sirovine i detektovanje pojave požara na istim;
- praćenje stanja napona u sigurnosnim stubovima podzemnih prostorija i stubova u otkopnim komorama . . .



Slika 3. *Termovizijski snimak i standardna fotografija bagera Komatsu PC 4000*



Slika 4. *Termovizijski snimak i standardna fotografija rudničkog transformatora*

ANALIZA RIZIKA U RUDARSTVU

Moderni multivarijabilni pristup aspektu problema bezbednosti nameće uslove za velikim stepenom pouzdanosti i sigurnosti procesa u rudarstvu. Takvi zahtevi su opravdani činjenicom da postoji potreba za smanjenje rizika. Rudarska industrija je oblast od posebnog interesa gde se mogu primeniti naučna znanja u sferi rizika. Prethodni napori u odnosu na zahteve u procesu projektovanja sistema i potrebu za redizajniranje postojećih koji funkcionišu duže vreme. Bezbedno, sigurno funkcionisanje sistema je ugroženo. Takve se greške moraju u potpunosti izbegavati - eliminisati. Greška može da utiče na konačni ishod u većoj ili manjojmeri, na direktan ili indirektan način, dok sistem za pozicioniranje smislu ograničenja rizika – mogućnost nastanka rizićnih događaja. Kao knačan ishod može izazavati upotrbu dodatnih finansijskih sredstava. Bezbedno, sigurno funkcionisanje sistema je ugroženo. Takve se greške moraju u potpunosti izbegavati - eliminisati.

Danas, za procenu rizika postoje više modernih metoda kao što su FTA (analza stabla grešaka) i FMECA (modeli otkaza, efekti i analiza kritičnosti). Na njihovim osnovama razvijeno je mnoštvo alata i programa za analizu rizika (Design Safe, Asent, Item ToolKit, …)[5].

Slika 5. *Neki od otkaza rudarske mehanizacije, [6]*

Pogodnost održavanja je naročito prikladna za ocene izvršenih izmena ili poboljšanja određenog sistema održavanja ili tehničkog sistema koji se odražava, a znatno manje ako se upoređuju različiti sistemi. Na pogodnost održavanja utiče veći broj faktora kao što su: uslovi eksploatacije, kvalitet sistema održavanja, kvalitet logističke podrške, a najveći uticaj ima unugodnosti održavanja jeste da obezbedi maksimalnu gotovost sistema uz minimalne troškove održavanja i minimalne zastoje, odnosno minimalno vreme održavanja uz minimalnu logističku podršku. [7].

Funkcija pogodnosti održavanja se, po definiciji, izražava u obliku:

$$P_0(t_i) = \int_0^{t_1} f(t_0)dt_0 \quad \text{.................} (1)$$

gde su:

t_o- vreme trajanja održavanja

$f(t_o)$- funkcija gustine ovog vremena, [7].

Tehnički sistemi i procesi u toku svog radnog veka su pod dejstvom raznih destruktivnih uticaja koji mogu ozbiljno smanjiti kvalitet njihovog rada. Šanse pojavljivanja i očekivane posledice događaja u ciklusu smatraju se rizikom u sistemu analize tokom perioda uvođenja ili određenog procesa (kombinovanje učestalosti i verovatnoće pojavljivanja, kao i rezultat određenog štetnog događaja), [8].

ZAKLJUČAK

Primena modrenih metoda FTA (analiza stabla greške) i FMECA (modeli otkaza, efekti i analiza kritičnosti) za identifikaciju, analizu tipa, efekata kritičnih otkaza i analize rizika može dati veliki doprinos poboljšanju održavanja rudarskih sistema. Upotreba termovizije u industriji omogućava pračenje rada sistema u neometano funkcinisanje mašina i postrojenja, i veoma kratkom roku otkriva lokacije na kojima može doći do havarije. Upotrebom termovizije u industrijskom održavanju smanjuju se direktni troškovi održavanja, smanjiju se gubici usled zastoja i prekida proizvodnje i omogućava izradu efikasnog plana preventivnog održavanja

Kombinovanjem ova dva načina za praćenje i analizu i upotrebom modenih softverskih alata (programa Design Safe, Asent, Item ToolKit, …) može se smanjiti broj otkaza sistema i cena koštanja održavanja rudarskih sistema.

LITERATURA

[1] www.flirthermography.com/about

[2] Biocanin R, Lojančić R., Martinović B.: Bio-effects of ionizing radiation and protection, 10th International conference ”Research and Development in Mechanical Industry” - RaDMI 2010, Donji Milanovac, 16-19. September 2010. p 726-733;

[3] Jovanić P. Damnjanović Z. and Petrović D.: Thermal analysis of SCHRS 800 continous excavator construction frame on open pit Drmno, 10th International conference ”Research and Development in Mechanical Industry” - RaDMI 2010, Donji Milanovac, 16-19. September 2010. p 600-609;

[4] Radosavljević S., Lilić N., Ćurčić S, Radosavljević M.: Risk assessment and managing technical systems in case of mining industry, Strojniški Vestnik – Journal of Mechanical Engineering 55 (2009) 2, p. 119-130;

[5] http://www.fmea-fmeca.com

[6] Bošnjak S., Zrnić N., Gašić V., Petković Z.: Changeability as a basic working load characteristic of machinery for mechanization, 10th International conference ”Research and Development in Mechanical Industry” - RaDMI 2010, Donji Milanovac, 16-19. September 2010. p 58-67;

[7] Bogdanović B., Dašić P.: Evaluation of maintence the air-driven fans and work safety in the underground mine, Rudarski Radovi – Mines Engineering 1/2007 p 38-45;

[8] Dašić, P., Natsis, A., Petropoulos, G.: Models of reliability for cutting tools: Examples in manufacturing and agricultural engineering. Strojniški vestnik – Journal of Mechanical Engineering, vol. 54 no. 2 (2008), p. 122-130.

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USE OF MODERN COMPUTER EQUIPMENT AND TOOLS TO REDUCE THE OCCURRENCE OF ACCIDENTS IN THE MINING SISTEMS

Abstract

Large mining systems require extensive maintenance that needs to asset a lot of large financial assets that burden the business enterprises. If it is added to this that the most systems are not properly maintained for years, our word is disrepair, then there is always a doubt which way to go. This paper gives a description of thermography use in the industry as the efficient way of monitoring the system condition. Thermal imaging analysis can quickly and precisely find the critical parts in the system that can result into a failure of the same. The wheel excavator SchRs 800 was used as an example. By thermography analyzing, the areas with higher temperature on the wheel excavator construction can be located due to the dynamic tensions during the system operation. By combining the thermal imaging techniques with tension measurements using the measuring tape, ITC and use of FTA(Fault Tree Analysis) and FMECA (Failure Models, Effects and Criticality Analysis) modern methods for identification, the analysis of types in the effects of critical failures with the risk analysis can make a great contribution to the maintenance improvement of mining systems.

Key words: *thermography, thermal camera, risk analysis, tension, wheel excavator*

INTRODUCTION

Development of technology in mining has led to the creation of complex technical systems that can hardly be seen without a systematic approach to the analytical and methodological terms. Technical systems in mining represent distinctive conditions of some specific technologies in a context of functional features, from simple to the most complex work activities. The basic mining processes in their operation are subjected to the destructive impact of various activities that can significantly reduce their quality.

ABOUT THERMOGRAPHY

Thermography is recording of object heat. It is known that all objects emit a certain amount of heat (even ice). Monitoring of heat emissions has found wide application in monitoring of different phenomena in various fields of industry. Measurements of thermal cameras belong to a group that testing without destroying materials and provide continuous, accurate and quick determination of distribution system temperature that is analyzed in real conditions. Therefore, it allows without contact temperature measuring. IR camera

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is similar in the construction to a digital video camera. Certain infrared cameras have built-in software that allows user to focus on specific areas of OMS and calculate the temperature. Other systems use a computer or data system with specialized software that allows the temperature analysis.

Analyzing the obtained thermovision information gives a possibility if multi important parallel comparison of thermograms and other measured values allowing a comprehensive analysis of problems and preventive action.

Thermal cameras, sometimes referred to as the infrared cameras, are able to register minimum differences in temperature and convert them into a clear thermal image, which can spot the smallest details. Unlike other technologies that require a small amount of light to give an image, thermal technology can see in total darkness. It does not need a light.

Thermal cameras record images in infrared area of 7.5-13 μm with a spectral resolution of 1.3 mrad. The infrared spectrum in this area gives the information on distribution of temperatures on the surface of observed object or process [1].

The results of these IR analyses is the image, visual information with intensity, where the intensities of measured IR radiations are represented by color. It should be noted that the obtained thermal imaging images are pseudo-images, obtained using the appropriate LUT tables or program linking temperature for color. In this way the user can get immediate information on distribution of temperature on the observed object in the form of visual information.

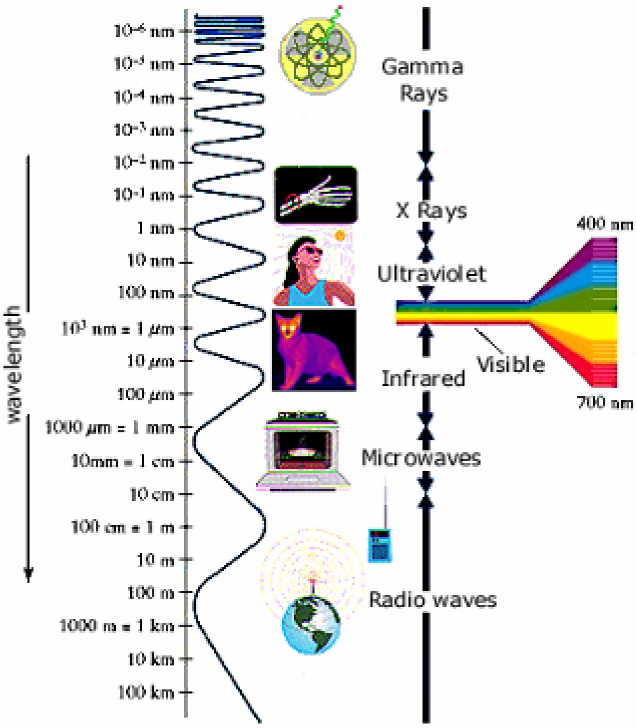

Figure 1. *Electromagnetic spectrum with IR part of spectrum used by the mography [2]*

Thermography has found a large use in all spheres of society: mechanical and electrical industry, construction, mining, processing industry, wood processing industry, car industry, medicine, police, rescue and fire services…

THERMOGRAPHY IN MINING

Possibility of use the thermo vision camera in mining industry is very large, for the simple reason that the processes of ore mining and processing are very complex with the use of complex machinery and equipment. Therefore the production is accompanied by numerous delays due to the failures on equipment and machinery. That is real place for action and implementation the thermal cameras in mining on monitoring and early detection the critical elements of system and preventive action.

Monitoring of temperature changes by thermal camera on equipment and facilities, as the consequence of tension, is applicable in nearly all phases of underground and surface mining, such as:

- detecting and monitoring the changes of tension on parts of excavators (arrow, bucket carrier, bucket and driving device);
- temperature control of some electric motor parts on trucks;
- temperature monitoring of braking device for braking on trucks;
- temperature measuring of electric motors, couplings, bearings, axles and construction of driving and recurrent stations of belt conveyors;
- tension measuring and checking on constructions of reloading bridges and disposer of belt conveyors;
- temperature measuring of bearings and electrical motors of mills for ore grinding, pump aggregates, crushing plants, hoisting machines;
- determination of mill lining thickness and tension in the same;
- determination of spots on the underground truck boxes with the highest tensions;
- temperature measuring of engine parts, device for cooling and exhaust system of underground trucks;
- condition analysis of underground truck tires;
- in electrical substations for detection the overloaded fuses, electrical transformers, electrical cables, switchers…

Figure 2 presents one of many example of use the thermal camera for temperature measuring on the working device of wheel excavator.

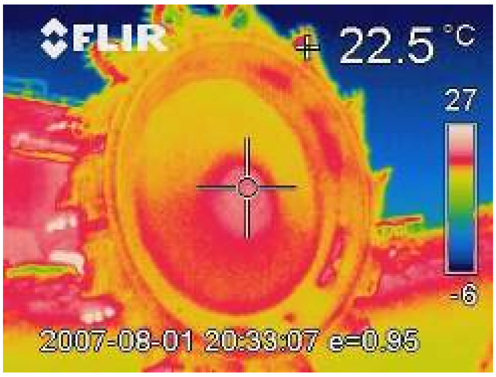

Figure 2. *Thermal camera image and standard photo of wheel excavator [3]*

Thermal camera can be also used for:

- detection and monitoring cracks in the sides of open mine;
- detection of cracks in buildings that are close to the open pit (crushing plant stands, workshops, stands of belt conveyors);
- detection of the mine parts where the oxidative processes occur as direct indicator of mine fires;
- monitoring of oxidative processes on landfills of coal and detection of fire occurrences in the same;
- monitoring of tensions in the security pillars around underground chambers and pillars in rooms for excavation…

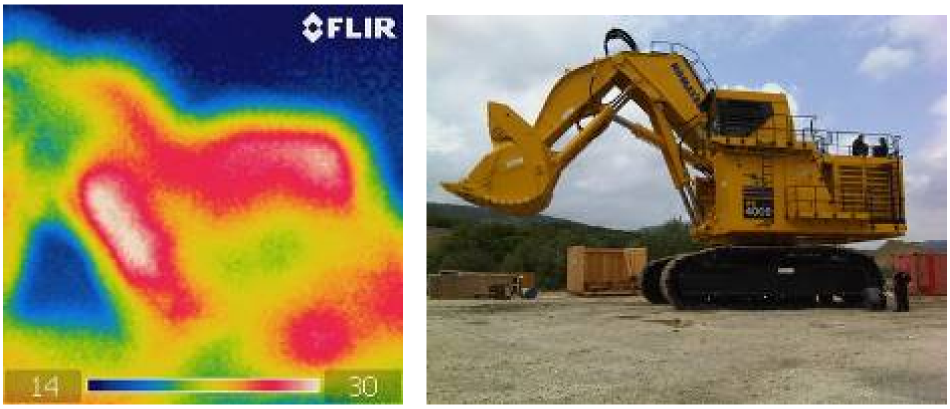

Figure 3. *Thermal camera image and standard photo of Komatsu PC 4000 excavator*

Figure 4. *Thermal camera image and standard photo of mine transformer*

RISK ANALYSIS IN MINING

Modern multi-aspect approach to the occupational safety problems imposes the requirements for high degree of reliability and safety of the process in mining. Such requirements are justified by the fact that there is a need for risk reduction. Mining industry is a field of particular interest concerning the use of scientific knowledge within the sphere of risk. Previous efforts in relation to the requirements in the process of system design and the need for redesign the existing ones that have worked a long time. A fault can affect the final outcome to greater or lesser extent, in a direct or indirect way, while the positioning system within the context of risk limits / possibility of occurrence the risky events. As the final outcome, it can cause the use of unplanned financial resources. Safe and secure function of the system is threatened. Such faults need to be completely avoided/eliminated, [4].

Today, many modern methods exist for risk analysis such as FTA (Fault Tree Analysis) and FMECA (Failure Models, Effect and Criticality Analysis). On theirs bases is developed many tools and programs for risk analysis (Design Safe, Asent, Item ToolKit,..) [5].

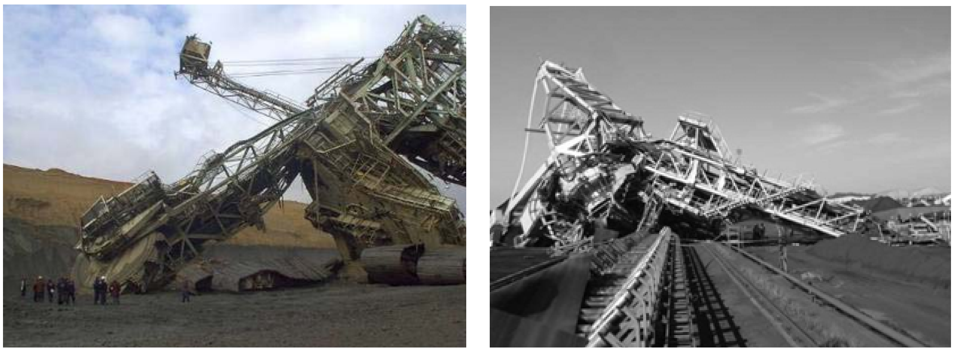

Figure 5. *Some failures of mining mechanization [6]*

Maintainability is especially suitable for evaluation the completed changes or improvements to a certain system maintenance or technical system that reflects, and considerably less if different systems are compared. Number of factors has influence on the benefit of maintenance such as mining conditions, quality of maintenance system, quality of logistic support and the highest benefit of maintenance is maximum impact of the system with minimum maintenance costs and minimum downtime, that is minimum time of maintenance with minimum logistic support, [7].

Maintainability function, by definition, is expressed by the next formula:

$$P_0(t_i) = \int_0^{t_1} f(t_0)dt_0 \quad ....(1)$$

where:

to- maintenance time

f(to)- density function of this time

Technological systems and processes during their life cycle are under various destructive influences which can considerably reduce the quality of their operation. The chances of unwanted events and anticipated consequences of the events in the cycle are considered to be a risk in the system analysis during the established length of time or a certain process (the combination of frequency and chances of appearing, as well as the result of certain adverse event) [8].

CONCLUSION

The use of FTA (Fault Tree Analysis) and FMECA (Failure Models, Effects and

Criticality Analysis) modern methods for identification, analysis of types, effects of critical failures and risk analysis can lead to a high benefit in maintenance the mining systems. The use of themography in industry allows the system monitoring without stoppage of operation the machinery and equipments, and in a very short period of time reveals locations in the system where damages may occur. Using thermography recording and monitoring in the industrial maintenance, the direct maintenance costs could be reduced, losses could be reduced due to delays and interruption of production, and allows development of effective preventive maintenance plan.

Combining these two ways for monitoring and analysis and using modern computer tools (programs Design Safe, Asent, Item ToolKit …) number of delays and cost of maintaining mining systems could be reduced.

REFERENCES

[1] www.flirthermography.com/about

[2] Biocanin R, Lojančić R., Martinović B.: Bio-effects of Ionizing Radiation and Protection, 10th International Conference ”Research and Development in Mechanical Industry” - RaDMI 2010, Donji Milanovac, 16-19 September 2010, pgs. 726-733 (in Serbian)

[3] Jovanić P., Damnjanović Z., and Petrović D.: Thermal Analysis of SCHRS 800 Continuous Excavator Construction Frame at the OpenPit Drmno, 10th International Conference ”Research and Development in Mechanical Industry” - RaDMI 2010, Donji Milanovac, 16-19 September 2010, pgs. 600-609(in Serbian)

[4] Radosavljević S., Lilić N., Ćurčić S., Radosavljević M.: Risk Assessment and managing Technical Systems in a Case of Mining Industry, Strojniški Vestnik – Journal of Mechanical Engineering 55 (2009) 2, pgs. 119-130

[5] http://www.fmea-fmeca.com

[6] Bošnjak S., Zrnić N., Gašić V., Petković Z.: Changeability as the Basic Working Load Characteristic of Machinery for Mechanization, 10th International Conference ”Research and Development in Mechanical Industry” - RaDMI 2010, Donji Milanovac, 16-19 September 2010, pgs. 58-67 (in Serbian);

[7] Bogdanović B., Dašić P.: Evaluation of Maintenance the Air-driven Fans and Work Safety in the Underground Mine, Mining Engineering 1/2007, pgs. 38-45(in Serbian)

[8] Dašić, P., Natsis, A., Petropoulos, G., Models of Reliability for Cutting Tools: Examples in Manufacturing and Agricultural Engineering, Strojniški Vestnik – Journal of Mechanical Engineering, Vol. 54, No. 2 (2008), pgs. 122-130

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KOMITET ZA PODZEMNU EKSPLOATACIJU MINERALNIH SIROVINA UDK: 622

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ODLAGANJE JALOVINE IZ SEPARACIJE KVARCA LEŽIŠTA "KAONA" KOD KUČEVA

Izvod

Ležište kvarcnih minerala "Kaona" je dobilo ime po istoimenom zaseoku blizu koga se nalazi. Od Kučeva kao najbližeg grada ležište "Kaona" je udaljeno oko 6,5 km. Minerali kvarca u ležištu su u najvećoj meri zastupljeni srednje sitnim i sitnim frakcijama, najčešće zaprljanim limonitnim i glinenim prevlakama. Radi dobijanja kvalitetnih - tržišnih proizvoda, potrebno je rovni kvarcni pesak prethodno podvrgnuti procesu pranja i separacije. Proizvodi separacije kvarcnog peska su čist pesak i nečistoće koje predstavljaju definitivnu jalovinu, koju treba trajno deponovati na jalovištu. U radu su opisani osnovni tehnološki parametri budućeg separacijskog jalovišta.

Ključne reči: *Ležište Kaona, kvarcni pesak, jalovište*

UVOD

Ležište kvarcita "Kaona" se nalazi u istočnoj Srbiji, zapadno od Kučeva na udaljenosti od oko 6,5 km. U administrativno teritorijalnom pogledu ležište pripada brani-čevskom okrugu i opštini Kučevo. U cilju definisanja geoloških rezervi rađena su u više navrata geološka istraživanja počevši od 1969 godine. Kompletna istraživanja su završena 2007 godine, tako da se na osnovu dobijenih rezultata može zaključiti da je moguće nakon čišćenja rovnog peska dobiti nekoliko kvalitetnih komercijalnih proizvoda.

Kako rovni pesak nakon površinske eksploatacije sadrži nečistoće koje se najčešće ogledaju u limonitnim i glinenim prevlakama (opnama) neophodno je nakon eksploatacije kvarcni pesak podvrgnuti postupcima pranja odnosno čišćenja. Kvarcni pesak se nakon pranja, prosejava u komercijalne proizvode i skladira na privremenim depoima.

Za postupak pranja i čišćenja kvarcnog peska se koristi čista voda, koja se iz vodozahvata sa obližnjeg potoka pumpama transportuje do bazena iznad pogona separacije. Osim vode za čišćenje kvarcnog peska ne koriste se druga hemijska sredstva. Posle faze čišćenja, s obzirom na konfiguraciju terena, voda zajedno sa nečistoćama se gravitacijski transportuje kanalom do separacijskog jalovišta. Na jalovištu se vrši taloženje finih muljevitih čestica, nakon čega se čista tehnološka voda vraća ponovo u tehnološki proces separacije, čime se smanjuje upotreba sveže vode na najmanju moguću meru.

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KONCEPCIJSKO REŠENJE IZGRADNJE SEPARACIJSKOG JALOVIŠTE

Ulazni tehnološki parametri

Prilikom projektovanja separacijskog jalovišta korišćeni su tehnološki parametri obrađeni u tehnološkom delu studije izvodljivosti. Osnovni parametri su prikaani u narednoj tabeli 1.

Tabela 1. *Tehnološki parametri separacijske jalovine*

R. br.	PARAMETAR	Oznaka	J.M.	Oznaka na teh. šemi 19
1	Maseni protok čvrste faze	$\mathbf{Q_Č}$	t/h	1,3677
2	Maseni protok čvrste faze	$\mathbf{M_Č}$	%	3,96
3	Gustina čvrste faze	$\boldsymbol{\rho_Č}$	t/m^3	2,720
4	Zaprem protok čvrste faze	$\mathbf{V_R}$	m^3/h	0,4939
5	Sadržaj čvrstog u pulpi	**Č** ili **p**	%	2,12
6	Razređenje pulpe	**R**	Del.j	46,17
7	Zaprem protok vode	$\mathbf{V_V}$	m^3/h	63,1556
8	Zaprem protok pulpe	$\mathbf{V_P}$	m^3/h	63,6495
9	Maseni protok pulpe	$\mathbf{Q_P}$	t/h	64,514
10	Gustina pulpe	$\boldsymbol{\rho_P}$	kg/m^3	1,0136
11	Krupnoća jalovine	**d**	mm	-0,106 + 0,0

Izbor lokacije jalovišta

Pre projektovanja ekipa projektanata IRM-a je obišla Kaonu kao i lokacije koje se eventualno mogu iskoristiti za izgradnju separacije i jalovišta.

Nekoliko lokacija je evidentirano kao moguće lokacije za smeštaj jalovine iz separacije. Analiziranjem sledećih tehničko-tehnoloških parametara uticajnih na izbor lokacije za jalovište, izabrana lokacija predstavlja optimalno rešenje:

- topografske karakteristike terena,
- geološke, geotehničke i hidrološke karakteristike terena,
- odnos mogućeg i potrebnog kapaciteta jalovišta,
- dužinu kao i mogućnost gravitacijskog transporta jalovine,
- uslove i mogućnost korišćenja povratne vode.

Izabrana lokacija se nalazi oko 220 m jugozapadno od pogona separacije. Kako se separacija nalazi na koti K+280 mnv a završna kota jalovišta K+250 mnv gravitacijski transport jalovine iz sparacije je moguć tokom celog radnog veka jalovišta, što značajno umanjuje troškove transporta pulpe svodeći ih praktično na nulu.

Opis tehnologije izgradnje jalovišta

Separacijsko jalovište u Kaoni se izgrađuje od zemlje - materijala iz pozajmišta, koje se bira unutar budućeg akumulacionog polja. Na taj se način efektivno povećava zapremina slobodnog akumulacionog prostora za zapreminu zemlje koja se ugrađuje u telo pregradne brane.

Brana se gradi sa sledećim geometrijskim parametrima:

- nagib spoljašnje kosine 1:2,
- nagib unutrašnje kosine 1:2,
- širina krune brane na završnoj koti K+250 mnv je 4 m,
- širina brane u nožici u najširem delu je 38 m,
- najveća visina brane je između kota K+240 mnv i K+250 mnv i iznosi 10 m,
- ukupna dužina brane na koti K+250 mnv iznosi 175 m,

Sl. 1. *Detalj polaganja vodonepropusne folije na unutrašnju kosinu brane*

Da bi se omogućila izgradnja brane prikazane geometrije sa koeficijentima stabilnosti koji su zakonom propisani potrebno je uraditi sledeće:

- unutrašnju kosinu brane treba obložiti vodonepropusnom folijom tipa HDPE debljine 2 mm,
- na spoljašnjoj kosini treba izgraditi drenažnu prizmu od kamenog agregata sa površinskog kopa, celom dužinom spoljašnje nožice, ukupne dužine od oko 182 m,
- pored drenažne prizme treba izgraditi drenažni kanal koji će sakupljati drenažne vode i usmeravati ih u pravcu drenažnog sabirnika odakle će se voda prepumpavati nazad u akumulaciono jezero,
- zemlju za izgradnju brane sabijati u slojevima od oko 40 cm valjkom, vibro-pločom ili sličnom mehanizacijom, do propisane zbijenosti koja se zahteva odgovarajućim standardom,
- nakon izgradnje brane spoljašnju kosinu kao i krunu brane treba odmah rekultivirati, sejanjem trave ili busenovanjem, radi sprečavanja dejstva erozije na branu.

Transport pulpe od separacije do jalovišta obavljaće se gravitacijski kanalom pravougaonog poprečnog preseka 0,4x0,5 m. Kanal će biti iskopan u zemlji i obložen daskama debljine 2 cm. Ukupna dužina kanala će biti oko 200 m.

BILANS MASA, ZAPREMINA JALOVIŠTA I VEK EKSPLOATACIJE

Bilans masa

Separacijsko jalovište u Kaoni spada u jalovišta dolinskog tipa, pri čemu se akumulacioni prostor za deponovanje jalovine dobija izgradnjom jedne nizvodne pregradne brane. Maksimalna kota brane iznosi K+250 mnv, sa kotom osnovice na K+240 mnv i svojom maksimalnom visinom od 10 m. Kako je ukupna jalovina krupnoće 100% - 0,106 mm sastavljena od veoma finih i muljevitih čestica, ista se ne može upotrebiti za izgradnju brane, tako da se brana gradi od materijala iz pozajmišta. Radi povećanja ukupnog akumulacionog prostora jalovišta pozajmište se predviđa unutar akumulacionog prostora.

U narednoj tabeli 2 prikazan je bilans masa kao i slobodna zapremina jalovišta za predviđeni period eksploatacije od 10 godina, sa planiranom godišnjom dinamikom eksploatacije od 150.000 t rovnog peska.

Kako maseni udeo jalovine u ukupnoj raspodeli masa čvrste faze iznosi 3,96% (prema tabeli 1) godišnje je na separacijsko jalovište potrebno deponovati oko 5.45,43 t jalovine.

Kako je zapreminska masa jalovine koja se deponuje oko 1,3 t/m^3 to praktično znači da godišnje treba za deponovanje jalovine obezbediti akumulacioni prostor od približno 4.573,41 m^3.

U narednoj tabeli 2 dat je bilans jalovine koju je potrebno deponovati na separacijsko jalovište za predviđeni period rada površinskog kopa, u skladu sa godišnjom dinamikom.

Tabela 2. *Bilans masa jalovine za period od 10 godina*

Godina	Količina jalovine t /god	Količina jalovine kumulativno t	Zapremina jalovine m^3/god	Zapremina jalovine kumulativno m^3
1	5945,43	5945,43	4573,41	4573,41
2	5945,43	11890,86	4573,41	9146,82
3	5945,43	17836,29	4573,41	13720,23
4	5945,43	23781,72	4573,41	18293,64
5	5945,43	29727,15	4573,41	22867,05
6	5945,43	35672,58	4573,41	27440,46
7	5945,43	41618,01	4573,41	32013,87
8	5945,43	47563,44	4573,41	36587,28
9	5945,43	53508,87	4573,41	41160,69
10	5945,43	**59454,30**	4573,41	**45734,10**

Kako se iz prethodne tabele može videti prema predviđenoj dinamici otkopavanja na površinskom kopu u Kaoni i preradi u separaciji, za 10 godina je potrebno deponovati ukupno 59,454,3 t jalovine, za šta je potrebno obezbediti akumulacioni prostor od oko 45.734,1 m^3.

Zapremina i vek eksploatacije jalovišta

Prema predviđenoj dinamici proizvodnje rovnog peska na površinskom kopu i rada separacije za period od 10 godina potrebno je obezbediti prostor za trajno odlaganje za 45,734,1 m^3 separacijske jalovine.

Da bi se to omogućilo potrebno je izgraditi jalovište sa minimalnom zapreminom akumulacionog prostora od oko 46.000 m^3. Na ovu zapreminu treba dodati retenzioni prostor koji mora da postoji u slučaju velikih kiša (sa povratnim periodom od 1.000 godina) kako bi se zaštitila naselja koja se nalaze nizvodno od jalovišta, jer po važećem zakonodavstvu nije dozvoljeno nikakvo ispuštanje otpadnih voda i jalovine u okolni prostor, odnosno van kontura jalovišta.

Kako je u pitanju veoma fina jalovina neodgovarajućih fizičko-mehaničkih karakteristika za izgradnju brane jalovišta (100% - 0.106 mm) pregradna brana za formiranje akumulacionog prostora za deponovanje jalovine biće izgrađena od zemlje. Unutrašnja kosina brane biće obložena vodonepropusnom folijom. Nožica brane biće na koti K+240mnv, sa krunom brane na koti K+250 mnv, tako da će maksimalna visina brane iznositi oko 10 m. Akumulacioni prostor koji će služiti za odlaganje jalovine biće prostor visinski ograničen kotama K+240 mnv do K+ 249 mnv, pri čemu će preostala visina od 1 m do kote K+250 mnv služiti kao retenzioni prostor, naročito u poslednjim godinama eksploatacije kopa i separacijskog jalovišta, kada ukupna aktivna zapremina jalovišta bude smanjena.

Kako je početna kota izgradnje jalovišta K+240 mnv sa branom izgrađenom do kote K+250 mnv ukupna zapremina jalovišta će biti:

$$V_J = V_B + V_A$$

gde su:

V_J - ukupna slobodna zapremina jalovišta, m^3

V_B - zapremina brane do K+250 mnv, m^3

V_A - zapremina akumulacionog prostora do K+249 mnv, m^3

$$Vj = 18\ 141,4 + 28\ 658,6 = 46\ 800\ m^3$$

$$\mathbf{V_j = 46\ 800\ m^3}$$

Kako je za odlaganje godišnje količine jalovine iz separacije potreban prostor od 4573,41m^3 to će vek eksploatacije jalovišta za kotu zapunjavanja od K+249 mnv biti:

$$Te = \frac{Vj}{Vg} = \frac{46800}{4573,41} = 10,23 \text{ godine}$$

odnosno gde je:

Vg - godišnja zapremina jalovine, m^3

Te = 10 godina i 3 meseca

Jalovište pripremljeno i projektovano na prikazan način omogućuje sigurnu i stabilnu eksploataciju narednih 10 godina sa projektovanim godišnjim kapacitetom.

ZAKLJUČAK

Pri dizajniranju separacijskog jalovišta ležišta kvarcita "Kaona" vodilo se računa o svim važećim zakonskim normama kao i savremenim ekološkim metodama za projektovanje deponija i odlagališta. Bez obzira što se za pranje - čišćenje rovnog kvarcnog peska u separaciji koristi voda bez dodataka hemijskih sredstava separacijsko jalovište je projektovano sa vodonepropusnom folijom, čime se sprečava u potpunosti infiltriranje vode iz akululacionog prostora jalovišta u okolni teren. Ekološki pristup se takođe ogleda i u maksimalnom korišćenju povratne tehnološke vode iz akumulacionog jezera jalovišta za rad pogona separacije, uz minimalan dotok sveže vode iz vodozahvata, čime se štite okolni vodeni resursi.

Kako ukupna zapremina jalovišta iznosi 46.800 m^3 ukupni vek eksploatacije jalovišta sa projektovanim kapacitetom eskploatacije rovnog peska od 150.000 t godišnje, iznosi preko 10 godina.

Po završetku eksploatacije separacijskog jalovišta izvršiće se kompletna rekultivacija jalovišnog prostora, čime se stvaraju uslovi za njegovo vraćanje prvobitnoj nameni i potpunog uklapanja u okolni prostor.

LITERATURA

[1] Ljubiša Obradović: "Studija izvodljivosti separacije kvarcnog peska iz ležišta "Kaona " Kučevo - deo odlaganja separacijske jalovine, Institut za rudarstvo i metalurgiju Bor, 2009.

[2] Dragan Milanović i sar. "Separacija kvarcnih mineralnih sirovina iz ležišta "Kaona" kod Kučeva, Rudarstvo 2010/Mining 2010 - I Međunarodni simpozijum, 24-26 maj Tara 2010, Zbornik radova.

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DEPOSITION OF TAILINGS FROM THE QUARTZ SEPARATION PLANT OF THE "KAONA" DEPOSIT NEAR KUČEVO

Abstract

The "Kaona" deposit of quartz minerals was named according to the same small village near which it is located. The "Kaona" is located about 6.5 km from Kučevo as the nearest town. Quartz minerals in the deposit are mostly represented by small and medium-small fractions, usually dirty with limonite and clay coatings. In order to obtain the high quality – market products, the run-of-mine quartz sand is necessary to undergo the process of washing and separation. The separation products of quartz sand are clean sand and impurities as the final tailings, which should be permanently deposited on the tailing dump. This paper describes the basic technological parameters of future separation tailing dump.

***Key words**: Kaona deposit, quartz sand, tailing dump*

INTRODUCTION

The "Kaona" deposit of quartz minerals is located in eastern Serbia, on the west of Kučevo at a distance of about 6.5 km. In terms of administrative and territorial position the deposit belongs to the Braničevo district and Kučevo municipality. In order to define the geological reserves, the geological explorations were made on several occasions starting in 1969. Complete explorations were completed in 2007, so based on these results it can be concluded that it is possible, after cleaning the run-if-mine sand, to get a number of quality commercial products.

As the run-of-mine sand after the surface mining operation contains impurities that are commonly seen in limonite and clay coatings (membranes), it is necessary, after mining operation, to subject the quartz sand to the washing or cleaning procedures. After washing the quartz sand is screened into commercial products and stored at the temporary depots.

The pure water is used for washing and cleaning procedure of quartz sand, which is the water from a nearby stream transported by pumps to the pool above the separation plant. Other chemical agents

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than water are not used for cleaning the quartz sand. After the cleaning stage, regarding to the terrain configuration, the water with impurities is transported gravitationally by canal to the separation tailing dump. Deposition of fine slurry particles is done on the tailing dump, after which the pure technological water is returned back into the technological process of separa tion, thus reducing the use of fresh water to a minimum.

CONCEPTUAL SOLUTION FOR CONSTRUCTION THE SEPARATION TAILING DUMP

Input technological parameters

In designing the separation tailings, the technological parameters were used which were processed in the technological part of feasibility study. The basic parameters are shown in the following Table 1.

Table 1 *Technological parameters of tailings separation*

Ord. No.	PARAMETER	Mark	Unit	Marko on techn. scheme 19
1	Mass flow of the solid phase	Q_s	t/h	1.3677
2	Mass flow of the solid phase	M_s	%	3.96
3	Density of the solid phase	ρ_s	t/m^3	2.720
4	Volumetric flow of solid phase	V_R	m^3/h	0.4939
5	Solid content in the pulp	S or p	%	2.12
6	Dilution of the pulp	R	Parts of unit	46.17
7	Volume of the water flow	V_V	m^3/h	63.1556
8	Volume of the pulp flow	V_P	m^3/h	63.6495
9	Mass flow of the pulp	Q_P	t/h	64.514
10	Pulp density	ρ_P	kg/m^3	1.0136
11	Size range of the tailings	d	mm	-0.106 + 0.0

Selection of tailing dump location

Before the design, a team of designers from the Mining and Metallurgy Institute visited Kaona as well as the locations that may be used for construction the separation and tailing dump.

Several locations were recorded as the possible locations for placement the tailings from separation. By analyzing the following technical and technological parameters affecting the selection of location for tailings, the selected location presents an optimum solution:

- Topographic characteristics of the terrain,
- geological, geotechnical and hydrological characteristics of the terrain,
- relationship of possible and required capacity of the tailing dump,

- length and possibility of gravitational transport of tailings,
- conditions and possibility of using the feedback water.

The selected site is located about 220 m southwest of the separation plant. As the separation plant is at elevation K+280 m altitude, and the final elevation of tailing dump K+250 m altitude, the gravity transport of tailings from the separation plant is possible throughout the lifetime of tailing dump, thereby reducing the transport costs of pulp by practically reduction to zero.

Description of construction technology for tailing dump

Separation tailing dump in Kaona is built of ground - material from borrow pits, which is selected within the future accumulation field. By this way, the volume of free accumulation space is effectively increased for ground volume that is built into the body of separating dam.

The dam is built with the following geometric parameters:

- fall of outer slope 1:2,
- fall of inner slope 1:2,
- width of dam crest at the final elevation K+250 m is 4 m,
- dam width in the base of wider part is 38 m,
- the highest dam height between elevations K+240 m and K+250 m and is 10 m,
- total dam length at elevation K+250 m is 175 m,

Figure 1. *Detail of laying the waterproof film on the inner slope of dam*

To enable the construction of dam with shown geometry with the stability coefficients, required by the law, it is necessary to do the following:

- the inner slope of dam should be covered with a waterproof film, type HDPE, thickness 2 mm,
- a drainage prism of stone aggregate from the open pit should be built on the outer slope, in whole length of external pins, the total length of about 182 m,
- in addition to the drainage prism, a drainage channel should be built to collect drainage water and guide them in the direction of drainage hopper from where the water will be repumped back into the accumulation lake,
- compress the land for dam construction in layers of about 40 cm using roller, vibrating plate or similar machinery to the prescribed density, required by the applicable standards,
- after dam construction, the outer slope and crown of dam should be immediately reclamated by grass seeding or sodding, to prevent the effects of erosion on the dam.

Transport of pulp from separation to the tailing dump will be carried out by the gravity channel with rectangular cross-section 0.4x0.5m. The channel will be dug in the ground and covered with planks of 2cm thickness. The total length of channel will be about 200 m.

MASS BALANCE, VOLUME OF TAILING DUMP AND SERVICE LIFE

Mass balance

Separation tailing dump in Kaona belongs to the tailing dumps of a valley type, with an accumulation area for disposal of tailings received by building a downstream partition dam. Maximum elevation of dam is K +250 m altitude, with the base elevation of K +240 m altitude and its maximum height of 10 m. As the total tailings, size range 100% - 0.106 mm, is composed of very fine and muddy particles, the same cannot be used for dam construction, so the dam is constructed of materials from the borrow pit. To increase the total storage space of tailing dump, the borrow pit is predicted inside the storage space.

The following Table 2 shows the mass balance as well as free volume of tailing dump for predicted operation period of 10 years, with the planned annual dynamics of exploitation of 150000 tons run-of-mine sand.

As the mass proportion of tailings in the total mass distribution of solid phase is 3.96% (according to Table 1), about 5945.43 tons of tailings annually is required for deposition on the separation tailing dump.

As the density mass of deposited tailings is about 1.3 t/m^3, it means that the annual need for providing the tailings disposal area is about 4573.41 m^3.

The following Table 2 gives a balance of tailings that needs to be deposited on the separation tailing dump for intended operation period of the open pit, according to the annual dynamics.

Table 2. *Mass balance of tailings for a period of 10 years*

Year	Quantity of tailings t /year	Cumulative quantity of tailings t	Volume of tailings m^3/year	Cumulative quantity of tailings m^3
1	5945.43	5945.43	4573.41	4573.41
2	5945.43	11890.86	4573.41	9146.82
3	5945.43	17836.29	4573.41	13720.23
4	5945.43	23781.72	4573.41	18293.64
5	5945.43	29727.15	4573.41	22867.05
6	5945.43	35672.58	4573.41	27440.46
7	5945.43	41618.01	4573.41	32013.87
8	5945.43	47563.44	4573.41	36587.28
9	5945.43	53508.87	4573.41	41160.69
10	5945.43	**59454.30**	4573.41	**45734.10**

As it can be seen from Table above according to the anticipated schedule for open pit mining in Kaona and processing in separation, the total of 59,454.3 tons of tailings is required to be deposited for 10 years, to what is necessary to provide an accumulation area of about 45,734.1 m^3.

Volume and service life of tailing dump

According to the planned schedule of raw sand production at the open pit and operation of work separation for a period of 10 years, it is necessary to provide a space for permanent disposal of 45,734.1 m^3 separation tailings.

To make this possible, it is necessary to build a tailing dump with minimum volume of accumulation space of about 46,000 m^3. The retention area should be added to this volume that must exist in the case of heavy rains (with the return period of 1000 years) to protect the settlements located downstream from the tailing dump, since the current legislation does not allowed any discharge of waste water and tailings into the environment or outside the contours of tailing dump.

As it is quite fine tailings of inadequate physical - mechanical characteristics for construction the tailings dam (100% - 0.106 mm), a dividing dam for formation the accumulation space for tailings disposal will be built from the ground. Inner slope of dam will be lined with waterproof film. Foot dam will be at elevation of K +240 m altitude, with the dam crest at elevation +250 K m altitude, so maximum height of dam will be about 10 m. Accumulation space that will be used for disposal of tailings will be limited space in height with the elevations from K +240 to K + 249 m altitude, where the remaining height of 1 m to the elevation K+250 m altitude will serve as the retention area, especially in the last years of open pit mining and separation tailing dump, when the total active volume of tailing dump would be reduced.

As the initial elevation of construction the tailing dump K +240 m altitude with the built dam up to the elevation K +250 m altitude, the total volume of tailings will be:

$$V_J = V_B + V_A$$

where:

V_J - total free volume of tailing dump, m^3
V_B – dam volume to K+250 m, m^3
V_A – volume of accumulation space up to K+249 m, m^3

$$Vj = 18\ 141.4 + 28\ 658.6 = 46\ 800\ m^3$$

$$V_j = 46\ 800\ m^3$$

As the space of 4573.41 m^3 is required for disposal of annual quantity of tailings, the service life of tailing dump for filling elevation K +249 m altitude will be:

$$\mathbf{Te} = \frac{Vj}{Vg} = \frac{46800}{4573{,}41} = 10.23 \text{ years or}$$

where:

Vg – annual volume of tailings, m^3

Te = 10 years and 3 months

The prepared and designed tailing dump by the shown way provides a secure and stable exploitation in the next 10 years, with designed annual capacity.

CONCLUSION

In designing the separation tailing dump of the "Kaona" deposit of quartz minerals, the all applicable legal standards and modern ecological methods for design of landfills and dumps were taken into account.

Regardless a fact that water without added chemicals is used for washing – cleaning of run-of-mine quartz, the separation tailing dump was designed with a waterproof film, what prevents the full infiltration of water from the accumulation space of tailing dump into the surrounding terrain. The ecological approach is also reflected in maximum use of feedback process water from accumulation in lake of tailing dump for the separation plant operation, with minimum flow of fresh water from the water intake, thus protecting the surrounding water resources.

As the total tailing dump volume is 46,800 m^3, the total service life of tailing dump with a design capacity of exploitation the run-of-mine sand of 150,000 tons per year, is over 10 years.

Upon completion the exploitation of separation tailing dump, a complete reclamation of tailing dump area will be done, thus creating the conditions for its return to its original purpose and complete integration with the surrounding area.

REFERENCES

[1] Lj. Obradović: "Feasibility Study of Separation the Quartz Sand from the Deposit "Kaona" near Kučevo - Part of Deposition the Separation Tailings", Mining and Metallurgy Institute Bor, 2009 (in Serbian)

[2] D. Milanović et all. "Separation of Quartz Minerals from the Deposit "Kaona" near Kučevo", Mining 2010 – Ist International Symposium, 24-26 May 2010, Tara, Proceedings (in Serbian)

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MODELIRANJE NAPONSKO-DEFORMACIJSKOG STANJA NUMERIČKIM METODAMA KOD ŠIROKOČELNOG OTKOPAVANJA

Izvod

U ovom radu se u kratkoj formi daje prikaz mogućnosti primjene numeričkih metoda u modeliranju naponsko-deformacionog stanja u stijenskom masivu za slučaj širokočelne eksploatacije ležišta mineralne sirovine. Opisane su osnovne metode sa navedenim prednostima i nedostacima. Navedeni su osnovni komercijalni programski paketi i dati primjeri primjene istih na problemu širokočelnog otkopavanja. Za MKE je opisan postupak razvoja 3D modela, diskretiziranje na konačne elemente uzevši u obzir nehomogenost i elasto-plastično ponašanje slojevitog materijala.

Ključne riječi: *jamski pritisak, širokočelna metoda, modeliranje, naponsko-deformacijsko stanje, numeričke metode i metoda konačnih elemenata.*

1. UVOD

Izradom jamskih prostorija, a naročito otvaranjem otkopa, otvara se slobodna površina krovine koja počinje da se deformiše, raslojava i puca i u toku vremena, ako nije na vrijeme osigurana podgradom zarušava. Ove deformacije i pritisci su posljedica preraspodjele naponskog stanja u masivu. Radi objašnjenja jamskog pritiska postoji niz teorija i hipoteza koje polaze od raznih pretpostavki, pa prema tome daju i različita tumačenja. Termin „jamski pritisak“ definisan je preko sila koje se javljaju u stijenskim masama pod uticajem narušavanja prvobitne ravnoteže i preraspodjele naprezanja sa ciljem da se uspostavi nova ravnoteža masiva. Ima više definicija jamskih pritisaka, neke od njih su bazirane na promjeni stanja, neke na stadiju razvoja faza deformacija stijena i formiranja zona deformacija u stijenskom masivu oko podzemne prostorije, a neke na karakteristikama podgrade. O kako složenom problemu se radi najbolje govori da ne postoji opće prihvaćena teorija koja bi bila prihvatljiva za sve rudarsko geološke slučajeve. Poznavanje naponsko-deformacijskog stanja u masivu od velikog je značaja za sigurno projektovanje i određivanje dimenzija jamskih prostorija, izbor podgrade i upravljanja krovinom.

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1.1. Uticajni faktori na pojavu i intenzitet jamskih pritisaka

Značajan uticaj na pojavu i manifestaciju jamskih pritisaka i deformacija pri podzemnoj eksploataciji imaju inženjersko-geološke, fizičko-mehaničke karakteristike masiva i tehnologija otkopavanja. Radna sredina može imati različite fizičko-mehaničke osobine, tako npr. krovina može biti od vrlo čvrstih stijena do vodonosnih pijesaka kao najnepovoljnijih materijala. Pored ovih postoji i niz drugi prirodnih faktora koji utiču na pojavu i intenzitet jamskih pritisaka kao što su anizotropija radne sredine, tektonske pukotine, klizne i kontaktne površine.

U osnovi možemo razlikovati tri slučaja:

- nekompaktna ili plastična stijenska masa je sredina gdje se podgrada mora blagovremeno ugrađivati da bi se obezbijedila potpuna ili djelimična stabilnost prostorije,
- srednje kompaktna stijenska masa je sredina gdje je obezbijeđena privremena stabilnost podzemne prostorije i,
- kompaktna stijenska masa je sredina u kojoj je podzemna prostorija stabilna. U ovakvim prostorijama podgrada nije potrebna.

Karakteristike masiva, za potrebe projekovanja jamskih prostorija, moraju biti u potpunosti definisane prethodnim istraživanjima pomoću raznih metoda: laboratorijskim ispitivanjima uzoraka, in-situ, geofizičkim ili nekim drugim prihvatljivim metodama. Ova ispitivanja moraju dati tačne i pouzdane rezultate što bitno utiče na izbor podgrade, dimenzionisanje prostorija i druge parametre potrebne za projektovanje. I pored svih istraživanja, zbog jako složenih rudarsko geoloških uslova, uvijek postoji opasnost od neželjenih pojava. Takav primjer je pojava „lažne“ krovine u „Staroj jami“ Zenica tektonski blok TB-1 (OP-1 i OP-2), gdje je krovina bila čvrsta i kompaktna, međutim između osnovne i „lažne“ krovine (čija je debljina u prosjeku oko 0,7 m) nalazi se proslojak uglja debljine manje od 0,5 mm, koji je fizički odvajao osnovnu krovinu. „Lažna“ krovina se ponašala dobro i sigurno sve dok se ne otvori prostorija (komora) takvih dimenzija da ona postaje nestabilna i da se počinje urušavati, pri čemu se ugrožava sigurnost rada.

Pored geoloških i geomehaničkih karakteristika terena na pojavu i intenzitet jamskih pritisaka značajan uticaj imaju i primijenjeni tehnološki procesi otkopavanja. Projektanti u fazi projektovanja izborom odgovarajuće metode otkopavanja, rasporedom i dimenzijama prostorija, dinamikom napredovanja i drugim rješenjima, mogu u znatnoj mjeri uticati na smanjenje uticaja jamskih pritisaka. Pri tome se mora tačno i na vrijeme ugraditi odgovarajuća podgrada da bi se uspostavio kontakt sa stijenskom masom.

Najviše korištena metoda otkopavanja slojeva uglja u podzemnoj eksploataciji je širokočelna metoda otkopavanja. Sa aspekta mehanike stijena postoji niz hipoteza za opis naponskog stanja i nastajanja jamskih pritisaka oko širokog čela.

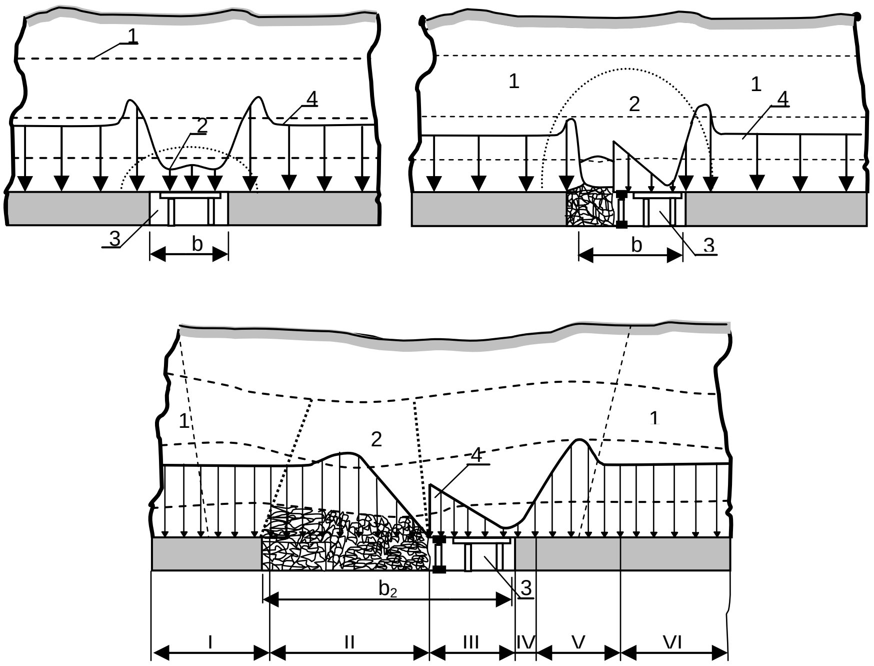
1.2 Jamski pritisci

Razlike u interpretaciji jamskih pritisaka dolazi najviše zbog različitog metoda pristupa ovom problemu, a pri čemu se mogu izdvojiti dva osnovna pristupa:

- primjena teorije elastičnosti za rješavanje problema naprezanja i deformacija raznih tipova jamskih prostorija,
- snimanje i mjerenje deformacija.

Ispitivanje jamskih pritisaka i mjerenje u jamskim uslovima omogućuje direktno opažanje ponašanja navedenih pojava u funkciji napredovanja širokog čela. Pri ovim mjerenjima teškoće pričinjavaju ograničenosti u posmatranom prostoru koji se svodi na opažanje deformacija u uskom pojasu krovine, bokova i podine, uslijed čega se registruju posljedice, a ne uzroci nastanka deformacija i preraspodjele napona u okolnim stijenama.

Da bi se u procesu otkopavanja moglo ovladati jamskim pritiscima potrebno je poduzeti niz tehničkih mjera i aktivnosti za zaštitu i održavanje jamskih prostorija. U ove mjere spadaju podgrađivanje, zarušavanje, zasipanje i ostavljanje neotkopanih zaštitnih ploča i stubova. Zadatak svih pomenutih mjera je postizanje potrebne sigurnosti u procesu podzemne eksploatacije a nazivaju se upravljanje jamskim pritiskom. Upravljanje jamskim pritiskom ne može se posmatrati odvojeno od ponašanja krovine, koja u procesu podzemnog otkopavanja ima jednu od najznačajnih uloga, zbog čega se upravljanje jamskim pritiskom svodi na problem upravljanja krovinom.



Sl.1: *Situacija otkopa i dijagram pritisaka na otkopu sa dinamikom kretanja otkopa*

1. Neporemećeni masiv; 2. Zona zarušavanja; 3. Otkop; 4. Dijagram pritisaka; b_2. širina otkopa;

I – Zona konstantnog pritiska; II – Zona oslonog pritiska u otkopu; III –Zona smanjenog pritiska u blizini čela otkopa; IV – Zona zdrobljenog uglja; V – Zona oslonog pritiska; VI – Zona normalnog naprezanja u neporemećenom masiv

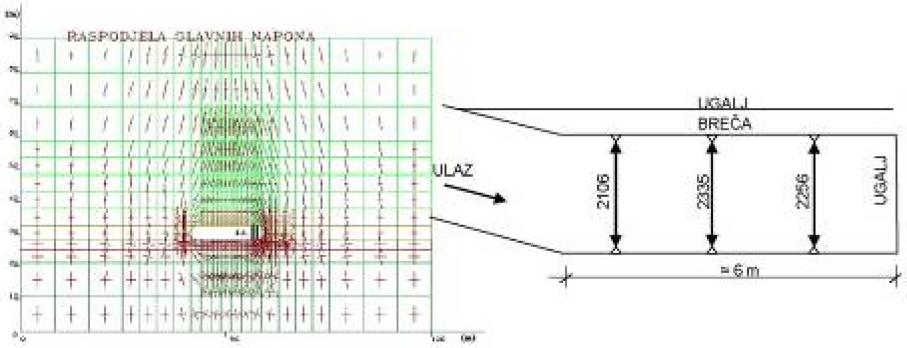
1.3 Ispitivanje i istraživanje karakteristika stijenskih materijala

Najobimnija ispitivanja i istraživanja radne sredine vrše se pri izgradnji podzemnih objekata, a u svrhu definisanja karakteristika prostora i sredine u kojem se gradi objekat. U tu svrhu neophodno je izvršiti prethodna i naknadna ispitivanja.

Prethodnim ispitivanjima određuju se rudarsko-geološke osobine stijenskog materijala u kojem se treba graditi objekat. Ova istraživanja treba da daju projektantima podloge na osnovu kojih mogu vršiti projektovanje podzemnih prostorija, čije karakteristike moraju obezbijediti funkcionalnost, sigurnost, ekonomičnost, trajnost i drugo što zahtijeva određeni objekat. Naknadnim istraživanjima se vrše ispitivanja i praćenja osobina radne sredine ili njene bliže okoline u fazi izrade i eksploatacije prostorija, pri čemu obim ispitivanja zavisi od vrste, namjene, trajnosti prostorije i drugih uticajnih faktora.

Istraživanje zakonitosti promjena napona i deformacija u stijenama predstavlja važnu djelatnost u izradi i eksploataciji podzemnih rudarskih prostorija. Ova istraživanja se mogu vršiti u laboratorijskim i u prirodnim uslovima. Laboratorijska ispitivanja odnosa napona i deformacija imaju niz faktora koji mogu znatno uticati na rezultate istraživanja. U ova istraživanja ubrajamo izradu prostornih modela od ekvivalentnih materijala. Na izradi ovih modela kod širokočelnih otkopavanja značajne rezultate je postigla grupa stručnjaka sa Rudarskog instituta u Tuzli, 70-tih godina prošlog vijeka. U novije vrijeme sve veću primjenu nalaze numeričke metode, korištenjem CAD-a inženjeri mogu lako da numerički modeliraju objekte. Računarskim modelima mogu se provjeriti stanja objekata izloženih raznim uticajnim faktorima bez dodatnih finansijskih ulaganja ili izgradnje prostornih modela za čiju izradu je potrebno više vremena.

Mjerenja u realnoj sredini i terenska mjerenje napona, deformacija i pritisaka ima veliki značaj za rješavanje teorijskih i praktičnih problema pri projektovanju i izradi podzemnih rudarskih prostorija. Terenska mjerenja se mogu vršiti na postojećim objektima u fazi eksploatacije prostorije ili na eksperimentalnim prostorijama i komorama. U jami „Sretno" – Breza tako je izrađena jedna eksperimentalna komora sa ciljem da se odredi nosivost jalovog proslojka (breče). Da bi dobili što pouzdanije podatke pored mjerenja na terenu izvršen je analitički proračun parametara nosivosti proslojka kao i analiza metodom konačnih elemenata. Ovakve uporedne analize imaju veliki teoretski i praktični značaj. U izrađenoj komori dimenzija oko 6,0x2,5x2,3 m, na određenim rastojanjima ugrađeni su reperi za mjerenje deformacije prostorije. Deformacije su mjerene svakodnevno sve do trenutka loma krovine. Prednost ovog opita je u tome što su se mjerenja mogla vršiti do samog loma krovine (proslojka) dok se kod eksploatacionih prostorija, da bi se očuvala njena funkcionalnost i sigurnost, ispitivanja prekidaju prije očekivanog loma. Rezultati dobiveni „in situ" mjerenjima, analitičkom i numeričkom metodom (MKE) su bili u granicama prihvatljivih odstupanja i imala su praktičnu vrijednost za dalje radove (slika 2).



Sl. 2. *Raspodjela glavnih napona na ispitnoj komori*

1.4. Mjerenje pritisaka na širokom čelu

Instrumenti za mjerenje napona, deformacija i pritisaka mogu biti mehanički, hidraulički, optički i električni. Za mjerenja koja smo vršili u našim jamama korišteni su hidraulički uređaji za mjerenje reakcija mehanizovane hidrauličke podgrade (MHP), mjerenje reakcija stupaca, dinamometri za mjerenje pritisak i uređaji za mjerenje dužina. Ova mjerena se vrše na kontaktu podgrade i konture prostorije. Kod zahtjevnijih i složenijih objekata (temelji brana za hidrocentrale i sl.) ispitivanja se mogu vršiti u samom masivu ugradnjom hidrauličkih jastuka ili sondi u masiv.

Mjerenje reakcija MHP (npr. Raspotočje–Zenica, Mramor–Kreka) se vrši njemačkim uređajima Hydrostar (0-600 bar) koji se ugrađuju na hidraulički sistem sekcija širokog čela, pri čemu se kontinuirano prate reakcije podgrade. Rezultati mjerenja se automatski ispisuju na mjernu traku. Uređaji se postavljaju na tri sekcije, dva u blizini pristupnih prostorija i jedan u sredini širokog čela. Ova mjerenja traju 30 do 40 dana, zavisno od mogućnosti i potreba na terenu, nakon čega se uređaji skidaju sa sekcija a vrijednosti sa traka očitavaju i obrađuju.

Mjerenje reakcija na hidrauličkim stupcima širokog čela (npr. Omazići – Banovići) se vrše pomoću uređaja koji se spaja na ventil stupca pri čemu se direktno očitava pritisak u stupcu. Pri ovim mjerenjima vrši se izbor stupaca po dužini širokog čela ali se vodi računa o fazi rada na širokom čelu, što će kasnije analizi imati važan uticaj za analizu rezultata.

U toku ovih ispitivanja, u pristupnim prostorijama širokog čela (transportnom i ventilacionom hodniku), postavljeni su dinamometri za mjerenje pritisaka na određenoj udaljenosti od širokog čela. Na dinamometrima se prate promjene pritisaka u funkciji napredovanja širokog čela. Za mjerenje deformacija pristupnih prostorija postavljaju se reperi na osnovu kojih pratimo približavanje (konvergencija) ili udaljavanje (divergencija) zidova prostorije. Nakon svih izvršenih mjerenja na terenu prikupljeni podaci se obrađuju, pri čemu se mora voditi računa o fazama rada na širokom čelu a u funkciji vremena i izmjerenih veličina te eventualnih zastoja u radu širokog čela. Tako obrađeni podaci uzimaju se za analizu naponsko deformacijskog stanja.

Do sada su ove analize rađene po nekoj od mnogobrojni hipoteza postavljenih od strane teoretičara, stručnjaka u oblasti teorije elastičnosti (Kirsh, Kolosov, Mushelisvilli, Boussinesq, P. M. Cimbarevića, Grede, Labasova, K. V. Rupenejta i dr). Na osnovu dugogodišnjeg iskustva i proračuna u našim jamama najbolje je rezultate davala a i najčešće primjenjivana Hipoteza svoda.

Analitičke metode podrazumijevaju idealan, homogen, izotropan materijal za koji se pretpostavlja da je izložen naponima koji ne dovode do plastičnih deformacija te da je promjena oblika i zapremine zanemarivo mala. Osnovni skup jednačina koji opisuje naponsko-deformacijsko stanje masiva dat je na slici br. 3

$$\sum Fx = 0; \quad \sum Fy = 0; \quad \sum Fz = 0;$$

$$\frac{\partial\sigma_x}{\partial x} + \frac{\partial\tau_{xy}}{\partial y} + \frac{\partial\tau_{xz}}{\partial z} + \rho X = \rho\frac{\partial^2 u(X,t)}{\partial t^2}$$

$$\frac{\partial\tau_{yx}}{\partial x} + \frac{\partial\sigma_y}{\partial y} + \frac{\partial\tau_{yz}}{\partial z} + \rho Y = \rho\frac{\partial^2 v(X,t)}{\partial t^2}$$

$$\frac{\partial\tau_{zx}}{\partial x} + \frac{\partial\tau_{zy}}{\partial y} + \frac{\partial\sigma_z}{\partial z} + \rho Z = \rho\frac{\partial^2 w(X,t)}{\partial t^2}$$

$$u = u(x,y,z,t), v = v(x,y,z,t), w = w(x,y,z,t), \quad u(X,t) = u_0(X,t); \; v(X,t) = v_0(X,t); \; w(X,t) = w_0(X,t); \quad \forall X \in \Gamma_{u,v,w}$$

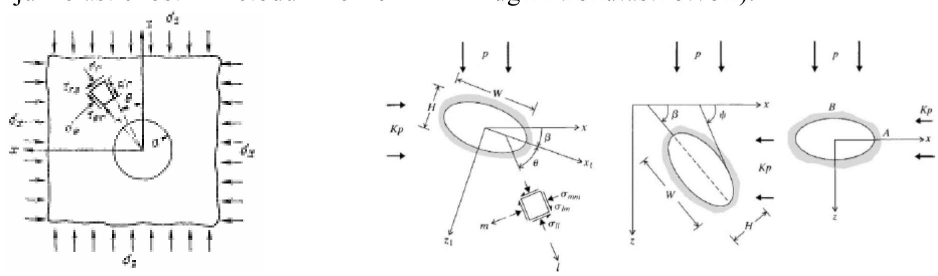
$$\sigma(X,t) = \sigma_0(X,t) \quad \forall X \in \Gamma_\sigma \qquad \varepsilon_{xx} = \frac{\partial u}{\partial x}, \; \varepsilon_{yy} = \frac{\partial v}{\partial y}, \; \varepsilon_{zz} = \frac{\partial w}{\partial z}; \; \varepsilon_{xy} = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}, \; \varepsilon_{xz} = \frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}, \; \varepsilon_{yz} = \frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}$$

KONSTITUTIVNA RELACIJA $\sigma = f(\varepsilon, \dot{\varepsilon}, \alpha, t)$

$$\begin{Bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{zz} \\ \sigma_{yz} \\ \sigma_{xz} \\ \sigma_{xy} \end{Bmatrix} = \begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} & c_{15} & c_{16} \\ & c_{22} & c_{23} & c_{24} & c_{25} & c_{26} \\ & & c_{33} & c_{34} & c_{35} & c_{36} \\ & & & c_{44} & c_{45} & c_{46} \\ & \text{sym.} & & & c_{55} & c_{56} \\ & & & & & c_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{zz} \\ \varepsilon_{yz} \\ \varepsilon_{xz} \\ \varepsilon_{xy} \end{Bmatrix}$$

Sl. 3. *Sistem osnovnih jednačina*

Sa ovakvim pretpostavkama, moguće je dati rješenja za nekoliko karakterističnih slučajeva proste geometrije koji su prikazani na slijedećim slikama. Ruski naučnik Kolosov je uveo u teoriju elastičnosti metodu konformnih preslikavanja baziranu na teoriji funkcija kompleksne promjenljive koja je omogućila da se od postojećih dobiju i neka rješenja za slučajeve složenije geometrije (eliptični, približno pravougli i trokutasti otvori).



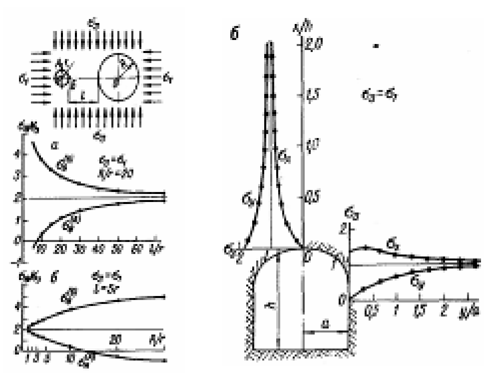
$$\sigma_{rr} = \frac{p}{2}\left[(1+K)\left(1-\frac{a^2}{r^2}\right) - (1-K)\left(1-4\frac{a^2}{r^2}+\frac{3a^4}{r^4}\right)\cos 2\theta\right]$$

$$\sigma_{\theta\theta} = \frac{p}{2}\left[(1+K)\left(1+\frac{a^2}{r^2}\right) + (1-K)\left(1+\frac{3a^4}{r^4}\right)\cos 2\theta\right]$$

$$\sigma_{r\theta} = \frac{p}{2}\left[(1-K)\left(1+\frac{2a^2}{r^2}-\frac{3a^4}{r^4}\right)\sin 2\theta\right]$$

$$u_r = -\frac{pa^2}{4Gr}\left[(1+K) - (1-K)\left\{4(1-\nu) - \frac{a^2}{r^2}\right\}\cos 2\theta\right]$$

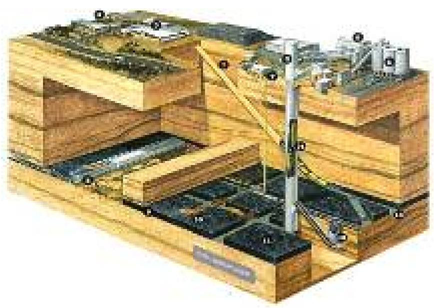
$$u_\theta = -\frac{pa^2}{4Gr}\left[(1-K)\left\{2(1-2\nu) + \frac{a^2}{r^2}\right\}\sin 2\theta\right]$$

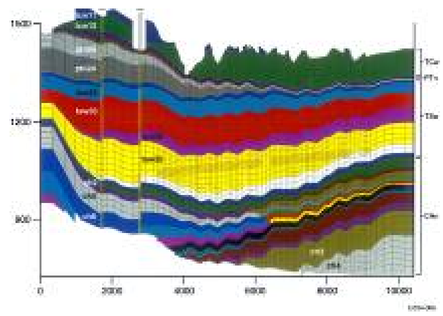


Sl. 4. *Oblici prostorija za koje su moguća analitička rješenja*

2. NUMERIČKE METODE

Uslovi u kojima se izvodi proces širokočelnog otkopavanja često se bitno razlikuju od onih navedenih kao pretpostavke za analitička rješenja naponsko-deformacione distribucije. Prije svega domena u kojoj se odvija proces uglavnom je izrazito nehomogena, fragmentirana, slojevita i ispresijecana rasjedima. Zatim materijali koji učestvuju u procesu se ponašaju anizotropno, neelastično a mnogi pokazuju i vremenski zavisne karakteristike tj. efekte viskoplastičnosti ili puzanja. Geometrija radnog prostora je složena, deformacije nisu zanemarivo male a naponi se često iznad granica elastičnosti. Ovo čini da su analitičke metode imaju ograničenu primjen u oblasti širokočelnog otkopavanja.



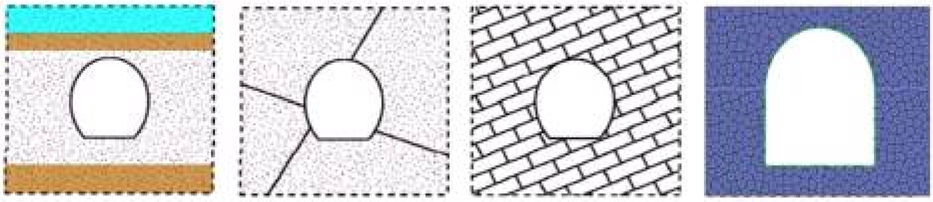


Sl. 5. *Širokočelna metoda, opšta dispozicija (a), slojevitost i rasjedi (b)*

Kao alternativno rješenje za određivanje napona i deformacija nameće se mogućnost numeričke simulacije. Numeričkom analizom omogućeno je:

- Modeliranje široke klase geomehaničkih materijala, prije svega, stijenskih masiva, tla, betona, čeličnih elemenata, drveta i drugih materijala koji se pojavljuju u podzemnoj eksploataciji.
- Omogućeno je modeliranje vremenski zavisnih modela ponašanja (viskoplastičnost, puzanje)
- Mogućnost analiza za slučaj geometrijske nelinearnosti (velika deformacija), materijalne nelinearnosti (konstitutivna relacija) ili kontaktne nelinearnosti.
- Dinamičke analize koje obuhvataju seizmičke i efekte uslijed miniranja

Numeričke metode su sredstvo i alat kojim se savremena geomehanika intenzivno koristi. Grubo govoreći, postoji podjela na kontinualne i diskontinualne metode. Ova podjela je napravljena na osnovu geomehaničkih karakteristika medija tj. stijenskog materijala u kome se odvija proces eksploatacije tj. u kome se metoda primjenjuje. Metode zasnovane na mehanici kontinuuma (BEM, FEM i CDM) mogu se primjenjivati u problemima kod kojih materijal ima približno karakteristike kontinuuma ili je domena podijeljena u blokove poznatih dimenzija i oblika koji se ponašaju kao kontinualni, sl. 6, a i b.



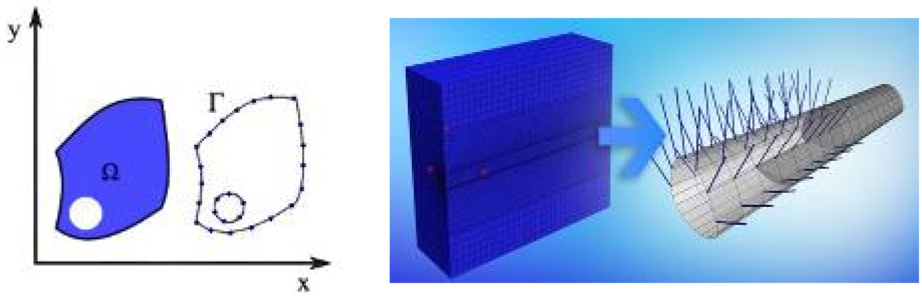
Sl. 6. *Osnovni modeli sredine u kojoj se izvodi podzemna eksploatacija [2]*

Ukoliko je domena izrazito diskretna tj. fragmetirana primjenjuju se diskretne metode pod uslovom da je moguće odrediti oblike i položaje diskretnih elemenata. Ukoliko je materijal fragmentiran na tako sitne komade da su njihove dimenzije zanemarive u odnosu na geometrijske razmjere domene može se primijeniti metoda pseudo-kontinuuma.

Proces numeričkog modeliranja metodama kontinuuma se izvodi u nekoliko koraka. Prvi korak podrazumijeva izradu 3D geometrijskog modela koji predstavlja domen u kome se odvija proces deformacije stijenskog masiva. Za njegovu realizaciju potrebno je precizno poznavati dimenzije svih prostorija te položaje, oblike i pravce prostiranja svih slojeva materijala. Drugi korak je pravilno modeliranja ponašanja svih materijala pod opterećenjem. Osnovu za taj korak čini geomehaničko ispitivanje uzoraka litoloških članova uzetih neposredno na terenu. Treći korak je nelinearna naponsko-deformaciona analiza koja se obavlja MKE, BEM ili CDM metodama. MKE metoda je trenutno dominantna za analizu nelinearnih elasto-plastičnih problema. U poslednjem koraku, post-procesiranju rezultata, vrši se kritička analiza prikazanih rezultata distribucije napona i deformacija te, po potrebi, korekcije modela. Bitne prednosti koje se ostvaruju primjenom navedene procedure ogledaju se u mogućnosti određivanja svih komponenti napona u uslovima složene geometrije i nehomogenosti materijala kao i mogućnost analiziranja raznih varijanti i parametara eksploatacije s obzirom na nosivost podgrade ili karakteristike opreme. S druge strane, tačnost i pouzdanost rezultata simulacije zavisi od tačnosti geometrije modela, tačnosti, kvaliteta i obima ispitivanja uzoraka materijala kao i složenosti analize izvedene pomoću numeričke simulacije. U cilju verifikacije i validacije i kalibrisanja modela, potrebno je u odgovarajućem broju tačaka imati i podatke o naponima dobijenim eksperimentalno.

2.1 Metod graničnih elemenata (Boundary element method - BEM)

U problemima kod kojih je odnos površine i zapremine domene vrlo mali (velike 3D domene) metoda konačnih elemenata nije posebno pogodna zbog vrlo velikog broja DOF. U tom slučaju BEM metoda je povoljnija posebno ako je potrebno odrediti napone ili deformacije samo na određenim površinama domene koja može biti proizvoljno velikih dimenzija i oblika. Generisanje modela je jednostavnije i brže a potrebna količina podataka je manja. Ovom metodom diskretizira se samo konturna linija domene (za 2D probleme) ili konturna površina (3D problemi). Time se dimenzionalnost problema smanjuje za 1 a time i broj DOF te je ova metoda efikasna za 3D probleme. Numerička procedura se sastoji u svođenju sistema diferencijalnih jednačina pomoću uticajnih koeficijenata i interpolacijskih funkcija na sistem linearnih algebarskih jednačina koje opisuju pomake u čvornim tačkama elemenata na konturi. Ova metoda je efikasna za probleme gdje se materijal modelira kao linearan. Za složenije modele materijala obim računanja se drastično povećava. Takođe ako je potrebno odrediti napone u unutrašnjosti modela, potrebno je vršiti dopunske interpolacije (smanjena tačnost) ili uzimati nove presjeke ili konture (povećanje obima računanja). Dio prednosti u odnosu na FEM se gubi i zbog toga što sistemske matrice nisu trakaste i simetrične kao što je to slučaj sa FEM. Zbog prethodno navedenog, ova metoda se koristi za elastične simulacije velikih 3D modela i kao pomoćna metoda za neke presjeke, u kombinaciji sa FEM-om. Od komercijalnih programa baziranih na ovoj metodi ističu se BEFE++ , BEMFF I BEMSAD.



Sl. 7. *Diskretizacija metodom graničnih (rubnih) elemenata*

2.2. Metod konačnih razlika (Finite difference method-FDM)

Metoda konačnih razlika je jedna od prvih numeričkih metoda koja se primjenjuje u oblasti geomehanike. Domena (radni prostor) se diskretizira mrežom čvornih tačaka u kojima se računaju čvorni pomaci kao primarna rješenja. Parcijalni izvodi u sistemu diferencijalnih jednačina koji opisuje proces deformacije domene se zamjenjuju konačnim razlikama. Poznavajući granične uslove, formira se sistem algebarskih jednačina koji se rješava pomoću linearnog solvera. Izvedene varijable se dobijaju u post-procesorskom postupku.

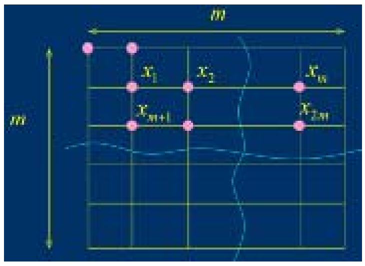
Osnovni algoritamski koraci FDM metoda:

Generiše se diskretna mreža tačaka u domenu jednačine (2D ili 3D)

- U osnovnim jednačinama zamjenjuju se izvodi sa konačnim razlikama
- Sistem PDJ se pretvara u sistem algebarskih jednačina. Traži se numeričko rešenje u čvornim tačkama
- Za razliku od vremenski zavisnih problema, rešenje se ne određuje napredovanjem korak po korak po vremenskoj osi, već se približno rešenje određuje u svim tačkama mreže simultano rješavanjem jednog sistema algebarskih jednačina.

$$\frac{\partial u}{\partial x}=\frac{u_{i+1}^{k}-u_{i}^{k}}{\Delta x};\quad \frac{\partial^2 u}{\partial x^2}=\frac{u_{i+1}^{k}-2u_{i}^{k}+u_{i-1}^{k}}{(\Delta x)^2}$$

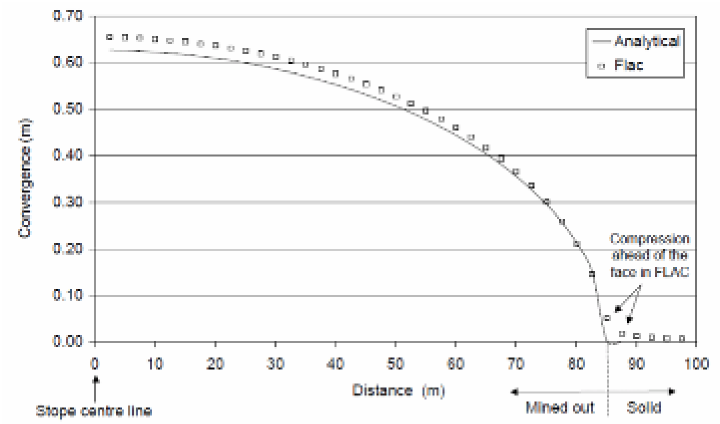
$$\underbrace{\frac{u_{j+1}-2u_j+u_{j-1}}{\Delta x^2}}_{u_{xx}};\quad \underbrace{\frac{u_{j+m}-2u_j+u_{j-m}}{\Delta y^2}}_{u_{yy}};\quad i=1,\dots,n$$



Sl. 8. *Zamjena izvoda konačnim (centralnim) razlikama i diskretizacija domene*

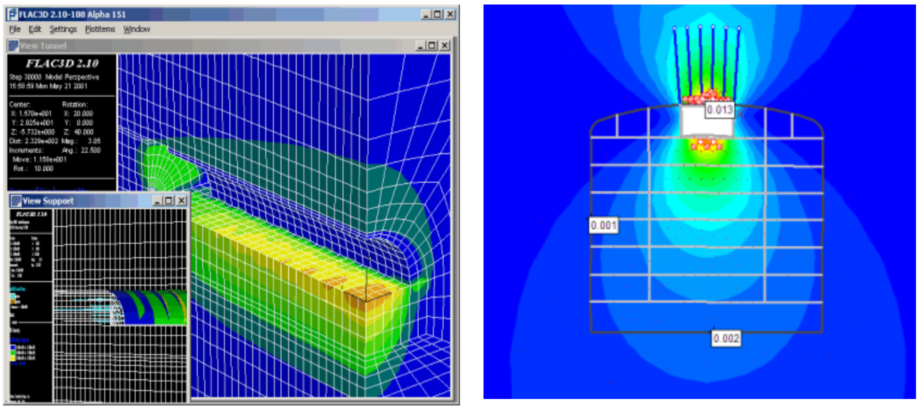
Metoda se može primijeniti za statičke i dinamičke probleme koji osim prostorne zahtijevaju i vremensku diskretizaciju sistema osnovnih jednačina. Dinamičke analize obuhvataju seizmičku kao i problematiku rudarskog miniranja i uglavnom koriste eksplicitnu integracijsku shemu i koncept koncentrisane mase čime se u numeričkom smislu povećava efikasnost algoritma.

Osnovni nedostatak ovog metoda je problem oko opisa domene nepravilnog oblika i nehomogenosti materijala što je čest slučaj kod modeliranja širokočelne metode otkopavanja. Ipak u problemima sa homogenom sredinom i jednostavnijom geometrijom, ova metoda daje rezultate koji se dobro poklapaju sa mjerenjima na terenu.



Sl. 9. *Poređenje numeričkog (FLAC) i analitičkog rezultata za veličinu pomaka čvornih tačaka*

Najpoznatiji komercijalni program pogodan za probleme modeliranja napona kod širokočelnog otkopavanja a baziran na FDM je FLAC (za 2D) i FLAC3D za 3D modele razvijen od kompanije „Itasca Co“ u SAD (www.itasca.com).



Sl. 10. *Primjer korisničkog interface-a programa FLAC 3D*

Program ima vlastiti preprocesor kojim se izgrađuje geometrija modela i automatski generiše 2D i 3D mreža čvornih tačaka. Solver je baziran na metodu FDM (statički i dinamički problemi, hidrologija tj. strujanje podzemnih voda u poroznoj sredini, termalna opterećenja i dr.). Program ima kolekciju modela osnovnih geo materijala koji obuhvataju i opisuju elastično, plastično, visko-elasto-plastično, puzanje, modele porozne sredine i dr.

2. 3. MKE u analizi naponskih stanja kod širokočelnog otkopavanja

MKE je savremena numerička metoda za rješavanje PDJ. Suština metode je u aproksimaciji funkcije rješenja (u,v,w) diskretnim skupom funkcija (polinoma) i diskretizaciji domene konačnim skupom konačnih elemenata. Tri osnovna koncepta na kome se definiše savremena MK:

- Raleigh-Ritz ov varijacijski princip
- Galerkin-ov princip težinskog reziduala
- Princip minimuma kvadrata greške (Laest square principle)

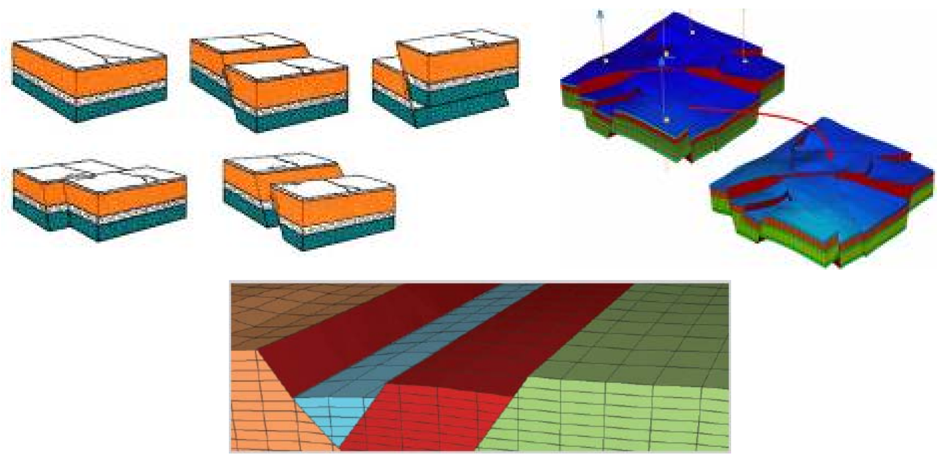
U oblasti određivanja naponskih stanja u geomehanici MKE se primjenjuje skoro od samog nastanka. Prednosti u odnosu na druge numeričke metode:

- Složena geometrija, proizvoljni oblik domene
- Složeni granični uslovi (opterećenja i oslonci, konturne sile i pomaci)
- Složene (nelinearne) konstitutivne relacije
- Kombinovanje različitih elemenata i materijala
- Visoka tačnost na koju se može uticati

Budući da ova metoda spada u kontinualne metode, njezina primjena u problemima određivanja naponskog stanja kod širokočelne metode otkopavanja je ograničena na one slučajeve koji se mogu aproksimirati kontinuumom, kao što je prethodno već navedeno. U slučajevima kontinualne ali slojevite sredine ispresijecane rasjedima moguće je, ako se poznaju geometrijske i materijalne karakteristike slojeva te geometrija rasjeda napraviti realističan model koji može pratiti ponašanje masiva. Na sl.br.11 prikazani su osnovni tipovi i načini modeliranja rasjeda.

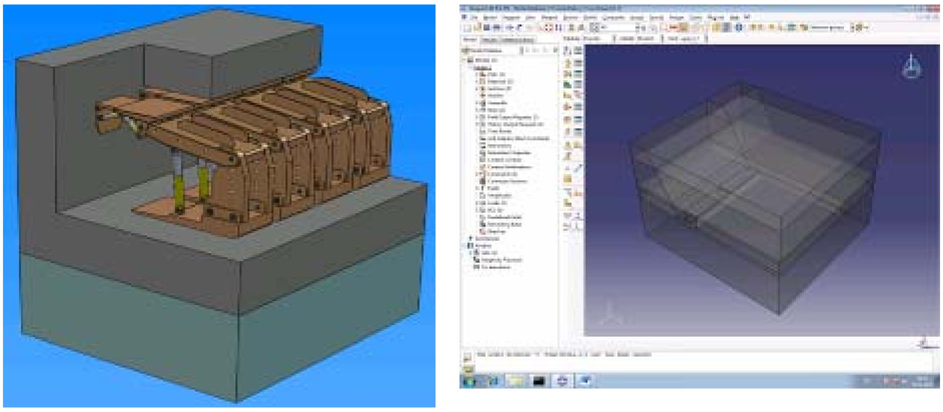
Uzimanje u obzir rasjeda podrazumijeva modeliranje elasto-plastičnog kontakta između odgovarajućih slojeva. Time se analiza u numeričkom smislu znatno usložnjava ali savremeni softveri mogu rješavati probleme i sa takvim modelima. Kao i za ostale probleme, za naponsku analizu kod širokočelnog otkopavanja, MKE analiza se sastoji iz slijedećih koraka:

1. Izrada prostornog modela širokog čela sa svim bitnim geometrijskim detaljima uključujući podgrade
2. Određivanje slojeva sa različitim materijalima te eventualnih rasjeda ukoliko su položaji istih poznati (particija modela)
3. Izbor modela materijala i pridruživanje materijala i graničnih uslova odgovarajućim dijelovima modela (particijama)
4. Definisanje kontakta za slučaj rasjeda
5. Diskretizacija domene na konačne elemente odgovarajućeg tipa
6. Pokretanje solvera čime se formiraju elementske i sistemske matrice i vektori i direktno ili indirektno rješava rezultujući sistem linearnih jednačina
7. Postprocesiranje rezultata, računanje sekundarnih varijabli
8. Kritička analiza i korekcija modela



Sl. 11. *Osnovni tipovi rasjeda i načini geometrijskog modeliranja rasjeda*

Svaka od ovih stavki zahtijeva dobro poznavanje fizike problema, numeričkog postupka te softvera kojim se rješava problem. U opštem slučaju najviše vremena se troši na prve četiri stavke i od istih najviše zavisi tačnost rezultata. Stavke 5, 6, 7 se izvode u velikoj mjeri automatski od strane software-a dok je za poslednju 8 stavku potrebno praktično znanje i iskustvo u problematici naponske analize.

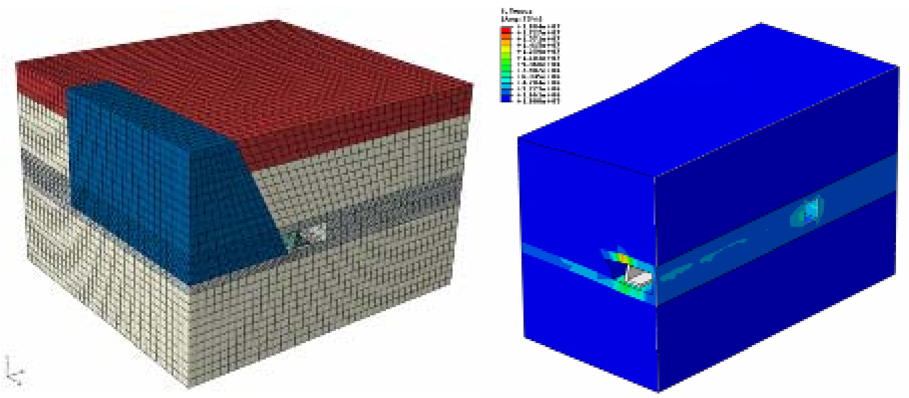


Sl. 12. *Modeliranje geometrije podgrade i ležišta*

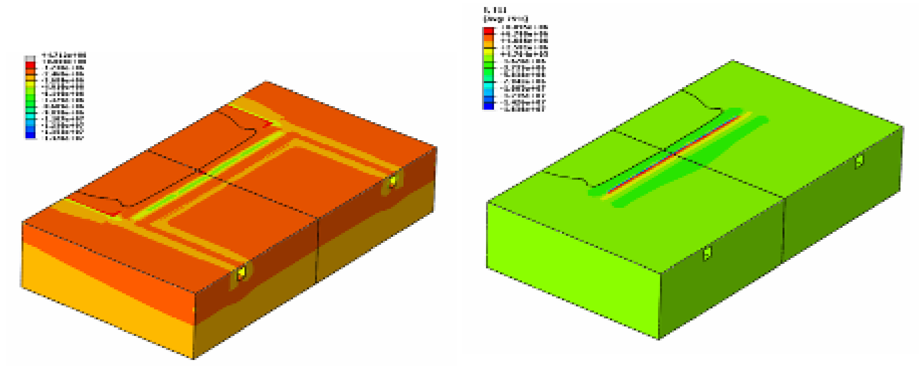
Osnovni problemi i ograničenja s kojima se susrećemo kod primjene MKE u analizi širokog čela su:

- Nepoznavanje položaja i karakteristika slojeva, nepoznavanje položaja rasjeda
- Problemi kontaktnih interakcija između podgrade i stijenskog masiva
- Velika plastična deformacija koja dovodi do gubitka konvergencija
- Pojava pukotine u dijelu materijala automatski dovodi do prekida iterativnog postupka i obustave analize

Zbog velikih dimenzija domene (3D) te uzimanja u obzir malih detalja, automatski mesh generatori generišu mrežu elemenata koja često broji nekoliko stotina hiljada ili preko milion stepeni slobode. Ovako veliki problemi kod kojih se dopunski pojavljuju kontakti i plastične deformacije koje dovode do velikog broja iteracija fizički su težak problem za „male“ PC računare jer zahtijevaju ogroman broj kalkulacija i veliku količinu radne memorije. Paralelno procesiranje na multiprocesorskim mašinama predstavlja jedino rješenje ukoliko nije moguće uprostiti model.



Sl. 13. *3D diskretizacija i postprocesiranje rezultata analize širokog čela*

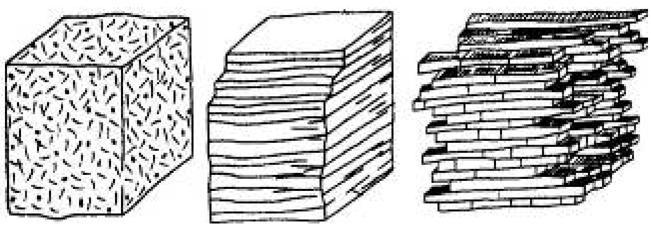


Sl. 14. *Postprocesiranje rezultata analize kod širokog čela, distribucija (a) i maksimalni verikalni naponi ispred fronta čela (b)*

2.3.1 Osnovne konstitutivne relacije (modeli materijala) za MKE analizu

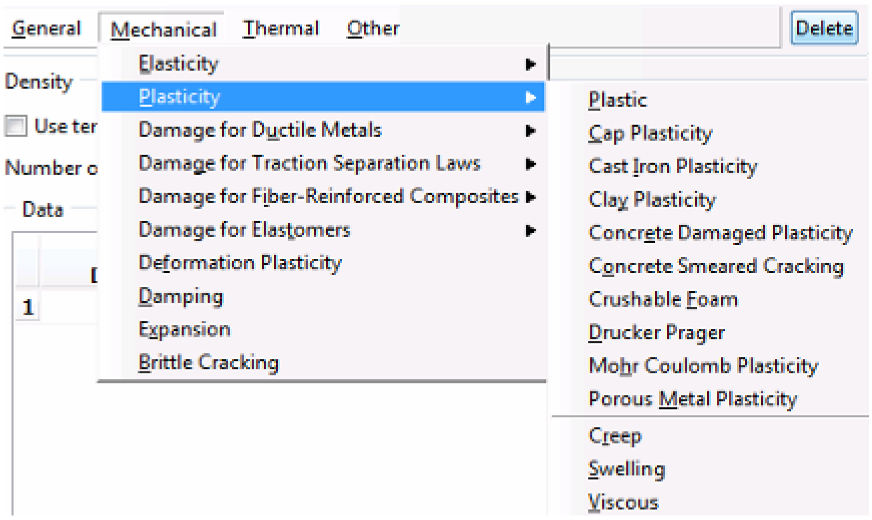
Jedna od najvažnijih stavki u postupku analize svakako je i izbor odgovarajućeg modela tj. konstitutivne relacije za materijale s kojima se susrećemo u zoni čela. Savremeni MKE softveri imaju implementirane sve osnovne modele ponašanja geo materijala. Operator treba da izabere odgovarajući model te da za isti unese odgovarajuće parametre. To podrazumijeva eksperimentalno ispitivanje geo-mehaničkih karakteristika materijala u laboratoriji i na terenu. Taj dio posla ima veliki uticaj (često najznačajniji) na validnost same analize.

Anizotropija: Većina stijenskih materijala (sedimentne i metamorfne stijene) pokazuje anizotropno ponašanje. U nekim slučajevima materijali se ponašaju ortotropno (3 glavne ose anizotropije) ili imaju transverznu anizotropiju tj. izotropiju u ravni. U tom slučaju za numeričko modeliranje potrebno je poznavati pravce glavih osa i odgovarajući broj parametara materijala za svaku osu.



Sl. 15. *Izotropnost, ravna anizotropija, ortotropnost*

Savremeni softveri (Abaqus, Adina, Ansys, Flac…) imaju implementirane elastične a u poslednjim verzijama i neke inelastične anizotropne modele materijala.



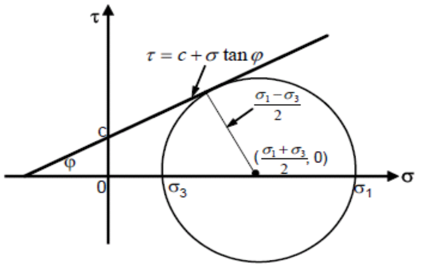
Sl.16. *Osnovni modeli materijala implementirani u komercijalnom programu Abaqus*

Plastičnost: Naponsko-deformaciona analiza se zbog nelinearnosti odvija u malim inkrementima porasta opterećenja (gravitaciono opterećenja) i isključivanja elemenata iz mreže tj. „umiranje elemenata“ čime se simulira kopanje. Nakon svakog inkremena računaju se naponi u svim integracijskim tačkama a zatim se isti porede sa kriterijem plastičnosti, u zavisnosti od usvojenom modela materijala. Mogući su slijedeći slučajevi:

$f(\sigma_{ij}, Y) < 0$	Elastično ponašanje
$f(\sigma_{ij}, Y) = 0$	Na granici površine klizanja
$f(\sigma_{ij}, Y) > 0$	Plastificiranje,nedozvoljeno područje

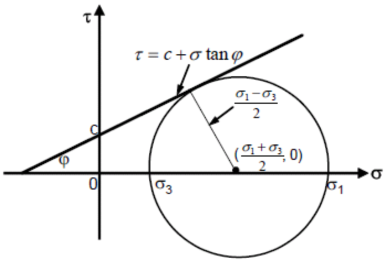
U slučaju da je otkrivena tačka u kojoj dolazi do plastičnog tečenja, u iterativnoj proceduri se naponi preraspoređuju dok se ne postigne naponska ravnoteža. Tada se prelazi na novi inkrement.

Osnovni modeli elasto-plastičnog ponašanja materijala materijala u zoni širokog čela su: MC (Mohr-Coulomb), MCSS, Drucker-Prager, Drucker-Prager-Cap, Cam-Clay. U zavisnosti od uslova na terenu, moguće je da korisnik implementira vlastiti model pomoću opcije korisničkog materijala date u vodećim programima.



$$\sigma_1 > \sigma_2 > \sigma_3$$
$$f = \sigma_1 - \sigma_3 + (\sigma_1 + \sigma_3)\sin\phi - 2c\cos\phi$$
$$\sigma_1 \frac{1+\sin\phi}{2c\cos\phi} - \sigma_3 \frac{1-\sin\phi}{2c\cos\phi} = 1$$
c = *kohezija*

ϕ = *ugao unutrašnjeg trenja*



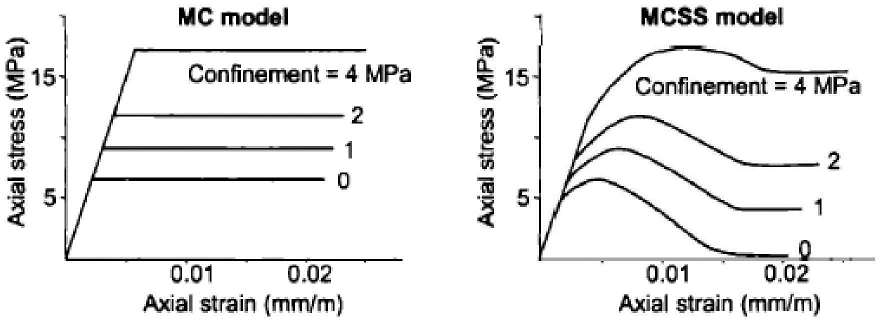
$$\sigma_1 > \sigma_2 > \sigma_3$$
$$f = \sigma_1 - \sigma_3 + (\sigma_1 + \sigma_3)\sin\phi - 2c\cos\phi$$
$$\sigma_1 \frac{1+\sin\phi}{2c\cos\phi} - \sigma_3 \frac{1-\sin\phi}{2c\cos\phi} = 1$$
c = *kohezija*

ϕ = *ugao unutrašnjeg trenja*

Sl. 17. *MC i DP-Cap modeli plastičnosti*

2.3.2 Model materijala za opis ponašanja ugljenog sloja

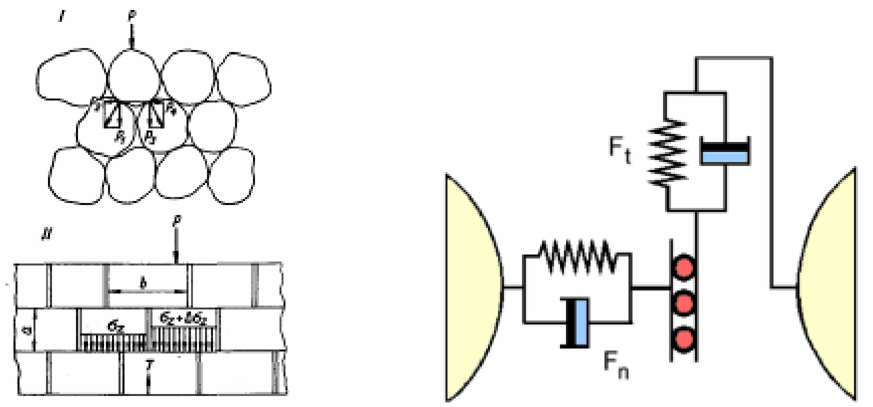
Dosadašnja iskustva iz prakse pokazala su da se deformaciono ponašanje ugljenog sloja može najadekvatnije opisati pomoću MCSS materijala, napredne verzije klasičnog Mohr-Coulomb modela koja omogućava uzimanje u obzir slabljenje materijala nakon dostizanja odgovarajućeg naponskog nivoa koji dovodi do plastične deformacije (Strain-Softening). Na slici su prikazani numerički simulirani triaksijalni testovi sa klasičnim MC i naprednim MCSS modelom za iste parametre koji se dobro poklapa sa eksperimentalnim ispitivanjima na uzorcima.



Sl. 18. *Model MCSS za modeliranje ponašanja ugljenog sloja*

3. DEM (Discrete Element Method)

Metoda diskretnih elemenata je numerička metoda koja se koristi za računanje napona i deformacija u sredinama koje se sastoje od velikog broja pojedinačnih čestica, komada ili zrna. Takav (granulisan) materijal se modelira kao skup krutih čestica proizvoljnog oblika sa unaprijed definisanim kontaktnim interakcijama između istih. Oblik i karakteristike partikula definiše sam korisnik u zavisnosti od vrste problema. Najčešće se koriste sfere, pravilni poligonalni ili elipsoidalni oblici.



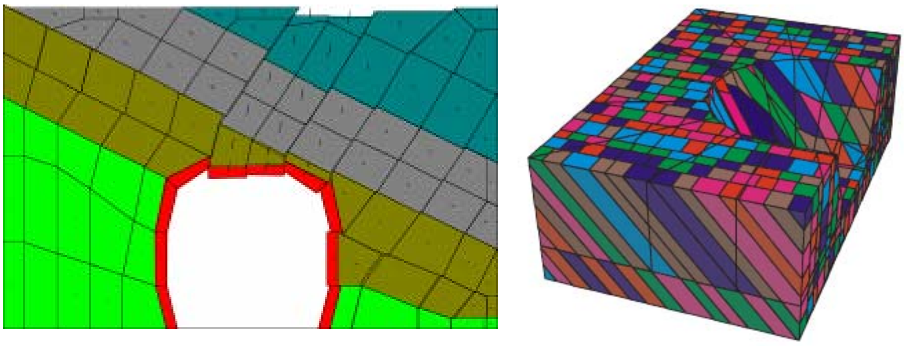
Sl. 19. *DEM metoda, diskretizacija (a) i kontaktni model (b)*

Između partikula se mogu prenijeti normalne i tangencijalne kontaktne sile, gravitaciona sila, potisak fluida, sila kohezije, hemijske veze i druge interakcije. Osnovni problem u numeričkom smislu je efikasna detekcija svih mogućih kontakta svih partikula koje učestvuju u modelu. Ovo zahtijeva velike računarske resurse. Diferencijalna jednačina koja definiše kretanje svakog diskretnog (distinktnog) elementa data je sa:

$$M\ddot{U}+C\dot{U}+KU=F_{EXT}$$

pri čemu su M, C i K sistemske matrice mase, prigušenja i krutosti respektivno a F_{ext} vektor eksterne sile, rezultante na diskretni element.

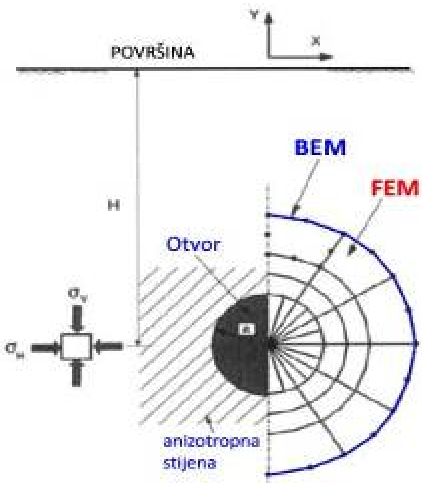
Navedena matrična jednačina predstavlja sistem jednačina kojih ima koliko i stepeni slobode ukupno u domeni. Glavina vremena i računarskog resursa se ipak ne odnosu na rješavanje ovog sistema jednačina nego na otkrivanje i praćenje kontaktnih interakcija između svih elemenata. Uglavnom se diskretni elementi smatraju krutim međutim ima i izvedbi kod kojih su pojedinačni elementi deformabilini. DEM je novija ali brzo razvijajuća metoda čija se primjena u oblasti mehanike stijena sve više povećava. Od komercijalnih kodova baziranih na ovoj metodi vrijedi pomenuti UDEC i 3DEC razvijenim od strane Itasca Co, istog proizvođača kao i Flac3D. Program 3DEC posebno je pogodan za dinamičke analize u problemima miniranja u podzemnim rudnicima.



Sl. 20. *DEM – primjer 2D i 3D modela*

4. HIBRIDNE METODE

Praksa je pokazala da se kombinovanjem nekih od prethodno navedenih metoda mogu iskoristiti prednosti i umanjiti nedostaci drugih metoda. Tako nastaju hibridne metode analize koje podrazumijevaju slijedeće kombinacije: FEM/BEM, DEM/FEM i DEM/BEM. Ovakav koncept često se koristi u naponskoj analizi širokočelne i klasične metode otkopavanja. Prva od njih (FEM/BEM) se najčešće koristi u slučaju velike domene kod koje postoje mjesta koja predstavljaju singularitete (mali i nepravilni otvori ili pukotine). U tom slučaju se naponsko polje dovoljno udaljeno od singulariteta (linearno elastično stanje) dobija BEM metodom dok se diskretizacija domene i analiza u kritičnom prostoru (nelinearna analiza) vrši pomoću MKE s tim da se na manji dio domene prenose već dobijeni BEM rezultati u formi graničnih uslova. Time je smanjeno vrijeme analize i olakšano modeliranje uz eventualno mali gubitak tačnosti.



Sl. 21. *Hibridna BEM-FEM metoda*

5. ZAKLJUČAK

Određivanje naponsko-deformacionog stanja u zoni rudarskih radova u podzemnoj eksploataciji je složen i odgovoran zadatak. Rješavanje istog zahtijeva poznavanje veličina svih komponenti napona stijenskom masivu. Pod pretpostavkom da se podzemna eksploatacija vrši u idealno elastičnoj i homogenoj sredini, za prostorije proste geometrije moguće je analitički odrediti distribuciju napona. Na žalost, u praktičnim uslovima, analitičko određivanja naprezanja u stijenskom masivu je ograničenih mogućnosti, nepouzdano ili nemoguće. Eksperimentalno mjerenje naprezanja je slijedeća mogućnost. Ista se odlikuje pouzdanošću rezultata ali zahtijeva skupu opremu, specijalizovano osoblje i često ometa proces proizvodnje. Takođe u projektnoj fazi nije moguće imati mjerne podatke o podzemnim pritiscima jer prostorije još ne postoje. Stoga se kao perspektivne nameću metode numeričke simulacije, samostalno ili u kombinaciji sa prethodno navedenim. Prikazane metode daju zadovoljavajuće rezultate uz pravilnu pripremu modela i interpretaciju rezultata. Od istih, posebno se ističe MKE, danas osnovna metoda analize u geomehaničkim problemima, u koje spada i naponsko-deformaciona analiza kod širokočelne metode otkopavanja. MKE omogućava dobijanje pouzdane informacije o distribuciji napona ukoliko se sredina u kojoj se odvija proces može smatrati kontinuumom te ako su sve stavke od kojih se sastoji analiza izvedene pravilno. Ako je domena (radni prostor) fragmentiran ali u formi da se može procijeniti srednji oblik i veličina i raspored fragmenata ona se uz odgovarajuće uslove, DEM metodom mogu dobiti rezultati koji omogućavaju uvid i procjenu procesa deformisanja. Navedene metode su verificirane na brojnim primjerima i njihova široka primjena u svijetu uz rastući broj programa i teorijskih modela najsigurniji su pokazatelj opravdanosti primjene istih u problemima podzemne eksploatacije.

6. LITERATURA:

[1] S. Helwany: Applied soil mechanics", John Wiley & Sons Ltd, 2006

[2] A. Bobet: „Numerical Methods in geomechanics", The Arabian Journal for Science and Engineering, Volume 35, Number 1B, 2010

[3] L. Jing and J. A. Hudson, "Numerical Methods in Rock Mechanics", International Journal of Rock Mechanics and Mining Sciences, 39(2002), pp. 409–427.

[4] L. Jing, "A Review of Techniques, Advances and Outstanding Issues in Numerical Modeling for Rock Mechanics, and Rock Engineering", International Journal of Rock Mechanics and Mining Sciences, 40(2003), pp. 283–353.

[5] A. A. Borisov, „Proračuni podzemnog pritiska" (prijevod) Tuzla, 1970

[6] B. H. G. Brady, "Boundary Element and Linked Methods for Underground Excavation", in Analytical and Computational Methods in Engineering Rock Mechanics. Ed. E.T. Brown, London, England: Allen & Unwin, 1987, pp. 164–204.

[7] G. N. Pande, G. Beer, and J. R. Williams, Numerical Methods in Rock Mechanics. West Sussex, England: John Wiley & Sons, Ltd., 1990.

[8] M. Stević, „Mehanika tla i stijena" Rudarsko-geološki fakultet Tuzla, 1991

[9] Memić M., Hadžić E., Karadžin Z., „Savremene teorije i rporačuni podzemnih pritisaka" Rudarski institut u Tuzli, 2006

[10] S. L. Crouch and A. M. Starfield, Boundary Element Methods in Solid Mechanics. London, England: Allen and Unwin, (1983)
[11] J. P. Carter and B. Xiao: „A 2d coupled finite element and boundary Element scheme to simulate the elastic Behaviour of jointed rocks“ International journal for numerical and analytical methods in geomechanics, vol. 18, 49-71 (1994)
[12] P. A. Cundall and O. D. L. Strack, "A Discrete Numerical Model for Granular Assemblies", Geotechnique, 29(1)(1979), pp. 47–65.
[13] R. Hart, P. A. Cundall, and J. Lemos, "Formulation of a Three-Dimensional Distinct Element Model – Part II. Mechanical Calculations for Motion and Interaction of a System Composed of Many Polyhedral Blocks", International Journal of Rock Mechanics and Mining Sciences, 25(3) (1998)
[14] M. Ljubojev, R. Popović, M. Avdić, L. Đ. Ignjatović, V. Ljubojev, Defining the legality of gray sandstone rock strength testing in a complex state of stress, TTEM Journal of society for development of teaching and business processes in new net environment in B&H, vol. 5, No. 3 2010, pp. 437-443
[15] R. Popović, M. Ljubojev, D. Ignjatović, V. Ljubojev, L. Đ. Ignjatović, Geomechanical laboratory conditions of rock fracture, TTEM Journal of society for development of teaching and business processes in new net environment in B&H, vol. 5, No. 3 2010, pp. 544-547
[16] M. Ljubojev, M. Avdić, V. Ljubojev, D. Ignjatović, L. Đ. Ignjatović, Observation of chenges and measurment of subsidence on the collector under the open pit „Bogutovo selo“ in Ugljevik, Rudarski radovi, br. 1/2010, str. 25-31

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Salko Ćosić, Hasan Okanović***

MODELING OF STRESS-DEFORMATION STATE USING THE NUMERICAL METHODS IN THE WIDE FACE MINING

Abstract

This paper presents in the short form the possibilities of potential use the numerical methods in modeling the stress-deformation condition in rock massif for the case of wide face exploitation of mineral deposits. The basic methods are described with the advantages and disadvantages. The basic commercial software packages and examples of application on problems of wide face mining are given. For the MKE, the procedure for development of 3D model, discretization on finite elements taking into account the inhomogeneity of the elastic-plastic behavior of layered material.

Key words: *pit pressure, wide face method, modeling, stress-deformation condition, numerical methods, finite elements method*

1. INTRODUCTION

Development of mining workings and especially the opening of stopes, the free surface of roof is opened which begins to deform, separation and fracture and in the course of time, if it is not supported, breaks down.

These strains and pressures resulting from the redistribution of stress state of the massif. For an explanation of pit pressure there are many theories and hypotheses which start from different assumptions, and therefore give the different interpretations. The term “pit pressure” was defined by forces that occur in rock masses under the influence of distortion of the original balance and redistribution of stresses in order to establish a new equilibrium range. There are several definitions of underground pressures, some of them are based on changing conditions, some of the stages of the development phase of deformation of rocks and formation of deformation zones in rock massif around the underground chamber and some of the characteristics of support. On complexity the problem, the best proof is that there is no generally accepted theory to all mining and geological cases. Knowledge of the stress-strain state of the massif is of great importance for the safe design and determination the dimensions of parts of the mine, the choice of support and management of roofing.

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1.1. Influential factors on the occurrence and intensity of pitpressures

Significant impact on the occurrence and manifestation of pit pressures and deformations in the underground mining are geological, physical and mechanical characteristics of massif and mining technology. The work environment can have different physical and mechanical characteristics, so, for example, the roof of can be very hard rock to the water-bearing sands as the worst material. Besides these, there are number of other natural factors that influence the occurrence and intensity of pit pressures such as anisotropy in the working environment, tectonic fractures, sliding and contact surfaces.

Basically, three cases can be distinguished:

- Non-compact or plastic rock mass is the environment where the support has to be installed timely in order to provide full or partial stability of the room,
- Medium compact rock mass is the environment with provided temporary stability of underground room, and
- Compact rock mass is the environment with the stable underground room. The support is not required in these rooms.

Characteristics of massif, for the needs of design the mining workings, must be completely defined, by the previous studies using different methods: laboratory testing of samples, in-situ geophysical or other acceptable methods. These tests must provide accurate and reliable results what significantly influences the choice of support, sizing of the rooms and other parameters needed for design. Despite all researches due to very complex mining and geological conditions, there is always a risk of side effects. Such example is the appearance of "false" roof in the "Old Pit" Zenica tectonic block TB-1 (OP-1 and OP-2), where the roof was solid and compact, but between the basic "false" roof (with average thickness about 0.7 mm) there is a coal band of thickness less than 0.5 mm, which physically separated the basic roof. The "false" roof behaved well and safe until the opening of the room of such sizes that it becomes unstable and begins to fall down with endangering the safety of operation.

Besides the geological and geotechnical characteristics of the terrain, the applied technological processes of excavation have also a significant effect on the occurrence and intensity of pit pressures.

Designers at the design stage by selection the appropriate mining method, layout and sizes of the rooms, dynamics of progress and other solutions, can significantly affect to the reduction of influence the pit pressures. The suitable support must be accurately and timely installed to establish a contact with the rock mass.

The wide face mining method is the most used method for mining the coal layers in the underground mining. From the point of rock mechanics, there are a number of hypotheses for description the stress state and emergence of pit pressures around the wide face.

1.2. Pit pressures

Differences in interpretation the pit pressures mainly come due to different methods of approaching to this issue, and where two basic approaches could be emphasized:

- the use of elasticity theory to solve the problems of stress and deformation the various types of mining workings,
- recording and measurement of deformations.

Testing of pit pressures and measurement in the mining conditions allows direct observation the behavior of these phenomena in the function of advancing the wide face. In these measurements the difficulties cause limitations in the observed area that comes down to the observation of deformation in the narrow strip of roof, sides and floor causing a registration of consequences, but not the causes of formation the deformations and stress redistribution in the surrounding rocks.

In order manage the pit pressures in the excavation process, it is necessary to undertake a series of technical measures and activities for protection and maintenance the mining workings. These measures include supporting, caving, stowing and leaving the unexcavated protective plates and pillars. The task of these measures is to achieve the required safety in the process of underground mining and they are called the control of pit pressure. Control of pit pressure cannot be considered separately from behavior of roof, which in the process of underground mining has one of the most important role why the control of pit pressure is reduced to the problem of roof control.

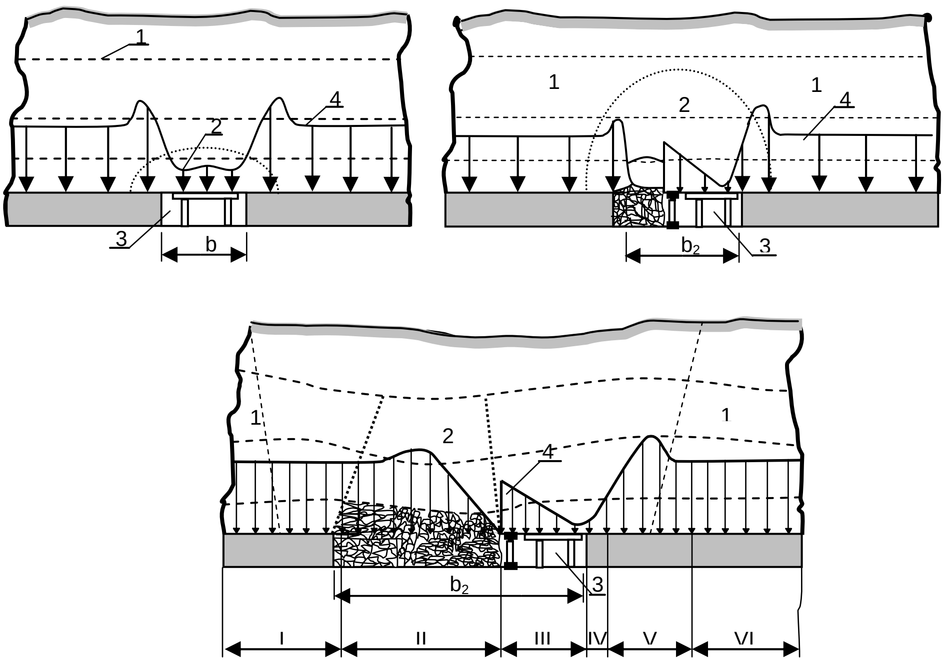

Figure 1. *Situation of excavation and diagram of pressures at the stope with the dynamics of stope movement*

1. Undisturbed massif, 2. Caving zone, 3. Stope, 4. Pressure diagram, b2 stope width,
I – Zone of constant pressure, II – Zone of abutment pressure in the stope,
III – Zone of reduced pressure near the stope face, IV – Zone of crushed coal,
V – Zone of abutment pressure, VI – Zone of normal stress in the undisturbed massif.

1.3. Testing and study the characteristics of rock materials

The most extensive testing and research of work environment are made in the construction of underground facilities for the purpose of defining the characteristics of the space and environment in which the facility is built. For this purpose, it is necessary to carry out the previous and subsequent tests. Previous testing is used to determine the mining-geological characteristics of rock material where the facility should be built. These researches should give the background to the designers based on which they will design the underground chambers, whose characteristics must provide the functionality, security, economy, durability and other required things for the facility. By subsequent researches, the investigations are carried out as well as monitoring the features of working environment or its immediate surroundings in the stage of development and exploitation of the rooms, while the scope of these tests depends on the type, purpose, duration of the rooms and other influential factors.

Research the law on stress and deformation changes in rocks is an important activity in development and exploitation the underground mining facilities. These researches can be done in the laboratory and natural conditions. Laboratory tests on the relationship of stress and deformation have a number of factors that might influence on the testing results. These researches include development of spatial models of equivalent materials. A group of experts of the Mining Institute in Tuzla, in the 70 of the last century, have achieved the significant results in development of these models of wide face mining. In recent years, the numerical methods have found much more use and the engineers could easily numerically model the facilities using the CAD. Computer models can check the state of facilities exposed to various influential factors with no additional financial investments or construction the spatial models which need more time for development.

Measurements in the real environment and field measurement of stresses, deformations and pressures is of great importance for solving theoretical and practical problems in the design and construction the underground mining facilities. Field measurements can be made on existing facilities in the exploitation phase of the room or on the experimental facilities and chamber. In the pit, "Sretno" – Breza - thus an experimental chamber was constructed in order to determine the bearing capacity of barren band (breccia).

To obtain more reliable data in addition to field measurements, an analytical calculation of parameters and load bands with finite element analysis were carried out. Such comparative analyses have great theoretical and practical importance. In the drawn chamber, size about 6.0 x 2.5 x 2.3 m, at certain distances, the benchmarks are embedded for measuring the deformations of the room. Deformations were measured on a daily basis until the moment of the roof fracture. The advantage of this experiment is that the measurements could be made to the fracture of roof (bands) while in the exploitation room, in order to preserve its functionality and security, the tests were interrupted before the expected fracture. The obtained results by "in situ" measurements, analytical and numerical methods (MKE) were within the acceptable limits of error and had practical value for further work (Figure 2).

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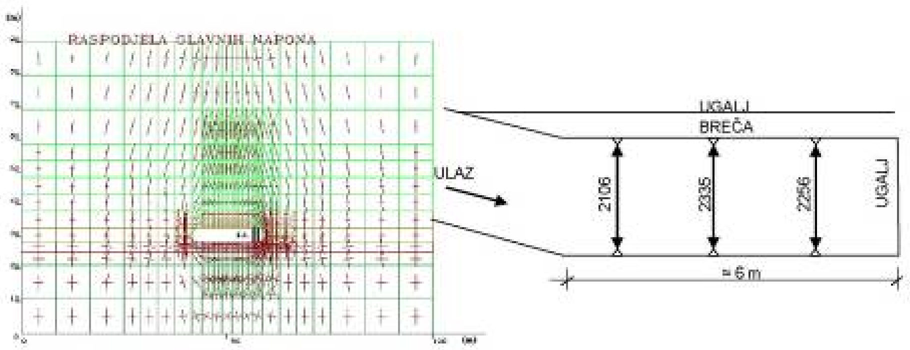


Figure 2. *Distribution of main stresses on a test chamber*

1.4. Pressure measurements on a wide face

Instruments for measuring the stresses, deformations and pressures can be mechanical, hydraulic, optical or electrical. For measurements that are carried out in the pits, hydraulic devices were used for measuring the response of mechanical hydraulic support (MHP), measuring the reaction of columns, dynamometers for measuring the pressure and devices for measuring the length. These measurements are carried at the contact of support and contour of the room. In more demanding and more complex objects (foundations of dams for hydroelectric power plants, etc...) tests can be carried out in the massif by installing the hydraulic cushions or probes into the massif.

Measuring of IHL response (e.g. Raspotočje-Zenica, Marble-Kreka) is performed using the German HydroStar devices (0-600 bar) that are installed on the hydraulic system section of a wide face, with continuously monitoring of support reaction. The results of measuring are automatically recorded on the measuring tape. Devices are placed into three sections, two near the access rooms and one in the middle of a wide face. These measurements take 30 to 40 days, depending on the opportunities and needs in the field, after what the devices are removed from sections and the values of tapes are read and processed.

Measuring of response on the hydraulic columns of wide face (e.g. Omazići - Banovići) are made using a device that is connected to the valve of column where the pressure is read directly in the column. In these measurements, the selection of columns is done in length of wide face but the phase of work on a wide face is taken into account, which would later have a significant impact to an analysis of the results.

During these tests, in the access facilities of a wide face (transport and ventilation gate), the dynamometers were installed to measure the pressure at certain distance from the wide face. Dynamometers monitor the changes in pressure in the function of advancing the wide face. Measuring the deformation of access rooms is carried out by the benchmarks for monitoring the convergence or divergence of the room walls. After all carried out measurements in the field, the collected data are processed, where the stages of work on a wide face must be taken into account and in a function of time and measured values and possible downtime in the operation of a wide face. Thus processed data are taken for analysis of stress and deformation state.

Until now, these analyses were carried out by one of many hypotheses set by the scholars, experts in the field theory of elasticity (Kirsh, Kolosov, Mushelisvilli, Boussinesq, P. M. Cimbarevič, Greda, Labasov, K. V. Rupeneit, etc.). Based on a long year experience and calculations in our pits, the arch hypothesis has given the best results and it was the most frequently used.

Analytical methods include an ideal, homogeneous, isotropic material, which is assumed to be subjected to stresses that do not cause plastic deformation and that the change in form and volume is negligible small. The basic set of equations describing the stress-deformation state of mass is given in Figure.

$$\sum Fx = 0; \quad \sum Fy = 0; \quad \sum Fz = 0;$$

$$\frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z} + \rho X = \rho \frac{\partial^2 u(X,t)}{\partial t^2}$$

$$\frac{\partial \tau_{yx}}{\partial x} + \frac{\partial \sigma_y}{\partial y} + \frac{\partial \tau_{yz}}{\partial z} + \rho Y = \rho \frac{\partial^2 v(X,t)}{\partial t^2}$$

$$\frac{\partial \tau_{zx}}{\partial x} + \frac{\partial \tau_{zy}}{\partial y} + \frac{\partial \sigma_z}{\partial z} + \rho Z = \rho \frac{\partial^2 w(X,t)}{\partial t^2}$$

$$u = u(x,y,z,t), v = v(x,y,z,t), w = w(x,y,z,t), \quad u(X,t) = u_0(X,t); \; v(X,t) = v_0(X,t); \; w(X,t) = w_0(X,t); \quad \forall X \in \Gamma_{u,v,w}$$

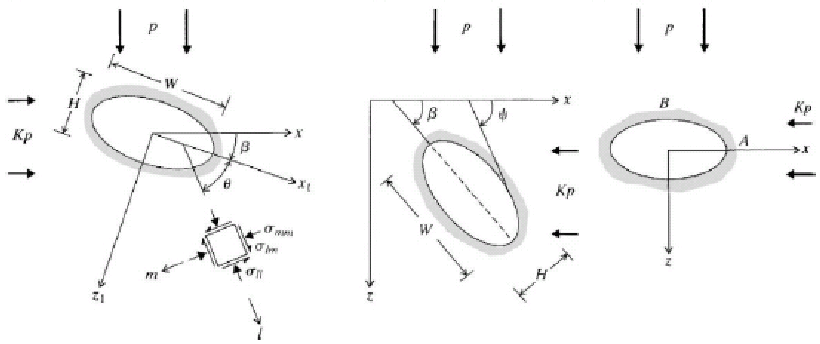
$$\sigma(X,t) = \sigma_0(X,t) \quad \forall X \in \Gamma_\sigma \qquad \varepsilon_{xx} = \frac{\partial u}{\partial x}, \; \varepsilon_{yy} = \frac{\partial v}{\partial y}, \; \varepsilon_{zz} = \frac{\partial w}{\partial z}; \; \varepsilon_{xy} = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}, \; \varepsilon_{xz} = \frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}, \; \varepsilon_{yz} = \frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}$$

KONSTITUTIVNA RELACIJA $\sigma = f(\varepsilon, \dot{\varepsilon}, \alpha, t)$

$$\begin{Bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{zz} \\ \sigma_{yz} \\ \sigma_{xz} \\ \sigma_{xy} \end{Bmatrix} = \begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} & c_{15} & c_{16} \\ & c_{22} & c_{23} & c_{24} & c_{25} & c_{26} \\ & & c_{33} & c_{34} & c_{35} & c_{36} \\ & & & c_{44} & c_{45} & c_{46} \\ & \text{sym.} & & & c_{55} & c_{56} \\ & & & & & c_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{zz} \\ \varepsilon_{yz} \\ \varepsilon_{xz} \\ \varepsilon_{xy} \end{Bmatrix}$$

Figure 3. *System of basic equations*

With these assumptions, it is possible to provide solutions for several typical cases of simple geometry shown in the following pictures. The Russian scientist Kolosov introduced the conformal mapping method in the theory of elasticity, based on the theory of functions the complex variable, which made possible to obtain from the existing and some solutions for the cases of complex geometry (elliptical, roughly rectangular and triangular openings).



$$\sigma_{rr} = \frac{p}{2}\left[(1+K)\left(1-\frac{a^2}{r^2}\right)-(1-K)\left(1-4\frac{a^2}{r^2}+\frac{3a^4}{r^4}\right)\cos 2\theta\right]$$

$$\sigma_{\theta\theta} = \frac{p}{2}\left[(1+K)\left(1+\frac{a^2}{r^2}\right)+(1-K)\left(1+\frac{3a^4}{r^4}\right)\cos 2\theta\right]$$

$$\sigma_{r\theta} = \frac{p}{2}\left[(1-K)\left(1+\frac{2a^2}{r^2}-\frac{3a^4}{r^4}\right)\sin 2\theta\right]$$

$$u_r = -\frac{pa^2}{4Gr}\left[(1+K)-(1-K)\left\{4(1-\nu)-\frac{a^2}{r^2}\right\}\cos 2\theta\right]$$

$$u_\theta = -\frac{pa^2}{4Gr}\left[(1-K)\left\{2(1-2\nu)+\frac{a^2}{r^2}\right\}\sin 2\theta\right]$$

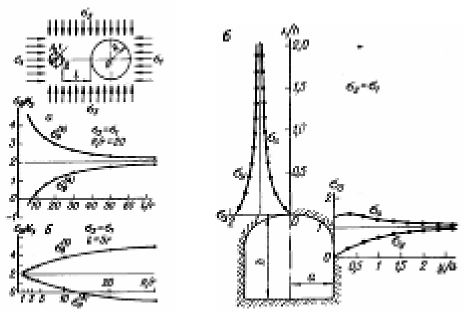


Figure 4. *Shapes of the rooms for which the analytical solutions are possible*

2. NUMERICAL METHODS

Conditions of the wide face mining process are often significantly different from those mentioned as a prerequisite for the analytical solutions of stress-deformation distribution. First of all, the domains in which the process takes place is mostly highly unhomogeneous, fragmented, layered and intersected with faults. Then, the materials involved in the process behave anisotropic, inelastic and many of them have time-dependent characteristics, ie. the effects of viscoplasticity or creep. The geometry of the workspace is complex, deformations are not negligible and the stresses are oftenover the limits of elasticity. It seems that the analytical methods have limited application in the field wide face mining.

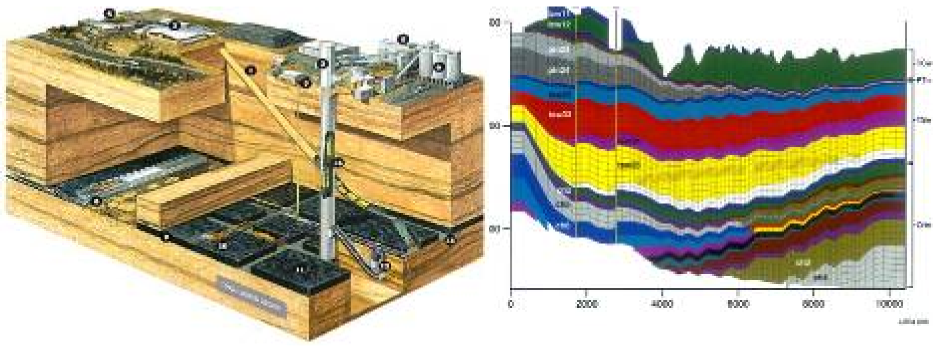


Figure 5. *Wide space method, general disposition (a), layers and faults (b)*

As an alternative solution for determining the stress and deformations there is the possibility of numerical simulation. Numerical analysis has enabled:

- Modeling the large class of geotechnical materials, primarily rock massives, soil, concrete, steel elements, wood and other materials appearing in the underground mining,
- Modeling the time-dependent models of behavior (visco-plasticity, creep) is enabled,
- Possible analyzing in a case of geometric nonlinearities (large deformations), the material nonlinearity (constitutive relation) or contact nonlinearity.
- Dynamic analyses that include the seismic and effects due to the mining.

Numerical methods are means and tool that makes extensive use in modern geomechanics. Roughly speaking, there is a division on the continuous and discontinuous methods. This division was based on geo-mechanical characteristics of the media ie. rock material where the process of exploitation is developed, that is in which the method is applied. Methods based on the continuum mechanics (BEM, FEM and CDM) could be applied to the problems where the material has approximate characteristics of continuum or the domain is divided into blocks of known sizes and shapes that act as a continuous, Figure 6a and b.

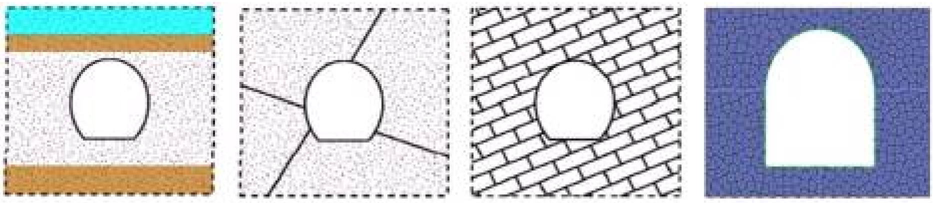


Figure 6. *Basic models of medium where underground mining is developed [2]*

If the domain is very discrete ie. Fragmented, the discrete methods are used under a condition that it is possible to determine the shapes and positions of discrete elements. If the material is fragmented in such small pieces that their sizes are negligible compared to the geometric scale of domain, the pseudo-continuummethod can be applied. The process of numerical modeling using the continuum methods is done in several steps. The first step is a development of 3D geometric model that represents a domain within which the process of rock mass deformation is developed. For its realization, it is necessary to know the precise sizes of all rooms and positions, shapes and strike direction of all material layers. The second step is correctly modeling the behavior of all materials under load. The basis for this step includes the geomechanical testing of samples of lithologic members taken in the field. The third step is a nonlinear stress-deformation analysis that is carried out using the MKE, BEM or CDM methods. MKE method is currently dominant for the analysis of nonlinear elastic-plastic problems. In the last step, the post-processing of results, a critical analysis of present results of stress and deformation distribution is carried out and, if necessary, a model correction. The essential advantages, achieved by the use of given procedure, are the possibility of determining all components of stress in the conditions of complex of geometry and material inhomogeneity as well as the ability to analyze various options and parameters of mining with respect to the carrying capacity of support or equipment characteristics. On the other hand, the accuracy and reliability of simulation results depends on the accuracy of geometry, accuracy, quality and range of testing the material samples as well as the complexity of analysis performed by means of numerical simulation. In order to verify, validate and calibrate the model, it is required to have also the data on stresses, obtained experimentally, in the appropriate number of points

2.1. Boundary element method - BEM

In problems where the ratio of surface to volume of domain is very small (large 3D domains) the finite element method is not particularly suitable due to very large number of DOF. In this case the BEM method is favorable especially if it is necessary to determine the stresses or deformations only in the certain areas of domain which can be arbitrarily with large sizes and shapes. Model generating is simpler and faster and needs less amounts of data. This method discretizes only a contour line of domains (for 2D problems) or contour surface (3D problems).Thus, the problem dimensionality is reduced by 1 and thus the number of DOF, and this method is effective for 3D problems.

Numerical procedure consists in reduction the system of differential equations in terms of influence coefficients and the interpolation of functions to the system of linear algebraic equations describing the shifts in nodal points of elements on a contour. This method is effective for problems where the material is modeled as a linear.

For more complex models of material, the volume of calculation is drastically increased. Also, if it is necessary to determine the stresses inside a model, it is necessary to perform the additional interpolations (reduced accuracy) or take the new sections or contours (increasing the volume of calculation. Part of advantages over the FEM is lost and because the system matrices are not bandy and symmetrical as it is the case with FEM. Due to the above given, this method is used for elastic simulations of large 3D models and as an auxiliary method for some sections, combined with the FEM. Of commercial program, based on this method, the BEFE + +, BEMFF and BEMSAD are stood out.

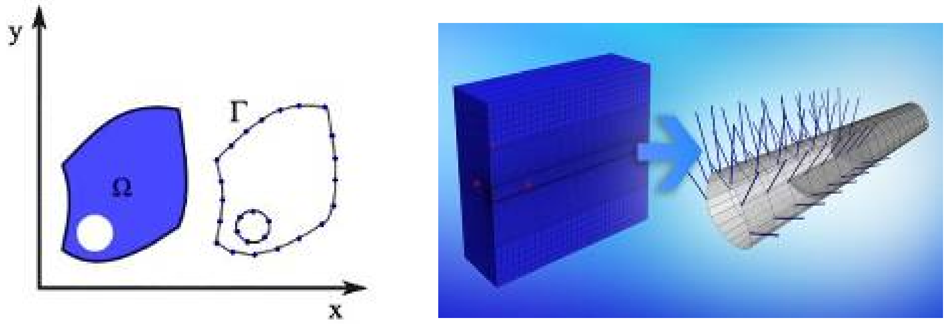


Figure 7. *Discretization by the method of boundary elements*

2.2. Finite difference method-FDM

Finite difference method is one of the first numerical methods used in the field of geomechanics. Domain (working area) is discretized by the network nodes where the nodal displacements are calculated as the primary solution. Partial derivatives in the system of differential equations, describing the process of deformation domains, are replaced by the finite differences. Knowing the boundary conditions, form a system of algebraic equations is formed that is solved using the linear solver. Derived variables are obtained in the post-processing procedure.

The basic algorithmic steps of FDM methods:

- A discrete network of points in the domain of equation (2D or 3D) is generated,
- The statements are replaced by the finite differences in basic equations,
- PDJ system is converted to a system of algebraic equations. The numerical solution of nodal points is required,
- In contrast to the time-dependent problems, the solution is not determined by the step by step progress by the timeline, but the approximate solution is determined simultaneosly in all points of network solving one system of algebraic equations.

$$\frac{\partial u}{\partial x}=\frac{u_{i+1}^k-u_i^k}{\Delta x};\quad \frac{\partial^2 u}{\partial x^2}=\frac{u_{i+1}^k-2u_i^k+u_{i-1}^k}{(\Delta x)^2}$$

$$\underbrace{\frac{u_{j+1}-2u_j+u_{j-1}}{\Delta x^2}}_{u_{xx}};\quad \underbrace{\frac{u_{j+m}-2u_j+u_{j-m}}{\Delta y^2}}_{u_{yy}};\quad i=1,\dots,n$$

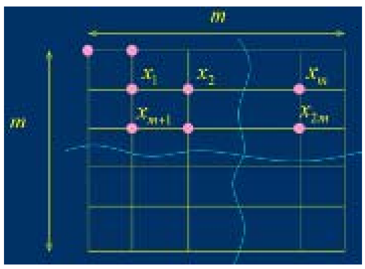


Figure 8. *Replacement of statement by the finite (central) differences and domain discretization*

The method could be used for static and dynamic problems that require also, except the spatial, the temporal discretization of system of basic equations. Dynamic analyses include seismic as well as problems of mining blasting and mainly use an explicit integration scheme and concept of concentrated mass element what in numerical terms increase the efficiency of algorithm.

The main disadvantage of this method is the problem of description the domains of irregular shape and material inhomogeneity that is often the case in modeling the wide face mining method. However, in the problems with a homogeneous environment and simpler geometry, this method produces results that correspond well with the field measurements.

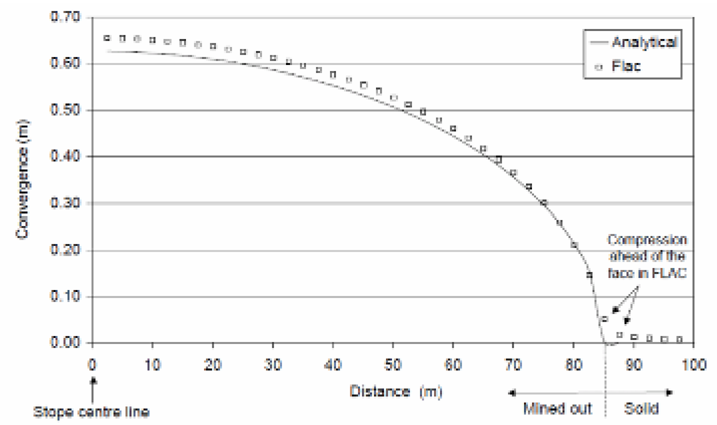


Figure 9. *Comparison of numerical (FLAC) and analytical results for the value of node shift*

The best-known commercial software suitable for modeling the problems of stress in the wide face mining and based on FDM is FLAC (2D) and FLAC3D for 3D models, developed by “Itasca Co.“ in the USA (www.itasca.com).

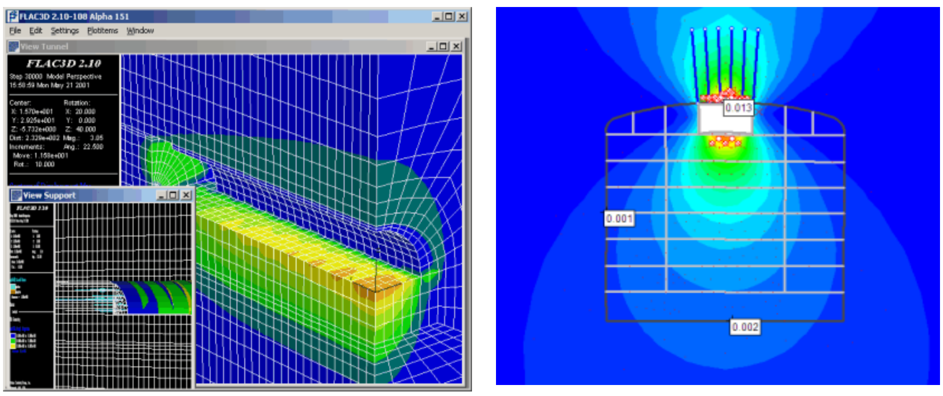


Figure 10. *An example of the user interface program FLAC 3D*

The program has its own preprocessor which builds the model geometry and automatically generates the 2D and 3D network nodes. Solver is based on the FDM method (static and dynamic problems, hydrology, ie. underground water flow in porous media, thermal loads, etc...). The program has a collection of models of basic geo materials that include and describe the elastic, plastic, visco-elastic-plastic, creep, models of porous media and others.

2.3. MKE in the analysis of stress states in the wide face mining

MKE is a modern numerical method for solving the PDJ. The essence of method is the approximation of solution functions (u,v,w) using a discrete set of functions (polynomials) and discretization the domain by the finite set of finite elements. Three basic concepts in defining the modern MK are:

- The Raleigh-Ritz variational principle,
- The Galerkin principle of weight residual,
- Least square principle.

In the area of determining the stress states in geomehanici, MKE is applied from the beginning. The advantages over other numerical methods are:

- Complex geometry, random shape domain
- Complex boundary conditions (load and supports, contour forces and displacements)
- Complex (nonlinear) constitutive relations
- Combining the different elements and materials
- High accuracy, which may be affected

Since this method is one of the continuous methods, its application to the problems of determining the stress state inthe wide gace mining method is limited to those cases that can be approximated by a continuum, as previously stated. In the cases of continuous but layered environment intersected by faults, it is possible, if the geometric and material characteristics of layers and the geometry of fault are known, to make a realistic model which can track the behavior of massif. Figure 11 shows the basic types and ways of fault modeling.

Taking into account the fault involves modeling of elastic-plastic contacts between the corresponding layers. This analysis of the numerical terms is more complicated, but modern software can solve problems with such models. As for other problems, the stress analysis for wide face mining, FEM analysis consists of the following steps:

1. Development of physical model of a wide face with all relevant geometric detail of support including supports,
2. Determination of layers with different materials, and any faults if the positions are well-known (model partition),
3. Selection of material model and joining of materials and boundary conditions to the corresponding parts of model (volumes),
4. Defining a contact in case of fault,
5. Discretization of the domain on the final elements of appropriate type,
6. Starting the solver what forms the element and system matrices and vectors, and directly or indirectly solves the resulting system of linear equations,
7. Post-processing of the results, calculation of secondary variables,
8. Critical analysis and model correction.

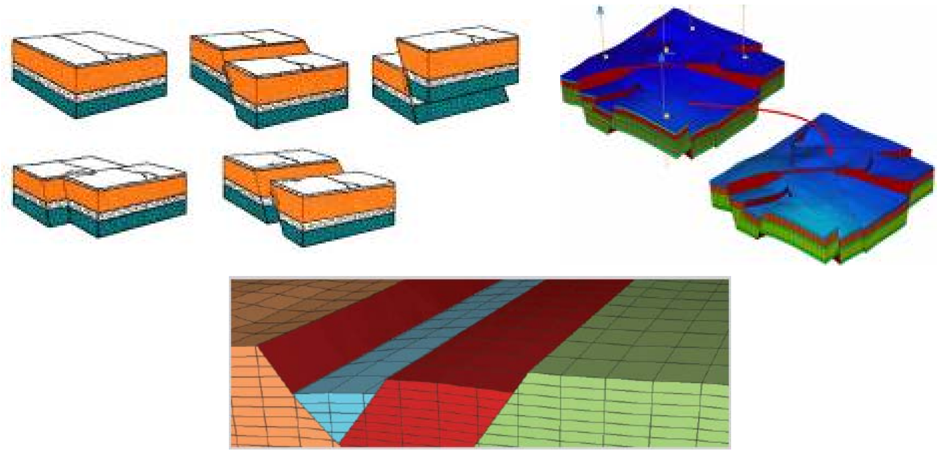


Figure 11. *Basic fault types and methods of geometric fault modeling*

Each of these items requires a good knowledge of physics problems, the numerical procedure and software that solves the problem. In general the most time is spent on the first four items, and the result accuracy the result accuracy depends on most of them. Items 5, 6 and 7 are largely performed automatically by the software until for the last 8 item, the practical knowledge and experience in stress analysis problems is required.

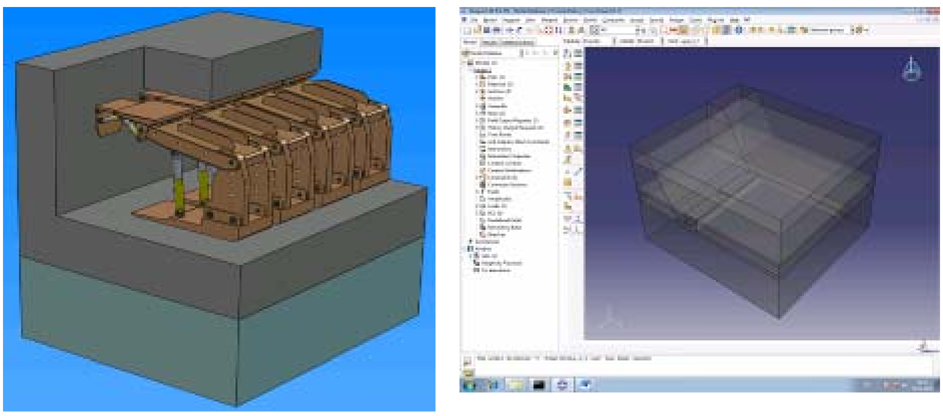


Figure 12. *Modeling the geometry of support and deposit*

The main problems and limits encountered in the MKE use in the analysis of wide face are:

- Lack of knowledge on the position and characteristics of layers, unknowing the location of faults,
- Problems of contact interactions between the support and rock massif,
- High plastic deformation which leads to the loss of convergence,
- The appearance of cracks in a part of material automatically leads to the

interruption of iterative procedure and suspension of analysis.

Because of the large-scale domain (3D) and taking into account small details, the automatic mesh generators generate a network of elements that is often several hundred thousand or one million degrees of freedom. Such great problems, where the additional contacts and plastic deformations occur that lead to a large number of iterations, are physically difficult problem for "small" PCs because they require a huge number of calculations and a large amount of RAM. Parallel processing on multiprocessor machines is the only solution if it is not possible to simplify the model.

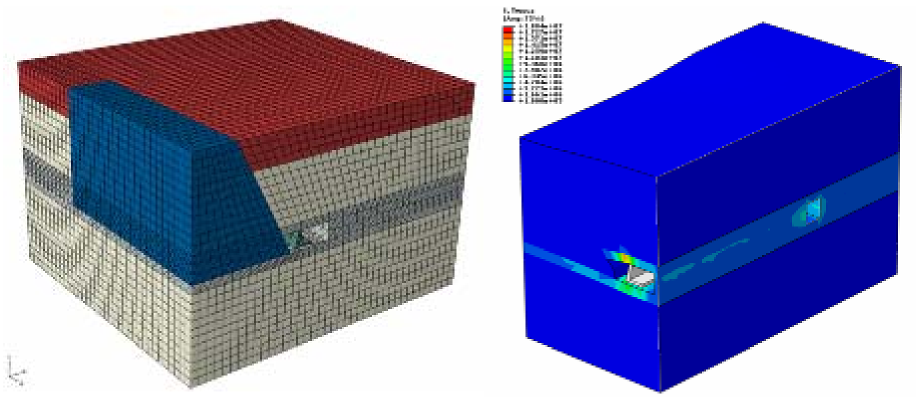


Figure 13. *3D discretization and post processing the results of wide face analysis*

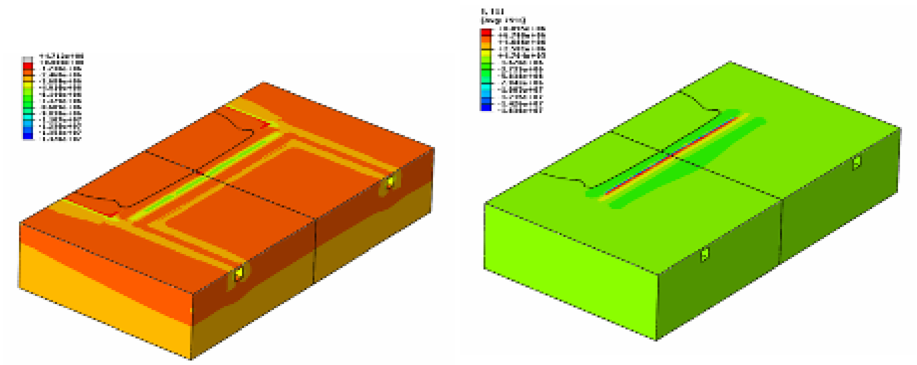


Figure 14. *Post processing analysis the results of analysis in a wide face, distribution (a) and maximum vertical stresses ahead of the face front (b)*

2.3.1 Basic constitutive relations (material models) for MKE analysis

One of the most important items in the process of analysis is certainly a selection of appropriate model, i.e. constitutive relation for materials encountered in the face zone. Modern MKE softwares have implemented all basic patterns of geo materials. The operator should choose the appropriate model and to enter the suitable parameters for it. It includes the experimental testing of geo-mechanical characteristics of materials in the laboratory and field. This work has great impact (often the most important) on the validity of analysis.

Anisotropy: Most rock materials (sedimentary and metamorphic rocks) show the anisotropic behavior. In some cases the materials behave orthotropic (3 principal axis of anisotropy) or have a transverse anisotropy, i.e. isotropy in the plane. In this case, the numerical modeling is necessary to know the directions main axis and corresponding number of material parameters for each axis.

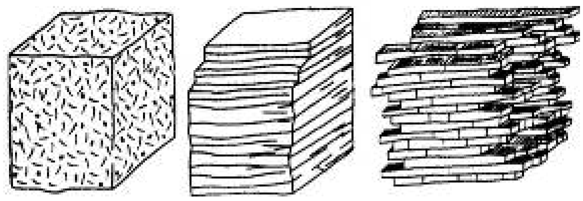


Figure 15. *Isotropy, flat anisotropy, orthotropy*

Modern softwares (Abaqus, Adina, Ansys, Flac,...) havet he implemented elastic and in the recent versions some inelastic anisotropic material models.

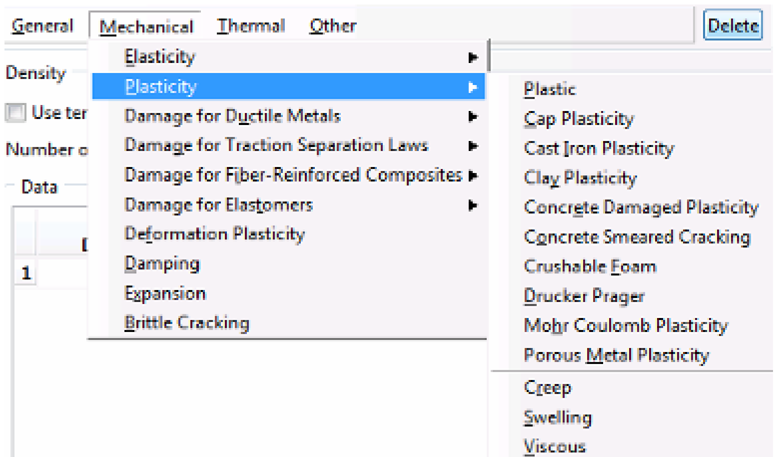


Figure 16. *Basic material models implemented in the commercial program Abaqus*

Plasticity: Stress-deformation analysis, due to the nonlinearity, is developed in small increments of load increase (gravity loads) and exclusion of elements from the network, i. e. “dying of elements” what simulates stoping. After each increment, the stresses are counted in all integration points and then compared with the same criterion of plasticity, depending on the adopted material model. Possible cases are the following:

$f(\sigma_{ij}, Y) < 0$ - elastic behavior

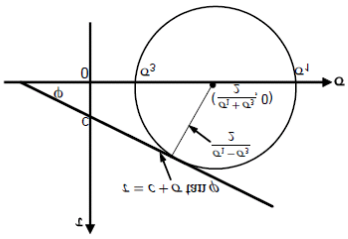
$f(\sigma_{ij}, Y) = 0$ - at the limit of sliding surface

$f(\sigma_{ij}, Y) > 0$ - plastification,

unauthorized area

If the item is discovered that leads to plastic flow, the stresses are reordered in the iterative procedure until the voltage balance is attained. Then it moves to a new increment.

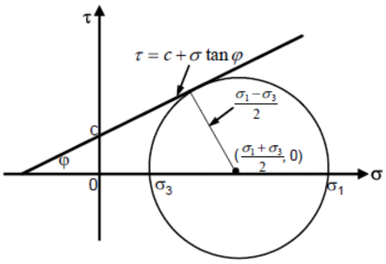
The basic models of elastic-plastic material behavior in the zone of wide face are: MC (Mohr-Coulomb), MCSS, Drucker-Prager, Drucker – Prager - Cap, Cam - Clay. Depending on the conditions in the field, it is possible that user could implement its own model using the user material option given in the leading program.



$$\sigma_1 > \sigma_2 > \sigma_3$$
$$f = \sigma_1 - \sigma_3 + (\sigma_1 + \sigma_3)\sin\phi - 2c\cos\phi$$
$$\sigma_1 \frac{1+\sin\phi}{2c\cos\phi} - \sigma_3 \frac{1-\sin\phi}{2c\cos\phi} = 1$$

c = cohesion

ϕ = angle of internal friction



$$\sigma_1 > \sigma_2 > \sigma_3$$
$$f = \sigma_1 - \sigma_3 + (\sigma_1 + \sigma_3)\sin\phi - 2c\cos\phi$$
$$\sigma_1 \frac{1+\sin\phi}{2c\cos\phi} - \sigma_3 \frac{1-\sin\phi}{2c\cos\phi} = 1$$

c = cohesion

ϕ = angle of internal friction

Figure 17. *MC and DP-Cap models of plasticity*

2.3.2. Material models for description the behavior of coal seam

Previous experiences have shown that the deformation behavior of coal seam can be adequately described by the MCSS material, the advanced version of the classical Mohr-Coulomb model that allows taking into account the weakening of material after reaching the appropriate stress level that leads to the plastic deformation (Strain-Softening). Figure 18 shows the numerically simulated triaxial tests with conventional MC and advanced MCSS model for the same parameters that are coincided well with the experimental tests on samples.

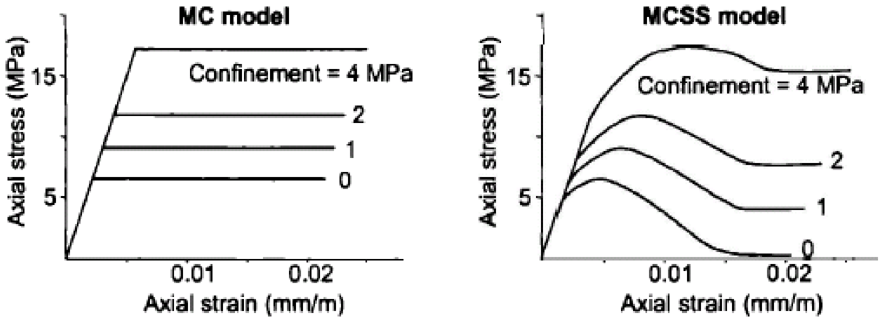


Figure 18. *Model MCSS for modeling the behavior of coal seam*

3. DEM (DISCRETE ELEMENT METHOD)

Discrete element method is a numerical method used to calculate stresses and strains in media that consist of a large number of individual particles, pieces or grains. Such (granulated) material is modeled as a set of rigid particles of random shape with pre-defined contact interactions between them. The shape and characteristics of particles are defined by the user himself depending on the types of problems. Sphere, regular polygonal or ellipsoidal shapes are the most commonly used.

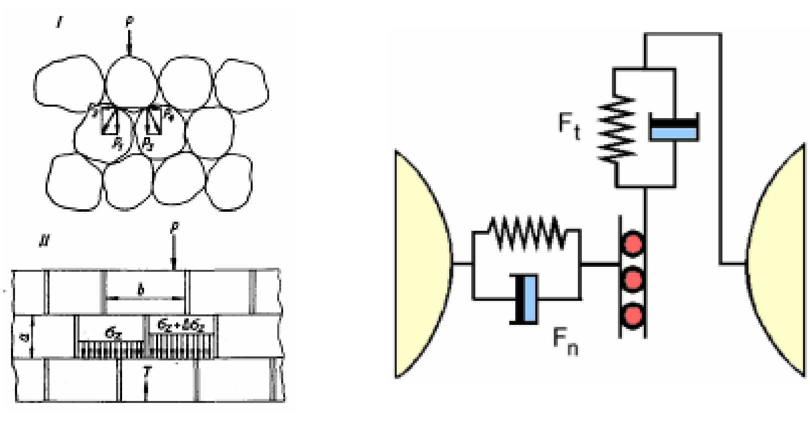


Figure 19. *DEM method, discretization (a) and contact model (b*

Normal and tangential contact force, the force of gravity, thrust fluid, the force of cohesion, chemical bonding and other interactions can be transferred between the particles. The main problem in numerical terms is the effective detection of all possible contacts of all particles participating in the model. This requires large computing resources. Differential equation which defines the movement of each discrete (distinctive) element is given by

$$M\ddot{U} + C\dot{U} + KU = F_{EXT}$$

where M, C and K system matrices of mass, damping and stiffness respectively and F_{ext} vector of external forces, the resultant on discrete element.

The above matrix equation is a system of equations which have as the total degrees of freedom in the domain. Hub time and computer resources, however, not compared to the solution of this system of equations, but the detection and monitoring of contact interaction between all elements. Generally considered as discrete elements, however, has a solid performance in which the individual elements are deformable. DEM is a newer but rapidly developing method with the growing up use in the field of rock mechanics. It is worth to mention UDEC and 3DEC commercial codes, developed by Itasca Co., based on this method, the same manufacturer as the Flac3D. 3DEC program is particularly suitable for dynamic analysis of blasting problems in the underground mines.

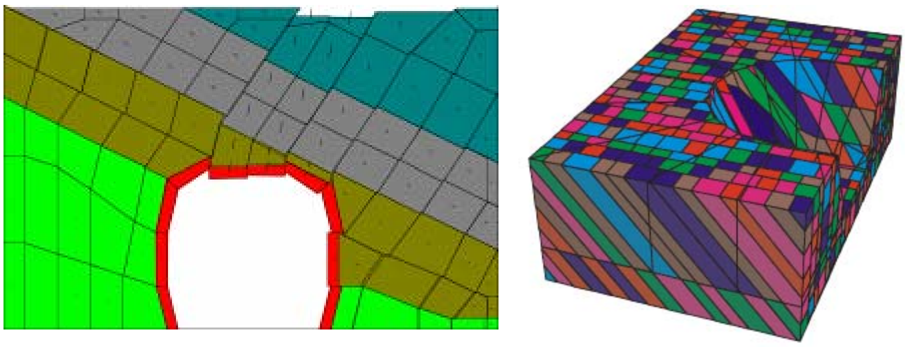


Figure 20. *DEM – example of 2D and 3D models*

4. HYBRID METHODS

Practice has shown that combining of some the above methods can take advantage and reduce disadvantages of other methods. The results of this are the hybrid methods of analysis that include the following combinations: FEM/BEM, DEM/FEM and DEM/BEM. This concept is often used in the stress analysis of wide face and classical methods of mining. The first of these (FEM / BEM) is commonly used in the case of large domains in which there are places which are singularities (small and irregular openings or cracks). In this case, the stress field far enough from the singularity (linear elastic state) is obtained by BEM method while the discretization domain and analysis in the critical area (non-linear analysis) is done using MKE provided that already obtained BEM results, in the form of border conditions, are transferred to a smaller part of domain This reduces the analysis time and simplified modeling with possibly small loss of accuracy.

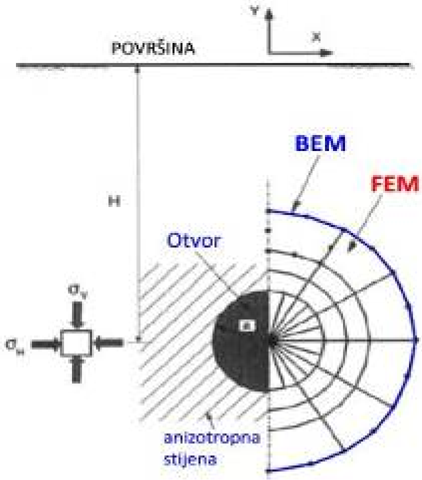


Figure 21. *Hybrid BEM-FEM method*

5. CONCLUSION

Determination of the stress-deformation state in the zone of mining activities in underground mining is a complex task. Addressing the same size requires knowledge of all components of rock massif stress. Assuming that the underground mining is done in an ideal elastic and homogeneous environment, it is possible to analytically determine the stress distribution for the rooms simple geometry. Unfortunately, in practical terms, the analytical determination of stresses in rock massif of the limited resources is unreliable or impossible. Experimental measurement of stress is the next option. The same is characterized by the results reliability, but requires expensive equipment, specialized personnel and often interferes the production process. Also, in the design stage it is not possible to have measurement data on groundwater pressures because the room does not yet exist. Therefore, as the perspective are imposed the numerical simulation methods, alone or in combination with the above. Presented methods give satisfactory results with proper preparation and interpretation of model results. Out of them, MKE is especially distinctive, now the main method for analyzing in geomechanical problems, which include the stress-deformation analysis of the wide face mining method. MKE allows obtaining reliable information on stress distribution if the environment in which the developed process can be considered as a continuum, and if all items that make up the analysis are carried out properly. If the domain (work place) is fragmented but in a form that mean shape and size and arrangement of the fragments can be estimated, it with appropriate conditions, using DEM method can give the results that provide insight and evaluation of deformation process. The above methods were verified in numerous examples and their wide application in the world with a growing number of applications and theoretical models are the surest indicators of the feasibility of use the same in the problems in underground mining.

6. REFERENCES

[1] S. Helwany: Applied Soil Mechanics", John Wiley & Sons Ltd, 2006

[2] A. Bobet: „Numerical Methods in Geomechanics“, The Arabian Journal for Science and Engineering, Volume 35, Number 1B, 2010

[3] L. Jing and J. A. Hudson, "Numerical Methods in Rock Mechanics", International Journal of Rock Mechanics and Mining Sciences, 39(2002), pp. 409–427

[4] L. Jing, "A Review of Techniques, Advances and Outstanding Issues in Numerical Modeling for Rock Mechanics, and Rock Engineering", International Journal of Rock Mechanics and Mining Sciences, 40(2003), pp. 283–353

[5] A. A. Borisov, "Calculation of the Underground Pressure“, Tuzla, 1970 (in Serbian)

[6] B. H. G. Brady, "Boundary Element and Linked Methods for Underground Excavation", in Analytical and Computational Methods in Engineering Rock Mechanics. Ed. E.T. Brown, London, England: Allen & Unwin, 1987, pp. 164–204

[7] G. N. Pande, G. Beer, and J. R. Williams, Numerical Methods in Rock Mechanics. West Sussex, England: John Wiley & Sons, Ltd., 1990

[8] M. Stević, "Soil and Rock Mechanics“, Mining and Geology Faculty Tuzla, 1991 (in Serbian)

[9] Memić M., Hadžić E., Karadžin Z., "Modern Theories and Calculations of the Underground Pressures", Mining Institute in Tuzla, 2006 (in Serbian)

[10] S. L. Crouch and A. M. Starfield, Boundary Element Methods in Solid Mechanics, London, England: Allen and Unwin, 1983

[11] J. P. CARTER AND B. XIAO: "A 2d Coupled Finite Element and Boundary Element Scheme to Simulate the Elastic Behaviour of Jointed Rocks“, International Journal for Numerical and Analytical Methods in Geomechanics, Vol. 18, 49-71 1994)

[12] P. A. Cundall and O. D. L. Strack, "A Discrete Numerical Model for Granular Assemblies", Geotechnique, 29(1), 1979, pp. 47–65

[13] R. Hart, P. A. Cundall, and J. Lemos, "Formulation of a Three-Dimensional Distinct Element Model-Part II. Mechanical Calculations for Motion and Interaction of a System Composed of Many Polyhedral Blocks", International Journal of Rock Mechanics and Mining Sciences, 25(3), 1998

[14] M. Ljubojev, R. Popović, M. Avdić, L. Đ. Ignjatović, V. Ljubojev, Defining the legality of gray sandstone rock strength testing in a complex state of stress, TTEM Journal of society for development of teaching and business processes in new net environment in B&H, vol. 5, No. 3 2010, pp. 437-443

[15] R. Popović, M. Ljubojev, D. Ignjatović, V. Ljubojev, L. Đ. Ignjatović, Geomechanical laboratory conditions of rock fracture, TTEM Journal of society for development of teaching and business processes in new net environment in B&H, vol. 5, No. 3 2010, pp. 544-547

[16] M. Ljubojev, M. Avdić, V. Ljubojev, D. Ignjatović, L. Đ. Ignjatović, Observation of chenges and measurment of subsidence on the collector under the open pit „Bogutovo selo“ in Ugljevik, Rudarski radovi, No. 1/2010, pp. 25-31

UDK: 340.134:628.4(045)=861

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PREGLED AKTUELNOG DOMAĆEG ZAKONODAVSTVA IZ OBLASTI UPRAVLJANJA I DEPONOVANJA OTPADA

Izvod

Donošenjem Zakona o Upravljanju otpadom Republike Srbije 2009. godine ("Sl. glasnik RS", broj 36/09), stvoreni su neophodni preduslovi za uvođenje reda u predmetnoj oblasti. U radu je dat pregled aktuelne, domaće zakonske regulative iz oblasti upravljanja otpadom, ambalažom i ambalažnim otpadom. Takođe su hronološki prikazane sve aktivnosti koje je Republika Srbija sprovela u cilju usklađivanja domaćeg zakonodavstva sa zakonodavstvom Evropske Unije iz domena zaštite životne sredine i upravljanja otpadom, počevši od 2000. godine koji se smatra teoretskim početkom pridruživanja EU (kada je RS uključena u proces Stabilizacije i pridruživanja), preko 2004. godine koji se smatra praktičnim početkom pridruživanja EU (kada je u Narodnoj skupštini usvojena Rezolucija o pridruživanju Evropskoj Uniji), pa sve do 2008. godine kada je Narodna Skupština ratifikovala Sporazum o stabilizaciji i pridruživanju Republike Srbije EU.

***Ključne reči**: deponija, otpad, zakonodavstvo, pridruživanje EU*

UVOD

Usaglašavanje nacionalnog zakonodavstva sa pravnim tekovinama EU (acquis communautaire - je pravna tekovina EU koja sadrži pored osnivačkih ugovora i više od 20.000 propisa iz sekundarnog zakonodavstva i 4.000 sudskih presuda) je teoretski započeto 2000 godine, kada je Republika Srbija uključena u proces stabilizacije pridruživanja. Praktično je ovaj proces započet oktobra 2004. godine usvajanjem u Narodnoj skupštini Rezolucije o pridruživanju Evropskoj Uniji. Proces je dalje nastavljen septembra 2008. godine, kada je Republička Skupština ratifikovala Spora-zum o stabilizaciji i pridruživanju. U okto-bru 2008. godine Vlada RS je usvojila Nacionalni program za integraciju (NPI) Republike Srbije u Evropsku Uniju, kao strateški dokument koji objedinjuje sva dokumenta i akcione planove neophodne za proces evropskih integracija i definiše obaveze svih aktera za period do kraja 2012. godine.

Proces evropskih integracija sastoji se od tri ključna elementa:

- prenošenje zakonodavstva EU u nacionalno zakonodavstvo i njegova efikasna primena;
- uspostavljanje odgovarajućih administrativnih i institucionalnih kapaciteta na svim nivoima u cilju pravilnog prenošenja i primene propisa EU;
- obezbeđivanje finansijskih sredstava i ekonomskih instrumenata.

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Harmonizacija propisa je obiman i neodložan proces za državu koja pretenduje na članstvo u EU. Oblast životne sredine osim što je najobimnija u stalnom je razvoju, pa se shodno potrebi pravnog regulisanja ove oblasti obim EU propisa konstantno povećeva, što zahteva stalno praćenje razvoja EU zakonodavstva radi usaglašavanja sa domaćim propisima. U NPI dokumentu, ova oblast je podeljena na sledeća poglavlja: horizontalno zakonodavstvo, kvalitet vazduha i klimatske promene, upravljanje otpadom, zaštita i upravljanje vodama, zaštita prirode, hemikalije, kontrola industrijskog zagađenja i upravljanje rizikom, genetički modifikovani organizmi, zaštita od buke, šumarstvo i civilna zaštita. Iskustvo novih zemalja članica EU pokazuje da su najsloženiji delovi acquis-a neke od direktiva iz oblasti kvaliteta vazduha, voda, otpada i industrijskog zagađenja.

HRONOLOŠKI PREGLED DOSADAŠNJIH AKTIVNOSTI U VEZI SA UPRAVLJANJEM OTPADOM SA PRIKAZOM POSTOJEĆEG STANJA

U Republici Srbiji je do pre nekoliko godina, praktično jedini način upravljanja otpadom bio odlaganje na lokalne deponije, koje u najvećoj meri (izuzetak su samo nekoliko) ne zadovoljavaju ni osnovne higijenske i tehničko-tehničke uslove. Nacionalna strategija upravljanja otpadom usvojena 2003. godine, predstavlja osnovu za racionalno i održivo upravljanje otpadom, i u njoj su implementirani osnovni principi EU u oblasti upravljanja otpadom. Tokom 2005. godine u Agenciji za zaštitu životne sredine implementiran je projekat "Inoviranje katastra deponija u Republici Srbiji", prema kome su u našoj zemlji locirane 164 deponije koje koriste opštinska javno komunalna preduzeća za odlaganje otpada. Tokom 2009. godine, Sektor za kontrolu i nadzor Ministarstva je izvršio inventar divljih deponija na teritoriji R. Srbije, prema kome je evidentirana ukupno 4.500 divljih deponija. U najvećem broju divlje deponije se nalaze u seoskim sredinama, najčešće duž saobraćajnica u putnom pojasu (na kosinama i u nožici nasipa puteva gde je čišćenje veoma otežano), kao i na obalama vodotokova. U 2006. godini Agencija za zaštitu životne sredine je prikupljala i obrađivala podatke o količinama komunalnog otpada, kao i broj domaćinstva iz kojih se otpad organizovano sakuplja. Količine komunalnog otpada na godišnjem nivou su proračunate na osnovu merenja otpada u referentnim opštinama. Rezultati merenja ukazuju da gradsko stanovništvo prosečno dnevno generiše 1 kg komunalnog otpada po stanovniku na dan (u Beogradu je 1,2 kg/ stanovniku/dan), dok seosko stanovništvo prosečno generiše 0,7 kg otpada/stanovniku /dan, tako da prosečna količina komunalnog otpada po stanovniku u Republici Srbiji iznosi 0,87 kg/stanovniku/dan, odnosno 318 kg/godišnje. Procena je da se u R. Srbiji organizovano sakuplja oko 60% komunalnog otpada (u gradskim sredinama to negde prelazi i 80% dok u pojedinim seoskim sredinama procenat organizovanog sakupljanja ide i ispod 20%).

Što se organizacije upravljanja opasnim otpadom u Republici Srbiji tiče, ona je na niskom nivou i zahteva integralan pristup u svim fazama - od trenutka nastajanja, preko sakupljanja, transporta, tretmana do odlaganja. Postoje postrojenja za tretman pojedinih vrsta posebnih tokova otpada kao što su korišćeni akumulatori, elektronski i električni otpad, otpadna ulja i otpadna vozila. Ne postoje postrojenja za trajno skladištenje opasnog otpada, a privremeno odlaganje se uglavnom vrši u krugu preduzeća u kom je otpad proizveden, i to vrlo često na neadekvatan način.

U okviru projekta "Jačanje kapaciteta životne sredine 2003" (CARDS program) izvršena je procena štete prouzrokovane nepropisnim upravljanjem otpadom u R. Srbiji koja na godišnjem nivou iznosi između 98 i 276 miliona €, što je ekvivalentno 0,4 - 1,1% BDP-a. Isti projekat je obuhvatio i izradu Inventara otpada operatera koji podležu izdavanju integrisane dozvole u Republici Srbiji. U toku prve polovine 2008. godine formirana je baza podataka opasnih materija na lokacijama operatera, sačinjena na osnovu prikupljenih podataka od 400 operatera koji obavljaju delatnost sa opasnim materijama. Ova baza je tokom prve polovine 2009. godine proširena na ukupno 600 operatera.

Prema podacima Ministarstva za zaštitu životne sredine u 2007. godini proizvedeno je oko 5.200.000 t opasnog otpada, a u 2008. godini 5.700.000 t. Od ove ukupne količine više od 5.000.000 t otpada na lebdeći pepeo iz termoelektrana. Značajne količine opasanog otpada proizvode i operateri koji ne podležu izdavanju integrisane dozvole, i te količine nisu obuhvaćene prikazanim ukupnim količinama za prethodne 2 godine.

Usvajanjem Zakona o upravljanju otpadom i Zakona o ambalažnom otpadu ("Sl. glasnik RS", broj 36/09) obezbeđen je pravni okvir za uspostavljanje integralnog sistema upravljanja otpadom, odnosno ambalažom i ambalažnim otpadom. U narednom periodu treba očekivati završetak svih podzakonskih akata koji će u potpunosti urediti sistem upravljanja otpadom (razni pravilnici i uredbe).

Problem opasnog industrijskog otpada je u njegovom nepropisnom skladištenju koji nije u skladu sa zakonom, kao i nepostojanje sistemskog rešenja za taj problem. Delimično rešenje je izvoz opasnog otpada na trajno zbrinjavanje u drugim zemljama koji je zastupljen sa svega 6%. Republička vlada je u decembru 2008. usvojila Zaključak o izgradnji postrojenja za fizičko-hemijski tretman opasnog otpada, a u junu 2009. Zaključak o privremenom skladištenju opasnog otpada nepoznatog vlasnika. Izdvajanje komponenti koje se mogu reciklirati iz otpada je takođe uređeno zakonom. Razvojem reciklažne industrije u Srbiji uz podršku ministarstva stvaraju se uslovi za otvaranje novih radnih mesta u novoj industrijskoj grani.

Spaljivanje otpada u Srbiji uz energetsku valorizaciju u ovom trenutku ne postoji, jer ne postoje pogoni za insineraciju (spaljivanje) otpada. Deo otpada koje predstavljaju otpadne gume je počeo da se koristi kao energetski resurs/supstituenat u cementarama u Srbiji.

Poseban problem u Srbiji predstavlja takođe i medicinski otpad koji se godišnje generiše u količini od 48.000 t (bez privatnog sektora i sektora veterinarske medicine), od čega oko 20% predstavlja infektivni otpad, koji se jedino kontrolisanim spaljivanjem u autoklavima može adekvatno uništiti. Deo ovog otpada se zbrinjava na odgovarajući način spaljivanjem u 78 autoklava širom Republike Srbije ali je ovaj broj još uvek nedovoljan.

Osnovni uzroci neadekvatnog upravljanja otpadom u Republici Srbiji su:

- loša infrastruktura za tretman i odlaganje otpada; zajedničko odlagane komunalnog i opasnog otpada iz domaćinstava; nepostojanje organizovanog sistema sakupljanja, transporta i odlaganja otpada, posebno u seoskim sredinama; nedovoljni i ograničeni kapaciteti postrojenja za reciklažu otpada;
- nedostatak postrojenja za skladištenje, tretman i odlaganje opasnog otpada;
- nedovoljni kapaciteti za upravljanje nekim posebnim tokovima otpada (otpadne baterije i akumulatori, otpadna ulja, PCB, otpad i ambalaža pesticida, medicinski otpad, otpad iz klanica, elektronski i električni otpad, otpadne gume i vozila itd.);
- niske/neekonomske cene usluga sakupljanja i odlaganja komunalnog otpada;
- nedovoljna efikasnost javnih komunalnih preduzeća; nedostatak finansijskih sredstava; nizak nivo svesti javnosti u pogledu upravljanja otpadom;
- nepostojanje geoloških i hidrogeoloških podloga za mikrolokacije komunalnog i opasnog otpada; nedovoljno korišćenje geoekološkoh materijala u toku izgradnje deponija različitih tipova otpada i saniranje zagađenih površina.

Loše i neadekvatno upravljanje otpadom utiče na životnu sredinu kroz:

- zagađenje površinskih i podzemnih voda i zemljišta procednim vodama;
- zagađenje vazduha prouzrokovano nekontrolisanjem paljenjem otpada na smetlištima i u kontejnerima, posebno emisijom gasova polihlorovanih dibenzofurana i dioksina (PCDF/D);
- emisiju metana koja doprinosi stvaranju efekta staklene bašte;
- degradaciju prostora nepropisnim odlaganjem otpada.

PRIORITETNI CILJEVI ZAŠTITE ŽIVOTNE SREDINE, OBLAST UPRAVLJANJA OTPADOM

Iz domena upravljanja otpadom definisani su sledeći prioritetni ciljevi zaštite životne sredine: kratkoročni 2010-2014, srednjoročni 2015-2019 i kontinuirani ciljevi 2010-2019.

U kratkoročne ciljeve 2010-2014. godine spadaju sledeći ciljevi:

- usklađeni nacionalni propisi iz oblasti upravljanja otpadom sa EU zakonima;
- razvijeni regionalni i lokalni planovi upravljanja otpadom;
- povećan broj stanovnika buhvaćen sistemom sakupljanja otpada na 75%;
- uspostavljen nacionalni kapacitet za tretman opasnog otpada;
- unapređen sistem upravljanja posebnim tokovima otpada (otpadnim gumama, otpadnim uljima, otpadnim vozilima, otpadnim baterijamai akumulatorima);
- povećati stope ponovnog iskorišćenja i reciklaže ambalažnog otpada (staklo, papir/karton, metal, plastika i drvo) na 25% od njegove količine;
- izvršena detaljna geološka i hidrogeološka istraživanja za mikrolokacije komunalnog i opasnog otpada;
- razvijen informacioni sistem upravljanja otpadom;
- razvijen program upravljanja otpadom animalnog porekla.

U srednjoročne ciljeve 2015-2019. godine spadaju sledeći ciljevi:

- zbrinuti PCB otpad, otpad od napuštenih pesticida i ambalažni otpad od pesticida prema rešenjima iz operacionih planova;
- uvesti reciklažu pojedinih vrsta industrijskog otpada (jonska smola, mineralna vuna, pepeo itd.).

U kontinuirane ciljeve 2010-2019. godine spadaju sledeći ciljevi:

- uvođenje odvojenog sakupljanja i tretmana opasnog otpada iz domaćinstva i industrije;
- izgradnja regionalnih centara za upravljanje otpadom u svakom regionu prema tehničkim i operativnim zahtevima Direktive o deponijama 1999/31/EZ i odgovarajućom zakonskom regulativom;
- obezbediti kapacitete za spaljivanje organskog, industrijskog i medicinskog otpada;
- podsticati korišćenje otpada kao alternativnog goriva u cementarama, železarama i termoelektranama-toplanama, u skladu sa principom hijerarhije otpada;
- unapređenje efikasnosti uspostavljenih sistema za upravljanje posebnim tokovima otpada uz konstantno približavanje ciljevima koji su zadati EU zakonodavstvom;
- sanirati postojeća smetlišta i izvršiti remedijaciju istih, koja predstavljaju najveći rizik po životnu sredinu;
- jačanje profesionalnih i institucionalnih kapaciteta za upravljanje opasnim otpadom;
- uspostaviti sistem upravljanja građevinskim otpadom koji sadrži azbest;
- povećanje količina kompostiranog zelenog otpada.

SPISAK DOMAĆIH PROPISA IZ DOMENA UPRAVLJANJA OTPADOM, AMBALAŽOM I AMBALAŽNIM OTPADOM

Kada je u pitanju upravljanje otpadom ono je direktno definisano sa: jednim Zakonom, tri Uredbe i sedam Pravilnika. U pitanju su sledeći propisi Republike Srbije:

- Zakon o upravljanju otpadom ("Sl. glasnik RS" broj 36/09).
- Uredba o određivanju pojedinih vrsta opasnog otpada koje se mogu uvoziti kao sekundarne sirovine ("Sl. glasnik RS", broj 60/09).
- Uredba o listama otpada za prekogranično kretanje, sadržini i izgledu dokumenta koji prate prekogranično kretanje otpada sa uputstvima za njihovo popunjavanje ("Sl. glasnik RS", broj 60/09).
- Uredba o proizvodima koji posle upotrebe postaju posebni tokovi otpada, obrascu dnevne evidencije i količini i vrsti proizvedenih i uvezenih proizvoda i godišnjem izveštaju, načinu i rokovima dostavljanja godišnjeg izveštaja, obveznicima plaćanja naknada, kriterijumima za obračun, visinu i način obračunavanja i plaćanja naknade ("Sl. glasnik RS", broj 89/09).
- Pravilnik o kriterijumima za određivanje lokacije i uređenje deponija otpadnih materija ("Sl. glasnik RS", broj 54/92).
- Pravilnik o sadržini dokumentacije koja se podnosi uz zahtev za izdavanje dozvole za uvoz, izvoz i tranzit otpada ("Sl. glasnik RS", broj 60/09).
- Pravilnik o obrascu Dokumenta o kretanju opasnog otpada i uputstvu za njegovo popunjavanje ("Sl. glasnik RS", broj 72/09).
- Pravilnik o obrascu Dokumenta o kretanju otpada i uputstvu za njegovo popunjavanje ("Sl. glasnik RS", broj 72/09).
- Pravilnik o obrascu zahteva za izdavanje dozvole za skladištenje, tretman i odlaganje otpada ("Sl. glasnik RS", broj 72/09).
- Pravilnik o sadržini i izgledu dozvole za skladištenje, tretman i odlaganje otpada ("Sl. glasnik RS", broj 96/09).
- Pravilnik o načinu i postupku upravljanja otpadnim gumama ("Sl. glasnik RS", broj 104/09).

Kada je u pitanju ambalaža i ambalažni otpad ono je direktno definisano sa: jednim Zakonom, jednom Uredbom i osam Pravilnika. U pitanju su sledeći propisi Republike Srbije:

- Zakon o ambalaži i ambalažnom otpadu ("Sl. glasnik RS", broj 36/09).
- Uredba o ambalaži i ambalažnom otpadu ("Sl. glasnik RS", broj 36/09).
- Pravilnik o uslovima i načinu razvrstavanja, pakovanja i čuvanja sekundarnih sirovina ("Sl. glasnik RS", broj 55/01 i 72/09).
- Pravilnik o godišnjoj količini ambalažnog otpada po vrstama za koje se obavezno obezbeđuje prostor za preuzimanje, sakupljanje, razvrstavanje i privremeno skladištenje ("Sl. glasnik RS", broj 70/09).
- Pravilnik o kriterijumima za određivanje šta može biti ambalaža sa primerima za primenu kriterijuma i listi srpskih standarda koji se odnose na osnovne zahteve koje ambalaža mora da ispunjava ("Sl. glasnik RS", broj 70/09).
- Pravilnik o vrsti ambalaže sa dugim vekom trajanja ("Sl. glasnik RS", broj 70/09).
- Pravilnik o vrsti i godišnjoj količini ambalaže korišćene za upakovanu robu stavljenu u promet za koju proizvođač, uvoznik, paker/punilac i isporučilac nije dužan da obezbedi

upravljanje ambalažnim otpadom ("Sl. glasnik RS", broj 70/09).

- Pravilnik o načinu numerisanja, skraćenicama i simbolima na kojima se zasniva sistem identifikacije i označavanja ambalažnih materijala ("Sl. glasnik RS", broj 70/09).
- Pravilnik o graničnoj vrednosti ukupnog nivoa koncentracije olova, kadmijuma, žive i šestovalentnog hroma u ambalaži i njenim komponentama, izuzecima od primene i roku za primenu graničnih vrednosti ("Sl. glasnik RS", broj 70/09).
- Pravilnik o sadržini i načinu vođenja registra izdatih dozvola za upravljanje ambalažnim otpadom ("Sl. glasnik RS", broj 76/09).

Osim navedenih Zakona i podzakonskih akata koji se direktno odnose na upravljanje otpadom, ambalažom i ambalažnim otpadom postoje i drugi zakoni (sa pripadajućim podzakonskom aktima) koji u manjoj ili većoj meri imaju uticaja na navedenu oblast, i to su pre svega sledeći zakoni:

- Ustav Republike Srbije ("Sl. glasnik RS", broj 98/06).
- Zakon o zaštiti životne sredine ("Sl. glasnik RS", broj 135/04, 36/09, 72/09).
- Zakom o fondu za zaštitu životne sredine ("Sl. glasnik RS", broj 72/09).
- Zakon o zaštiti prirode ("Sl. glasnik RS", broj 36/09).
- Zakon o proceni uticaja na životnu sredinu ("Sl. glasnik RS", broj 135/04i 36/09).
- Zakon o strateškoj proceni uticaja na životnu sredinu ("Sl. gl. RS", broj 135/04).
- Zakon o integrisanom sprečavanju i kontroli zagađivanja životne sredine ("Sl. glasnik RS", broj 135/04).
- Zakon o hemikalijama ("Sl. glasnik RS", 36/09).
- Zakon o zaštiti vazduha ("Sl. glasnik RS", broj 36/09).
- Zakon o vodama ("Sl. glasnik RS", 46/91, 53/93, 67/93, 48/94, 54/96, i 101/05).
- Zakon o poljoprivrednom zemljištu ("Sl. glasnik RS", broj 62/06, 65/08, 41/09).
- Zakon o energetici ("Sl. glasnik RS", broj 84/04).
- Zakon o rudarstvu ("Sl. glasnik RS", broj 135/04).
- Zakon o planiranju i izgradnji ("Sl. glasnik RS", broj 72/09), kao i drugi zakoni.

ZAKLJUČAK

U radu su na jednostavan i razumljiv način, hronološki prikazane sve dosadašnje aktivnosti koje su u Republici Srbiji sprovedene, a tiču se u najvećoj meri upravljanju otpadom, kao i deponovanju različitih vrsta otpada na deponijama.

Takođe je dat i pregled svih propisa iz domena upravljanja otpadom, ambalažom i ambalažnim otpadom, uključujući kako zakone tako i sva podzakonska akta (važeće uredbe i pravilnici). Ovo je veoma bitno jer se po prvi put na jednom mestu mogu sagledati svi propisi, što je naročito bitno kako za stručnjake iz navedenih oblasti tako i za buduće istraživače, studente, komunalne i druge organizacije koje se bave sakupljnjem i odlaganjem otpada, NVO i drugi zainteresovani subjekti i pojedinci.

LITERATURA

[1] Zakon o zaštiti životne sredine ("Sl. glasnik RS", 135/04, 36/09).

[2] Zakon o Upravljanju otpadom ("Sl. glasnik RS", broj 36/09).

[3] Zakon o ambalaži i ambalažnom otpadu ("Sl. glasnik RS", broj 36/09).

[4] "Jačanje kapaciteta životne sredine 2003", CARDS program 2003.

[5] Nacionalna strategija upravljanja otpadom, usvojena 2003. godine.

[6] Nacionalna strategija održivog razvoja Republike Srbije, ratifikovana maja 2008.

[7] Nacionalni program zaštite životne sredine Republike Srbije za period 2010-2019.

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REVIEW OF CURRENT NATIONAL LEGISLATION IN THE FIELD OF WASTE MANAGEMENT AND DISPOSAL

Abstract

By passing the Law on Waste Management of the Republic of Serbia in 2009 ("Official Gazette RS", No. 36/09), the necessary preconditions for the introduction of order in the subject area were created. This paper gives an overview of current, domestic legal regulations for the waste management, packaging and packaging waste. The all conducted activities by the Republic of Serbia are also chronologically displayed in order to harmonize the domestic legislation with the European Union in the field of environmental protection and waste management, starting in 2000 that is considered as the theoretical beginning of EU accession (when the RS is included in the Stabilization and Association process), through 2004 that is considered as the practical beginning of EU accession (when the National Assembly adopted the Resolution on European Union) all by 2008 when the National Assembly ratified the Stabilization and Association Agreement of the Republic of Serbia to the EU.

Key words: *landfill, waste, legislation, association to the EU*

INTRODUCTION

Harmonization of the national legislation with the EU legislation regulates (acquis communautaire – is the legislation regulative which also includes, in addition to the founding treaties, more than 20,000 regulations from the secondary legislation and 4,000 court rulings) has theoretically started in 2000, when the Republic of Serbia is involved in the stabilization and association process.

Practically, this process began in October 2004 by adoption the Resolution on European Union in the National Assembly. Process is still continued in September 2008 when the Republican Parliament ratified the Stabilization and Association Agreement. In October 2008, the Government has adopted the National Program for Integration (NPI) of the Republic of Serbia into the European Union as the strategic document

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that brings together the all documents and action plans necessary for the process of European integrations and defines the responsibilities of all actors for the period until end of 2012.

The process of European integrations consists of three key elements:

- transposition of EU legislation into national legislation and its effective implementation;
- establishment of appropriate administrative and institutional capacities at all levels in order of correct transfer and application of EU regulations;
- providing the financial resources and economic instruments.

Harmonization of the regulations is a comprehensive and immediate process for a country that aspires to the EU membership. The area of environment in addition to being the most voluminous it is also constantly in development, so that under appropriate legal regulation of this area, the volume of EU legislation is constantly increased, what requires constant monitoring of development the EU legislation regarding to a comply with the national regulations. In the NPI document, this area is divided into the following chapters: horizontal legislation, air quality and climate changes, waste management, water protection and management, nature protection, chemicals, industrial pollution control and risk management, genetically modified organisms, noise protection, forestry and civil protection. The experience of new EU member states shows that the most complex parts of the acquis are some of directives in the field of air quality, water, waste and industrial pollution.

CHRONOLOGICAL REVIEW OF THE PREVIOUS ACTIVITIES RELATED TO THE WASTE MANAGEMENT WITH THE PRESENTATION OF EXISTING CONDITION

In the Republic of Serbia, a few years ago, practically the only way for waste management was disposal at the local landfills, which in most cases (exceptions are only a few) do not meet even the basic sanitary and technical-technical requirements. National Waste Management Strategy, adopted in 2003, presents the basis for rational and sustainable waste management, and it is implemented by the basic principles of EU in the field of waste management. In 2005, the project “Innovation of Cadastre of Landfills in the Republic of Serbia” was implemented in the Agency for Environmental Protection under which 164 landfills, used by the municipal public utilities for waste disposal, are located in our country .In 2009, the Department for control and supervision of the Ministry has carried out an inventory of illegal landfills in the territory of the Republic of Serbia, in which the total of 4500 illegal dumps was recorded. In the majority of illegal landfills are located in rural areas, mostly along the roads in the road area (on the slopes and foot embankment where the road is very difficult to clean), and on the banks of waterways.

In 2006, the Agency for Environmental Protection has collected and processed information on the quantities of municipal waste, and the number of households from which the waste is collected organized. The quantities of municipal waste per year are calculated based on the measurement of waste in relevant municipalities. The measurement results indicate that the urban residents generate a daily average of 1 kg municipal waste per capita per day (in Belgrade 1.2 kg/capita/day), while the rural population generates an average of 0.7 kg waste per capita per day, so that the average amount of municipal waste per capita in the Republic of Serbia is 0.87 kg/capita/day or 318 kg per year. It is estimated that in the Republic of Serbia about 60% of municipal waste (in urban areas it goes somewhere and 80%, while in some rural areas the percentage of organized collection goes below 20%) is from organized collection.

Regarding to the organization of hazardous waste management in Serbia, it is at low level and requires an integrated approach at all stages - from the moment of creation, through the collection, transport, treatment and disposal. There are plants for treatment the certain types of special waste streams such as used batteries, electronic and electrical waste, waste oil and waste vehicles. There are no facilities for permanent storage of hazardous waste, and a temporary storage is mainly done within the company in which the waste is generated, and very often by inadequate manner.

Within the project “Strengthening the Capacity of the Environment in 2003" (CARDS Program), the evaluation of damage was made, caused by improper waste management in the Republic of Serbia, which annually amounts between 98 and 276 million €, what is equivalent 0.4 to 1.1% of GDP. The same project also included making the Inventory of waste operators subjected to the issuing of integrated license in the Republic of Serbia. In the first half of 2008, the data base of hazardous substances at operator sites was made on the basis of collected data from 400 operators who perform activities involving dangerous substances. This data base was expanded to the total of 600 operators in the first half of 2009.

According to the data of the Ministry for Environmental Protection, around 5.2 million tons of hazardous waste was produced in 2007 and 5.7 million tons in 2008. From this total amount, more than 5 million tons of waste is the fly ash from power plants. Significant quantities of hazardous waste are also produced by the operators that are not subjected to the issuance of integrated license, and these amounts are not included in the total shown amounts for the last 2 years.

Adoption of the Law on Waste Management and the Law on Packaging Waste (“Official Gazette RS”, No. 36/09) has provided the legal framework for establishment the integrated waste management system, i.e. packaging and packaging waste. The next period we expect Completion of all by-laws that will completely regulate the waste management system (various rules and regulations) will be expected in the next period.

The problem of hazardous industrial waste is in its improper storage that does not comply with the law as well as the lack of a systemic solution to this problem. Partial solution is in export of hazardous waste for permanent disposal in other countries, which accounts for only 6%. The Republic Government has adopted in December 2008 the Conclusion on construction the facilities for physical-chemical treatment of hazardous wastes, and in June 2009, the Conclusion on temporary storage of hazardous waste of unknown owner. Separation of components that can be recycled from waste is also regulated by the law. Development of recycling industry in Serbia with the support of the ministry creates the conditions for opening the new job positions in the new industry.

Burning of waste with the energy evaluation does not exist at this moment, because there are no facilities for waste incineration (burning). A part of waste, presented by the waste tires, has begun to be used as energy resource/substitutes in the cement factories in Serbia.

Medical waste is also a special problem in Serbia that is generated annually in the amount of 48,000 t (without the private sector and the sector of veterinary medicine), out of which about 20% is the infectious waste, which can be properly destroyed by the controlled burning in autoclaves. Part of this waste is disposed properly by incineration in 78 autoclaves throughout the Republic of Serbia, but this number is still insufficient.

The main causes of inadequate waste management in Serbia are:

- poor infrastructure for waste treatment and disposal; the joint disposal of municipal and hazardous waste from households; the lack of organized system for waste collecting, transport and disposal particularly in the rural areas; the insufficient and limited capacities of the plant for waste recycling;
- lack of facilities for storage, treatment and disposal of hazardous waste;
- insufficient capacities for manage of some special waste streams (waste batteries and accumulators, waste oils, PCB, waste and packaging of pesticides, medical waste, waste from slaughterhouses, electronic and electrical waste, waste tires and vehicles, etc...);
- low/non-economic prices of services for collection and disposal of municipal waste;
- insufficient efficiency of the public utility services; the lack of financial resources; low level of public awareness regarding the waste management;
- lack of geological and hydro geological basis for the micro location of municipal and hazardous waste; the insufficient use of geoecological materials in the construction of various types of waste landfills and remediation of contaminated areas.

Poor and inadequate waste management affects the environment through:

- pollution of surface and ground water and soil by the leachate water;
- air pollution caused by the out-of-control burning of waste in garbage dumps and containers, especially by the gas emissions of polychlorinated dibenzofurans and dioxins (PCDF/D);
- methane emission that contribute to the creation of greenhouse effect;
- degradation of space by the improper waste disposal.

PRIORITY OBJECTIVES OF THE ENVIRONMENT PROTECTION, WASTE MANAGEMENT AREA

In the field of waste management, the following priority objectives of environmental protection are defined: the short-term 2010-2014, medium-term 2015-2019. and continuous objectives from 2010 to 2019.

The short-term objectives 2010-2014 include the followings:

- harmonized national regulations in the field of waste management with the EU legislation;
- developed regional and local waste management plans;
- increased number of inhabitants covered by the system of waste collection to 75%;
- established national capacity for hazardous waste treatment;
- improved management system of specific waste streams (waste tires, waste oil, waste vehicles, waste batteries and accumulators);
- increase the rate of re-utilization and recycling of packaging waste (glass, paper/cardboard, metal, plastic and wood) to 25% of its quantity;
- realized detailed geological and hydro geological studies for micro locations of municipal and hazardous waste;
- developed information system for waste management;
- developed program on waste management of animal origin.

The medium-term objectives 2015-2019 include the followings:

- disposed PCB waste, waste from the abandoned pesticides and pesticide packaging waste according to the solutions in operational plans;
- introduce recycling of certain types of industrial waste (ion resin, mineral wool, ash, etc.).

The continuous objectives include the followings:

- introduction the separate collection and treatment of hazardous waste from homes and industry;
- construction the regional waste management centers in each region based on technical and operational requirements of the Directive 1999/31/EC on the landfills and appropriate legislation;
- provide facilities for incineration of organic, industrial and medical waste;
- encourage the use of waste as alternative fuel in cement factories, steel mills and thermoelectric-power plants, in accordance with the principle of waste hierarchy;
- improving the efficiency of established systems for management of specific waste streams with a constant approximation to the objectives set in EU legislation;
- rehabilitation the existing dumpsites and remediation the same ones, that pose the biggest risk to the environment;
- strengthening the professional and institutional capacities for management of hazardous waste;
- establishment the management system of construction waste containing asbestos;
- increasing the amounts of composted green waste.

LIST OF NATIONAL REGULATIONS IN THE AREA OF MANAGEMENT THE WASTE, PACKAGING AND PACKAGING WASTE

When the waste management is in question, it is directly defined by: 1 Law, 3 Regulations and 7 Rulebooks. Those are the following regulations of the Republic of Serbia:

- Law on waste management ("Official Gazette RS", No. 36/09).
- Regulation on determining the certain types of hazardous waste that can be imported as secondary raw materials ("Official Gazette RS", No. 60/09).

- Regulation on waste lists for trans-boundary movement, the content and format of document accompanying the trans-boundary movement of waste containing the instructions for their filling ("Official Gazette RS", No. 60/09).
- Regulation on products that after use become more specific waste streams, the form of daily records and the quantity and types of manufactured and imported products and annual report, the methods and timeframe for submission of annual reports, taxpayers of the fees, criteria for calculation, the amount and method of calculation and payment of compensation ("Official Gazette RS", No. 89/09).
- Rulebook on criteria for determining the location and arrangement of waste landfills ("Official Gazette RS", No. 54/92).
- Rulebook on content of documents to be submitted with the application for issuing the permit for import, export and transit of waste ("Official Gazette RS", No. 60/09).
- Rulebook on the form of document of movement the hazardous waste and instructions for its filling ("Official Gazette RS", No. 72/09).
- Rulebook on the form of application for issuing the permit for waste storage, treatment and disposal ("Official Gazette RS", No. 72/09).
- Rulebook on content and appearance of permit for waste storage, treatment and disposal ("Official Gazette RS", No. 96/09).
- Rulebook on the way and procedure for waste tire management ("Official Gazette RS", No. 104/09).

When the packaging and waste packaging are in a question, that is directly defined by: 1 Law, 1 Regulation and 8 Rulebooks. Those are the following regulations of the Republic of Serbia:

- Law on Packaging and Packaging Waste ("Official Gazette RS", No. 36/09).
- Regulation on Packaging and Packaging Waste ("Official Gazette RS", No. 36/09).
- Rulebook on conditions and way of classification, packaging and storage of raw materials ("Official Gazette RS", Nos. 55/01 and 72/09).
- Rulebook on the annual amount of packaging waste by categories with necessary providing the space for taking, collecting, sorting and temporary storage ("Official Gazette RS", No. 70/09).
- Rulebook on criteria for determining what may be the packaging with examples for criteria usage and the list of Serbian standards relating to the basic requirements that packaging must meet ("Official Gazette RS", No. 70/09).
- Rulebook on the type of packaging material with high durability ("Official Gazette RS", No. 70/09).
- Rulebook on the type and annual amount of packaging used for packaged goods placed on the market for which the manufacturer, importer, packer/filler and supplier is not obliged to provide the management of packaging waste ("Official Gazette RS", No. 70/09).
- Rulebook on numbering, abbreviations and symbols on which the system of identification and marking of packaging materials is based ("Official Gazette RS", No. 70/09).

- Rulebook on the limit value the total concentration levels of lead, cadmium, mercury and hexavalent chromium in packaging and its components, exceptions to the use and the deadline for usage the limit values ("Official Gazette RS", No. 70/09).
- Rulebook on content and way of keeping the register of issued permits for management of packaging waste ("Official Gazette RS", No. 76/09).

In addition to the above laws and by-law deeds that are directly related to waste management, packaging and packaging waste, there are also other laws (with associated by-law deeds) that a greater or lesser extent have the influence on specified area, and these are primarily the following laws:

- Constitution of the Republic of Serbia ("Official Gazette RS", No. 98/06).
- Law on Environmental Protection ("Official Gazette RS", Nos. 135/04, 36/09, 72/09).
- Law on Fund for Environmental Protection ("Official Gazette RS", No. 72/09).
- Law on Nature Protection ("Official Gazette RS", No. 36/09).
- Law on Impact Assessment on Environment ("Official Gazette RS", Nos. 135/04 and 36/09).
- Law on Strategic Environmental Impact ("Official Gazette RS", No. 135/04).
- Law on Integrated Prevention and Control of Environmental Pollution ("Official Gazette RS", No. 135/04).
- Law on Chemicals ("Official Gazette RS", No. 36/09).
- Law on Air Protection ("Official Gazette RS", No. 36/09).
- Law on Water ("Official Gazette RS", Nos. 46/91, 53/93, 67/93, 48/94, 54/96, and 101/05).
- Law on Agricultural Land ("Official Gazette RS", Nos. 62/06, 65/08, 41/09).
- Energy Law ("Official Gazette RS", No. 84/04).
- Mining Law ("Official Gazette RS", No. 135/04).
- Law on Planning and Construction ("Official Gazette RS", No. 72/09), and other laws.

CONCLUSION

This paper presents chronologically all current activities by a simple and understandable way, realized in the Republic of Serbia with a concern in most cases to the waste management as well as dumping of various types of waste on landfills.

A review of all regulations in the field of waste management, packaging and packaging waste was also given including both the laws and by-law deeds (applicable statutes and regulations).

This is very important because for the first time all rules can be looked in one place, what is particularly important both for professionals in these areas and for future researchers, students, community and other organizations dealing with waste collecting and disposal, NGO and other interested entities and individuals.

REFERENCES

[1] Law on Environmental Protection ("Official Gazette RS", Nos. 135/04, 36/09).

[2] Law on Waste Management ("Official Gazette RS", No. 36/09).

[3] Law on Packaging and Packaging Waste ("Official Gazette RS", No. 36/09).

[4] "Strengthening of the Environment Capacity 2003", CARDS Program 2003.

[5] National Waste Management Strategy, adopted in 2003.

[6] National Sustainable Development Strategy of the Republic of Serbia, ratified May 2008.

[7] National Environmental Strategy of the Republic of Serbia for the period 2010-2019.

INSTITUT ZA RUDARSTVO I METALURGIJU BOR — YU ISSN: 1451-0162
KOMITET ZA PODZEMNU EKSPLOATACIJU MINERALNIH SIROVINA — UDK: 622

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DEFORMABILNOST I NOSIVOST NASUTOG MATERIJALA U NEPOSREDNOJ BLIZINI OTVORA OKNA NA P. K. "ZAGRAĐE" – KOP - 2

Izvod

Ovaj rad je proistekao iz proučavanja deformabilnosti i nosivosti tla na području neposredno pored postojećeg gornjeg otvora okna na P.K. „Zagrađe“ kop 2. Rezultati merenja su prikazani grafički i tabelarno.

Ključne reči: *Modul stišljivosti nasutog materijala, sleganje merne tačke, tangentni modul stišljivosti*

UVOD

Zbog neophodnosti poznavanja podatka o nosivosti tla na području neposredno pored postojećeg gornjeg otvora okna na površinskom kopu „Zagrađe“ kop 2, radi proračuna zaštitne rešetke otvora, izvršena su detaljna merenja deformabilnosti i nosivosti tla nasutog materijala. Izgled nasutog materijala prikazan je na slici broj 1. Merenja su izvršena na četiri karakteristične tačke.

Sl.1. *Dubina nasutog sloja*

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Modul stišljivosti nasutog materijala predstavlja meru sleganja ispitivanog materijala "in situ". Prema standardu modul stišljivosti se određuje opterećenjem ispitivane podloge postepeno rastućim pritiskom posredstvom kružne ploče tačno utvrđenih dimenzija. Za određivanje modula stišljivosti neophodna je sledeća oprema (slika 2):

- hidraulični cilindar sa manometrom za očitavanje pritiska,
- tri komparatera sa područjem merenja preko 10 [mm] i tačnosti od 0,01 [mm],
- stabilan držač komparatera, čiji su oslonci udaljeni minimum 1,5 [m] od kružne ploče,
- čelična kružna ploča prečnika 29,86 [cm].

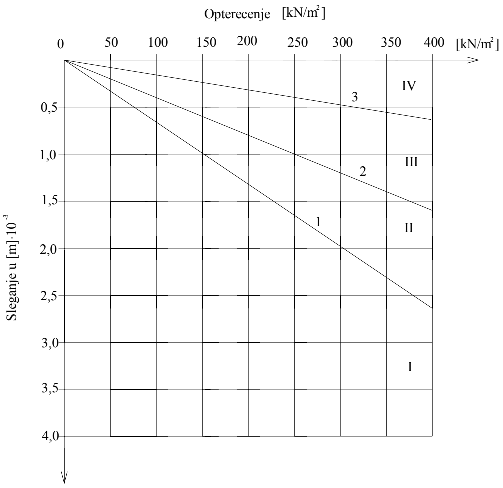
Sl.2. *Izgled kružne ploče sa pratećim priborom*

Rezultati ispitivanja se predstavljaju grafički dijagramom u kome se na apscisi nanosi opterećenje ploče "P" [kN/m^2], a na ordinati sleganje podloge s [mm] (Slika 3.) i brojčano, izračunavanjem modula stišljivosti po obrascu:

$$M_s = \frac{\Delta P}{\Delta s} \cdot d \qquad \left[kN/m^2\right],$$

gde je:

- ΔP, razlika dva opterećenja [kN/m^2],
- Δs, odgovarajuća razlika sleganja
- d, prečnik kružne ploče.



Sl. 3. *Granične linije sleganja*

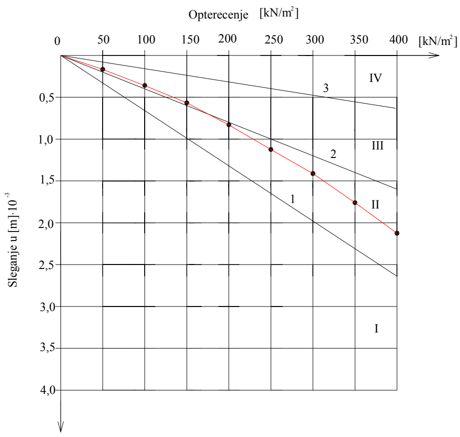
Na dijagramu slike. 3. granične linije sleganja dele dijagram na četiri zone:

- *Zona I*, ispod linije 1, pripada tlu nedovoljne nosivosti,
- *Zona II*, između linija 1 i 2, pripada tlu dovoljne nosivosti,
- *Zona III*, između linija 2 i 3, pripada donjem nosećem sloju dovoljne nosivosti,
- *Zona IV*, iznad linije 3, pripada gornjem nosećem sloju dovoljne nosivosti.

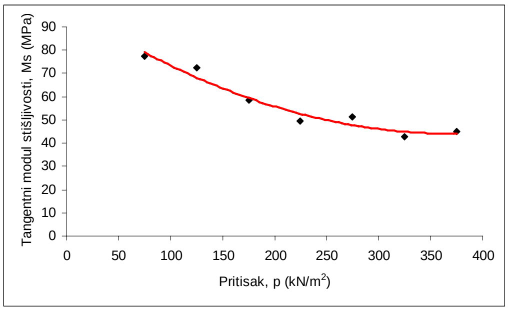
REZULTATI ISPITIVANJA PARAMETARA DEFORMABILNOSTI

Rezultati parametara deformabilnosti tačke 1.

Sl. 4. *Kružna ploča na tački 1.*



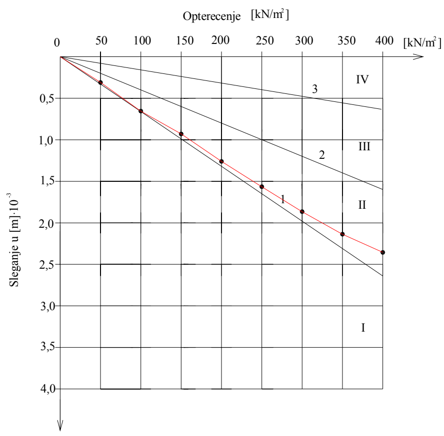
Sl. 5. *Sleganje tačke 1*



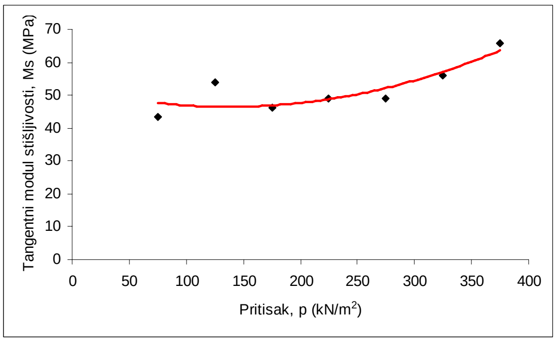
Sl. 6. *Odnos tangetnog modula stišljivosti i pritiska, tačka 1*

Rezultati deformabilnosti tačke 2.

Sl. 7. *Kružna ploča na tački 2.*



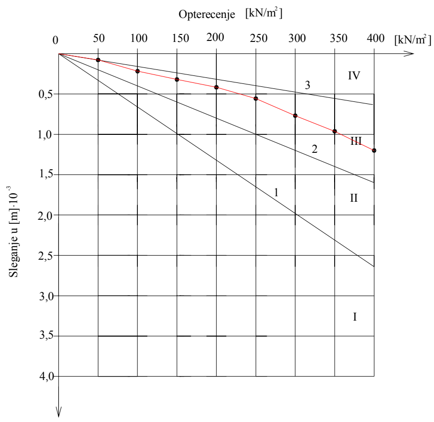
Sl. 8. *Sleganje tačke 2*



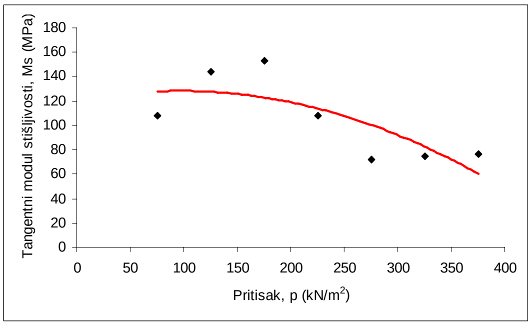
Sl. 9. *Odnos tangetnog modula stisljivosti i pritiska, tačka 2*

Rezultati deformabilnosti tačke 3.

Sl. 10. *Kružna ploča na tački 3.*



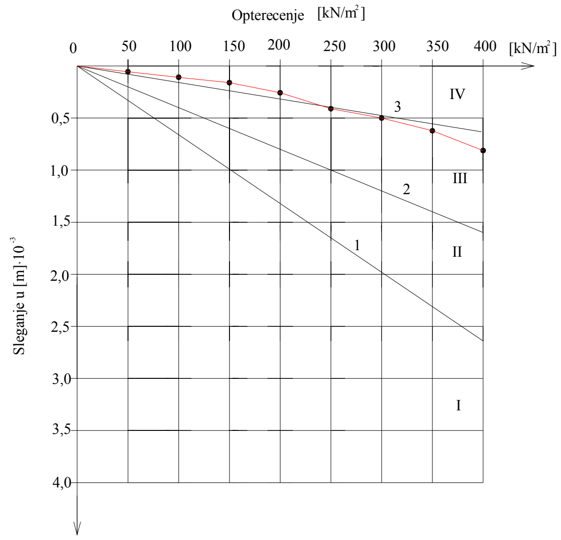
Sl. 11. *Sleganje tačke 3*



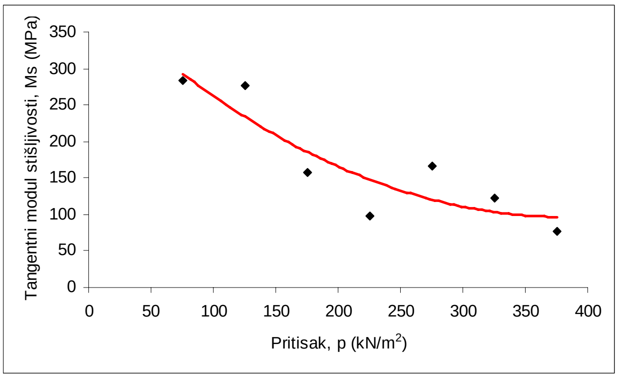
Sl. 12. *Odnos tangetnog modula stisljivosti i pritiska, tačka 3*

Rezultati parametara deformabilnosti tačke 4.

Sl. 13. *Kružna ploča na tački 4.*



Sl. 14. *Sleganje tačke 4*



Sl. 15. *Odnos tangetnog modula stisljivosti i pritiska, tačka 4*

NOSIVOST NASUTOG MATERIJALA

Suština projektovanja i analiza temelja zavisi od nosivosti materijala temeljnog dna. U ovom slučaju pod navedenim pojmom nosivost materijala se podrazumeva čvrstoća materijala ispod temeljnog dna koja se suprotstavlja lomu usled smičućih napona.

Za temeljnu stopu u obliku trake, Terzaghi-ev obrazac za izračunavanje granične nosivosti ima sledeći oblik:

$$q_f = c \cdot N_c + \gamma_1 \cdot h \cdot N_q + 0{,}5 \cdot \gamma_2 \cdot B \cdot N_\gamma$$

c = 0, - kohezija nasutog krečnjačkog materijala

$Nc, Nq, N\gamma$, - faktori nosivosti i zavise od ugla unutrašnjeg trenja

$Nq = 40; N\gamma = 40$

$h = 0,35$ i $0,5$ $[m]$ – dubina temeljenja

$\gamma_1 = 16,68$ $[kN/m^3]$ – zapreminska težina nasutog materijala

$\gamma_2 = 16,68$ $[kN/m^3]$ – zapreminska težina ispod temeljnog dna

$B = 0,5$ $[m]$ – širina temelja

Tabela 1.

Dubina temelja [m]	Širina temelja [m]	Granična nosivost temeljnog materijala $[kN/m^3]$
0,35	0,35	350,28
0,50	0,35	450,36
0,50	0,50	500,40

ZAKLJUČAK

Izračunata granična nosivost je prikazana u tabeli 1. i kreće se od 350,28 do 500,40 $[kN/m^3]$ u zavisnosti od dubine temeljenja i njihove širine.

Na osnovu dobijenih rezultata granične nosivosti temeljnog materijala, može se zaključiti da je potrebno izvršiti dodatno sabijanje terena, kako bi se ujednačila i povećala zbijenost.

LITERATURA

[1] Izveštaj o deformabilnosti i nosivosti nasutog materijala u neposrednoj blizini otvora okna na P.K. "Zagrađe" Kop-2, Bor, Oktobar 2008. Godine

[2] M. Ljubojev, M. Avdić, V. Ljubojev, D. Ignjatović, L. Đ. Ignjatović, Opažanje promena I merenje sleganja na kolektoru VZO P.K. "Bogutovo selo" u Ugljeviku, Rudarski radovi, 1/2010, str. 25-36

[3] M. Ljubojev, M. Avdić, D. Ignjatović, L. Đ. Ignjatović, Uticaj flotacijskog jalovišta polja 2 na stabilnost tunela Kriveljske reke, Rudarski radovi, 2/2009, str. 21-28

[4] M. Ljubojev, R. Popović, Osnove geomehanike, RTB Bor, Institut za bakar Bor, 2006.

[5] R. Popović, M. Ljubojev, Principi rešavanja problema u geomehanici, RTB Bor, Institut za bakar, Indok centar, 2007.

[6] M. Ljubojev, M. Avdić, M. Bugarin, R. Popović, i D. Ignjatović, Tunnel analysis in fault zones and the effects of stress distribution on the support, Journal of mining and metallurgy, section A, 1, 2009, str. 49-57

[7] M. Ljubojev, M. Ivković, J. Miljanović i L. Đurđevac. Ignjatović, Testing of geomechanical properties of coal series in order for support determination of the mechanized stope on the example of „stara jama“ mine in „Lubnica“, Journal of mining and metallurgy, section A, 1, 2009, str. 58-70

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Dragoslav Rakić[**]

DEFORMATION AND BEARING CAPACITY OF BURRIED MATERIAL NEAR THE SHAFT OPENING AT THE OPEN PIT MINE ”ZAGRADJE”-OPEN PIT 2

Abstract

This paper is the result of study the deformation and bearing capacity of soil in the area near the existing upper opening of shaft at the the open pit mine “Zagradje” open pit 2. The results of measurement are presented graphically and in tables.
Key words: *compressibility module, buried material, subsidence of measuring point, tangent module of compressibility*

INTRODUCTION

Due to the necessity of knowing the data on soil bearing capacity in the area near the existing upper opening of shaft at the the open pit mine „Zagradje" open pit 2, due to calculate the protective grid of openings, detailed measurements of deformation and bearing capacity of the buried material were carried out. The view of buried material is shown in Figure 1. Measurements were carried out at four characteristic points.

Figure 1. *Depth of buried layer*

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Module of compressibility of buried material is a measure of subsidence the tested material "in situ". According to the standard, the module of compressibility is determined by the load of tested surface gradually by increasing pressure through a circular plate of accurate defined sizes. To determine the module of compressibility, the following equipment is required (Figure 2):

- hydraulic cylinder with pressure gauge for pressure reading,
- three comparators with the measuring range more than 10 [mm] and accuracy of 0.01 [mm],
- stable holder of comparator with supports at distance minimum 1.5 [m] from circular plate
- steel circular plate with diameter 29.86 [mm].

Figure 2. *View of circular plate with accessories*

Test results are presented graphically by diagram where the load of plate, "P" [kN/m^2], is applied on the abscissa, and the base subsidence, s [mm] (Figure3), and numerically, by calculating the compressibility module per pattern:

$$M_s = \frac{\Delta P}{\Delta s} \cdot d \qquad \left[kN/m^2 \right],$$

where:

- ΔP, difference of two loads [kN/m^2],
- Δs, suitable difference of subsidence.
- d, diameter of circular plate

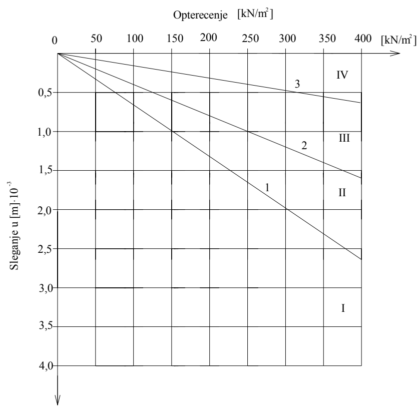

Figure 3. *Boundary lines of subsidence*

In diagram in Figure 3, the limit lines of subsidence divide diagram into four zones:

- *Zone I,* below the line 1, belongs to the ground of insufficient bearing capacity,
- *Zone II,* between the lines 1 and 2, belongs to the ground of sufficient capacity,
- *Zone III,* between lines 2 and 3, belongs to the lower carrying layer of sufficient capacity,
- *Zone IV,* above the line 3, belongs to the upper carrying layer of sufficient capacity.

TEST RESULTS OF DEFORMATION PARAMETERS

The results of deformation parameters of point 1:

Figure 4. *Circular plate at point 1*

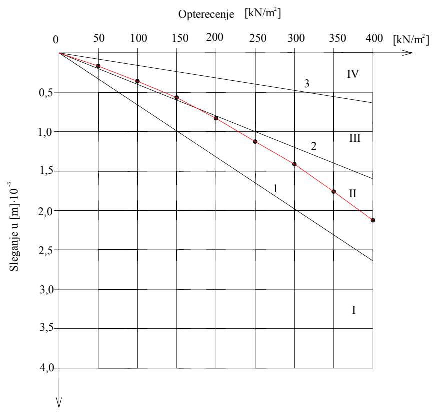

Figure 5. *Subsidence of point 1*

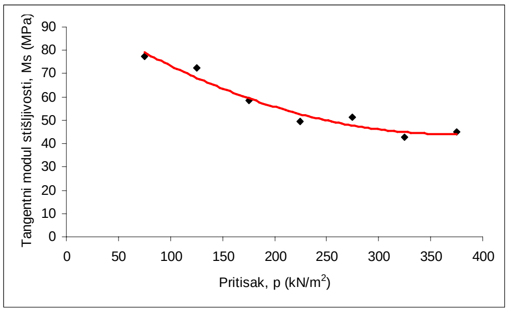

Figure 6. *Ratio of tangential module of compressibility and pressure, point 1*

The results of deformation parameters of point 2:

Figure 7. *Circular plate at point 2*

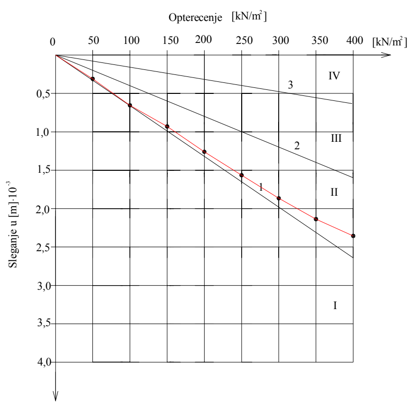

Figure 8. *Subsidence of point 2*

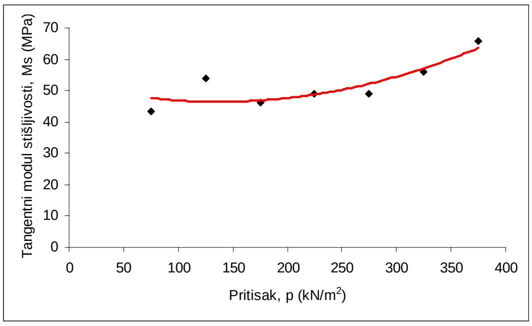

Figure 9. *Ratio of tangential module of compressibility and pressure, point 2*

The results of deformation parameters of point 3:

Figure 10. *Circular plate at point 3*

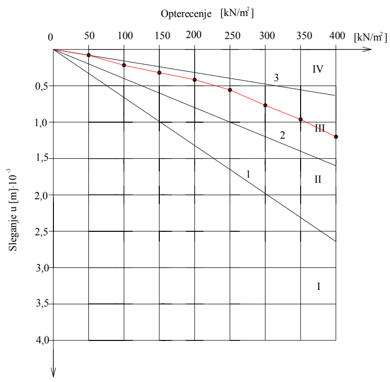

Figure 11. *Subsidence of point 3*

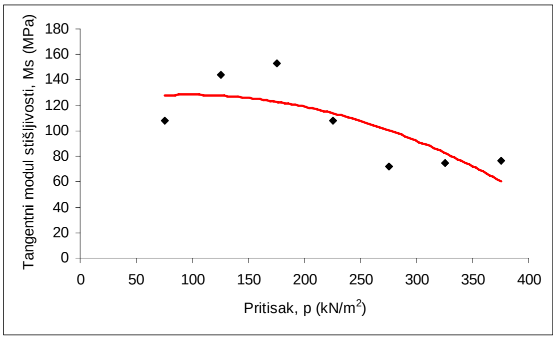

Figure 12. *Ratio of tangential module of compressibility and pressure, point 3*

The results of deformation parameters of point 4:

Figure 13. *Circular plate at point 4*

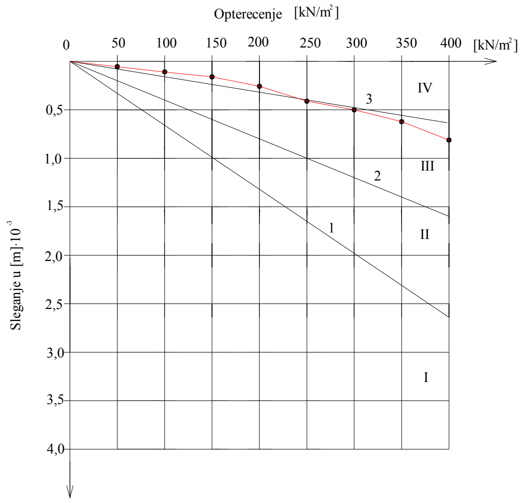

Figure 14. *Subsidence of 4*

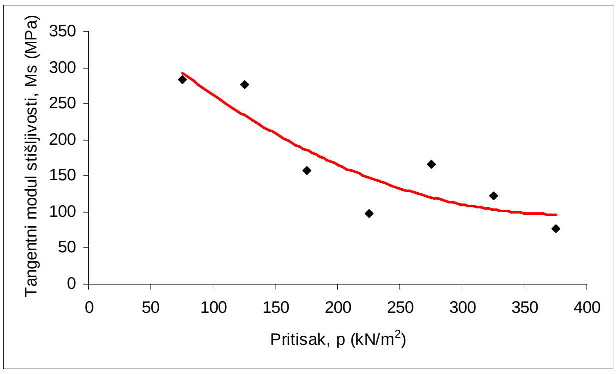

Figure 15. *Ratio of tangential module of compressibility and pressure, point 4*

BEARING CAPACITY OF THE BURRIED MATERIAL

The essence of design and analysis of foundations depends on the material capacity of foundation bottom. In this case, the said concept of material carrying capacity means the material strength below foundation bottom in contrast to the fracture due to shear stresses.

For footing in the form of tape, the Terzaghi form to calculate the limit bearing capacity is expressed as follows:

$$q_f = c \cdot N_c + \gamma_1 \cdot h \cdot N_q + 0{,}5 \cdot \gamma_2 \cdot B \cdot N_\gamma$$

$c = 0$ - cohesion of the buried limestone material

N_c, N_q, N_γ - load factors, depending on the angle of internal friction

$N_q = 40$; $N_\gamma = 40$

h = 0.35 and 0.5 [m] – depth of foundation

γ_1 = 16.68 [kN/m^3] – volumetric weight of the buried material

γ_2 = 16.68 [kN/m^3] – bulk density below the foundation bottom

B = 0.5 [m] – width of foundation

Table 1

Depth of foundation [m]	Width of foundation [m]	Limit bearing capacity of foundation material [kN/m^3]
0.35	0.35	350.28
0.50	0.35	450.36
0.50	0.50	500.40

CONCLUSION

The calculated limit bearing capacity is presented in Table 1 and ranges from 350.28 to 500.40 [kN/m^3] depending on the depth of foundation and its width.

Based on the obtained results of limit bearing capacity of foundation material, it can be concluded that it is necessary to carry out further compaction of terrain in order to obtain the uniform and increase density.

REFERENCES

[1] Report on Deformation and Bearing Capacity of Buried Material near the Shaft Opening at the Open Pit Mine “Zagradje” Open Pit-2, Bor, October 2008 (in Serbian)

[2] M. Ljubojev, M. Avdić, V. Ljubojev, D. Ignjatović, L. Dj. Ignjatović, Observation of Changes and Measurement of Subsidence on the collector VZO OP “Bogutovo selo” in Ugljevik, Mining Engineering, 1/2010, pp. 25-36

[3] M. Ljubojev, M. Avdić, D. Ignjatović, L. Dj. Ignjatović, The Effect of Flotation Tailing Dump of the Field 2 on stability of the Kriveljska River Tunnel, Mining Engineering, 2/2009, pp. 21-28

[4] M. Ljubojev, R. Popović, Fundamentals of the Soil Mechanics, RTB Bor, Copper Institute Bor, 2006 (in Serbian)

[5] R. Popović, M. Ljubojev, Principles of the Problem Solving in Geomechanics, RTB Bor, Copper Institute Bor, INDOC Center, 2007 (in Serbian)

[6] M. Ljubojev, M. Avdić, M. Bugarin, R. Popović, and D. Ignjatović, Tunnel analysis in fault zones and the effects of stress distribution on the support, Journal of mining and metallurgy, section A, 1, 2009, pp. 49-57

[7] M. Ljubojev, M. Iivkovićdić, J. Miljanović and L. Đurđevac. Ignjatović, Testing of geomechanical properties of coal series in order for support determination of the mechanized stope on the example of „stara jama“ mine in „Lubnica“, Journal of mining and metallurgy, section A, 1, 2009, pp. 58-70

UDK: 340.134:628.4(045)=861

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ODLAGANJE OPASNOG OTPADA NA DEPONIJE U SKLADU SA DIREKTIVOM EVROPSKE UNIJE O DEPONIJAMA br. 1999/31/EU

Izvod

Izbor lokacije i uređenje deponija otpadnog materijala se u Srbiji vrši prema važećem Pravilniku o kriterijumima za određivanje lokacije i uređenje deponija otpadnih materijala iz 1992. godine ("Sl. glasnik RS", br. 54/92). Ovim Pravilnikom su sve deponije svrstane u isti "koš", odnosno za izbor i uređenje lokacija važe isti kriterijumi bez obzira da li se radi o deponiji kućnog odnosno komunalnog otpada, inertnog otpada u koji spadaju razni građevinski otpadi (otpadi nastali u toku rada i uređenje na gradilišima), kao i otpadi koji su po svojim karakteristikama svrstani u opasne otpade. Donošenjem Zakona o Upravljanju otpadom RS 2009. godine, stvoreni su preduslovi za projektovanje i izgradnju i drugih vrsta deponija, koje ovaj zakon prepoznaje i svrstava u tri kategorije, zavisno od karakteristika samog otpada, odnosno od njegovog štetnog uticaja na životnu sredinu. U radu je detaljno obrađena Direktiva o deponijama otpada br. 1999/31/EU, koja po preporuci Ministarstva za zaštitu životne sredine predstavlja osnovni dokument, na osnovu koga će se izraditi novi pravilnici o odlaganju svih vrsta otpada u Republici Srbiji.

Ključne reči: *direktiva 1999/31/EU, deponija, opasan otpad, projektovanje*

UVOD

Usaglašavanje zakonodavstva Republike Srbije sa zakonodavstvom Evropske Unije iz domena zaštite životne sredine i upravljanja otpadom je teoretski započeto 2000. godine, kada je RS uključena u proces Stabilizacije i pridruživanja. Praktičnim početkom pridruživanja EU uzima se oktobar 2004. godine, kada je u Narodnoj Skupštini usvojena Rezolucija o pridruživanju Evropskoj Uniji. Dalji proces pridruživanja EU je septembra 2008. godine dobio zakonsku potporu kada je Narodna Skupština ratifikovala Sporazum o stabilizaciji i pridruživanju Republike Srbije EU. Na osnovu ovog Sporazuma Vlada RS je oktobra 2008. godine usvojila Nacionalni program za integraciju (NPI) Republike Srbije u Evropsku Uniju, kao strateški dokument koji objedinjuje sva dokumenta i akcione planove neophodne za proces evropskih integracija i definiše obaveze svih aktera za period do kraja 2012. godine.

Od 1992. godine do danasnjih dana izbor lokacije i uređenje deponija otpadnog materijala se u Srbiji vrši prema važećem

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Pravilniku o kriterijumima za određivanje lokacije i uređenje deponija otpadnih materijala iz 1992. godine ("Sl. glasnik RS", br. 54/92). Ovaj pravilnik sve otpade svrstava u jednu kategoriju, tako da se za projektovanje budućih komunalnih i industrijskih deponija koriste ista pravila i metodologija. To je i razumljivo ukoliko se zna da je zakon o upravljanju otpadom donet tek u leto 2009. godine.

Pravilnik o kriterijumima za određivanje lokacije i uređene otpadnim materija iz 1992. godine propisuje osnovne kriterijume za određivanje lokacija i uređenje deponija otpadnih materija radi zaštite životne sredine.

U skladu sa navedenim Pravilnikom opšta definicija deponije je: *deponija otpadnih materija jeste sanitarno-tehnički uređen prostor na kome se odlaže čvrst otpad koji kao otpadni materijal nastaje na javnim površinama, u domaćinstvima, u procesu proizvodnje odnosno rada, u prometu ili upotrebi, a koji nema svojstva opasnih materija i ne može se prerađivati, odnosno racionalno koristiti kao industrijska sirovina ili energetsko gorivo*.

Pravilnik zabranjuje odlaganje opasnog otpada na komunalne deponije, ali smo svedoci da se svakodnevno ovaj Pravilnik krši, jer se u nedostatku adekvatnog prostora za njegovo trajno odlaganje opasan otpad odlaže na postojeća smetlišta i komunalne deponije, često uz saglasnost javnih komunalnih preduzeća. Poslednji takav primer je pokušaj odlaganja 800 t industrijskog otpada na komunalnoj deponiji u Lazarevcu uz saglasnost JKP iz Lazarevca, koji je sprečen od strane nadležnih republičkih inspektora, po prijavi lokalnog stanovništva. Kako u Srbiji ne postoji nijedna regionalna deponija za odlaganje opasnog otpada, razumljivo je da se organizacije i industrijski pogoni koji generišu opasne otpade (otpadi koji imaju najmanje jednu opasnu karatretistiku po životnu okolinu), snalaze na sve moguće načine, često izbegavajući ili svesno kršeći važeće zakonske propise, plaćajući kazne ili penale zbog svojih postupaka. To naravno važi za one privrednike koje republičke i druge inspekcijske službe spreče u svojim namerama (ili pravovremeno budu oktriveni), ali se često dešava da se otpad neadekvatno odloži a da to niko i ne sazna.

Ovo je posebno bitno iz razloga što se deponije u skladu sa važećim pravilnikom iz 1992. godine projektuju kao vodonepropusne sa koeficijentom propustljivosti terena na kome se deponija izgrađuje od najmanje: k=0,00001 m/s ($k=10^{-5}$cm/s), odnosno u metrima koeficijenat iznosi: k= 0,0000001 m/s ($k=10^{-7}$ m/s). Ovaj koeficijenat je nedovoljan jer ne sprečava na zadovoljavajući način zagađenje podzemnih i površinskih voda usled nekontrolisanog kretanja procednih voda iz deponije u okolni prostor.

ODLAGANJE OTPADA U SKLADU SA DIREKTIVOM 1999/31/EU

Direktiva Evropske Unije 1999/31/EU je usvojena 26. aprila 1999. godine i drugačije se naziva Direktiva o deponijama otpada. Ova Direktiva je obavezujuća za sve članice Evropske Unije. Države koje su uključene u proces stabilizacije i pridruživanja (kao što je slučaj sa R. Srbijom) su u obavezi da svoje propise o deponijama otpada usklade sa ovom Direktivom. Republika Srbija je taj proces započela pre dve godine donošenjem NPI u EU kao i više zakona iz ove oblasti, među kojima je i Zakon o Upravljanju otpadom.

Donošenjem Zakona o Upravljanju otpadom RS 2009. godine ("Sl. glasnik RS", broj 36/09), stvoreni su preduslovi za projektovanje i izgradnju i drugih vrsta deponija, koje ovaj zakon prepoznaje i svrstava u tri kategorije, zavisno od karakteristika samog otpada, odnosno od njegovog štetnog uticaja na životnu sredinu. Zakon o upravljanju otpadom u Članu 7 u zavisnosti od opasnih karakteristika otpada koje utiču na zdravlje ljudi i životnu sredinu, sve otpade svrstava u tri kategorije otpada:

1. opasan otpad jeste otpad koji po svom poreklu, sastavu ili koncentraciji opasnih materija može prouzrokovati opasnost po životnu sredinu i zdravlje ljudi i ima najmanje jednu od opasnih karakteristika utvrđenih posebnim propisima.;
2. neopasan otpad jeste otpad koji nema karakteristike opasnog otpada;
3. inertni je onaj otpad koji nije podložan fizičko/hemijskim ili biološkim promenama.

Na osnovu Zakona o Upravljanju otpadom RS i Diretive 1999/31/EU u Ministarstvu za Životnu sredinu je započeta izrada novih Pravilnika o deponijama u skladu sa navedenim Zakonom i Direktivom. To praktično znači da će u budućnosti projektovanje i izgradnja svih vrsta deponija u RS biti na adekvatan način definisana i precizirana. Preporuka je resornog Ministarstva RS da se do završetka navedenih podzakonskih akata (pravilnika i uredbi), pri projektovanju novih deponija koristi Direktiva EU o deponijama otpada br. 1999/31/EU, uz konsultacije sa odgovarajućim službama u resornom Ministarstvu.

a) Kratak opis Direktive 1999/31/EU i pripadajućih aneksa

Direktiva Saveta EU o deponijama otpada br. 1999/31/EU je usvojena 26. aprila 1999. godine, a potpisana je od strane predsednika saveta J. Fischera. Direktiva je obavezujuća za sve članice EU. Direktiva sadrži ukupno 20 Člana u kojima je preciznije obuhvaćeno sledeće: opšti cilj, definicije, obim primene, klase deponija, otpad koji treba da bude prihvaćen u različite klase deponija, zahtev za dozvolu, uslovi dozvole, sadržaj dozvole, troškovi deponije otpada, procedure prihvatanja otpada, procedure kontrole i monitoringa u operativnoj fazi, procedure zatvaranja i održavanja, postojeće deponije otpada, obaveza izveštavanja, odbor, procedura odbora, transpozicija, stupanje na snagu i adresati.

Osim izvornog dokumenta Direktiva obuhvata i tri pripadajuća Aneksa:

- Aneks I - Opšti zahtevi za sve klase deponija;
- Aneks II - Kriterijumi prihvatanja i procedure;
- Aneks III - Procedure kontrole i monitoringa u radu i fazama održavanja.

Članom 4 Direktive o deponijama otpada je precizirano da svaka deponija mora biti klasifikovana u jednu od sledećih klasa:

- Deponija za opasan otpad;
- Deponija za neopasan otpad;
- Deponija za inertni otpad.

b) Opšti zahtevi za sve klase deponija - Aneks I

Ovim Aneksom su bliže određeni sledeći parametri-pojmovi:

1. ***Lokacija*** - lokacija deponije mora uzeti u obzir pre svega uslove koji se odnose na: udaljenost deponije od stambenih i drugih urbanih objekata, vodotokova, poljoprivrednog zemljišta i dr.; postojanje podzemnih voda, primorskih voda ili zaštitnih prirodnih zona; geoloških i hidrogeoloških uslova u području; rizika od poplava, klizišta, sleganja; zaštize prirode i kulturne baštine u području.
2. ***Kontrola vode i upravljanje procednom vodom*** - mere koje se preduzimaju zavise od karakteristika deponija i metroroloških uslova i preduzimaju se u cilju: kontrole atmosferskih voda koje ulaze u telo deponije; sprečavanja ulaska površinskih i podzemnih voda u deponiju otpada; prikupljanja zagađene vode i procedne vode i nje-

nom tretiranju i prečišćavanju ako je to potrebno.

3. ***Zaštita zemljišta i voda*** - deponija mora da bude isprojektovana i izgrađena tako da ispunjava neophodne uslove za sprečavanje zagađenja zemljišta, podzemnih i površinskih voda i obezbedi efikasno sakupljanje procednih voda iz tela deponije. Zaštita voda i zemljišta se postiže kombinacijom geološke barijere i oblaganja dna nepropusnom folijom tokom operativne/aktivne faze i kombinacijom geološke barijere i oblaganja na vrhu tokom pasivne faze/posle zatvaranja. ***Geološka barijera*** je sastavljena od mineralnog sloja i određena je geološkim i hidrogeološkim uslovima ispod i u neposrednoj blizini lokacije deponije sa sledećim minimalnim koeficijentima propustljivosti:

– deponija opasnog otpada:

K ≤ 1,0 x 10-9 m/s; debljina ≥ 5 m;

– deponija neopasnog otpada:

K ≤ 1,0 x 10-9 m/s: debljina ≥ 1,0;

– deponija inertnog otpada:

K ≤ 1,0 x 10-7 m/s: debljina ≥ 1,0.

Ukoliko geološka barijera ne zadovoljava napred definisane uslove može se veštački ojačati materijalima sa drugih lokacija, dajući jednaku zaštitu. Debljina sloja veštački uspostavljene geološke barijere ne sme biti manja od 0,5 m.

Pored gore opisane geološke barijere, neophodno je izgraditi i odgovarajući drenažni sloj na dnu deponije radi održavanja akumulacije procednih voda na minimumu, u skladu sa tabelom 1.

Tabela 1. *Sakupljanje procednih voda i zaptivanje dna deponije*

Kategorija deponije	Neopasan otpad	Opasan otpad
Veštačka zaptivna obloga	potrebno	potrebno
Drenažni sloj ≥ 0,5 m	potrebno	potrebno

U narednoj tabeli 2 date su preporuke za izgradnju površinskog sloja za zaptivanje deponije po završetku eksploatacionog perioda.

Tabela 2. *Preporuke za zaptivanje površine deponije posle eksploatacije*

Kategorija deponije	Neopasan otpad	Opasan otpad
Drenažni sloj gasa	potrebno	nije potrebno
Veštačka zaptivna obloga	nije potrebno	potrebno
Nepropustljiv mineralni sloj	potrebno	potrebno
Drenažni sloj > 0,5 m	potrebno	potrebno
Površinski pokrivač zemljišta > 1 m	potrebno	potrebno

4. ***Kontrola gasa*** - sakupljanje, tretman i korišćenje deponijskog gasa vrši se na način koji minimizira oštećenja ili pogoršanja životne sredine i rizik po ljudsko zdravlje. Deponijski gas se sakuplja iz svih deponija koje primaju biorazgradivorganski otpad koji mora da se tretira i koristi. Ukoliko je količina sakupljenog gasa nedovoljna za isplativu proizvodnju enegrije on se spaljuje bez valorizacije.
5. ***Smetnje i opasnosti*** - preduzimaju se mere za smanjenje smetnji i opasnosti kroz: emisije neprijatnih mirisa i prašine, materijala raznetih vetrom, buke i saobraćaja, ptica, štetočina i insekata, formiranja aerosola, požara. Deponija se mora opremiti tako da nečistoće sa lokacije ne rasipava na javnim putevima i na okolno zemljište.
6. ***Stabilnost*** - Otpad na lokaciji se postavlja tako da se obezbedi stabilnost mase otpada i pratećih objekata, posebno u pogledu klizanja.
7. ***Barijere*** - deponija treba da bude osigurana adekvatnom ogradom i kapijom radi sprečavanja slobodnog i nekontrolisanog pristupa deponiji. Van radnog vremena kapija treba da bude zaključana. Takođe sistem za kontrolu i pristup svakom objektu treba da sadrži program mera za otkrivanje i sprečavanje ilegalnog deponovanja na objektu.

c) Kriterijumi prihvatanja otpada i procedure - Aneks II

Ovaj Aneks opisuje opšte principe za prihvatanje otpada na različite klase deponija. Buduća procedura klasifikacije otpada treba da bude zasnovana na tim principima. Ovaj Aneks se sastoji iz 5 poglavlja: Uvoda; Opštih principa; Opštih postupaka za ispitivanje i prihvatanje otpada; Smernica za preliminarne procedure prihvatanja otpada; Uzorkovanja otpada.

d) Procedure za kontrolu i monitoring u radu i fazama održavanja - Aneks III

Cilj ovog Aneksa je da obezbedi minimum procedura za monitoring za proveru:

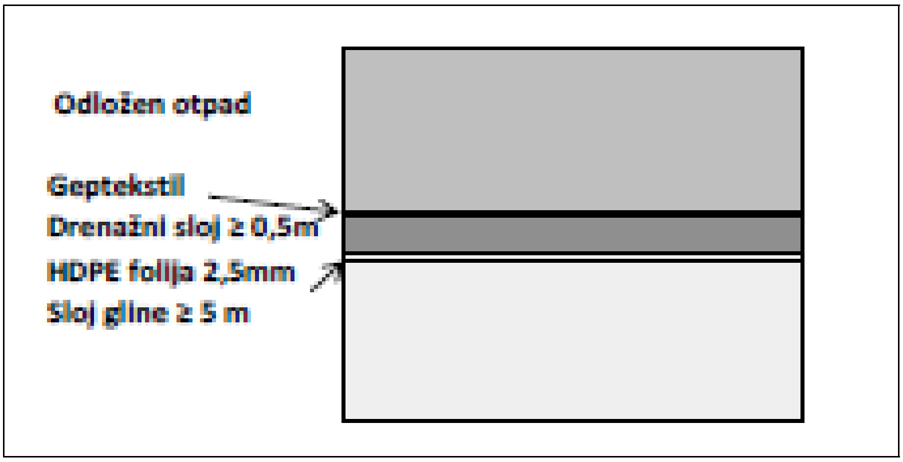
– da je otpad prihvaćen za odlaganje u skladu sa kriterijumima za datu kategoriju deponije;
– da su nastavljeni procesi u okviru rada deponije u skladu sa dokumentacijom;
– da sistemi zaštite životne sredine funkcionišu u potpunosti kao što je planirano;
– da su uslovi dozvole za deponije ispunjeni.

Aneks III se sastoji od ukupno 5 poglavlja i to su: Uvod; Meteorološki podaci; Podaci o emisiji voda, Procedne vode i kontrola gasa; Zaštita podzemnih voda; Topografija lokacije - podaci o telu deponije.

OSNOVNI ELEMENTI DEPONIJE OPASNOG OTPADA SAGLASNO DIREKTIVI

Na slici 1 je prikazan detalj formiranja glinenog sloja na dnu deponije sa koeficijentom propustljivoti $K \geq 10^{-9}$ m/s. Kako podloga ne poseduje odgovarajući koeficijenat dovozi se dodatan sloj gline koji se odgovarajućom mehanizacijom planira po dnu, sabija i ravna. Na slici 2 prikazan je detalj poprečnog preseka slojeva dna i bočnih strana deponije, u skladu sa Direktivom 1999/31/EU, za deponije opasnog otpada. Slika 3 prikazuje detalj spajanja - lepljenja deponije koji se izvodi na "toplo" pomoću posebnog uređaja. nakon spajanja svi varovi se proveravaju najmanje dva puta. Širina preklapajućeg sloja iznosi najmanje 0,3 m.

Sl. 1. *Planiranje, kompaktiranje i ravnanje dna deponije*



Sl. 2. *Poprečni presek dna/strana deponije sastavljen od različitih slojeva*

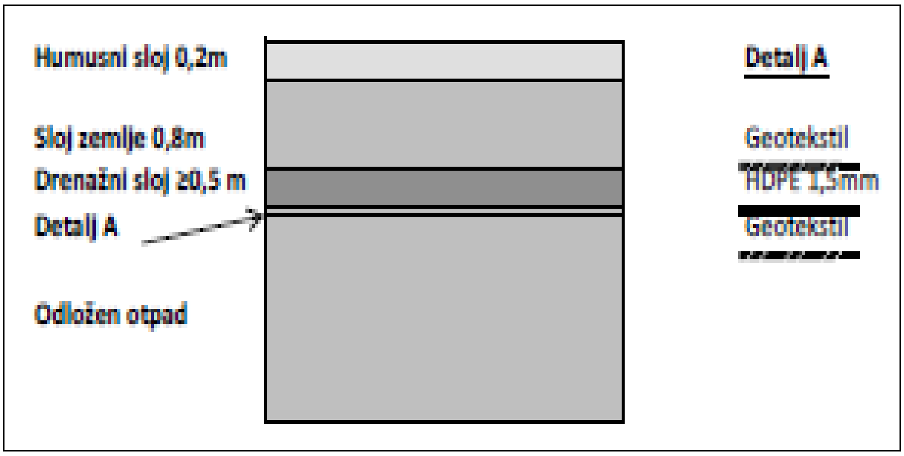
Sl. 3. *Detalj spajanja HDPE geomembrane*

Na slici 4 prikazan je način na koji se folija na krajevima oko deponije zateže. Zatezanje se izvodi pomoću zateznog rova dimenzija 0,5 x 0,5 m, u koji se postavlja folija i isti se zatrpa zemljom po celoj dužini. Ovaj način omogućava ravnomerno zatezanje folije oko deponije.

Sl. 4. *Zatezanje geomembrane pomoću zateznog rova i zemlje*

Sl. 5. *Polaganje drenažnih cevi po dnu deponije*

Kako se sa slike 5 može videti, po dnu deponije odmah na HDPE geomembranu (foliju) se postavljaju perforirane drenažne cevi, koje služe za sakupljanje i odvođenje procednih voda iz tela deponije (održava se nivo procednih voda na minimum). Preko drenažnih cevi se postavlja sloj šljunka debljine najmanje 0,5 m. Detalj pokrivnog sloja koji se postavlja na deponiju po završetku njene eksploatacije prikazan je na sledećoj slici 6. Tipičan izgled ravničarske deponije nakon faze rekultivacije prikazan je na slici 7.



Sl. 6. *Poprečni presek pokrivnog sloja deponije*

Sl. 7. *Tipičan izgled deponije nakon rekultivacije*

ZAKLJUČAK

U radu je na jednostavan i razumljiv način, prikazana kompletna Direktiva EU o deponijama otpada, br. 1999/31/EU, sa posebnim osvrtom na odlaganje opasnog otpada. Detaljnije su objašnjeni najvažniji članovi Direktive kao i pripadajući Aneksi. U poglavlju: ***Osnovni elementi deponije opasnog otpada saglasno Direktivi*** prikazan je potupak izgradnje najvažnijih delova deponije na slikovit i jednostavan način, razumljiv svim zainteresovanim licima, a ne samo stručnjacima iz predmetne oblasti. Ovo je veoma bitno sa stanovišta edukacije svih zainteresovanih subjekata (NVO, studenti, istraživači, lokalne samouprave, mesne zajednice, građanstvo i dr.), jer Srbiji predstoji izgradnja desetak regionalnih deponija za odlaganje opasnog otpada. Odlaganje opasnog otpada je po pravilu uvek vezano sa negodovanjem lokalnog stanovništva u čijoj se blizini planira iz-gradnja regionalnih deponija, posebno kada je u pitanju odlaganje opasnog otpada.

LITERATURA

[1] Direktiva Evropske Unije o deponijama otpada, br. 1999/31/EU.

[2] Pravilnik o kriterijumima za određivanje lokacije i uređenje deponija otpadnih materija, "Sl. glasnik RS", br. 54/92.

[3] Zakon o Upravljanju otpadom ("Sl. glasnik RS", broj 36/09).

[4] M. Ilić, S. Miletić - Osnovi upravljanja čvrstim otpadom, Knjiga, IMS, Beograd 1998. god.

[5] M. Ljubojev, R. Popović, M. Avdić, L. Đurđevac Ignjatović i V. Ljubojev, Defining the legallity of gray sandstone rock strength testing in a complex state of stress, Technics Technologies Education Management, Vol. 5, br. 3 2010, str. 437-443

[6] R. Rajković, D. Kržanović, R. Lekovski, Stability analysis innner waste dump „Kutlovaca" of the coal open pit mine „Potrlica" – Pljevlja using the geostusio 2007 software, Časopis Rudarski radovi, br. 1, 2010, str. 75-80

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DISPOSAL OF HAZARDOUS WASTE ON THE LANDFILL IN ACCORDANCE WITH THE COUNCIL DIRECTIVE OF THE EUROPEAN UNION ON THE LANDFILL OF WASTE No. 1999/31/EC

Abstract

The choice of location and arrangement of waste landfills in Serbia are carried out according to the current Regulation on criteria for determining the location and arrangement of waste landfills from 1992 ("Official Gazette RS", no. 54/92). By this Regulation, all landfills are classified in the same "basket", that is the same criteria are valid for the selection and arrangement of sites regardless whether it is a dump of household or municipal waste, inert waste, which includes various construction waste (produced waste during operation and arrangement of sites) as well as the waste classified according to its characteristics into the hazardous waste. By passing the Law on Waste Management the Republic of Serbia in 2009, the prerequisites for design and construction the other types of landfills, which this law recognizes and classifies into three categories, depending on the waste characteristics or its harmful impact on the environment. This paper gives in detail the Directive on the Landfill of Waste, No. 1999/31/EU that presents the main document by the recommendation of the Ministry of Environment document, based on which the new regulations for disposal of all types of waste in the Republic of Serbia will be created.
Key words: *directive 1999/31/EC, landfill, hazardous waste, design*

INTRODUCTION

Harmonization of the legislation of the Republic of Serbia with the European Union in the field of environmental protection and waste management is theoretically initiated in 2000 when the Republic of Serbia is included in the Stabilization and Association Process. Practical beginning of accession to the EU is taken in October 2004 when the National Assembly adopted the Resolution on European Union. Further accession process to the EU in September 2008 received the legal support when the National Assembly ratified the Stabilization and Association of the Republic of Serbia to the EU. Based on this Agreement, the Government of the

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Republic of Serbia in October 2008 adopted the National Program for Integration (NPI) of the Republic of Serbia into the European Union as the strategic document that brings together all documents and action plans necessary for the European integration process and define the responsibilities of all actors for the period until the end of 2012.

From 1992 to the present day, a selection of site and regulation of waste landfills in Serbia is carried out according to the current Rulebook on criteria for determining the location and arrangement of waste landfills from 1992 ("Official Gazette RS", No. 54/92). This Rulebook classifies all types of waste in one category, so that designing the future municipal and industrial landfills uses the same rules and methodologies. It is understandable if it is known that the Law on Waste Management was adopted in the summer of 2009.

The Rulebook on criteria for determining the location and arrangement the waste materials in 1992 lays down the basic criteria for determining the location and arrangement of waste landfills to protect the environment.

In accordance with this Rulebook, the general definition of landfill is: *a landfill of waste is the sanitary-technical landscaped area where the solid waste is disposed that as the waste material occurs in public areas, in households, in the production process or work, in traffic or use, and which has no properties of hazardous substances and cannot be processed and rational use as an industrial raw material or energetic fuel.*

The Rulebook prohibits the disposal of hazardous waste in the municipal landfills, but we are the witnesses of everyday violation of this Rulebook due to the lack of adequate space for permanent disposal, the hazardous waste is disposed of at the existing municipal landfills and dumps, often with the approval of public utility-companies. The last example is an attempt of disposal 800 tons of industrial waste in the municipal landfill in Lazarevac with the approval from the PUC Lazarevac, which is prevented by the Republican inspectors, upon notification of the local population. Since there is no regional landfill for hazardous waste in Serbia, it is understandable that organizations and industrial facilities that generate hazardous waste (waste with at least one dangerous characteristic for the environment), coping in every possible way, often avoiding or knowingly violating a valid legislation, paying fines or penalties for their actions. This is also applied to those entrepreneurs that Republic and other inspection services prevent in their intentions (or promptly being disclosed), but it often happens that the waste is inadequately disposed and no one does not know.

This is particularly important because the landfill in accordance with the applicable Rulebook from 1992 is designed as a watertight with the coefficient of terrain permeability on which the landfill is built of at least: k= 0.00001 m/s ($k=10^{-5}$cm/s), or in meters coefficient is: k= 0.0000001 m/s ($k=10^{-7}$ m/s). This ratio is insufficient because it does not satisfactorily prevent pollution of groundwater and surface water due to the uncontrolled movement of leachate from the landfill into the surrounding space.

WASTE DISPOSAL IN ACCORDANCE WITH THE DIRECTIVE 1999/31/EC

Council Directive of the European Union 1999/31/EC was adopted on 26 April 1999 and otherwise known as the Directive on the landfill of waste. This directive is binding on all members of the European Union. The involved states in the stabilization and association process (as is the case with the Republic of Serbia) are bound to comply their regulations on waste disposalwith this Directive.Republic of Serbia has started this process two years ago by making the National program for EU integration and more laws in this area, including the Law on Waste Management.

Passing the Law on Waste Management RS 2009 ("Official Gazette RS, No. 36/09), the prerequisites for design and construction and other types of landfills were formed, which this law recognizes and classifies into three categories, depending on the characteristics of waste, or its harmful effect on the environment. The Law on Waste Management in Article 7, depending on the characteristics of hazardous waste that affect the human health and environment, classifies all waste into three categories of waste:

1. hazardous waste is a waste that in its origin, composition or concentration of hazardous substances can cause danger to the environment and human health and has at least one of the hazardous characteristics defined by the special regulations;
2. non-hazardous waste is a waste that has the characteristics of hazardous waste;
3. inert waste is a waste that is not subjected to the physical/chemical or biological changes.

According to the Law on Waste Management of the Republic of Serbia and Directive 1999/31/EC, the Ministry of Environment has initiated a development of new Regulations on the landfills in accordance with these Law and Directive. This practically means that in the future design and construction of all types of landfills in the Republic of Serbia will to be adequately defined and specified. Recommendation of the relevant Ministry of the Republic of Serbia that to the completion of these by-laws (rulebooks and regulations), the design of new landfills use the EU Directive on the landfill of waste No. 1999/31/EU, in consultation with relevant departments in relevant Ministry.

a) A brief description of the Directive 1999/31/EC and associated annexes

Council Directive on the landfill of waste No. 1999/31/EC was adopted on 26th April 1999 and signed by the Council President J. Fischer. The directive is obligatory for all member states of EU. The Directive contains the total of 20 articles which more accurately included the following: Overall objective, Definitions, Scope, Classes of landfill, Waste and treatment not acceptable in landfills, Waste to be accepted in the different classes of landfill, Application for a permit, Conditions of the permit, Content of the permit, Cost of the landfill of waste, Waste acceptance procedures, Control and monitoring procedures in the operational phase, Closure and aftercare procedures, Existing landfill sites, Obligation to report, Committee, Committee procedure, Committee, Entry into force and Addressees.

In addition to the original document, the Directive includes the following three Annexes:

- Annex I – General requirements for all classes of landfills
- Annex II – Waste acceptance criteria and procedures
- Annex III – Control and monitoring procedures in operation and after-care phases.

Article 4 on the landfill of waste is specifies that each landfill must be classified into one of the following classes:

- Landfill for hazardous waste,
- Landfill for non-hazardous waste,
- Landfill for inert waste.

b) General requirements for all classes of landfill - Annex I

This Annex closer determines the following parameters - terms:

1. ***Location*** - location of a landfill must take into consideration requirements relating to: the distance of landfill from the residential and other urban sites, waterways, water bodies, agricultural land and others; the existence of groundwater, coastal water or nature protection zones; the geological and hydrogeological conditions in the area; the risk of flooding, subsidence, landslides; the protection of the nature or cultural patrimony in the area.
2. ***Water control and leachate management*** - measures shall be taken, with respect to the characteristics of the landfill and the meteorological conditions, in order to: control water from precipitations entering into the landfill body; prevent surface water and groundwater from entering into the landfilled waste; collect contaminated water and leachate and their treatment and purification, if it is necessary.
3. ***Protection of soil and water*** - A landfill must be designed and constructed so as to meet the necessary conditions for preventing pollution of the soil, groundwater or surface water and ensuring efficient collection of leachate from the landfill body. Protection of water and soil is achieved by the combination of a geological barrier and a bottom liner with non-permeable film during the operational/active phase and by the combination of a geological barrier and a top liner during the passive phase/post closure. ***Geological barrier*** consists of mineral layer and is determined by geological and hydrogeological conditions below and in the vicinity of a landfill site with the following minimum permeability coefficients:

- landfill for hazardous waste: $K \leq 1.0 \times 10^{-9}$ m/s; thickness ≥ 5 m;
- landfill for non-hazardous waste: $K \leq 1.0 \times 10^{-9}$ m/s: thickness ≥ 1.0;
- landfill for inert waste: $K \leq 1.0 \times 10^{-7}$ m/s: thickness ≥ 1.0.

Where the geological barrier does not naturally meet the above conditions it can be completed artificially and reinforced by materials from other locations giving equivalent protection. An artificially established geological barrier should be no less than 0.5 m thick.

In addition to the geological barrier described above a leachate collection and sealing system must be added in accordance with the following principles so as to ensure that leachate accumulation at the base of the landfill is kept to a minimum according to Table 1.

Table 1. *Leachate collection and sealing of landfill bottom*

Landfill category	Non hazardous waste	Hazardous waste
Artificial sealing liner	required	required
Drainage layer ≥ 0.5 m	required	required

The following Table 2 gives the recommendations for construction the surface sealing after exploitation period.

Table 2. Recommendation for surface sealing after exploitation period

Landfill category	Non hazardous waste	Hazardous waste
Gas drainage layer	required	not required
Artificial sealing liner	not required	required
Impermeable mineral layer	required	required
Drainage layer > 0.5 m	required	required
Top soil cover > 1 m	required	required

4. ***Gas control*** - The collection, treatment and use of landfill gas shall be carried on in a manner which minimizes damage to or deterioration of the environment and risk to human health. Landfill gas shall be collected from all landfills receiving biodegradable waste that must be treated and used. If the quantity of collected gas cannot be used to produce energy, it must be flared without valorization
5. ***Nuisances and hazards -*** measures shall be taken to minimize nuisances and hazards arising from: emissions of odors and dust; wind-blown materials; noise and traffic; birds, vermin and insects; formation and aerosols; fires. The landfill shall be equipped so that dirt originating from the site is not dispersed onto public roads and the surrounding land.
6. ***Stability*** - The emplacement of waste on the site shall take place in such a way as to ensure stability of the mass of waste and associated structures, particularly in respect of avoidance of slippages.
7. ***Barriers*** – the landfill shall be secured by the suitable fences and gates to prevent free and uncontrolled access to the site. The gates shall be locked outside operating hours. The system of control and access to each facility should contain a program of measures to detect and discourage illegal dumping in the facility.

c) Waste acceptance criteria and procedures - Annex II

This Annex describes the general principles for acceptance of waste at the various classes of landfills. The future waste classification procedure should be based on these principles. This Annex consists of 5 chapters: Introduction, General principles, General procedures for testing and acceptance of waste, Guidelines for preliminary waste acceptance procedures, Sampling of waste.

d) Control and monitoring procedure in operation and after-care phases - Annex III

The purpose of this Annex is to provide the minimum procedures for monitoring to be carried out to check:

- that waste has been accepted to disposal in accordance with the criteria set for the category of landfill in question;
- that the processes within the landfill proceed as desired;
- that the environmental protection systems are functioning fully as intended;
- that the permit conditions for the landfill are fulfilled.

Annex III consists of 5 chapters: Introduction, Meteorological data, Emission data on water, leachate and gas control, Protection of ground water, Topography of the site – data on the landfill body.

BASIC ELEMENTS OF THE HAZARDOUS WASTE LANDFILL ACC

Figure 1 shows a detail of formation the clay layer on the bottom of landfill with the coefficient of permeability K ≥ 10^{-9} m/s. As the base does not have the appropriate coefficient, an extra layer of clay t is brought by the adequate mechanization and planned on the bottom, compressed and flattened. Figure 2 shows a detail of cross-sectional layers of the bottom and sides of the landfill, in accordance with the Directive 1999/31/EC for the hazardous waste landfill. Figure 3 shows a detail of connecting – sticking the landfill that is carried out on “hot“ using a special device. After connecting, all welds are checked at least twice. The width of overlapping layer is at least 0.3 m.

Figure 1. *Planning, compacting and flattening the bottom of the landfill*

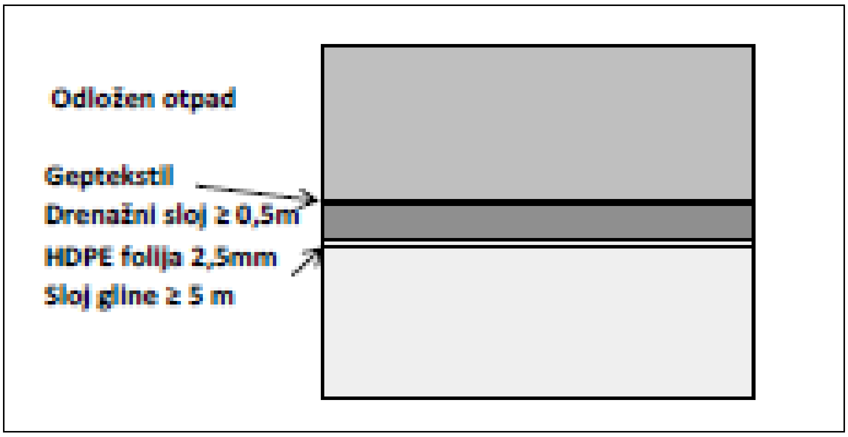

Figure 2. *Cross section of the bottom/side of the landfill made up of different layers*

Figure 3. *Detail of connecting the HDPE geomembrane*

Figure 4 shows the way in which the foil at the ends around the landfill is tightened. Tightening is done by the tension trench, size 0.5 x 0.5 m, where the foil is placed and the same is buried with earth throughout its length. This way enables the uniform film tension around the landfill.

Figure 4. *Geomembrane tension by tightening trench and earth*

Figure 5. *Laying of drainage pipes on the bottom of the landfill*

As it can be seen from Figure 5, the perforated drainage pipes, which are used for the collection and disposal of leachate from the landfill body (maintaining the level of leachate at minimum), are placed along the bottom of the landfill immediately on the HDPE geomembrane (foil). Alayer of gravel, thickness of at least 0.5 m, is placed over the drainage pipes. A detail of top layer, placed on the landfill after its exploitation, is shown in the following Figure 6. A typical view of plain landfill after reclamation phase is shown in Figure 7.

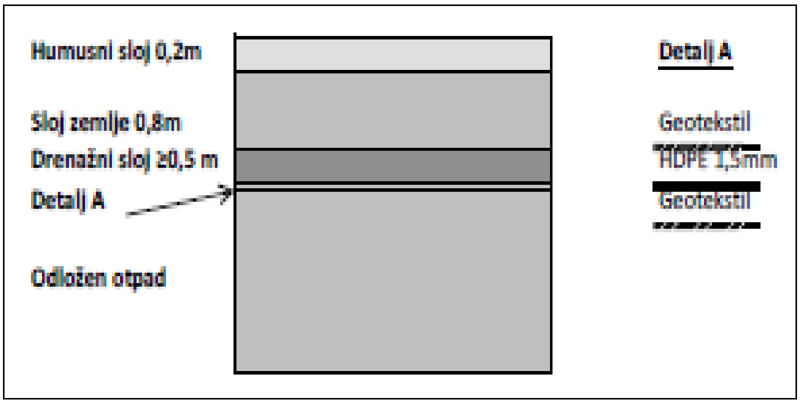

Figure 6. *Cross-section of top layer of the landfill*

Figure 7. *Typical view of the landfill after reclamation*

CONCLUSION

A complete Directive on the landfill of waste, No.1999/31/EC is present in this paper by a simple and understandable way, with a special reference to the disposal of hazardous waste. The most important articles of the Directive and associated annexes are explained in detail. The Chapter ***The Basic Elements of the Hazardous Waste Landfill in accordance with the Directive*** presents the procedure of building the most important parts of the landfill by a scenic and simple way, understandable to all interested parties, not only to the experts in the subject area. This is very important from the standpoint of education of all stakeholders (NGO, students, researchers, local governments, local communities, citizens, etc...) because the construction of a dozen of regional landfills for disposal of hazardous waste is going to be realized in Serbia. Disposal of hazardous waste is generally always connected to the displeasure of local population in the vicinity of planned construction of regional landfill, especially when it comes to disposal of hazardous waste.

REFERENCES

[1] European Union Directive on the Landfill of Waste, No. 1999/31/EC.

[2] Rulebook on the Criteria for Determining the Location and Arrangement of the Landfill of Waste Material, ("Official Gazette RS", No. 54/92).

[3] Law on the waste management, ("Official Gazette RS", No. 36/09).

[4] M. Ilić, S. Miletić – Basic on the Hazardous Waste Management, Book, IMS, Belgrade1998.

[5] M. Ljubojev, R. Popović, M. Avdić, L. Đurđevac Ignjatović and V. Ljubojev, Defining the legallity of gray sandstone rock strength testing in a complex state of stress, Technics Technologies Education Management, Vol. 5, No. 3 2010, pp. 437-443

[6] R. Rajković, D. Kržanović, R. Lekovski, Stability analysis innner waste dump „Kutlovaca" of the coal open pit mine „Potrlica" – Pljevlja using the geostusio 2007 software, Journal engineering mining, No. 1, 2010, pp. 75-80

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RECIKLAŽA OLOVNOG OTPADA

Izvod

U radu je opisan postupak recikliranja otpadnih olovnih cevi, počev od pripreme šarže, topljenja, rafinacije i livenja, pa sve do izrade novih proizvoda od recikliranih olovnih cevi.

Strukturu olovnog otpada za recikliranje čine: vodovodne i kanalizacione cevi iz građevinarstva i industrijskih pogona, koje se povlače iz upotrebe zbog štetnog uticaja na životnu sredinu.

Postupak recikliranja podrazumeva: ručnu separaciju-odvajanje olovnih komponenti od ostalih prisutnih elemenata na bazi drugih metala i legura (mesingani ventili, čelični priključci i dr.), mehaničko odstranjivanje nataloženog kamenca, sečenje na manje komade radi lakšeg šaržiranja u peć za topljenje i rafinaciju.

Pre pripreme šarže za topljenje, izvršena je hemijska analiza po osnovu koje je izvršen dalji postupak klasifikacije otpada u prvu grupu na osnovu čistoće olova.

Topljenje, rafinacija i livenje je obavljeno u lončastoj indukcionoj peći, a dobijeni ingoti su iskorišćeni za izradu novih proizvoda (za potrebe kablovske industrije, ingoti dolegirani sa antimonom za proizvodnju pojedinih delova akumulatora...).

Ključne reči: *olovni otpad, reciklaža, ingoti*

UVOD

Amortizacioni otpadak nastaje kao nus proizvod već upotrebljenih i iskorišćenih osnovnih sredstava i predmeta široke potrošnje. Izvori amortizacionog otpada su rashodovana osnovna sredstva u industriji, transportu, građevinarstvu, seoskim gazdinstvima, otpaci od generalnog i tekućeg remonta mašina, opreme i konstrukcija [2].

Vek upotrebe pojedinih delova i predmeta prema međunarodnim podacima je:

- olovni akumulatori .... 3-5 god.,
- olovna izolacija kablova...... 40 god.,
- olovne cevi .... 50 god.,
- lemovi .... 10 god.,

Udeo proizvodnog i amortizacionog otpada kod olova i njegovih legura iznosi 19% proizvodnog otpada i 81% amortizacionog otpada.

Predmet ovog rada je postavljanje tehnološkog postupka recikliranja olovnog otpada (vodovodne i kanalizacione cevi) i dobijanje tehnički čistog olova koji se može koristiti za izradu novih proizvoda:

- blokovi-gredice za kablovsku industriju,
- gredice za izradu legura u različitim oblastima primene (lemovi, osigurači..),
- lovačka sačma,
- balans tegovi i plombe,
- valjani proizvodi,
- elementi za olovne akumulatore...

Potrošnja energije za proizvodnju tehnički čistog olova iz navedenog

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olovnog otpada je manja za 50% u odnosu na energiju potrebnu za proizvodnju olova iz rude[1].

Posmatrano sa ekološkog aspekta, reciklaža olovnog otpada ne zahteva velika ulaganja u sistem za otprašivanje i ispuštanje gasova u atmosferu, ukoliko se poštuje propisana tehnološka procedura[4].

EKSPERIMENTALNI DEO

U toku rekonstrukcije vodovodne i kanalizacione mreže, u Institutu za rudarstvo i metalurgiju u Boru, izvršena je zamena celokupne vodovodne i kanalizacione instalacije. Tom prilikom izvedeni su eksperimenti na odbačenim olovnim cevima, sa ciljem izrade novih proizvoda od istih.

Selektiranje i priprema olovnih cevi

Selekcija otpadnih cevi je izvršena po osnovu dimenzija (prečnika) i namene. Tanke cevi za dovod vode do određenih potrošača su odvajane posebno od kanalizacionih cevi. Cevi su pre topljenja odvajane od mesinganih kolendera i ventila od mesinga.

Kanalizacione cevi su prethodno očišćene od nataloženih otpadnih materijala i kamenca i isečene na optimalne dužine, radi lakšeg šaržiranja u lonce za topljenje (slika 1).

Na reprezentativnim uzorcima cevi urađena je hemijska analiza (tabela 1).

Tabela 1 *Hemijska analiza otpadnih olovnih cevi*

Elementi	Sadržaj (%)
Sn	0,006
Bi	0,03
Fe	0,001
Pb	99,40
Sb	0,49
Cd	0,002
Cu	0,025

Slika 1. *Otpadne olovne cevi*

Topljenje i livenje

Pripremljena šarža od otpadnih olovnih cevi topljena je u dva agregata i to u grafitnom loncu tipa AC-100 u indukcionoj peći (slika 2) i grafitnom loncu uz pomoć autogenog topljenja (slika 3).

Slika 2. *Grafitni lonac tip AC-100*

Slika 3. *Grafitni lonac sa autogenim topljenjem*

Topljenje metalnog uloška se obavlja pod slojem drvenog uglja (ćumura). Ukoliko ima veću količinu rastresitog materijala, dobro je da se ubaci koks radi intenzivnije dezoksidacije rastopa, ali u tom slučaju može dići do kontaminacije rastopa metala sumporom iz koksa (što zavisi od prisutne količine sumpora u koksu) [3].

Temperatura topljenja otpadnog olova nije visoka, ali da bi nemetalni uključci isplivali na površinu potrebno je temperaturu podići do 500°C.

Pre livenja, rastop se ostavi da odstoji kraće vreme, da bi nemetalne primese i gasovi isplivali na površinu.

Livenje je obavljeno u grafitnim kokilama različitog oblika (slika 4 i 5).

Slike 4. i 5. *Grafitne kokile*

Na dobijenim odlivcima (ingotima), izvršena je hemijska analiza (tabela 2).

Tabela 2. *Hemijska analiza odlivaka (ingota)*

Elementi	Sadržaj (%)
Sn	0,39
Sb	0,51
Bi	0,027
Cu	0,021
S	0,004
Ag	0,005
Pb	99,00

ANALIZA REZULTATA

Reciklaža je obavljena u poluindustrijskoj laboratoriji, gde je izvršena adekvatna priprema otpadnih olovnih cevi. Na ovo ukazuje visok izvadak metala od 99 %.

Drugi bitan faktor koji je praćen u toku reciklaže je hemijski sastav ingota. Hemijska analiza je urađena na emisionom spektrometru. Analizirani su uzorci otpadnih cevi pre topljenja i uzorci odlivenih ingota. Analizom dobijenih rezultata uočava se razlika u hemijskom sastavu kod ingota u odnosu na cevi po osnovu prisutnih elemenata kalaja i srebra u ingotima usled prisutnih lemova kod cevi. razlika. Odlivci dobijeni pretapanjem otpadnih cevi koje su lemljene, imaju povećan sadržaj kalaja, jer je lemljenje obavljeno mekim lemom na bazi Sn-Pb.

I pored prisustva Sn i Sb u ingotima, to ne utiče bitno na ograničenje pri izradi novih proizvoda (cevi, limovi, kablovska industrija, izrada mekih lemova...) od recikliranih olovnih cevi.

PODRUČJE PRIMENE RECIK-LIRANOG OLOVNOG OTPADA

Na osnovu dobijenih rezultata hemijske analize recikliranog olovnog otpada, moguća je primena za izradu proizvoda širokog spektra. Prvenstveno za izradu cevi, limova i u oplaštavanju kablova. Najveću primenu reciklirano olovo nalazi u proizvodnji akumulatorskih baterija.

Reciklirano olovo se može koristiti i u proizvodnji niskotopivih lemova i za izradu većeg broja Vudovih legura, sa tačkom topljenja od 68°C do 138°C [1].

U Institutu za rudarstvo i metalurgiju proizvodi se veći broj ovih legura namenjenih tržištu, u čiji sastav pored olova ulaze još i Bi, Sn, Cd. U ovim legurama se sadržaj olova kreće od 25% težinskih do 50% težinskih.

Dobijeni proizvodi od recikliranih olovnih cevi prikazani su na slikama 6 i 7.

Slika 6 *Ingoti za dalju preradu*

Slika 7. *Finalni proizvodi od vudovih legura*

ZAKLJUČAK

Ukoliko se olovni amortizacioni otpad u obliku vodovodnih i kanalizacionih cevi dobro očisti od prljavštine nataložene u toku eksploatacije, i dobro odstrane zalemljena mesta, može se dobiti visokokvalitetno olovo.

Reciklirano visokokvalitetno olovo ima široku primenu kako u proizvodnji legura (niskotemperaturni lemovi, vudove legure), tako i u drugim granama industrije.

Reciklažu ovakvog olovnog otpada prati niska cena prerade, manje zagađenje okoline i štednja u energentima, čime se postiže velika konkurentnost u odnosu na olovo proizvedeno iz rude.

Analizom hemijskog sastava sekundarne sirovine i odlivaka posle reciklaže, potvrđuje se visok kvalitet recikliranog olovnog otpada.

LITERATURA

[1] N. M. Goldin, D. F. Černega, D. F. Ivančuk, V. V. Čistjakov-Tehnologija litejnogo proizvodstva – Cvetnoe litie, Moskva "Mašinostroenie" 1989

[2] I. Ilić, Z. Gulišija, N. Radovanović, M. Sokić, V. Matković, J. Marinković-"Resursi i reciklaža sekundarnih sirovina obojenih metala", Bor, 2002

[3] B. Kočovski - Metalurgija legura; obojenih metala, Bor 1996

[4] J. Krišto: Projekat - Prerada sekundarnih sirovina obojenih metala (II) deo, Beograda-Bor,1976

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RECYCLING OF LEAD WASTE

Abstract

The process of recycling the lead waste pipes includes the following steps: batch preparation, refining, casting, development and production of new products from recycled lead. The structure of lead waste for recycling are: water and sewer pipes from construction and industrial plants that are no longer in use because of its harmful impact on human and environment. The process starts with manual separation, which presents the separation of component with lead content from other metals and alloys (brass valves, steel fittings, etc..), followed by the mechanical removal of deposited scale, and cutting pieces into smaller pieces for batching into the melting furnace and refining process.

Chemical analysis of lead waste is necessary to be carried out before the melting process, in order to determine the purity of lead and its classification into the appropriate groups. Process of smelting, refining and casting were performed in the induction furnace. The resulting ingots were used for development of new products in cable industry or alloyed with antimony for production of some parts of battery ...).

Key words: *lead waste, recycling, ingot*

INTRODUCTION

The structure of lead waste for recycling are: water and sewer pipes from construction and industrial plants that are no longer in use because of its harmful impact on human and environment [2].

Lifetime of components made of lead or component that contain lead, according to the international data, are following [2]:

- lead batteries	3-5 years,
- lead insulation cables	40 years,
- lead pipes	50 years,
- solders	10 years.

Waste generated in the production process as by-product make 19% of the total waste based on lead, while 81% is waste generated after the life of lead-based products.

The aim of this paper is to define the parameters of technological process of recycling the lead waste (water and sewage pipes) and production the technically pure lead that can be used in manufacturing the new products:

- blocks-stringers for cable industry,
- beams for making the alloys in various fields of use (solders, fuses...),
- hunting pellets,
- balance weights and fillings,
- rolled products,
- lead battery elements.

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Recovery of lead from the waste has the advantages in easier and less energy consumption than production primary lead from the ore (production of recycled lead requires 35-40% of the required energy for lead production from the ore.).

From the ecological point of view, the recycling of lead waste do not require large investments into the system for dedusting and gas discharge into the atmosphere, if the regulated technological procedure is respected [4].

EXPERIMENTAL PART

During the reconstruction of water supply and sewerage networks in the Mining and Metallurgy Institute in Bor, the entire water and sewage installations were replaced. On that occasion, the experiments were carried out on discarded lead pipes, with the aim of development the new products from them.

Selection and preparation of lead pipes

The selection of waste pipes was made according to the pipe size (diameter) and purpose.

Thin pipes for water supply to the certain consumers were separated especially from sewerage pipes. The pipes were separated before melting from brass parts and valves. Sewage pipes were previously cleaned of accumulated waste materials and scale and cut to the optimum length for easy batching in the melting pots (Figure 1).

Chemical analysis was carried out on representative samples of pipes (Table 1).

Table 1. *Chemical analysis of the waste lead pipes*

Component	Content (%)
Sn	0.006
Bi	0.03
Fe	0.001
Pb	99.40
Sb	0.49
Cd	0.002
Cu	0.025

Figure 1. *Waste lead pipes*

Melting and casting

Prepared batch of waste lead pipes was melted in two sets as well as the graphite pot, type AC-100, in the induction furnace (Figure 2), and graphite pot with autogenous smelting (Figure 3).

Figure 2. *Graphite pot, type AC-100*

Figure 3. *Graphite pot with autogenous smelting*

Melting of the metal insert is performed under a layer of charcoal. If it has a large quantity of loose material, it is good to charge the coke for intensive desoxidation of melt, but in this case the contamination of molten metal sulfur from coke could appear (what depends on present sulfur quantity in coke) [3].

Melting point of waste lead is not high, but the presence of non-metallic inclusions requires higher melting temperature (about 500°C).

Before casting, the liquid phase is left to rest for a short time, in order of coming to the surface the non-metallic impurities and gases to the surface. Casting was done in the graphite moulds of various shapes (Figures 4 and 5).

Figures 4. and 5. *Graphite moulds*

Chemical analysis was carried out on the representative samples of ingots (Table 2).

Table 2. *Results of chemical analysis of the ingots*

Component	Content (%)
Sn	0.39
Sb	0.51
Bi	0.027
Cu	0.021
S	0.004
Ag	0.005
Pb	99.00

RESULTS AND DISCUSION

Recycling was carried out in the semi-industrial laboratory where the adequate preparation of waste lead pipes was done. This is indicated by high metal recovery of 99%.

Chemical composition of ingot is the second important parameter observed in the recycling process. Chemical analysis was carried out on the emission spectrometer. The samples of waste pipes were analyzed before melting and samples of cast ingots.

Analyzing the obtained results indicate

the difference in chemical composition of ingots regarding to the pipes, based on the present elements of tin and silver in the ingots, due to the present solders of the pipes. The ingots, obtained by the recycling of waste pipes with solders, have the increased tin content due to the soldering with soft solder, based on Sn-Sb.

Despite the presence of Sn and Sb in the ingots, it has no significant effect to the the limitation in development of new products (pipes, sheets, cable industry, manufacture of soft solders...) from the recycled lead pipes.

SCOPE OF USE THE RECYCLED LEAD WASTE

Based on the obtained results of chemical analysis of recycled lead waste, the usage for manufacturing the products of a wide spectrum is possible - primary, manufacturing of pipes, sheets and cable plating. The largest use of recycled lead is manufacturing of batteries.

Also, the recycled lead could be used in production of low temperature solder, low melting temperature alloys with the melting point of 68°C to 138°C, the Wood alloys. [1].

Mining and Metallurgy Institute Bor produce a large number of alloys intended for the market, with content of Bi, Sn and Cd besides lead. In these alloys, the content of lead is from 25% to 50% weight by weight.

The resulted products from recycled lead pipes are shown in Figures 6 and 7.

Figure 6. *Ingots for further processing*

Figuren 7. *Final products of the Wood's alloys*

CONCLUSION

If the lead waste, in the form of water supply and sewerage pipes, is thoroughly cleaned of dirt, accumulated during operation, and well removed the soldered places, the high-quality lead could be obtained.

The recycled high quality lead is widely used in the production of alloys (low-temperature solders, Wood alloys), and in other industries.

The recycling of such lead waste is followed by the low costs of processing, less environment pollution and energy savings, resulting in a major competition in respect to the lead produced from ore.

By analyzing the chemical composition of secondary raw materials and castings after recycling, the high quality of recycled lead waste is confirmed.

REFERENCES

[1] N. M. Goldin, D. F. Černega, D. F. Ivančuk, V. V. Čistjakov, Tehnologija litejnogo proizvodstva – Cvetnoe litie, Moskva "Mašinostroenie",1989

[2] I. Ilić, Z. Gulišija, N. Radovanović, M. Sokić, V. Matković, J. Marinković, Resources and Recycling the Secondary Raw Materials of Non-ferrous metals, Bor, 2002 (in Serbian)

[3] B. Kočovski, Metallurgy of Non-ferrous Metal Alloys, Bor, 1996 (in Serbian)

[4] J. Krišto, Project - Processing the Secondary Raw materials of Non-ferrous Metals, (II) Part, Belgrade - Bor,1976 (in Serbian)

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UTICAJ MEHANO-HEMIJSKE AKTIVACIJE FLOTACIJSKE JALOVINE NA STEPEN IZDVAJANJA KORISNIH KOMPONENTI[****]

Izvod

Prikazani rezultati odnose se na ispitivanje uticaja mehano-hemijske aktivacije flotacijske jalovine na stepen izluženja bakra, gvožđa i sumpora u sumporno-hloridnom rastvoru uz dodatak H_2O_2 kao oksidansa. Uzorak borske flotacijske jalovine (BFJ) sa lokacije starog borskog flotacijskog jalovišta sadrži 23% pirita i 75,23% jalovine kao osnovne komponente, a aktiviran je suvim postupkom u vibro mlinu bez i sa dodatkom NaOH kao hemijskog reagensa, uzorci BFJ1 i BFJ2, respektivno. Suvom magnetnom separacijom u visokogradijentnom magnetnom separatoru "Sala", uzorci su razdvojeni na magnetičnu i nemagnetičnu frakciju, BFJ MF i BFJ NMF, respektivno.

Luženje različito tretiranih uzoraka pokazalo je da je najviši stepen izluženja bakra, 98,7 %, postignut kod uzorka BFJ2 MF dok je stepen izluženja Fe i S viši kod nemagnetičnih frakcija, i kreće se do 92,46 % kod uzorka BFJ1 NMF za Fe i 80,62 % za S iz uzorka BFJ2 NMF.

***Ključne reči:**, flotacijska jalovina, mehano-hemijska aktivacija, magnetna separacija, luženje, Cu, Fe, S*

UVOD

Mehanohemijska aktivacija u oblasti rudarsko-metalurške prerade sve više dobija na primatu na nivou industrijske proizvodnje mineralnih sirovina(1). Efekti mehaničke aktivacije se odnose na preuređenje kristalne strukture mineralne sirovine fizičkim procesima i dobijanju metala bez predhodnog oksidacionog prženja a samim tim i bez emisije štetnog gasa SO_2 u atmosferu. Takodje i hidrometalurški procesi sve više dobijaju na značaju zahvaljujući sve strožim ekološkim pravilima.

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Tehnološka ispitivanja prerade mehanohemijski aktiviranog pirita borske flotacijske jalovine imala su za cilj ispitivanje uticaja mehano-hemijske aktivacije na stepen izluženja bakra, gvožđa i sumpora korišćenjem kombinovanog sumporno-hloridnog rastvora uz dodatak H_2O_2 kao oksidansa.

Mehanohemijska aktivacija uzorka BFJ uradena je u laboratorijama ITNMS – Beograd. Efektivnost izluženja korisnih komponenti u velikoj meri zavisi od stepena otvaranja minerala i otvorenosti površina [2]. Brzina prelaza elemenata u rastvor u opštem slučaju zavisi od veličine površine čvrstih čestica, a za neke tipove ruda krupnoća pretstavlja osnovni faktor izlužljivosti [3].

EKSPERIMENTALNA ISTRAŽIVANJA

Fizičko-hemijska karakterizacija uzorka borske flotacijske jalovine (BFJ)

Hemijska karakterizacija uzorka borske flotacijske jalovine korišćene za proces luženja kombinovanim sumporno-hloridnim rastvorom uz dodatak H_2O_2 kao oksidansa, prikazana je u tabeli 1, a mineraloška analiza, u tabeli 2.

Tabela 1. *Hemijska analiza BFJ*

Elemenat ili jedinjenje	Sadržaj %
Fe	4,82
S	6,20
Cu–oksidni	0,006
Al_2O_3	15,63
SiO_2	61,60
MgO	0,014
Cu–ukupno	0,131
Fe_3O_4	0,359
SO_4^{2-}	/

Tabela 2. *Mineraloška analiza uzorka BFJ*

Minerali	Kvalitativno, %
Pirit	23
Halkopirit	0,124
Pirotin	< 1 ppm
Rutil	0,98
Limonit	0,234
Jalovina	75,23

Rezultati sitovne analize koja je urađena standardnom metodom prosejavanja, na seriji sita tipa TYLER, prikazani su u tabeli 3.

Tabela 3. *Sitovna analiza uzorka BFJ*

Klasa krupnoće mm	Maseno učešće %
-0,600+0,425	2,40
-0,425+0,300	5,60
-0,300+0,212	10,00
-0,212+0,106	24,80
-0,106+0,075	9,60
-0,075+0,038	11,60
-0,038+0,020	7,20
-0,020	28,80

Za određivanje nasipne mase uzorka BFJ, koja iznosi 2930 kg m^{-3}, korišćena je VMK (Validna metoda kuće – IRM Bor) - Određivanje zapreminske mase i nasipne mase uzoraka (E.b.11:2007).

Postupak mehano-hemijskog tretmana (MC-H) uzorka BFJ vršen je u laboratorijskom vibro mlinu Humbolt. Mlin ima radnu temperaturu oko 340 K kada radi u kontinuitetu. Mlin može da ostvari rad dispergovanja u visini 7,3 x10^3 $KJmol^{-1}$.

To je, prema literaturnim podacima (1), dovoljna energija da izazove cepanje pet nivoa d orbitala slobodnog jona feruma iz pirita u oktaedarskom ligandnom polju. Izvršena su dva opita MC-H tretiranja BFJ suvim postupkom. U prvom opitu izvršeno je optimalno aktiviranje BFJ bez dodataka reagenasa (BFJ1).
U drugom opitu je dodat NaOH u količini od 4%, (BFJ2).

Magnetna koncentracija vršena je na visokogradijentnom magnetnom separatoru (HGMS) Sala u vodenoj sredini.

Ispitivanja lužljivosti Cu, Fe i S iz dobijenih frakcija izvedena su na opremi laboratorijskog tipa korišćenjem 0.8 M H_2SO_4 uz dodatak 30 % H_2O_2 kao oksidansa i uz prisustvo hlornih jona koji su u rastvor dodavani u obliku NaCl pri čemu je inicijalna koncentracija NaCl odgovarala 1M rastvoru.

Proces luženja odvijao se pri radnoj temperaturi rastvora od je 90±5°C, uz mešanje od 600 min^{-1}, pri odnosu Č:T = 1:20, u trajanju od 8 h.

Za hemijsku karakterizaciju korišćene su sledeće hemijske metode: za određivanje sadržaja S - gasna volumetrija (spaljivanje) na opremi Marsova peć a za odrešivanje sadržaja Cu i Fe – atomska apsorpciona spektrofotometrija, na opremi Atomsko apsorpcioni Spektrofotometar PERKIN ELMER 403.

REZULTATI I DISKUSIJA

Magnetni koncentrator (HGMS) daje dva proizvoda od kojih je jedan magnetična frakcija (MF) a drugi nemagnetična frakcija (NMF). Indukcija magnetnog polja (MP) je izabrana da bude B = 0,6 T. Paramagnetični minerali kao što je pirit, pri srednjem iznosu intenziteta (MP), imaju izvestan mali maseni udeo (MF). Oba MC-H tretirana uzorka BFJ podvrgnuta su postupku magnetne koncentracije. Rezultat odvajanja pojedinih frakcija prikazan je u tabeli 4. Dejstvu istog magnetnog polja B=0,6 T bio je izložen i uzorak *BFJ* koji nije *MC-H* aktiviran, i on je imao 90 g MF i 210 g NMF.

Tabela 4. *Rezultati magnetne koncentracije MC-H tretirane BFJ*

Uzorak BFJ	MC-H tretman bez reagensa	MC-H tretman sa NaOH
Nemagnetična frakcija, g	206	50
Magnetična frakcija, g	94	250
Ukupno, g	300	300

Za kompleks:

$$Na\left[\begin{matrix} SO_4 \\ Fe^{\cdots}(OH)_3 \end{matrix} \quad Fe^{\cdot\cdot} \quad \begin{matrix} Fe^{\cdots}(OH)_3 \\ SO_4 \end{matrix}\right]^{-}$$

vrednost magnetnog momenta je:

$$\mu_S = \sqrt{1(1+2)} \cdot \mu_B = 2{,}8\ \mu_B \ (5),$$

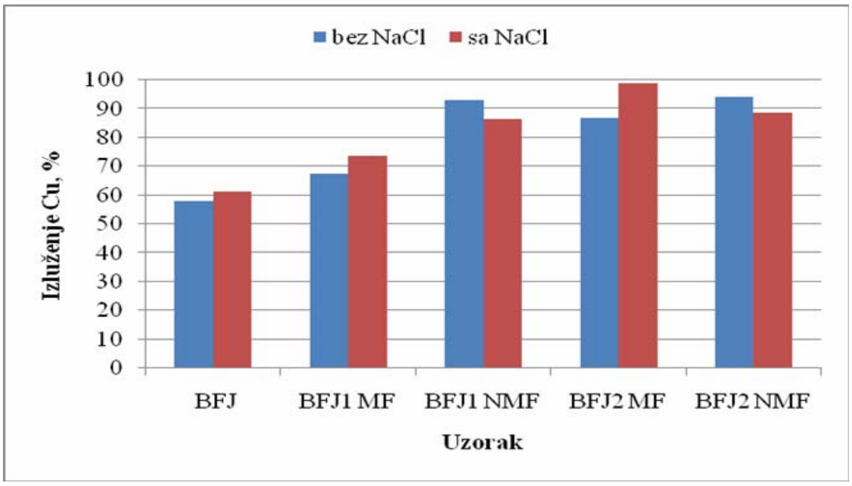
a upravo je i odnos magnetičnih frakcija iz opita magnetne koncentracije, tabela 4, približno 2,8 (94 x 2,8 = 263,2)

Tabela 5. *Hemijska karakterizacija frakcija dobijenih magnetnom separacijom*

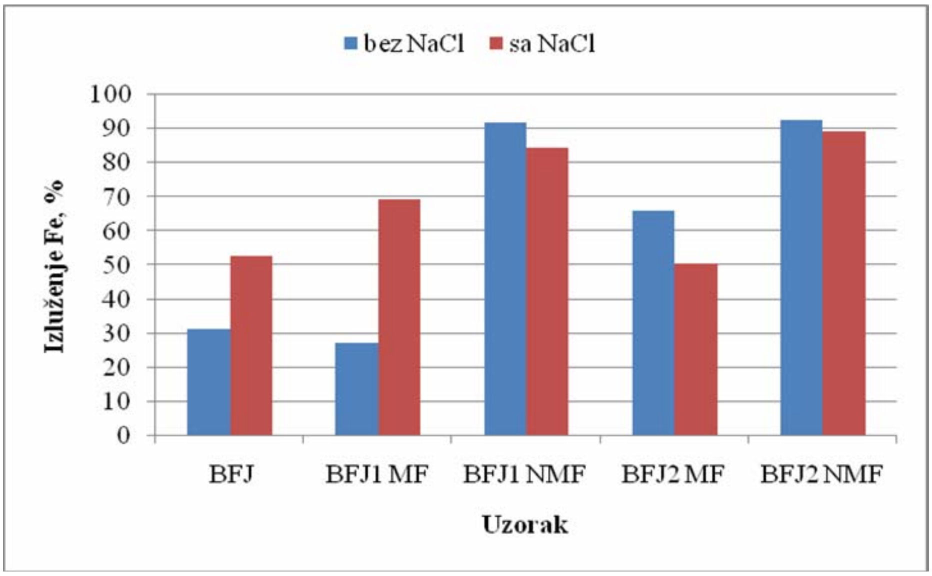
Opis	Oznaka uzorka			
	BFJ1 MF	BFJ1 NMF	BFJ2 MF	BFJ2 NMF
Fe, %	6,30	3,60	5,03	1,83
S, %	10,70	5,60	7,40	2,70
Cu–oxid, %	0,005	0,007	0,015	0,019
Al_2O_3, %	11,79	18,74	15,72	18,50
SiO_2, %	64,74	62,46	64,10	63,08
MgO, %	0,026	0,021	0,11	0,026
Cu–ukupno, %	0,152	0,153	0,135	0,134
Fe_3O_4, %	0,445	/	/	/
SO_4^{2-}, %	/	/		

Rezultati hemijske karakterizacije frakcija dobijenih magnetnom separacijom prikazani su u Tabeli 5.

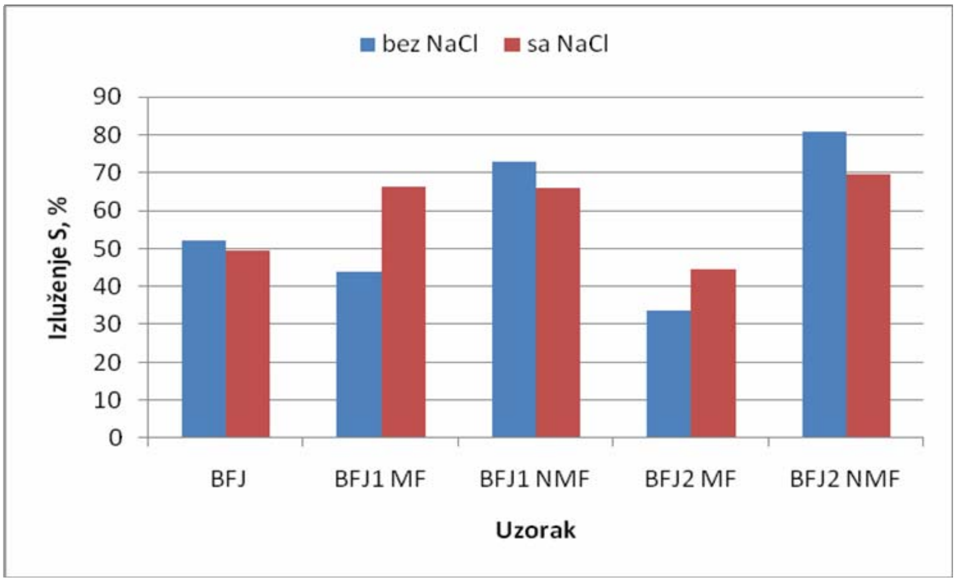
Rezultati postignutog izluženja Cu, Fe i S iz različitih uzoraka flotacijske jalovine, korišćenjem, u jednom slučaju sulfatnog rastvora bez dodatka NaCl a u drugom sa dodatkom NaCl, prikazani su na slikama 1, 2 i 3. Najviši stepen izluženja Cu postignut je kod uzorka BFJ2 MF u vrednosti od 98,75 %. Kod uzorka BFJ1 NMF karakteristično je da je postignut najviši stepen izluženja Fe a kod istog uzorka je postignut i najviši stepen izluženja S i to za proces luženja u sulfatnom rastvoru. Rezulatti izluženja pojedinih elemenata pokazuju da izluženje Cu, Fe i S ima isti trend kod svih uzoraka osim kod uzorka BFJ2 MF kod kog je izluženje gvožđa manje u kombinovanom sulfatno-hloridnom rastvoru.



Sl. 1. *Izluženje Cu iz različitih uzoraka BFJ primenom različitih lužnih rastvora*



Sl. 2. *Izluženje Fe iz različitih uzoraka BFJ primenom različitih lužnih rastvora*



Sl. 3. *Izluženje S iz različitih uzoraka BFJ primenom različitih lužnih rastvora*

ZAKLJUČAK

Na osnovu sprovedenih istraživanja vidi se da se uz pomoć *MC-H* tretmana i magnetne kocentracije može uticati na razvoj procesa koji bi omogućili odvajanje metaličnih od nemetaličnih minerala. Metalične mineralne sirovine imaju najmanje desetostruko veću vrednost u odnosu na nemetalične pa stoga treba u tom kontekstu shvatiti tehno-ekonomsku funkciju razvoja iznetog postupka tretiranja BFJ. Dalji tretman metalične i nemetaične komponente dovodi do izvlačenja korisnih komponenti i stvaranja uslova za korišćenje modifikovane nemetalične komponnte.

LITERATURA

[1] M. Petrov i dr, Mechano-chemical treatment of of mineral waste, Rudarski Radovi, Br. 2, (2009) 77-84,

[2] Z. Y. u etc, Hydrometallurgy, 56 (2006) 189 – 202.

[3] A. R. Kamali etc., Mineral Processing of Non-ferrous Metals, vol. 49, No. 1, (2008), 138-143.

[4] R. Murphy, D. Strongin, Surface reactivity of pyrite and related sulfides, Surface Science Reports, Novembar (2008), 24-36

[5] M. Ilić, „Specijalna Mineralogija deo II“, ICS Beograd, 1978 Beograd

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Radmila Marković[*], *Ljiljana Mladenović*[*], *Milan Petrov*[**], *Jasmina Stevanović*[***]

EFFECT OF MECHANICAL-CHEMICAL ACTIVATION OF FLOTATION TAILINGS ON REMOVAL THE USEFUL COMPONENTS[****]

Abstract

The presented results refer to the investigation of effect the mechanical-chemical activation of flotation tailings on copper, iron and sulfur leaching degree in the sulfuric-chloride solution with the addition of H_2O_2 as oxidant. A sample of the Bor flotation tailings (BFT) from the old Bor flotation tailing dump consists of pyrite and tailings as the main components, and is activated in a dry process of the vibro mill with (BFT1) and without (BFT2) addition of NaOH as the chemical reagent. Using the dry magnetic separation in thed high-gradient magnetic separator Sala, the samples were separated into magnetic and non-magnetic fraction, BFT MF and BFT NMF, respectively.

Leaching of various treated samples showed that the highest level of copper leaching (98.7 wt %), was obtained for BFJ2 MF sample while the leaching degree of Fe and S was higher in non-magnetic fractions, up to 92.46 wt % in BFT1 NMF sample for Fe and 80.62 wt % for S in BFT2 NMF sample.

Key words: *flotation tailings, mechanical-chemical activation, magnetic separation, leaching, Cu, Fe, S*

INTRODUCTION

Mechanical-chemical activation becomes and more significant in the field of mining and metallurgy processing and industrial production of minerals [1]. The effects of mechanical activation refer to the rearrangement of mineral crystal structure by physical processes and obtaining-metal without previous oxidation roasting and therefore without emission of harmful SO_2 gas into the atmosphere.

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Also, the hydrometallurgical processes [2,3] increasingly gain in importance due to more strict environmental regulations.

Technological investigations of treatment the mechanical-chemical activated pyrite from the Bor flotation tailings was aimed to the investigation the effect of mechanical-chemical activation on the leaching degree of copper, iron and sulfur using combined sulfur-chloride solution with addition of H_2O_2 as the oxidizdant. Mechanical-chemical activation of BFT samples was done in the ITNMS-Belgrade laboratories. The efficiency of useful components leaching processes largely depends on mineral and surfaces opening [4]. Solubility rate of elements generally depends on the size of solid particle surface and, for some ore types, the grain size represents the main dissolution factor.

EXPERIMENTS

Physical-chemical characterization of the Bor flotation tailings sample (BFT)

The results of chemical characterization the Bor flotation tailings sample, used for leaching process by the mixed sulfate-chloride solution with addition of H_2O_2 as the oxidant are presented in Table 1, and mineralogical analyse in Table 2.

Table 1. *Chemical analyses of BFT*

Elements	Content wt %
Fe	4.82
S	6.20
Cu–oxide	0.006
Al_2O_3	15.63
SiO_2	61.60
MgO	0.014
Cu–total	0.131
Fe_3O_4	0.359

Table 2. *Mineralogical analyses of BFT*

Minerals	Content wt %
Pyrite	23
Chalcopyrite	0.124
Pyrrhotine	< 1 ppm
Rutile	0.98
Limonite	0.234
Tailings	75.23

The results of sieve analysis, carried out by the standard sieve analysis, on standard TYLER sieve, are shown in Table 3.

Table 3. *Sieve analysis*

Particle size mm	Content wt %
-0.600+0.425	2.40
-0.425+0.300	5.60
-0.300+0.212	10.00
-0.212+0.106	24.80
-0.106+0.075	9.60
-0.075+0.038	11.60
-0.038+0.020	7.20
-0.020	28.80

A valid method of MMI Bor - Determination of Volume Density and Apparent Density (E.b.11: 2007 was used for determination the sample apparent density.

The mechanical-chemical treatment (MC-H) was achieved using the Humboldt Wedag vibrating mill. Mill has the working temperature of about 340 K during the continual work and can achieve the dispersion work at height 7.3 x10^3 KJmol^{-1}. This is according to the literature data [1] the enough energy to cause the splitting of five levels of d orbital of free ferrum ion from pyrite in the octahedral ligand field.

Two experiments of M-CH treatment of BFT were carried out using dry procedure. In the first experiment, an optimal activation of BFT was carried out without addition of reagents (BFT1). In the second experiment, NaOH was added to the amount of 4 wt% (BFT2).

High gradient magnetic separator (HGMS) SALA was used for the magnetic concentration in aqueous medium.

Copper, iron and sulphur leaching investigations from the obtained fractions were tested in laboratory equipment using 0.8 M H_2SO_4 and with addition of 30 % H_2O_2 as the oxidant. The chlorine ions in a form of NaCl salt, with the initial concentration of 1M, were also added into the leaching solution. The leaching process was carried out at the temperature of 90±5°C with 600 min^{-1} stirring, with the proportion of solid: liquid = 1:20, for 8 hours.

The following chemical methods were used for determination the sulphur concentration: the gas volumetry (incineration) in the Mars furnace and copper and iron determination: the atomic absorption spectrophotometer PERKIN ELMER 403.

RESULTS AND DISCUSSION

Magnetic concentrator (HGMS) gives two products, one of which is magnetic fraction (MF) and the other nonmagnetic fraction (NMF). Induction of magnetic field (MP) was chosen to be B = 0.6 T. Paramagnetic minerals, such as pyrite, in the average amount of intensity (MP) have some small mass share of magnetic fraction (MF).

Both M-CH treated samples of BFT were subjected to the magnetic concentration process. The result of separation of some fractions is shown in Table 4. A sample of BFT was subjected to the effect of same magnetic field B = 0.6 T that was not MC-H activated, and had 90g MF and 210g NMF.

Table 4. *Results of magnetic concentration BFT treated by MC-H treatment*

BFT sample	MC-H treatment without chemical reagents	MC-H treatment with NaOH
NMF, g	206	50
MF, g	94	250
Total, g	300	300

For complex:

$$Na\left[\begin{array}{ccc} SO_4 & & Fe^{\cdots}(OH)_3 \\ & Fe^{\cdots} & \\ Fe^{\cdots}(OH)_3 & & SO_4 \end{array}\right]^-$$

Na the value of magnetic moment is

$$\mu_S = \sqrt{1(1+2)} \cdot \mu_B = 2.8\ \mu_B \ (5),$$

and the relationship of magnetic fractions from the experiment of magnetic concentration, Table 4, is also approximately 2.8 (94 x 2.8 = 263.2).

Table 5. *Chemical characterization of fraction obtained by magnetic separation*

Element	Sample designation			
	BFJ1MF wt %	BFJ1 NMF wt %	BFJ2 MF wt %	BFJ2 NMF wt %
Fe	6.30	3.60	5.03	1.83
S	10.70	5.60	7.40	2.70
Cu–oxide	0.005	0.007	0.015	0.019
Al_2O_3	11.79	18.74	15.72	18.50
SiO_2	64.74	62.46	64.10	63.08
MgO	0.026	0.021	0.11	0.026
Cu–total	0.152	0.153	0.135	0.134
Fe_3O_4	0.445	/	/	/

Results of Cu, Fe and S leaching degree from different BFT samples using sulphuric acid solution without NaCl addition in one case, and sulphuric acid solution with NaCl addition in another case, are presented in Figures 1-3. The highest Cu leaching degree 98.75 wt % was obtained using BFT2 MF sample while the highest Fe and S leaching degree was obtained using BFJ1 NMF sample. The results of leaching the useful elements have shown that the possibility of Cu, Fe and S leaching have the same trend for all samples except for the BFJ2 MF sample where Fe leaching degree is lower in mixed sulphate-chloride solution.

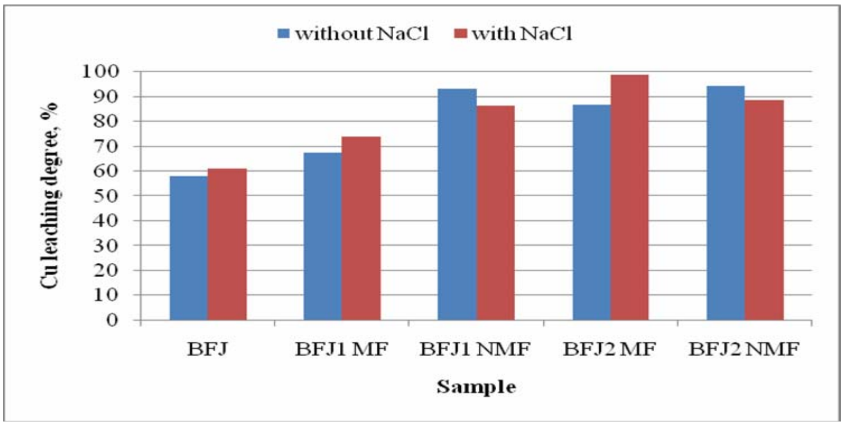

Figure 1. *Cu leaching degree from different BFT samples using various leaching solutions*

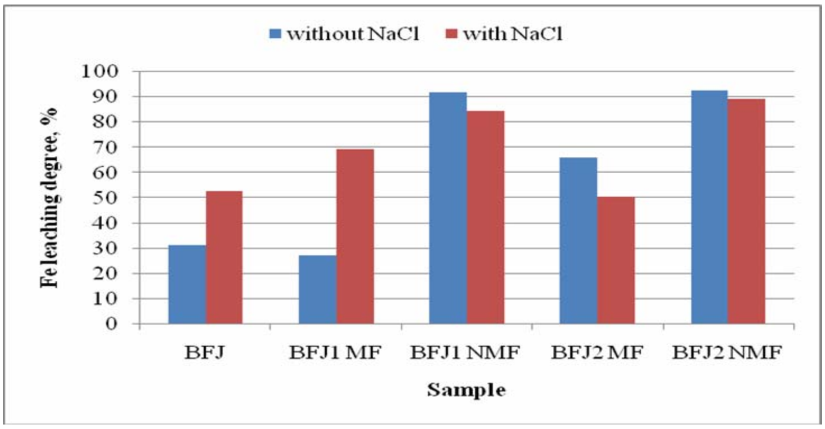

Figure 2. *Fe leaching degree from different BFT samples using various leaching solutions*

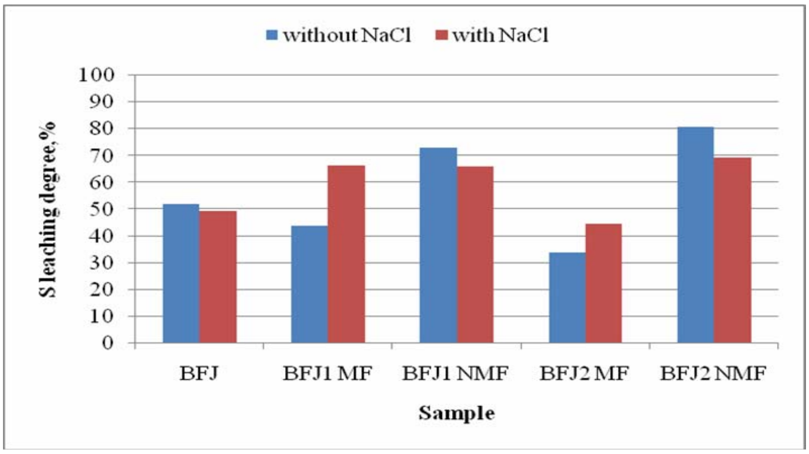

Figure 3. *S leaching degree from different BFT samples using various leaching solutions*

CONCLUSION

Based on realized investigations, it is seen that using MC-H treatment and magnetic concentration may affect a development process that would enable the separation of metallic from non-metallic phase from minerals. Metallic mineral resources have at least ten times higher value compared to non-metallic, and therefore it should be understood in this context the techno-economic development function of given treatment procedure of BFT. Further treatment of metallic and non-metallic fraction leads to obtaining the useful components and creating the conditions for use the modified non-metallic component.

REFERENCES

[1] M. Petrov et all., Mechano-chemical Treatment of Mineral Waste, Mineral Processing, Vol. 2, (2009), pgs. 77-84 (in Serbian)

[2] Z. Y. Lu et all., Hydrometallurgy, 56 (2006), pgs. 189 – 202

[3] A. R. Kamali et all., Mineral Processing of Non-ferrous Metals, Vol. 49, No. 1, (2008),pgs. 138-143.

[4] R. Murphy, D. Strongin, Surface Reactivity of Pyrite and Related Sulphides, Surface Science Reports, November (2008), pgs. 24-36

[5] M. Ilić, Special Mineralogy - Part II", ICS Belgrade, 1978, Belgrade (in Serbian)

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KOMITET ZA PODZEMNU EKSPLOATACIJU MINERALNIH SIROVINA | UDK: 622

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IZDVAJANJE BAKRA KOMBINOVANIM TRETMANOM KOPOVSKE RASKRIVKE KISELIM RUDNIČKIM VODAMA SA LOKACIJE RUDNIKA "CEROVO" I DOBIJANJE SOLI BAKAR-SULFAT PENTAHIDRATA***

Izvod

U radu su prikazani rezultati laboratoriskih istraživanja integralnog tretmana materijala sa lokacije zatvorenog rudnika "Cerovo" i to kopovske raskrivke sa sadržajem bakra od 0.21 mas. % koja je lužena rudničkim kiselim otpadnim vodama u kojima je sadržaj bakra 0.201 g dm-3a sve u cilju dobijanja kristala bakar-sulfata pentahidrata. Ispitivanjem procesa perkolacionog luženja pri različitim vrednostima pH (1.0, 1.5 i 2.0) zadovoljavajući rezultati su postignuti za pH vrednost 1.5 i to: koncentracija bakra 1.08 g dm^{-3} i koncentracija gvožđa 1.11 g dm^{-3}. Ovaj rastvor je podvrgnut procesu solventne ekstrakcije korišćenjem ekstragensa LIX 984N. Rastvor dobijen nakon procesa solventne ekstrakcije i višestepene reekstrakcije imao je sledeće karakteristike: koncentracija bakra - 42.29 g dm^{-3}, sumporna kiselina - 196.25 g dm^{-3} i gvožđe - 0.0017 g dm^{-3} i korišćen je za dobijanje kristala bakar-sulfata pentahirata. Hemijska karakterizacija dobijenih kristala pokazala je da je dobijena so čije hemijske karakteristike zadovoljavaju zahteve standarda za pesticide SRPS H.P1.058.

Ključne reči: *kopovska raskrivka, rudničke kisele otpadne vode, bakar-sulfat pentahidrat*

UVOD

Prisustvo velikih količina vanbilansnih delova ležišta na lokaciji zatvorenog rudnika "Cerovo" - RTB Bor kao i rudničkih voda, predstavlja permanentan izvor zagađenja kako okolnog područja tako i šireg slivnog područja.

Za vreme rada površinskog kopa „Cerovo – Cementacija 1“ i postrojenja za preradu rude, rasturne vode iz pogona za usitnjavanje i provirne vode koje su se pojavljivale po obodu kopa i odložene raskrivke bile su akumilirane u takozvanoj „ekološkoj brani“ i korišćene kao povratne u procesu pripreme rude. Nakon prestanka

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eksploatacije rude, više nije bilo potrebe za tehničkom vodom a u ekološkoj brani su se i dalje akumulirale vode čija je pH vrednost bila između 3 i 4, kao posledica luženja mineralnog sadržaja materijala usled dejstva atmosferilija. Na lokaciji zatvorenog rudnika bakra "Cerovo" nalazi se približno 25.000.000 tona raskrivke sa prosečnim sadržajem bakra od oko 0.2 mas. %. Usled dejstva atmosferskih padavina nastavlja se hemijski tretman ovog materijala, dolazi do formiranja zagađenih morfoloških potočića u kojima se koncentracija bakra kreće i do 1 g dm^{-3}, a koji gravitiraju ka rekama Cerovo, Valja Mare i dalje Kriveljskoj reci. Na taj način dolazi do direktnog ugrožavanja lokalnog stanovništva u reonu slivnog područja reka Cerovo i Kriveljske, koje ove vode koristi za svakodnevnu upotrebu.

Danas se u svetu za preradu sulfidnih bakronosnih ruda koriste pirometalurški procesi koji su ekonomski isplativi za rude bogate bakrom [1,2] dok se hidrometalurški procesi koriste prvenstveno za oksidne i niskosadržajne rude [3,4].

Cilj ovog rada bio je da ispita mogućnost dobijanja bakar-sulfata pentahidrata kombinacijom sledećih procesa: luženje bakra iz kopovske raskrivke rastvorom iz postojeće akumulacije – solventna ekstrakcija u cilju odvajanja bakra – kristalizacija soli bakra iz rastvora obogaćenog bakrom. Rezultati su pokazali da je kombinacijom navedenih procesa moguće dobiti bakar-sulfat pentahidrat čije krakteristike odgovaraju standardu SRPS H.P1.058.

EKSPERIMENTALNA ISTRAŽIVANJA

Karakterizacija uzoraka raskrivke i rudničkih voda sa lokacije rudnika "Cerovo"

Hemijska karakterizacija uzorka raskrivke korišćenog za proces luženja rudničkim vodama akumuliranim u dnu površinskog kopa Cerovo, prikazana je u tabeli 1, a karakterizacija uzorka rudničkih voda koji je korišćen kao rastvor za luženje, u tabeli 2.

Tabela 1. *Hemijska analiza uzorka raskrivke*

Element	Sadržaj, %
Cu_{total}	0.210
Cu_{ox}	0.136
Fe^{2+}	1.680
Fe^{3+}	3.870
Mg	1.530
Mn	0.027
Ca	2.020
Zn	0.009
Cd	/
SiO_2	62.980
Al_2O_3	17.070
Ag (g/t)	0.500
Au (g/t)	0.020

Tabela 2. *Hemijska analiza rudničkih voda*

Element	Sadržaj, g/dm^3
Cu	0.201
Fe	0.095
Ni	0.0004
As	/
Zn	0.026
Mn	0.041

Ostale karakteristike rudničkih voda: pH vrednost - 3.3, boja rastvora – crvena.

Nakon homogenizacije, uzorak raskrivke mase 8.300 g nasut je u kolonu sledećih dimenzija: prečnik – 150 mm, visina – 900 mm, koja je korišćena za proces perkolacionog luženja. Rastvor za luženje ukupne zapremine 20 dm^3, cirkulisao je kroz zatvoreni sistem koji se sastojao od sabirnog rezervoara, hemijske pumpe, dozer rezervoara, sistema cevovoda za povezivanje ovih celina i ventila za regulaciju protoka od 0,300 dm^3 h^{-1}. Vrednost protoka definisana je na osnovu literaturnih podataka za protok rastvora kroz poroznu sredinu tokom luženja bakarnih ruda [5]. Urađene su dve serije eksperimenata u cilju utvrđivanja uticaja pH vrednosti (pH: 1; 1,5 i 2) i koncentracije

Fe^{3+} jona (1; 5 i 10 g dm^{-3}). Svi eksperimenti izvedeni su pri atmosferskim uslovima u trajanju od 120 h uz recirkulaciju rastvora za luženje čija je pH vrednost na ulazu održavana konstantnom.

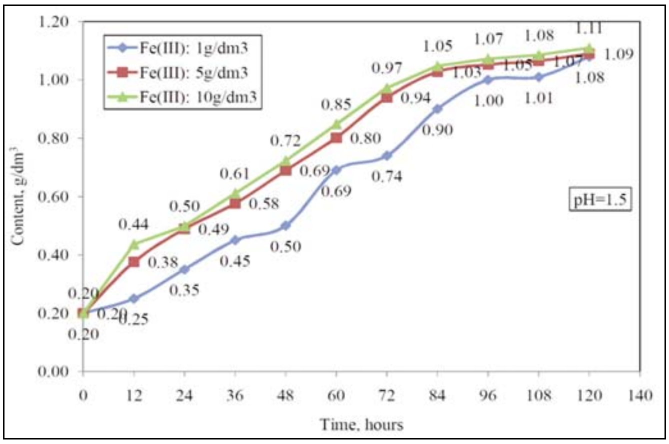
Rastvor dobijen nakon luženja korišćen je za proces solventne ekstrakcije bakra i njegovog koncentrisanja u procesu reekstrakcije. Za proces je korišćen Mixer-settler, tip "Polux C", sa pratećom opremom koja obezbeđuje cirkulaciju i adekvatno mešanje različitih rastvora, čija je zapremina miksera 85 cm^3 a razdvajača 175 cm^3. Kao ekstragens korišćen je 5% rastvor LIX 984N u kerozinu a sam proces se sastojao od dva procesa ekstrakcije pri čemi je odnos vodene i organske faze bio 1:1 i višestepenog procesa reekstrakcije korišćenjem 2M H_2SO_4.

Rastvor dobijen nakon procesa reekstrakcije korišćen je za kristalizaciju bakar-sulfat pentahidrata. Rastvor zapremine 0.400 dm^3 uparavan je uz neprekidno mešanje do vrednosti od oko 1/3 od polazne zapremine. Kristalizacija je ostvarivana naglim hlađenjem uz neprekidno mešanje u cilju postizanja maksimalno mogućeg stepena izdvajanja kristala.

Dobijeni kristali bakar-sulfata pentahidrata podvrgnuti su hemijskoj karakterizaciji saglasno zahtevima standarda SRPS H.P1.058 od 1988. koji se primenjuje za pesticide.

REZULTATI I DISKUSIJA

Rezultati serije eksperimenata tokom koje je ispitivan uticaj pH vrednosti na stepen izluženja bakra, pokazali su da sa porastom pH vrednosti u opsegu 1,0 – 2,0, nakon 120 sati luženja, dolazi do smanjenja sadržaja bakra u rastvoru od 1,08 g dm^{-3} do 0,99 g dm^{-3} što odgovara stepenu izluženja bakra od 79 mass % odnosno 68 mass %, respektivno. Smanjenje stepena izluženja bakra može se objasniti smanjenjem sadržaja prirodnog oksidansa, Fe^{3+} jona, usled formiranja hidroksida gvožđa pri pH-2. Rezultati za koncentraciju gvožđa u lužnom rastvoru potvrđuju da se sa smanjenjem kiselosti rastvora smanjuje i koncentracija izluženog gvožđa, tako je pri pH – 1.0 kon-centracija Fe - 2.28 g·dm^{-3} a pri pH - 2.0 koncentracija Fe je 0.54 g dm^{-3}. Visok sadržaj gvožđa u rastvoru predstavlja ograničavajući faktor za proces ekstrakcije tako da je za dalja istraživanja usvojeno da se za luženje koristi rastvor čija je pH vrednost 1,5 pri čemu su postignute sledeće koncentracije u izlaznom rastvoru: Cu – 1,08 g dm^{-3} i Fe – 1,11 g dm^{-3}.



Sl. 1. *Uticaj različite koncentracije Fe^{3+} jona na izluženje Cu*

Rezultati luženja bakra uz dodatak Fe^{3+} jona kao oksidansa (za koncentracije od (1; 5 i 10 g dm^{-3}), prikazani na slici 1., pokazuju da je stepen izluženja bakra neznatno povećan – za oko 3 % dok je koncentracija gvožđa neodgovarajuća za dalji proces ekstrakcije bakra.

U procesu solventne ekstrakcije i višestepene reekstrakcije bakra iz organske faze dobijen je rastvor sledećeg hemijskog sastava u pogledu sadržaja Cu, Fe i H_2SO_4:

- Cu: 42,29 g dm^{-3},
- H_2SO_4: 196,25 g dm^{-3},
- Fe: 0,0017 g dm^{-3}

Ovaj rastvor je korišćen u procesu dobijanja kristala $CuSO_4 \cdot 5H_2O$ a hemijska karakterizacija je prikazana u Tabeli 3.

Tabela 3. *Hemijska karakterizacija kristala* $CuSO_4 \cdot 5H_2O$

Element	Standard: SRPS H.P1.058	$CuSO_4 \cdot 5H_2O$ kristali
	%	
Cu	24.94 (min 98 mass % $CuSO_4 x 5H_2O$)	25.36
Fe	0.05	0.008
Nerastvorno u H_2O	0.2	0.002
Slobodna H_2SO_4	0.05	0.02
Higroskopna H_2O	1	0.2

Rezultati iz tabele 3., pokazuju da su hemijske karakteristike u skladu sa zahtevima važećeg standarda.

ZAKLJUČAK

Rezultati ispitivanja integralnog tretmana odložene kopovske raskrivke (luženje – solventna ekstrakcija - kristalizacija soli bakra) na lokaciji zatvorenog rudnika Cerovo kiselim rudničkim vodama akumuliranim na istoj lokaciji, pokazuju da je moguće izdvojiti bakar u obliku soli bakar-sulfat pentahidtrata. Primenom navedenog procesa sprečilo bi se nekontrilisano oticanje voda zagađenih štetnim i opasnim materijama sa lokacije zatvorenog rudnika Cerovo koje se preko lokalnih i regionalnih vodotokova Srbije ulivaju u Dunav. Takođe bi se postigao i ekonomski efekat prodajom dobijene soli koja po svojim hemijskim karakteristikama odgovara standardu za pesticide SRPS H.P1.058.

LITERATURA

[1] M. G. King, JOM Vol.59, No.2, (2007) 21.

[2] F. Habashi, Journal of Mining and Metallurgy, Section B. Metallurgy, 43(1)B (2007)

[3] Z. Stevanović i dr., Journal of Mining and Metallurgy 45 B (1) (2009) 45 – 57

[4] Lj. Obradović i dr., Rudarski radovi, br.1, (2009), 65-72.

[5] E. Cariaga i dr., Chemical Engineering Journal, 111(2-3) (2005), 151.

[6] Lj. Todorović, J. Petrović, Spectrofotometric determination of iron in copper electrolyte and products of electrolyte regeneration, časopis Bakar, br. 1, 2010 god., str. 41-48

[7] N. Mijatović, J. Petrović, Lj. Todorović, Comparative rezults of copper contents in samples of ore, slag and copper concentrate from flotation Veliki Krivelj, časopis Bakar, br. 1, 2010 god., str. 49-62

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COPPER REMOVAL USING THE COMBINED TREATMENT OF OVERBURDEN BY THE ACID MINE WATER FROM THE ABANDONED COPPER MINE "CEROVO" AND OBTAINING THE COPPER-SULPHATE PENTAHYDRATE***

Abstract

This paper presents the results of combined laboratory treatment the materials from location of the abandoned copper mine Cerovo as well as the overburden with copper content of 0.21 wt % , leached with the waste mine acid water with copper content of 0.201 g dm^{-3}, aimed to the obtaining the copper-sulphate pentahydrate cristals. The investigation of percolation leaching process at different pH values (1.0, 1.5 i 2.0) has given the satisfactory results for pH value of 1.5 and: copper concentration of 1.08 g dm^{-3} and iron concentrationi of 1.11 g dm^{-3}. This solution was used for the SX process using the extraction reagent LIX 984N. The characteristics of the solution, obtained during the extraction and multi-stage reextraction stage: copper concentration - 42.29 g dm^{-3}, sulphuric acid concentration- 196.25 g dm^{-3} and iron concentration - 0.0017 g dm^{-3}, and this solution was used for obtaining the copper-sulphate pentahydrate. The chemical characterization shown that the salt with chemical characteristics, according to the Standard for pesticides SRPS H.P1.058, was obtained using this combined treatment,

Key words: *overburden, waste mine acid water, copper-sulphate pentahydrate*

INTRODUCTION

The presence of large quantities of off-balance parts on the location of abandoned copper mine "Cerovo"-RTB Bor as well as the acid mine drainage (AMD) water, is a permanent source of pollution both the surrounding areas and wider catchment area. During the mining activities of the open pit “Cerovo – Cementacija 1“ and operation of the ore processing plant, the waste technological water from the plant for grinding and leachates, appeared on the edge of the mine and overburden, were accumulated in the so-called "ecological dam"; and used as the feedback in the ore preparation process. After cessation of ore exploitation, there was no need for technical water, but the solutions with pH values between 3 and 4, were still accumulated in

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the "ecological barrier" as the result of leaching the mineral content of materials due to the atmospheric conditions.

Approximately 25 million tons of overburden, dumped with the average copper content of about 0.2 wt %, is situated in the site of the closed copper mine "Cerovo".

Due to the atmospheric conditions, the chemical treatment of this material was continued; the polluted streams are formed with copper concentration of about 1 gdm^{-3} and gravitate to the rivers Cerovo, Valja Mare and further to the Krivelj river.

Thus, the direct threat of local population appears in the catchment areas of the rivers Cerovo and Krivelj, who use this water for everyday use.

Today, in the world, the pyrometallurgical processes are used for processing the sulphide copperbearing ores because they are economically profitable for high-grade copper ores [1,2] while the hydrometallurgical processes are primarily used for oxide ore and low-grade copper ores[3,4].

The aim of this paper was investigation the possibility of copper-sulphate pentahydrate production using the combination of following processes: the copper leaching from overburden using the waste solutions from the existing accumulation – SX process aimed to the copper concentration – copper salt crystallization from the pregnant solution. The results were shown that copper-sulphate pentahydrate, according to the Serbian Standard SRPS H.P1.058, is possible to obtain using the combination of mentioned processes.

EXPERIMENTS

Characterization of the Cerovo overburden and mine water samples from the "Cerovo" mine

Chemical characteristics of overburden sample, used for the leaching process by the use of AMD water, accumulated on the open pit bottom, are presented in Table 1, and the characteristics of AMD water sample, used as the leaching solution, in Table 2.

Table 1. *Chemical analyses of overburden sample*

Element	Content, wt %
Cu_{-total}	0.210
Cu_{ox}	0.136
Fe^{2+}	1.680
Fe^{3+}	3.870
Mg	1.530
Mn	0.027
Ca	2.020
Zn	0.009
Cd	/
SiO_2	62.980
Al_2O_3	17.070
Ag (g/t)	0.500
Au (g/t)	0.020

Table 2. *Chemical analyses of AMD water sample*

Element	Concentration, g dm^{-3}
Cu	0.201
Fe	0.095
Ni	0.0004
As	/
Zn	0.026
Mn	0.041

The other characteristics of AMD water sample are: pH value - 3.3, colour – red.

After homogenization, the overburden sample of 8300 g was poured into column of the following size: diameter – 150 mm, height – 900 mm, which was used for the percolation leaching process. Solution for the leaching (total volume 20 dm^3) was circulated through the closed system, consisted of collecting tank, chemical pump, dozer tank, piping system for these units connection and a control valve for 0.300 dm^3 h^{-1} flow rate. The flow rate value was defined according to the literature data for flow rate through porous materials during the copper ore leaching process [5]. Two different series of experiments were carried out to the aim of determining the influence of pH values (pH: 1, 1.5 and 2) and initial concentration of Fe^{3+} ions (1, 5 and 10 g dm^{-3}). All experiments were performed in the atmospheric conditions for the period of 120 h, with recirculation of leaching solution with constant pH value at the inlet.

The obtained solution upon leaching was used for the process of copper solvent extraction and its concentration. Mixer-Settler, type "Polux C", was used for the process, with support equipment for providing the circulation and suitable mixing of different solutions. The mixer volume was 85 cm^3 and settler volume 175 cm^3.

As the extraction reagent, 5% solution of LIX 984N in kerosene was used and the process consisted of two extraction processes and a multi-stage process of copper re-extraction using 2M H_2SO_4 (SX-process).

The loaded solution, obtained after the re-extraction process, was used for crystallization the copper sulphate pentahydrate. Solution volume of 0.400 dm^3 was evaporated with continuous stirring to the value of about 1/3 of initial volume. Crystallization was realized by the rapid cooling with continuous stirring in order to achieve the maximum possible separation degree of crystals.

The resulted crystals of copper-sulphate pentahydrate were subjected to the chemical characterization according to the requirements of Serbian Standard SRPS H.P1.058 1988, which is applied to pesticides.

RESULTS AND DISCUSSION

The results of series of experiments, where the effect of pH value on copper leaching degree was investigated, showed that with increased pH value in the range 1.0-2.0, after 120 hours of leaching, copper content in the solution decreased in the range from 1.08 g dm^{-3} to 0.99 g dm^{-3} what corresponds to the copper leaching degree in the range from 79 wt % to 68 wt %, respectively. Decreasing the copper leaching degree could be explained by lowering the content of natural oxidant, Fe^{3+} ions, due to the formation of iron hydroxide at pH-2. The results of iron concentration in the leaching solutions confirm that decrease of leaching solution acidity causes decreasing of leached iron concentration; for example, at pH-1.0, the iron concentration is 2.28 g dm^{-3} and, at pH-2.0, the iron concentration is 0.54 g dm^{-3}. High content of iron in the solution presents the limit factor for extraction process; therefore the leaching solution with pH value of 1.5 is adopted for further investigations. The following concentrations were realized in the output solution: Cu – 1.08 g dm^{-3} and Fe – 1.11 g dm^{-3}.

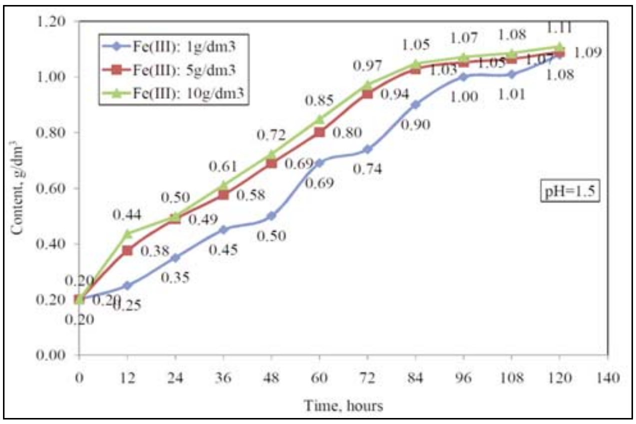

Figure1. *The effect of various concentrations of Fe^{3+} ions on copper leaching degree*

The results of copper leaching process with the addition of Fe^{3+} ions as the oxidizing agents (concentrations of 1.0, 5.0 and 10 g dm^{-3}), shown in Figure 1, have indicated that the copper leaching degree is slightly increased - about 3%, while the concentration of iron was unsuitable for further process of copper extraction.

The obtained solution after the re-extraction process of Cu from the organic phase has the following chemical composition:

- Cu concentration: 42.29 g dm^{-3},
- H_2SO_4 concentration: 196.25 g dm^{-3},
- Fe concentration: 0.0017 g dm^{-3}

This solution was used for the copper sulphate salt crystallization process and the chemical characterization is given in Table 3.

Table 3. *Chemical characterization of $CuSO_4 \cdot 5H_2O$*

Element	Standard: SRPS H.P1.058	$CuSO_4 \cdot 5H_2O$ crystals
	%	
Cu	24.94 (min 98 wt % $CuSO_4x5H_2O$)	25.36
Fe	0.05	0.008
Insoluble in H_2O	0.2	0.002
Free H_2SO_4	0.05	0.02
Hygroscopic H_2O	1	0.2

The results from Table 3, show that the chemical properties are in accordance with the requirements of valid Standard.

CONCLUSION

The results of combined treatment testing the overburden with AMD, accumulated in the abandoned copper mine "Cerovo", show that it is possible to extract copper in the form of copper-sulphate pentahydtrate (leaching - solvent extraction-crystallization of copper salt). Applying this process, it could be prevented the leakage of water contaminated with harmful and dangerous materials from the site of the closed mines "Cerovo" that through local and regional rivers empty into the Danube river. Also, the economic effect could be achieved by selling the salt with chemical properties in accordance with the Standard for pesticides SRPS H.P1.058.

REFERENCES

[1] M. G. King, JOM Vol. 59, No.2, (2007) 21.

[2] F. Habashi, Journal of Mining and Metallurgy, Section B. Metallurgy, 43(1)B (2007)

[3] Z. Stevanović et all., Journal of Mining and Metallurgy 45 B (1) (2009), pgs. 45-57 (in Serbian)

[4] Lj. Obradović et all, Mining Engineering, No.1, (2009), pgs. 65-72 (in Serbian)

[5] E. Cariaga et all., Chemical Engineering Journal, 111(2-3) (2005), pg.151.

[6] Lj. Todorović, J. Petrović, Spectrofotometric determination of iron in copper electrolyte and products of electrolyte regeneration, Cooper Journal, No. 1, 2010 g., pp. 41-48

[7] N. Mijatović, J. Petrović, Lj. Todorović, Comparative rezults of copper contents in samples of ore, slag and copper concentrate from flotation Veliki Krivelj, Cooper Journal, No.1, 2010g., pp.49-62

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