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CONTENS

SADR@AJ

MINING AND METALLURGY INSTITUTE BOR
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Ivana Mojsić[*], *Dejan Sokolović*[*]

ANALYSIS OF APPROVED EXPLORATION AREAS FOR DETAILED GEOLOGICAL EXPLORATIONS, VERIFIED RESERVES OF SOLID MINERAL RESOURCES AND INVESTMENTS IN THE PERIOD 2010-2014

Abstract

The Ministry of Mining and Energy (MME) in accordance with the Law on Mining and Geological Explorations ("Official Gazette RS" No. 88/2011) issues a solution for detailed geological explorations in the area of the Republic of Serbia, except the province of Vojvodina. This paper gives an analysis the approved exploration areas for detailed geological explorations, investments and verified reserves of solid mineral resources in the period 2010-2014.

Keywords: *MME, metals and nonmetals, detailed geological explorations, metallic raw materials, nonmetallic raw materials, reserves*

1 INTRODUCTION

Considering the overview of approved exploration rights for detailed geological explorations and verified reserves of mineral resources, certainly it must be taken into account that these analyses provide a broader picture of general condition for capital interest in geological explorations in Serbia.

2 THE EXISTING LEGAL REGULATIVE

The Ministry of Mining and Energy (MME) in accordance with the Law on Mining and Geological Explorations ("Official Gazette RS" No. 88/2011) issues a solution for detailed geological explorations in the area of the Republic of Serbia, except the province of Vojvodina. By this Law, in Article 1, among other things is that “this law regulates the conditions and method of performance the geological explorations and utilization the results of these explorations”.

In addition, this law also regulates development the studies on completed geological explorations, Article 3, paragraph 19 of this law states that the “study on the resources and reserves of mineral resources, groundwater and geothermal resources is a document on the results of geological explorations [1].

Development the study on geological explorations is regulated by the “Rulebook on contents of projects of geological explorations and studies on results of geological explorations” (“Official Gazette of RS” No. 51/96). This Rulebook shall determine the contents of projects of geological explorations and studies on results of geological explorations [2].

In accordance with the Law on Mining and Geological Explorations (“Official Gazette of RS” No. 88/2011), the company

[*] *Ministry of Mining and Energy of the Republic of Serbia*

exploiting mineral raw materials submits the study to the relevant Ministry on classification the reserves of mineral raw materials on exploratory or exploitation area for the purpose of determining and verifying the mineral reserves. Determining and verification of sorted mineral resources is performed by a commission formed by the minister in charge of geology.

3 APPROVED EXPLORATION RIGHTS FOR DETAILED GEOLOGICAL EXPLORATIONS

Analyzing the approved detailed geological explorations in the past five years, more precisely since the beginning of 2010 until the end of 2014, a significant variability in the number of approved investigations by years can be observed. The total of 413 geological explorations of various mineral raw materials was approved. By years, it looks like in Table 1.

Table 1 *Review of approved explorations by years*

Year	**2010**	**2011**	**2012**	**2013**	**2014**	**Total**
No. of explorations	108	111	115	41	38	413

Processed data are related to the approved research in the specified period regardless of whether they are later extended, terminated, completed or interrupted for various reasons.

Figure 1 presents the number of approved detailed geological investigations by years.

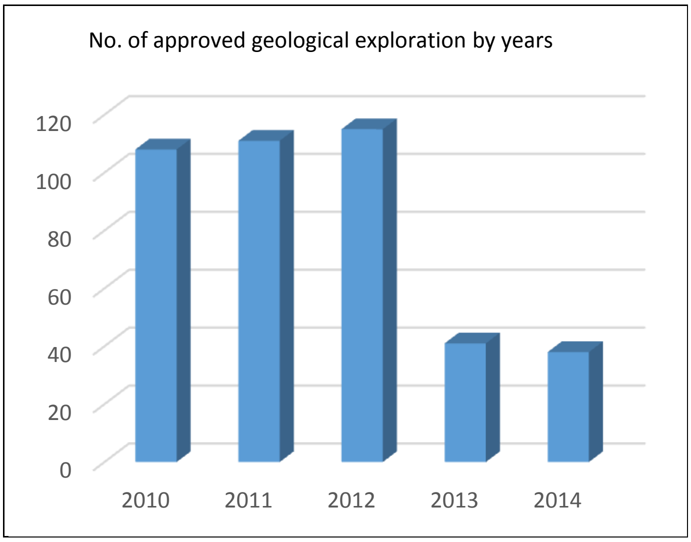
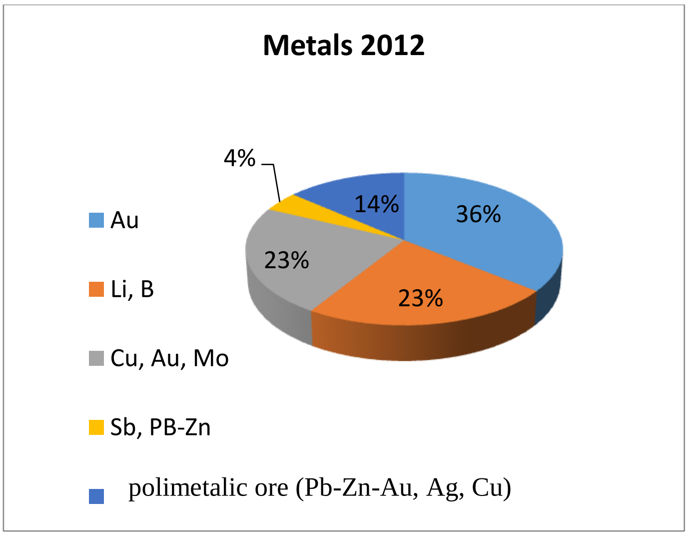


Figure 1 *Detailed geological explorations*

Data are individually processed for each year, by type of mineral resources which are approved for exploration as well as total for the entire period. Mineral resources of 28 kinds are selected, provided that mineral resources that are being explored from the same occurrences (for certain exploration field, paragenesis), are treated as one kind of raw material.

In total share of metallic and nonmetallic raw materials by years depending on exploratory year, a greater variability of exploration was observed in the field of mineral resources while the interest in nonmetallic mineral resources is more or less constant in each year. Figure 2 presents the percentage share of types of mineral resources within the procedures of approved detailed geological explorations in 2012.



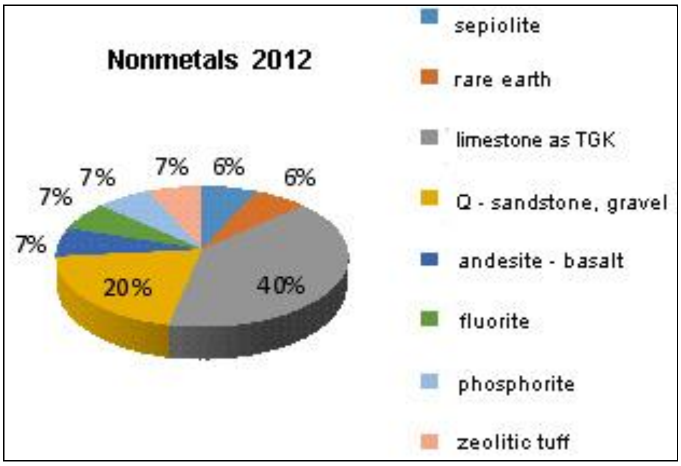


Figure 2 *Approved geological explorations in 2012, metals - nonmetals*

In terms of issued approvals for detailed geological explorations, the year 2012 is clearly separated during which the highest number of approvals was issued and therefore it deserves a separate analysis due to the observed trend of increasing interest in exploration of metallic mineral resources.

Just in 2012, the metallic mineral raw materials were explored on 95 exploration areas, and nonmetallic raw materials on 17 exploration areas, while geocological or geotechnical explorations were approved on remaining 3 exploration areas within the mine waste dump in Bor, the factory "Magnohrom" and PD "TE-KO Kostolac". In 2012, the greatest interest was shown for gold exploration (34 exploration areas or 36%), lithium and boron (22 exploration areas or 23%), ore of copper, gold and molybdenum (22 exploration areas or 23%), as well as polymetallic ores Pb-Zn-Au-Ag-Cu (13 exploration areas or 14%) and antimony ore (4 exploration areas or 4%). It can be seen on a diagram of nonmetallic mineral resources that particularly interesting geological explorations were for rare earth (RE from lanthanide) and sepiolite as nontraditional mineral resources and zeolitic tuff. In accordance with the multi-year research explorations, in 2012, earlier started explorations were continued for oil and gas in the entire territory of the Republic of Serbia; coal in the western part of the Kostolac coal basin and the western field of the coal bearing basin Sjenica; gold on the exploration areas “Potaj Čuka Tisnica” and "Breza" near Bor as well as lithium within the Jadar basin [4].

Geological explorations in 2014 were approved for different mineral resources, mainly metallic (gold on 4 exploration filds (17%), ore of copper, gold and associated metals on 8 exploration fields (29%); boron and lithium-B, Li on 3 exploration fields (13%), lead and zinc ore on 2 exploration fields (8%), Pb, Zn, Ag (13%) on 3 exploration fields, polymetallic ore (4%); iron ore on one exploration field and others.), and coal of energy resources.

In nonmetallic raw materials, the interest significantly increased in brick clay (28%), quartz quartz sandstone (18%), limestone (18%), dacite, zeolitic tuff, marble onyx (Figure 3). Metallic raw materials are investigated on 24 exploration areas, which make 63% of the total number (38) of approved explorations (Figure 4). If previously approved explorations of mineral resources are taken into account, which are still active, it appears that in 2014, the geological explorations of these mineral resources were performed on total of one hundred and thirty five (135) exploration areas. During 2014, earlier started explorations were continues such as lithium and boron in the Jadar neogene basin, gold in sedimentary formations, west of the Timok Magmatic Complex on exploration areas "Potaj Čuka Tisnica", gold on exploration areas "Brestovac-Jasikovo", “Ždrelo - Goli vrh“, “Železnik-Topla-Bor Lake-Manojlica“ and “Breza” near Bor, copper-gold on exploration area "Brestovac-Jasikovo", oil and gas on the whole territory of Serbia, coal in the western part of the Kostolac coal basin and others. Compared to the past few years, the explorations of architectural and technical construction stone have significantly stagnated both sedimentary (limestone and dolomite) and volcanic rocks.

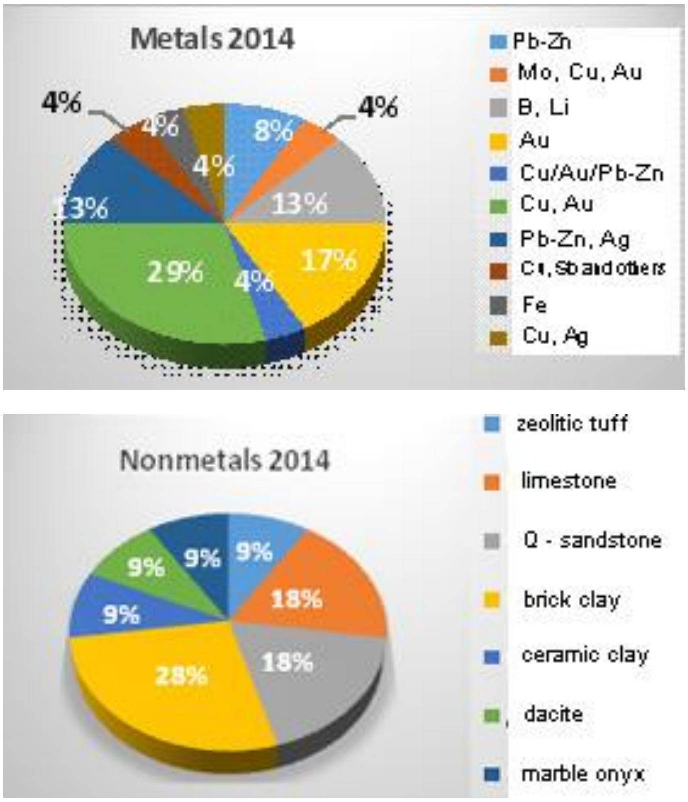


Figure 3 *Approved detailed geological explorations in 2014, metals - nonmetals*

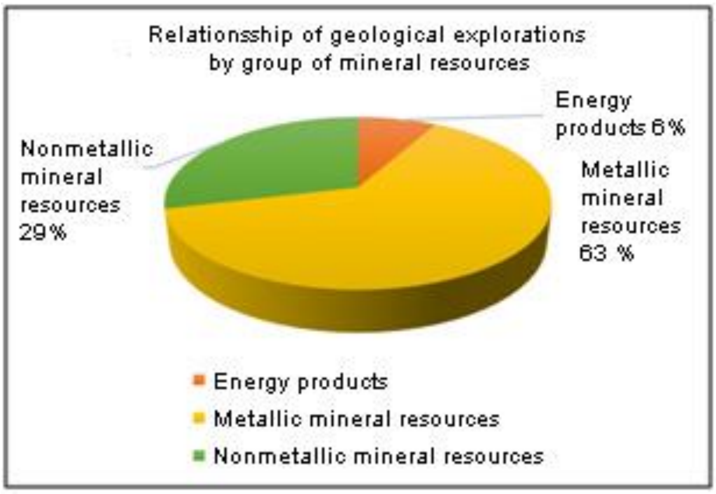


Figure 4 *Relationship of geological explorations by groups of mineral raw materials - 2014*

3.1 Conclusion on Approved Exploration Rights for Detailed Geological Explorations

Based on the above mentioned, it can be stated that the approvals for geological explorations of mineral raw materials were the most intense in 2012 and this year represents the year with almost double number of the new exploration rights than the approved ones in 2013 and 2014, together. This can be partly explained by higher interest of mainly foreign companies and continuing exploration trends from the previous period. After 2012, there was a sudden fall in the new approvals for exploration and in the last two years it is kept at ten-year minimum. The year 2014 presents the year with the least number of new explorations.

4 VERIFIED RESERVES OF MINERAL RESOURCES

On the territory of Serbia, the total of 147 reserves of mineral resources was verified. Based on the Book of Balance (2010, 2011, 2012, 2013 and 2014 - in preparation) by years, it looks like in Table 2.

Table 2 *Verified reserves by years*

Year	**2010**	**2011**	**2012**	**2013**	**2014**	**Total**
No. of reserves	38	49	24	17	19	147

The processed data are related to the total verified reserves, regardless of whether those are innovated reserves, verified reserves in the existing mining field or after presented explorations.

Figure 5 presents a graph showing the relationship of verified reserves of mineral raw materials by years.

Figure 5 *Verified reserves by years*

4.1 Conclusion on verified reserves of mineral resources

From verified mineral reserves, the total of 147 reserves was verifies, out of which the largest number of 49 un 2011. The largest number of verified reserves, as well as in exploration, was for raw materials for use in construction as architectural-construction stone and technical-construction stone.

5 INVESTMENTS OF DESIGNED EXPLORATION WORKS

Total value of all designed exploration works, approved in 2014, amounts to 344,194,440 RSD, or about € 2,821,266 (1 € = 122.0 RSD). If the value of exploration works, transferred from previous years ≈77,106,250 RSD (referring to the same projects from previous years) is added to this sum and the value of investments in several major multi-year projects of geological explorations of mineral resources, which are entered in the second or third phase of exploration, except oil and gas, which amounts to 2,621,189,103 RSD, it follows that the value of investments in geological explorations of mineral resources in 2014 amounted to approximately: 3,042,489,793 RSD or around € 24,938,441.

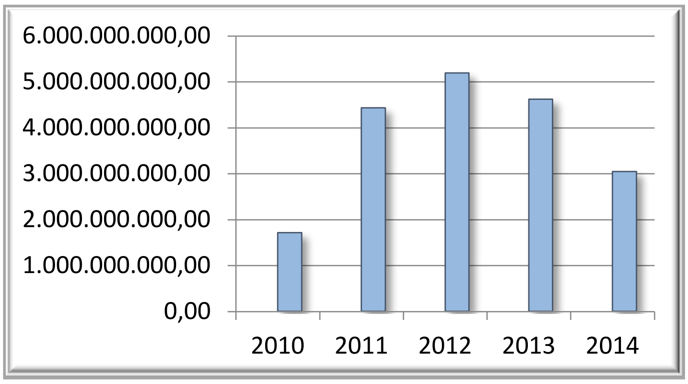


Figure 6 *Investments in Euros*

CONCLUSION

Investments in the field of geological explorations in Serbia for the period 2010 to the end of 2014 had different trends. It turned out that the highest intensity of increase was in 2012, and later in 2013 and 2014 there was a decline in issued approvals for detailed geological explorations, as it can be seen in the shown diagrams. A significant decline was registered in 2014.

High sensitivity of this industrial branch can be seen through the presentation of this basic analysis, whereby it should be noted that the expected increase in the plan of intensifying the geological explorations in the next period.

These analyses open a space for further data processing in this way. Further data processing is imminent, in terms of the rela tionship between the number of new exploration rights and verified reserves in the same areas, as well as the ratio of the number of old and innovated reserves. Also, comparative analyses can be further carried out by municipalities, as well as the areas of exploration works with the areas where the reserves are verified. Very interesting analyses, in addition, would be also to referred to the graphic presentation of relationship of the obtained exploration rights by raw materials, years and municipalities [7].

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[1] Law on Mining and Geological Explorations ("Official Gazette of RS" No. 88/2011), 2011;

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Ivana Mojsić, Dejan Sokolović**

ANALIZA ODOBRENIH ISTRAŽNIH PROSTORA ZA DETALJNA GEOLOŠKA ISTRAŽIVANJA, OVERENIH REZERVI ČVRSTIH MINERALNIH SIROVINA I INVESTICIJA U PERIODU 2010 - 2014. GODINE

Izvod

Ministarstvo rudarstva i energetike (MRE) u skladu sa Zakonom o rudarstvu i geološkim istraživanjima („Službeni glasnik RS" broj 88/2011), izdaje rešenja za detaljna geološka istraživanja na području Srbije, osim pokrajine Vojvodine. U ovom radu analizirani su odobreni istražni prostori za detaljna geološka istraživanja, investicije i overene rezerve čvrstih mineralnih sirovina u periodu od 2010-2014 godine.

Ključne reči: *MRE, metali i nemetali, detaljna geološka istraživanja, metalične mineralne sirovine, nemetalične mineralne sirovine, rezerve*

1. UVOD

Kada je reč o pregledu podataka odobrenih istražnih prava za detaljna geološka istraživanja i overenim rezervama mineralnih sirovina, svakako se moraju uzeti u obzir da ove analize daju jednu širu sliku opšteg stanja zainteresovanosti kapitala za geološka istraživanja u Srbiji.

2. POSTOJEĆA ZAKONSKA REGULATIVA

Ministarstvo rudarstva i energetike (MRE) u skladu sa svojim nadležnostima po Zakonu o rudarstvu i geološkim istraživanjima („Službeni glasnik RS" broj 88/2011), izdaje odobrenja za detaljna geološka istraživanja na području Srbije, osim pokrajine Vojvodine. Ovim zakonom, u članu 1. između ostalog stoji, da se „ovim zakonom uređuju uslovi i način izvođenja geoloških istraživanja i korišćenja rezultata tih istraživanja".

Osim toga, ovaj zakon uređuje i izradu elaborata o završenim geološkim istraži vanjima, čl. 3., stav 19. ovoga zakona kaže, da „elaborat o resursima i rezervama mineralnih sirovina, podzemnih voda i geotermalnih resursa je dokument o rezultatima geoloških istraživanja [1].

Izrada elaborata o geološkim istraživanjima regulisana je „Pravilnikom o sadržini projekata geoloških istraživanja i elaborata o rezultatima geoloških istraživanja" („Službeni glasnik RS" broj 51/96). Ovim pravilnikom bliže se određuje sadržina projekata geoloških istraživanja i elaborata o rezultatima geoloških istraživanja [2].

U skladu sa Zakonom o rudarstvu i geološkim istraživanjima („Službeni glasnik RS" broj 88/2011) preduzeće koje vrši eksploataciju mineralnih sirovina dostavlja

* *Ministarstvo rudarstva i energetike Republike Srbije*

resornom Ministarstvu elaborat o razvrstavanju rezervi mineralnih sirovina na istražnom, odnosno eksploatacionom prostoru radi utvrđivanja i overavanja rezervi mineralnih sirovina. Utvrđivanje i overu razvrstanih mineralnih sirovina vrši komisija koju obrazuje ministar nadležan za poslove geologije.

3. ODOBRENA ISTRAŽNA PRAVA ZA DETALJNA GEOLOŠKA ISTRAŽIVANJA

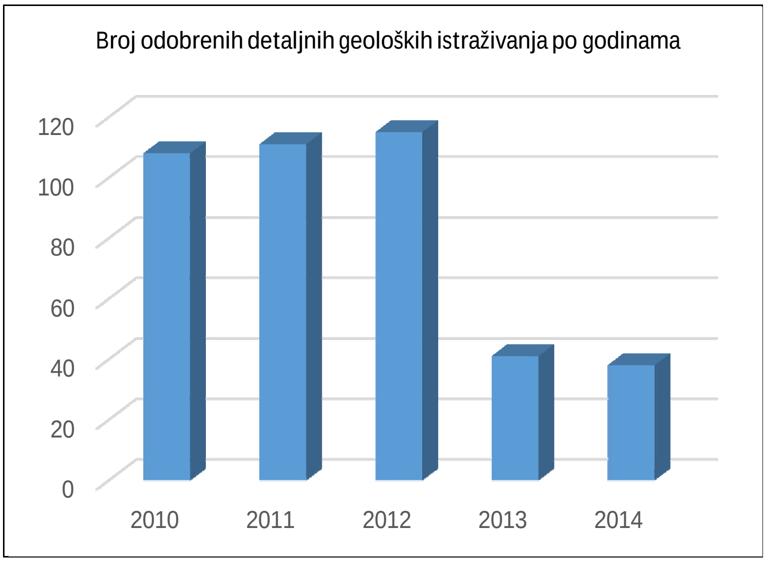
Analizirajući odobrena detaljna geološka istraživanja u prethodnih pet godina, tačnije od početka 2010. godine, pa do kraja 2014. godine, može se uočiti značajna promenljivost u broju odobrenih istraživanja po godinama. Ukupno je odobreno 413 geoloških istraživanja za različite mineralne sirovine, po godinama to izgleda kao u tabeli 1.

Tabela 1. *Prikaz odobrenih istraživanja po god.*

Godina	**2010.**	**2011.**	**2012.**	**2013.**	**2014.**	**Ukupno**
Broj istraživanja	108	111	115	41	38	413

Obrađeni podaci se odnose na odobrena istraživanja u naznačenom periodu bez obzira da li su kasnije produžena, ukinuta, završena ili prekinuta iz različitih razloga.

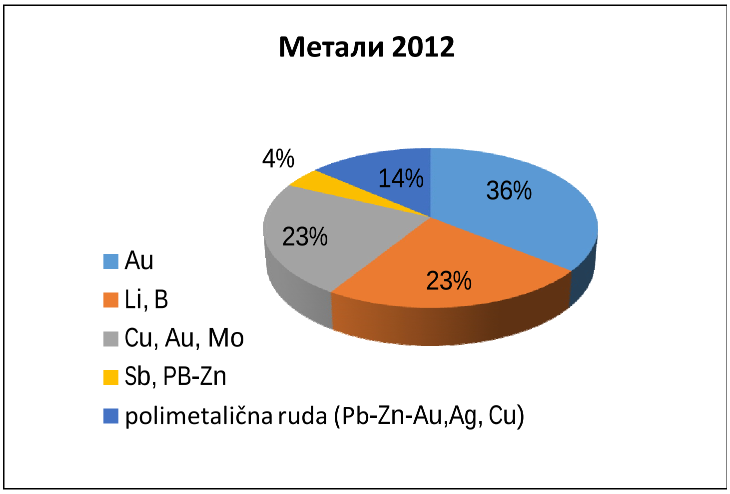
Na slici 1. prikazan je broj odobrenih detaljnih geoloških istraživanja po godinama.

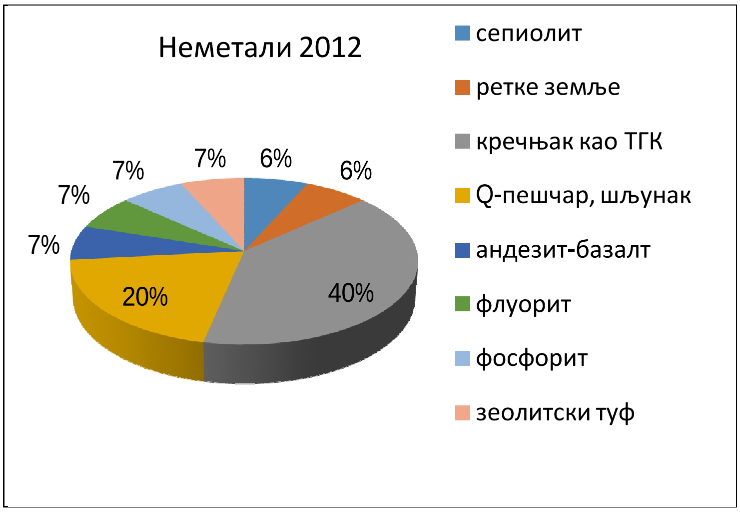


Sl. 1. *Detaljna geološka istraživanja*

Obrađeni su podaci pojedinačno za svaku godinu, po vrsti mineralne sirovine koje su odobrene za istraživanje, kao i ukupno za ceo period. Izdvojene su 28 vrste mineralnih sirovina, s tim, da su sirovine koje se istražuju iz istih pojava (za određeno istražno polje, parageneza), tretirane kao jedna vrsta sirovine.

U ukupnom udelu metaličnih i nemetaličnih sirovina po godinama u zavisnosti od istražne godine uočena je veća promenljivost istraživanja u oblasti metaličnih mineralnih sirovina dok je zainteresovanost za nemetalične mineralne sirovine manje više, konstantno u svakoj godini. Na slici 2. predstavljeno je procentualno učešće vrsta mineralnih sirovina u okviru postupaka odobrenih detaljnih geoloških istraživanja u 2012. godini.





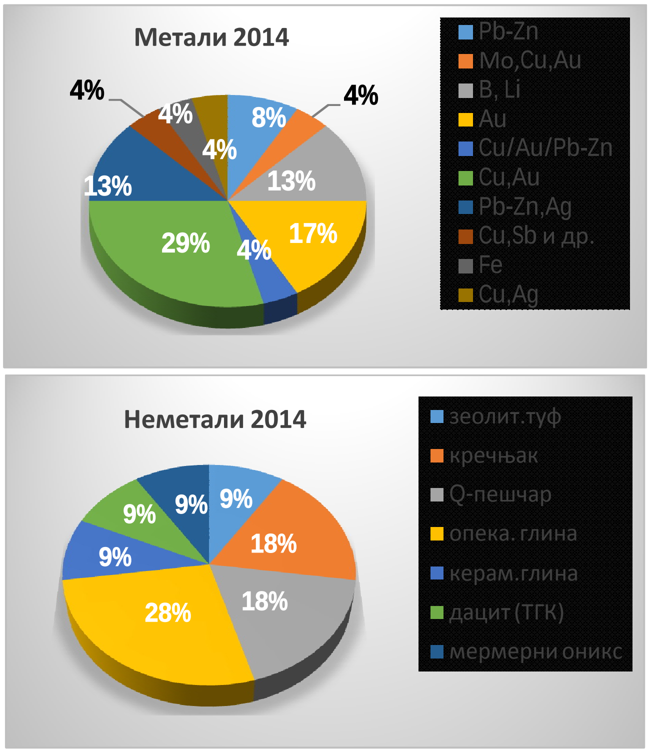
Sl. 2. *Odobrena detaljna geološka istraživanja u 2012. godini, metali - nemetali*

U pogledu izdatih odobrenja za detaljna geološka istraživanja jasno se izdvaja 2012. godina tokom koje je izdat najveći broj odobrenja pa samim tim ona zaslužuje posebnu analizu, jer se uočava trend porasta zainteresovanosti za istraživanja metaličnih mineralnih sirovina.

Samo u 2012. godini na 95. istražnih prostora istraživale su se metalične mineralne sirovine, a na 17. istražnih prostora nemetalične sirovine, dok su na preostala 3. istražna prostora u okviru rudničkog jalovišta u Boru, u krugu fabrike „Magnohrom" i PD „TE-KO Kostolac", bila odobrena geoekološka, odnosno geomehanička istraživanja. U 2012. godini, najveće interesovanje je iskazano za istraživanje zlata (34. istražna prostora ili 36%), litijuma i bora (22 istražna prostora ili 23%), rude bakra, zlata i molibdena (22 istražna prostora ili 23%), kao i polimetaličnih ruda Pb-Zn-Au-Ag-Cu (13 istražnih prostora ili 14%) i rude antimona (na 4. istražna prostora ili 4%). Na dijagramu nemetaličnih mineralnih sirovina vidi se da su bila posebno interesantna geološka istraživanja retkih zemalja (RZ - iz grupe lantanida) i sepiolita, kao netradicionalnih mineralnih sirovina i zeolitskog tufa. U skladu sa projektima višegodišnjih istraživanja, u 2012. godini su nastavljena ranije započeta istraživanja: nafte и gasa na celoj teritoriji Republike Srbije; uglja u zapadnom delu Kostolačkog ugljenog basena i zapadnom polju ugljonosnog basena Sjenice; zlata na istražnim prostorima „Potaj Čuka Tisnica" i „Breza" kod Bora, kao i litijuma u okviru Jadarskog basena [4].

Geološka istraživanja u 2014. godini odobrena su za različitemineralne sirovine, pretežno metalične(zlato na 4 istražna polja (17%), rude bakra, zlata i pratećih metala na 8 istražnih polja(29%); bor i litijum–B, Li na 3 istražna polja (13%), rude olova i cinka na 2 istražna polja (8%), Pb, Zn, Ag (13%) na 3 istražna polja, polimetalična ruda (4%); rude gvožđa na jednom istražnom polju i dr.), a od energetskih sirovina ugalj.

Kod nemetaličnih sirovina značajno je poraslo interesovanje za opekarsku glinu (28%), kvarcni peščar (18%), krečnjak (18%), dacit, zeolitski tuf, mermerni oniks (slika 3). Metalične mineralne sirovine se istražuju na 24 istražnih prostora, što čini 63% od ukupnog broja (38) odobrenih istraživanja (slika 4.). Ako se uzmu u obzir i ranije odobrena istraživanja mineralnih resursa koja su još uvek aktivna, proizilazi da su se u 2014. godini geološka istraživanja ovih mineralnih sirovina izvodila na ukupno sto trideset pet (135) istražna prostora. U toku 2014. godine nastavljena su ranije započeta istraživanja kao što su: litijum i bor u Jadarskom neogenom basenu, zlato u sedimentnim formacijama, zapadno od Timočke eruptivne oblasti, na istražnim prostorima „Potaj Čuka Tisnica", zlato na istražnim prostorima „Brestovac-Jasikovo", „Ždrelo-Goli vrh", „Železnik-Topla-Borsko jezero - Manojlica" i „Breza" kod Bora, bakar-zlato na istražnom prostoru „Brestovac-Jasikovo" nafte i gasa na celoj teritoriji Srbije, ugalj u zapadnom delu Kostolačkog ugljenog basena i dr. U odnosu na prethodnih nekoliko godina, značajno su stagnirala istraživanja arhitektonskog i tehničkog građevinskog kamena, kako sedimentnih (krečnjaka i dolomita) tako i eruptivnih stena.



Sl. 3. *Odobrena detaljna geološka istraživanja u 2014. godini, metali - nemetali*

Sl. 4. *Odnos geoloških istraživanja po grupama mineralni sirovina – 2014. g.*

3.1. Zaključak o odobrenim istražnim pravima za detaljna geološka istraživanja

Na osnovu gore iznetog može se konstatovati da su odobrenja za geološka istraživanja čvrstih mineralnih sirovina bila najintenzivnija u 2012. i ta godina predstavlja godinu sa skoro duplo većim brojem novih istražnih prava, nego odobrenih u 2013. i 2014. godini, zajedno. To se može jednim delom objasniti većom zainteresovanošću pre svega stranih kompanija i nastavkom tendencije istraživanja iz predhodnog perioda. Posle 2012. godine dolazi do naglog pada novih odobrenja za istraživanja i u poslednje dve godine drži se na desetogodišnjem minimumu. Godina 2014. predstavlja godinu sa najmanje novih istraživanja.

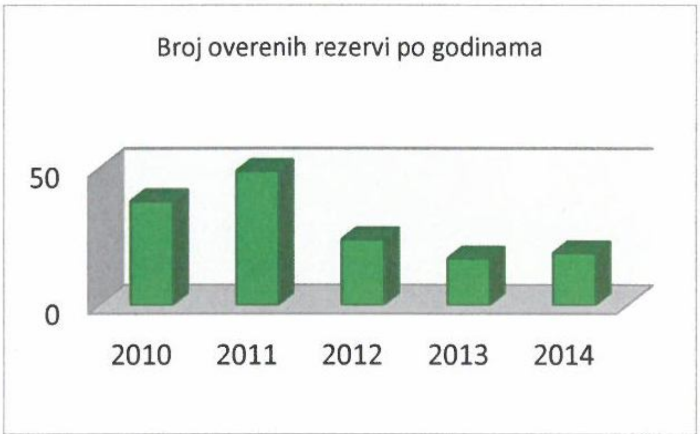
4. OVERENE REZERVE MINERALNIH SIROVINA

Na prostoru Srbije, overeno je ukupno 147 rezervi mineralnih sirovina. Na osnovu Knjige Bilansa (2010, 2011, 2012, 2013 i 2014 – u pripremi) po godinama to izgleda kao u tabeli 2.

Tabela 2. *Overene rezerve po godinama*

Godina	2010.	2011.	2012.	2013.	2014.	Ukupno
Broj rezervi	38	49	24	17	19	147

Obrađeni podaci se odnose na ukupne overene rezerve, bez obzira da li se radi o inoviranim rezervama, overenim rezervama na postojećem eksploatacionom polju ili nakon prikazanih istraživanja. Na slici 5. je grafički prikazan odnos overenih rezervi mineralnih sirovina po godinama.



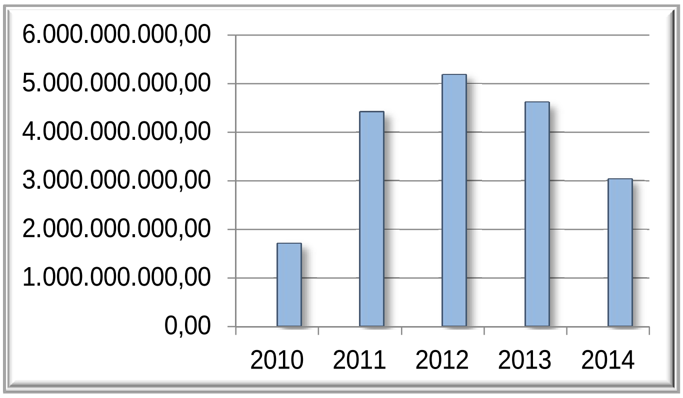
Sl. 5. *Overene rezerve po godinama*

4.1. Zaključak overenih rezervi mineralnih sirovina

Od overenih rezervi mineralnih sirovina ukupno je overeno 147, od čega najviše u 2011. godini, 49. Najveći broj overenih rezervi se kao i kod istraživanja odnosio na sirovine za upotrebu u građevinarstvu i to arhitektonsko-građevinski kamen i tehničko-građevinski kamen.

5. INVESTICIJE PROJEKTOVANIH ISTRAŽNIH RADOVA

Ukupna vrednost svih projektovanih istražnih radova, odobrenih u 2014. godini iznosi: 344.194.440 dinara, ili oko **2.821.266** € (1 € = 122,0 din.). Ako se ovoj sumi doda vrednost istražnih radova prenetih iz prethodnih godina ≈77.106.250 dinara (odnosi se na istraživanja istih projekata iz prêthodnih godina) i vrednost investicionih ulaganja na nekoliko najvećih višegodišnjih projekata geoloških istraživanja mineralnih resursa, koji su ušli u drugu ili treću fazu istra-živanja, sem nafte i gasa koja iznosi 2.621.189.103 din. proizilazi, da je vrednost investicionih ulaganja u geološka istraživanja mineralnih resursa u 2014. godini iznosio približno oko: 3.042.489.793 dinara, ili oko 24.938.441 €.



Sl. 6. *Investiciona ulaganja u evrima*

ZAKLJUČAK

Ulaganje u oblasti geoloških istraživanja u Srbiji za period 2010. god., do kraja 2014., su imala različite trendove. Pokazalo se da je najveći intenzitet porasta bio u 2012. godini, da bi kasnije u 2013 i 2014. godini došlo do opadanja izdatih odobrenja za detaljna geološka istraživanja, što se može videti na prikazanim dijagramima. Značajan pad se registruje u 2014. godini.

Velika osetljivost ove industrijske grane se može videti kroz prikaz ove osnovne analize, pri čemu treba naglasiti da se očekuje porast na planu inteziviranja geoloških istraživanja u narednom periodu.

Ove analize otvaraju prostor za dalju obradu podataka na ovakav način. Predstoji dalja obrada podataka, u smislu odnosa između broja novih istražnih prava i overenih rezervi na istim prostorima, kao i odnos broja starih i inoviranih rezervi. Takođe se dalje mogu vršiti uporedne analize po opštinama, kao i područja na kojima se vrše istražni radovi, sa područjima na kojima se overavaju rezerve. Veoma interesante analize, osim toga, svakako bi se odnosile na grafički prikaz odnosa dobijenih istražnih prava po sirovinama, po godinama i opštinama [7].

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ANALYSIS AND RELATIONSHIP OF SAFETY COEFFICIENT (Fs) AND CRITICAL FACTOR OF INFLUENCE THE STRESS REDUCTION (SRF) IN THE CASE OF EXTERNAL WASTE DUMP OF THE EAST WASTE DUMP - PROFILE III-III OPEN PIT "GACKO" GACKO***

Abstract

Analyzing the slope stability of work levels, final slopes and slope system was carried out in the area of the open pit "Gacko" according to the criteria required by the law of the Republic Srpska. This paper presents a comparative analysis of slope stability with three numerical methods by Bishop, Yanbu and Morgenstern-Price in various pore pressures $r_u=0$, $r_u=0.2$ $r_u=0.4$ and critical factor of influence the stress reduction at the same pore pressures that were already mentioned.

*The analyses of slope stability were carried out with the existing and newly obtained data. The software packages **SLIDE v6.0** and **PHASE^2 v8.0** of company **ROCSCIENCE** were used for calculation methods. The expected result is approximately the same value for the safety coefficient (Fs) and critical factor of influence the stress reduction (SRF) only at that point of analysis.*

Keywords: *stress conditions, stability coefficient, pore pressure*

INTRODUCTION

Analyzing the slope stability of work levels, final slopes and slope system was carried out in the area of the open pit "Gacko" according to the criteria required by the law of the Republic Srpska. This paper presents a comparative analysis of slope stability with three numerical methods.

The analyses of slope stability were carried out with the existing and newly obtained data. The software packages **SLIDE v6.0** and **PHASE^2 v8.0** of company **ROCSCIENCE** were used for calculation methods. Calculation of stability was carried out by the programs **SLIDE v6.0** and **PHASE^2 v8.0** in the conditions of boundary equilibrium according to the criteria that are nowadays used in the world:

- Bishop,
- Janbu,
- Morgenstern-Price,
- as well as using the critical factor of influence the stress reduction (SRF).

The basic characteristics of the programs **SLIDE v6.0** and **PHASE^2 v8.0** are:

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** *Innovation Centre of Faculty of Mechanical Engineering, Belgrade, e-mail: dr.dragan.zlatanovic@gmail.com*
*** *This paper is the result of the Project No. TR 33021 "Research and Monitoring the Changes of the Stress Strain State in the Rock Mass "In-Situ" around the Underground Rooms with Development of Models with Special Reference to the Tunnel of the Krivelj River and Pit Bor", funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia*

SLIDE v6.0 is a program used to analyze the stability of soil and rock masses. This program provides a user - friendly range of analyses, including design, which supports the given analysis, groundwater analysis using the finite element analysis and probability analysis. CAD, which is based on a graphical interface, provides a wide range of interpretations through modeling and data to enable fast and accurate analysss. Files can be transferred to the program **PHASE^2** for slope stability using the finite element method.

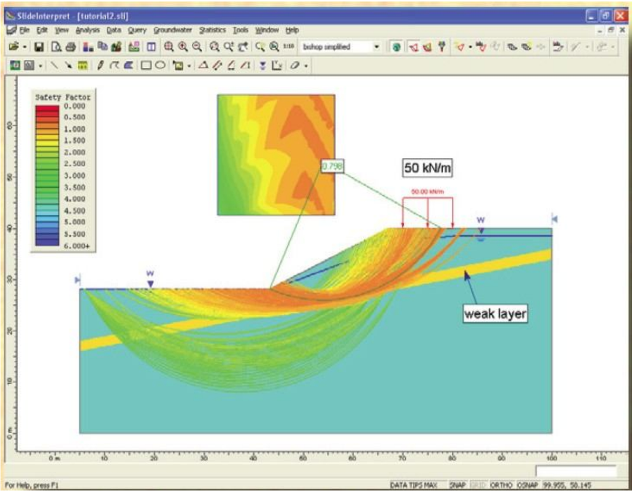

Figure 1 *An example of solving problems using the program SLIDE*

PHASE^2 v8.0 is a powerful 2D program of work based on the analysis of stress using the finite element method for both underground and surface mining of rock or soil. It can be used for a wide range of engineering projects, including the construction of tunnels, slope stability using the finite element, groundwater analysis, network modeling, analysis of probability and beyond. This program can quickly create and analyze a complex condition of models in several phases.

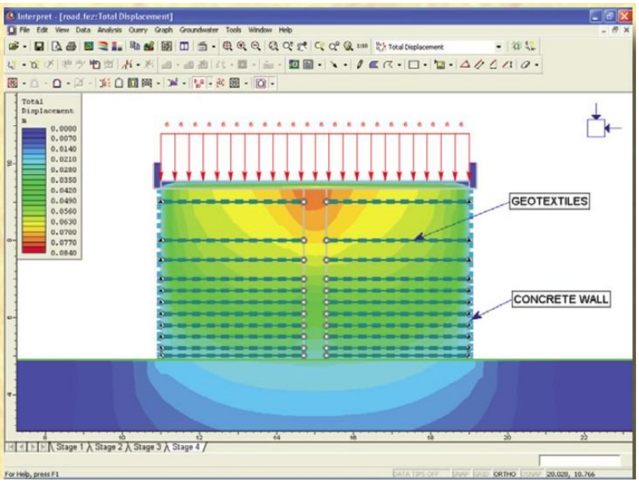

Figure 2 *An example of solving problems using the program PHASE2*

COURSE OF TESTING AND ANALYSIS OF STABILITY DATA

All geomechanical results obtained in some previously realized measurements were used as input data for programs **SLIDE v6.0** and **PHASE^2 v8.0**.

Slope stabilities are analyzed using the numerical methods by Bishop, Janbu and Morgenstern-Price while the stress-strain analysis of profiles, considering the geotechnical properties of the environment, was performed by Mohr-Columb's criterion of fracture and plastic behavior of the rock mass after fracture.

Calculation of safety factor is derived for different values of pore pressure, and the steps in the stability analysis were:

$r_u = 0.0$; $r_u = 0.2$ and $r_u = 0.4$.

The analysis of slope stability has taken into account a spreading of waves caused by the earthquake, in the most unfavorable direction, i.e. perpendicular to the forehead slope, and the adopted coefficient of seismicity which is Ks = 0.05.

Figure 3 *View of the slope on the external waste dump - East waste dump*

View of geological profile, used for analysis of safety coefficient (Fs) and co efficient of critical stress state (SRF), is shown in Figure 4.

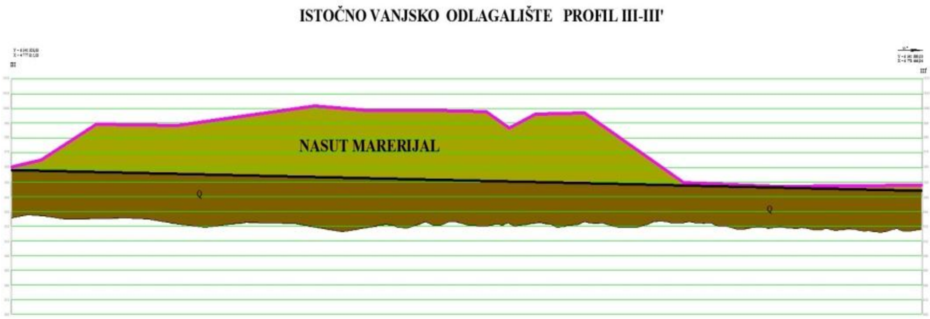

Figure 4 *Geological profile on which the stability analysis was carried out*

The adopted values of physica - mechanical parameters for analyzing the stability of operation and final slopes are:

Material	Bulk density in natural state γ [kN/m^3]	Cohesion C [kPa]	Angle of internal friction φ
Quaternary (Q)	18.30	29	13
Disposed material	15.3	22.7	36.2

Based on the engineering-geological profile of the III-III ' external waste dump - East waste dump, the stability analysis was carried out according to the said method and obtained the following safety coefficients:

Profile	Numerical methods	Safety coefficient F_s		
		Pore pressure coefficient		
		r_u = 0.0	r_u = 0.2	r_u = 0.4
III – III`	Bishop	1.493	1.185	0.886
	Janbu	1.304	1.008	0.787
	Morgenstern-Price	1.441	1.136	0.842

Graphically presented stability analysis by numerical methods, Bishop, Yanbu and Morgenstern - Price and changes of pore pressure (r_u) are given in Figures from Figure 5 to Figure 13.

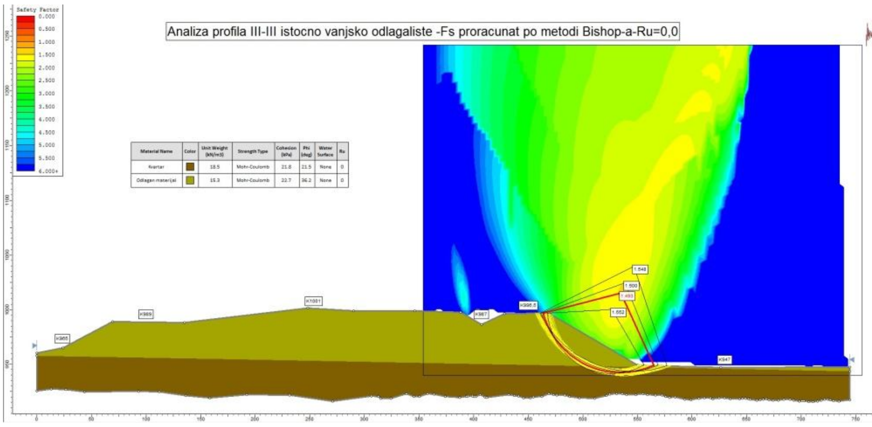

Figure 5 *Analysis of slope stability by numerical method Bishop at pore pressure r_u=0.0, Fs=1.493*

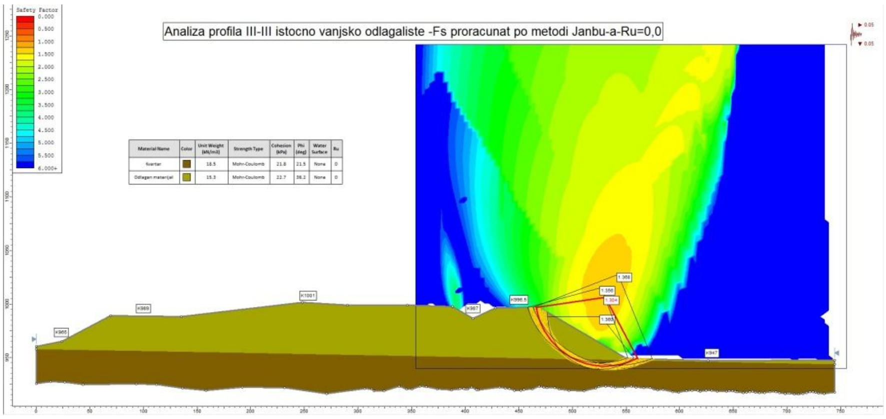

Figure 6 *Analysis of slope stability by numerical method Janbu at pore pressure r_u=0.0, Fs=1.304*

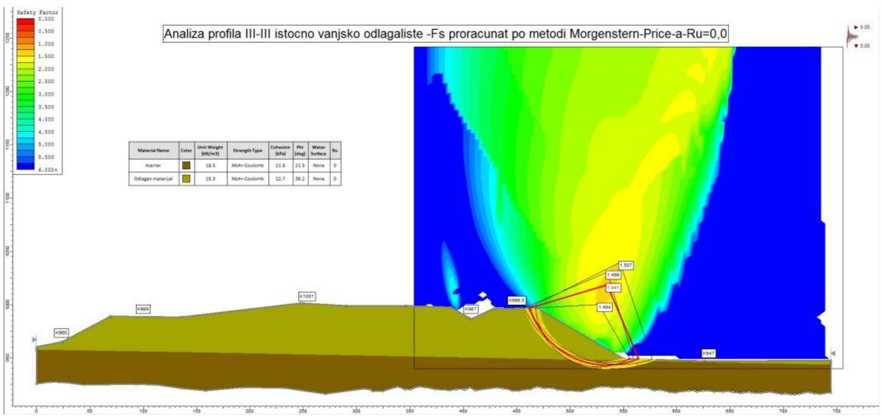

Figure 7 *Analysis of slope stability by numerical method Morgenstern-Price at pore pressure r_u=0.0, Fs=1.441*

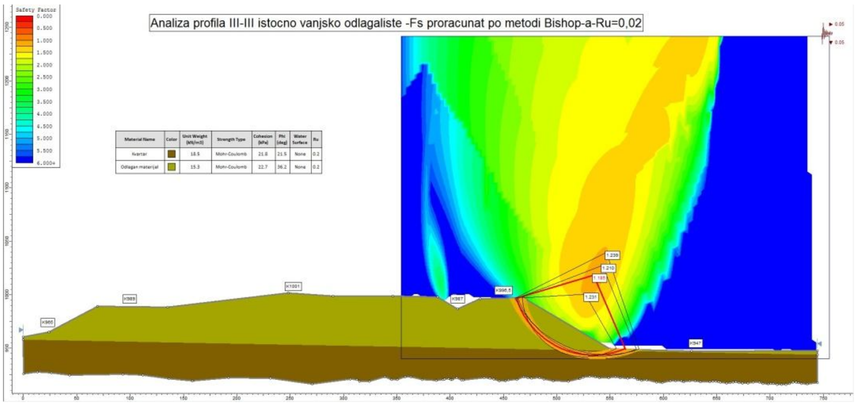

Figure 8 *Analysis of slope stability by numerical method Bishop at pore pressure r_u=0.2, Fs=1.185*

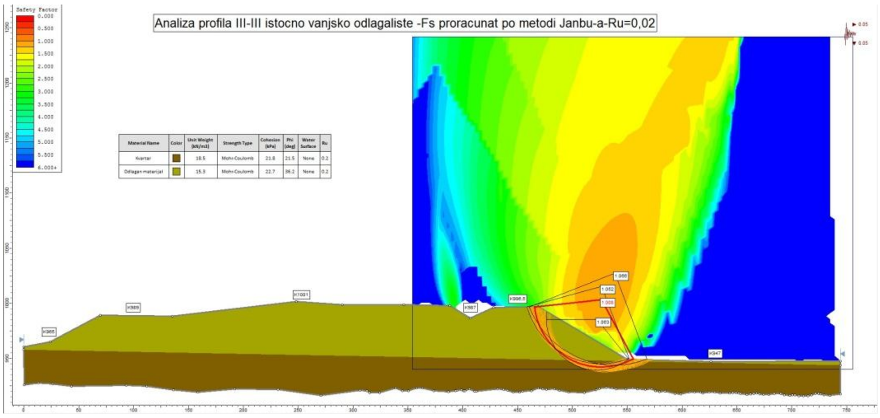

Figure 9 *Analysis of slope stability by numerical method Janbu at pore pressure r_u=0.2, Fs=1.008*

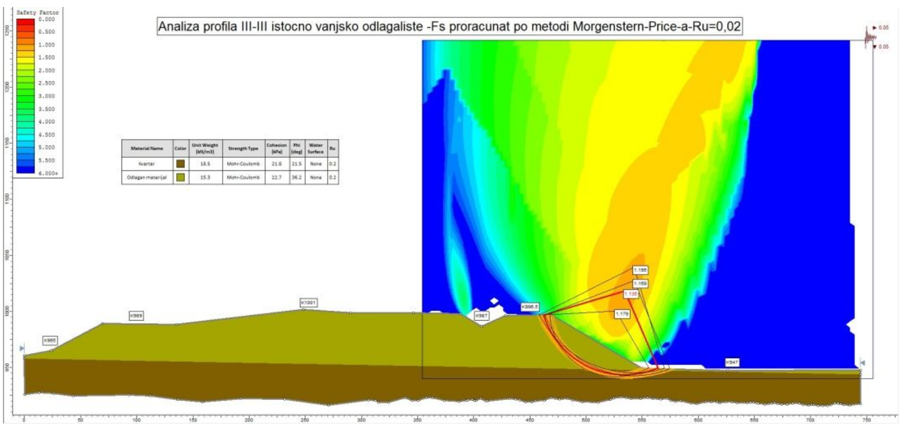

Figure 10 *Analysis of slope stability by numerical method Morgenstern-Price at pore pressure r_u=0.2, Fs=1.136*

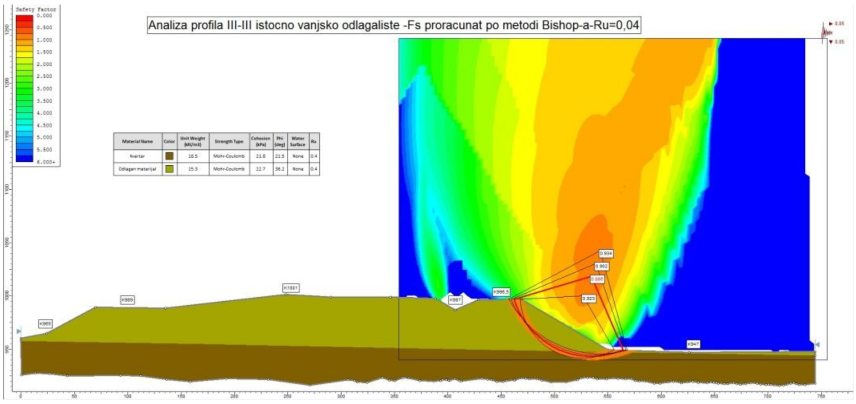

Figure 11 *Analysis of slope stability by numerical method Bishop at pore pressure r_u=0.4, Fs=0.886*

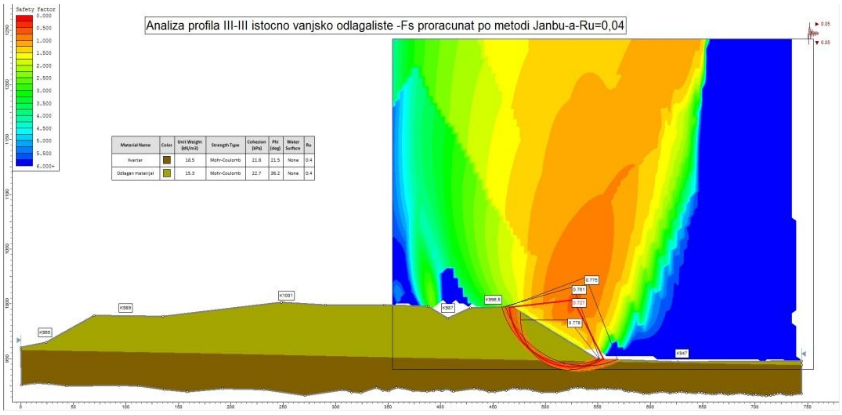

Figure 12 *Analysis of slope stability by numerical method Janbu at pore pressure r_u=0.4, Fs=1.787*

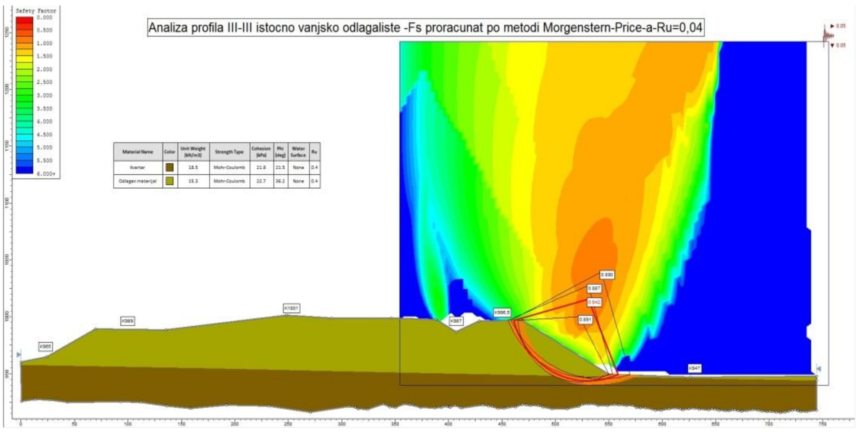

Figure 13 *Analysis of slope stability by numerical method Morgenstern-Price at pore pressure r_u=0.4, Fs=1.842*

Based on the engineering-geological profile of the III-III ' external waste dump - East waste dump, the stability analysis was carried out according to a mathematical model of finite element method with change of pore pressure (r_u) and the following coefficients critical stress state (SRF) were obtained:

Profile	**Coefficient of critical stress state (SRF)**		
	Coefficient of pore pressure		
	$r_u = 0.0$	**$r_u = 0.2$**	**$r_u = 0.4$**
III – III`	1.39	1.10	0.78

Graphically presented stability analyses over the coefficients of critical stress state (SRF) with a change in pore pressure (r_u) are given in Figures from Figure 14 to Figure16.

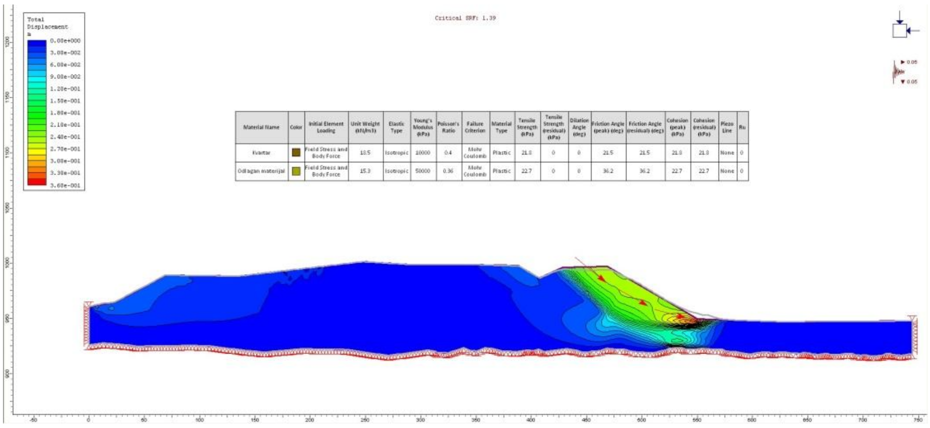

Figure 14 *Analysis of slope stability over stress conditions of material at pore pressure $r_u = 0.0$, SRF = 1.39*

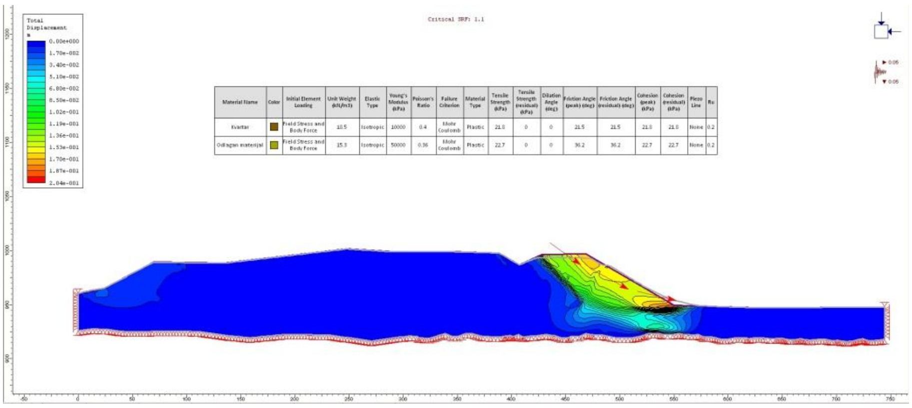

Figure 15 *Analysis of slope stability over stress conditions of material at pore pressure $r_u = 0.2$, SRF = 1.10*

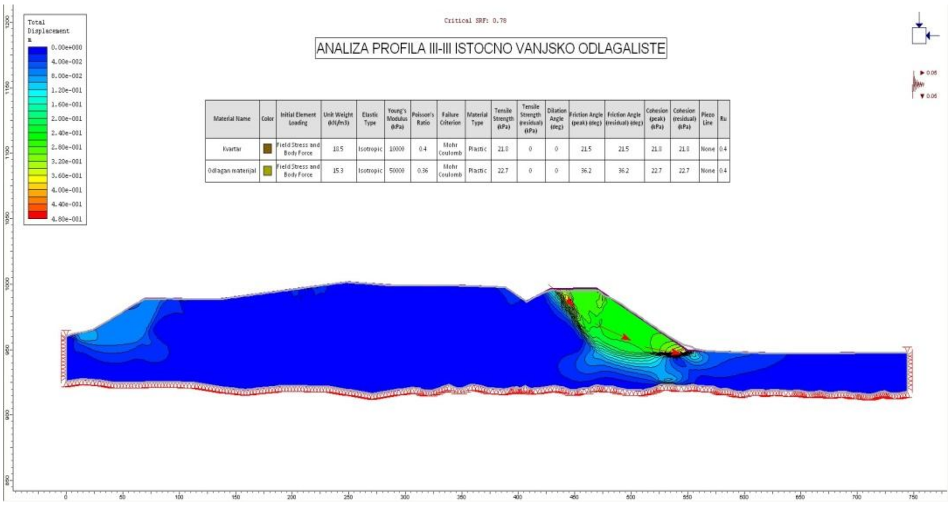

Figure 16 *Analysis of slope stability over stress conditions of material at pore pressure $r_u = 0.4$, SRF = 0.78*

CONCLUSION

Analyzing the results obtained in calculation for slope stability at pore pressures r_u=0.0; r_u = 0.2 and r_u = 0.4, using three numerical methods by Bishop, Janbu and Morgenstern-Price, as well as the finite element method for calculation the stress conditions, it can be concluded that the stability coefficient (F_s) and the coefficient of critical stress condition (SRF) only at this point of stress condition is almost identical.

It was confirmed by this analysis that in addition to the possibility of application the coefficient of critical stress condition (SRF) in checking the filed stability in relation to the stress conditions that occur within the soil, a control of stability coefficient (F_s) can be.

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ANALIZA I ODNOS KOEFICIJENTA SIGURNOSTI (Fs) I KRITIČNOG FAKTORA UTICAJA SMANJENJA NAPONA (SRF) NA PRIMERU VANJSKOG ODLAGALIŠTA JALOVINE, ISTOČNO ODLAGALIŠTE PROFIL III-III PK "GACKO" GACKO***

Izvod

Na području PK „Gacko" vršena je analiza stabilnosti kosina radnih etaža, završnih kosina i sistema kosina prema kriterijumima koje zahteva zakon Republike Srpske. U radu je izvršena uporedna analiza stabilnosti kosina sa tri numeričke metode, po Bishop—u, Janbu i Morgenstern-Price-u. pri različitin pornim pritiscima r_u=0, r_u=0,2 r_u=0,4 i kritičnog faktora uticaja smanjenja napona pri istim pornim pritiscima koji su već spomenuti

*Sa postojećim i novodobijenim podacima izvršene su analize stabilnosti kosina. Za proračunske metode korišćeni su paketi programa **SLIDE v6.0** i **PHASE^2 v8.0** firme **ROCSCIENCE.** Očekivani rezultat je, približno ista vrednost za koeficijenata sigurnost (Fs) i kritičnog faktora uticaja smanjenja napona (SRF) samo u toj tački analize*

***Ključne reči:** Naponska stanja, koeficijent stabilnosti, porni pritisak*

UVOD

Na području PK „Gacko" vršena je analiza stabilnosti kosina radnih etaža, završnih kosina i sistema kosina prema kriterijumima koje zahteva zakon Republike Srpske. U radu je izvršena uporedna analiza stabilnosti kosina sa tri numeričke metode

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Programom **SLIDE v6.0** i **PHASE^2 v8.0** proračun stabilnosti vršen je u uslovima granične ravnoteže prema kriterijumima koji se danas koriste u svetu:

- Bishop,
- Janbu,
- Morgenstern-Price,
- kao i pomoću kritičnog faktora uticaja smanjenja napona (SRF).

Osnovne karakteristike programa **SLIDE v6.0** i **PHASE^2 v8.0** su:

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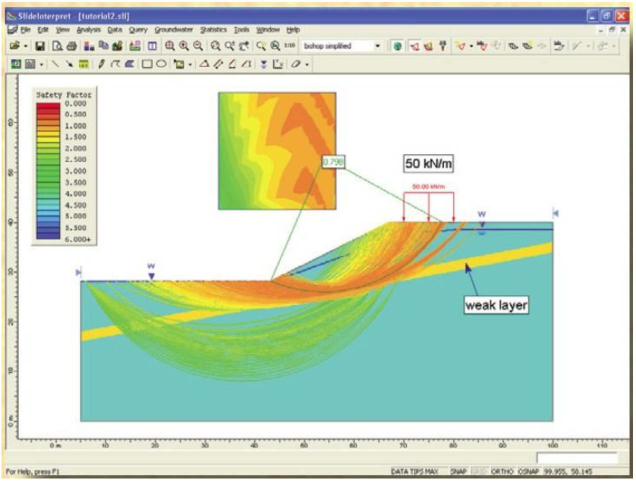
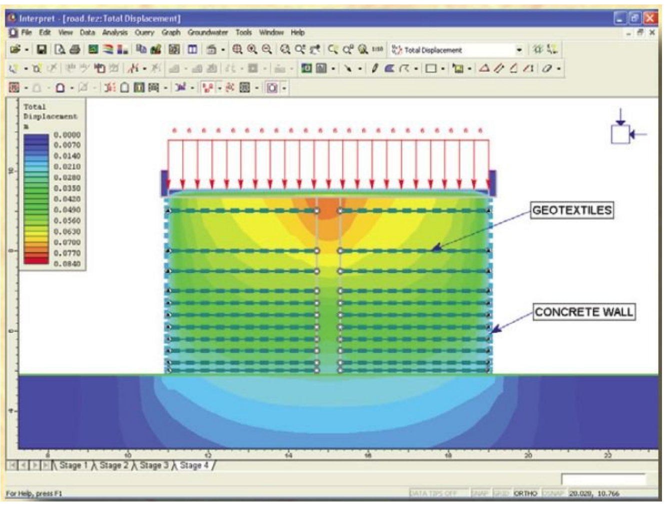
*** *Rad je proizašao iz projekta broj TR 33021 "Istraživanje i praćenje promena naponsko deformacijskog stanja u stenskom masivu „in-situ" oko podzemnih prostorija sa izradom modela sa posebnim osvrtom na tunel Kriveljske reke i Jame bor" koji je finansiran sredstvima Ministarstva za prosvetu, nauku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

SLIDE v6.0 je program koji se koristi za analizu stabilnosti tla i stenskih masa. Ovaj program obezbeđuje razumljiv spektar analiza, uključujući i dizajn, koji podržava datu analizu, analiza podzemnih voda metodom konačnih elemenata i analiza verovatnoće CAD, koji se bazira na grafičkom interfejsu, pruža široki spektar interpretacija putem modeliranja i podataka koje omogućavaju brze i tačne analize. Fajlovi se mogu preneti u program **PHASE^2** za stabilnost kosina metodom konačnih elemenata.



Sl. 1. *Primer rešavanja problema uz pomoć programa SLIDE*

PHASE^2 v8.0 je moćan 2D program koji svoj rad bazira na analizi napona uz pomoć metode konačnih elemenata, kako za podzemna tako i za površinska otkopavanja stena ili tla. Može se koristiti za široki spektar inženjerskih projekata, uključujući konstrukcije tunela, stabilnost kosina pomoću metode konačnih elemenata, analiza podzemnih voda, mrežno modeliranje, analiza verovatnoće i šire. Sa ovim programom se može brzo kreirati i analizirati kompleksno stanje modela u više faza.



Sl. 2. *Primer rešavanja problema uz pomoć programa* ***PHASE^2***

TOK ISPITIVANJA I ANALIZA PODATAKA STABILNOSTI

Svi geomehanički rezultati koji su dobijeni u nekim ranije vršenim merenjima korišćeni su kao ulazni podaci za programe SLIDE v6.0 i $PHASE^2$ v8.0.

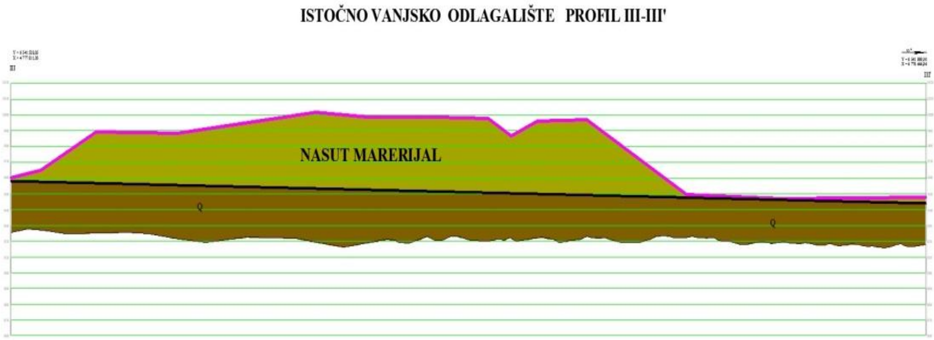
Stabilnosti kosina su analizirane uz pomoć numeričkih metoda po Bishop-u, Janbu i Morgenstern-Price-u dok je naponsko-deformaciona analiza profila, imajući u vidu geotehnička svojstva sredina, rađena po Mohr-Columb-ovom kriterijumu loma i plastičnim ponašanjem stenske mase nakon loma.

Proračun faktora sigurnosti izveden je za različite vrednosti pornog pritiska, a koraci pri analizi stabilnosti bili su: $r_u = 0{,}0$; $r_u = 0{,}2$ i $r_u = 0{,}4$.

U analizi stabilnosti kosina uzeto je u obzir prostiranje talasa, izazvanih zemljotresom, u najnepovoljnijem pravcu, tj. upravno na čelo kosine, a usvojeni koeficijent seizmičnosti koji iznosi Ks = 0,05.

Sl. 3. *Izgled kosine na vanjskom odlagalištu jalovine – Istočno odlagalište*

Izgled geološkog profila koji je poslužio za analizu koeficijent sigurnosti (F_s) i koeficijenta kritičnog naponskog stanja (SRF), dat je na slici 4.



Sl. 4. *Geološki profil na kome je vršena analiza stabilnosti*

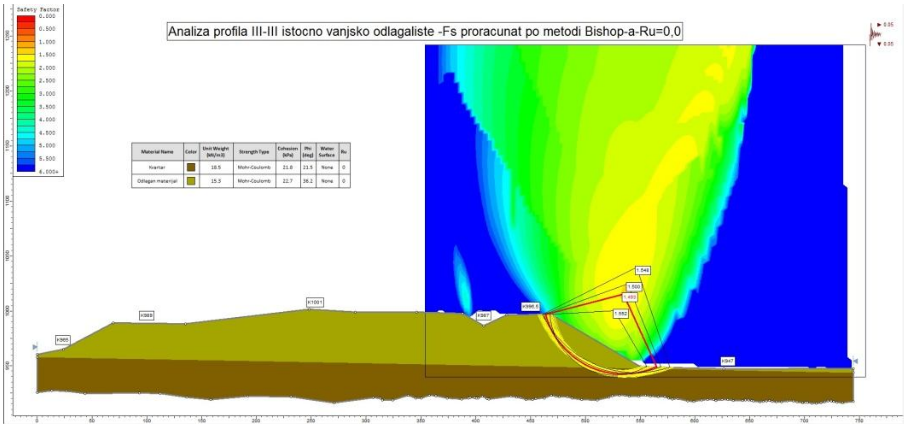
Usvojene vrednosti fizičko - mehaničkih parametara za analizu stabilnosti i radnih završnih kosina su:

Materijala	Zapreminska težina u prirodnom stanju γ [kN/m^3]	Kohezija C [kPa]	Ugao unutrašnjeg trenja φ
Kvartar (Q)	18,30	29	13
Odložen materijal	15,3	22,7	36,2

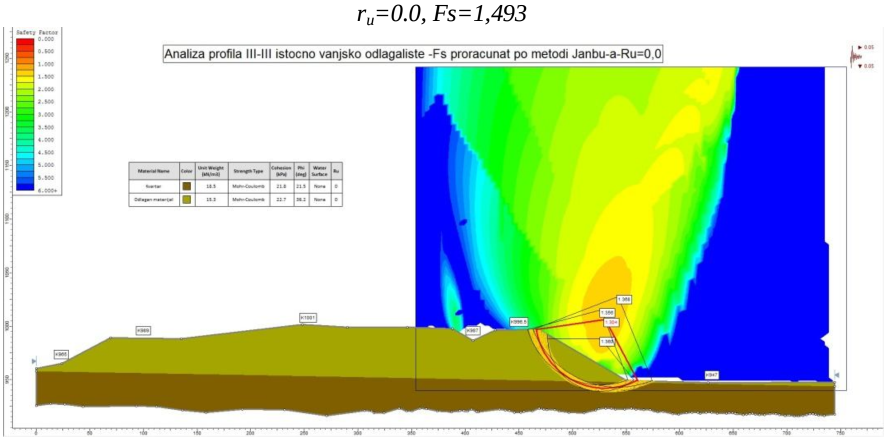
Na osnovu inženjersko-geološkog profila III - III' vanjskog *odlagališta* jalovine – Istočno odlagalište, urađena je analiza stabilnosti prema već rečenim metodama i dobijeni su sledeći koeficijenti sigurnosti:

Profil	Numeričke metode	Koeficijent sigurnosti F_s		
		Koeficijent pornog pritiska		
		$r_u = 0.0$	$r_u = 0.2$	$r_u = 0.4$
III – III`	Bishop	1,493	1,185	0,886
	Janbu	1,304	1,008	0,787
	Morgenstern-Price	1,441	1,136	0,842

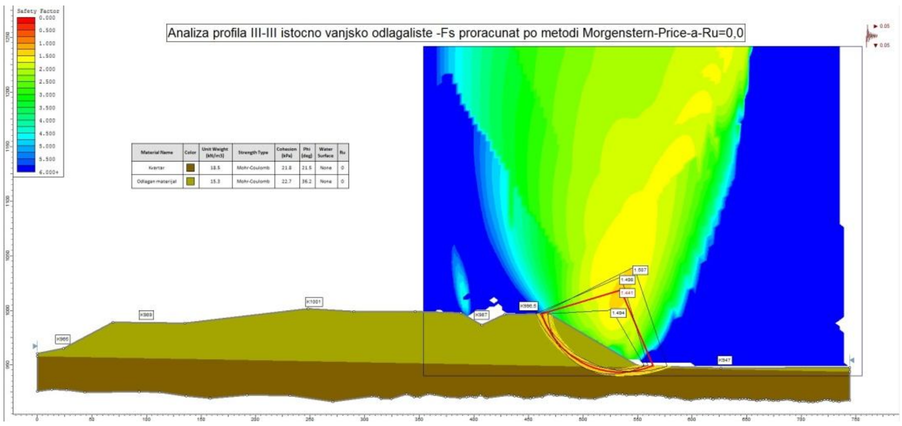
Grafički prikazane analize stabilnosti po numeričkim metodama, Bishop, Janbu i Morgenstern-Price i promeni pornog pritiska (r_u) date su na slikama od Sl. 5 do Sl. 13.



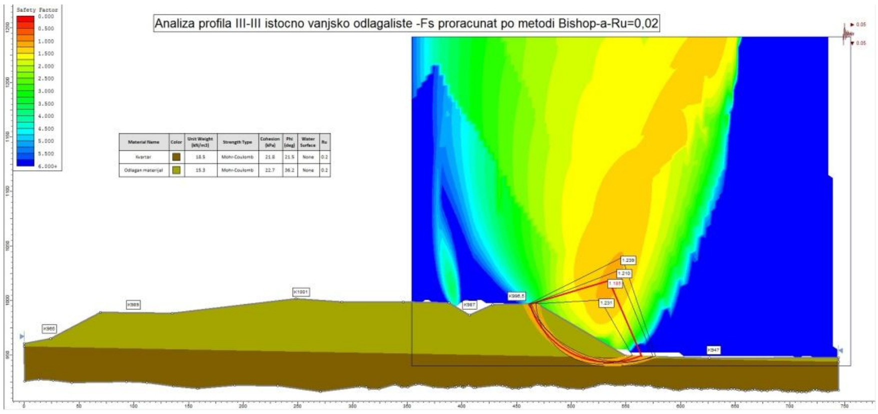
Sl. 5. *Analiza stabilnosti kosina po numeričkoj metodi Bishop pri pornom pritisku r_u=0.0, Fs=1,493*



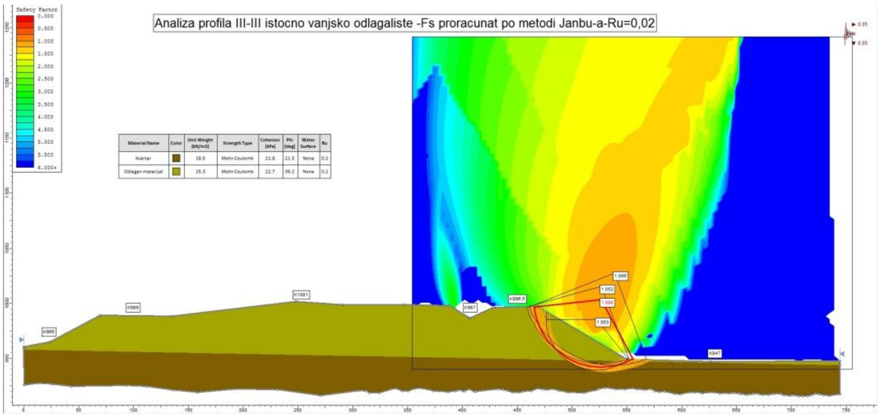
Sl. 6. *Analiza stabilnosti kosina po numeričkoj metodi Janbu pri pornom pritisku r_u=0.0, Fs=1,304*



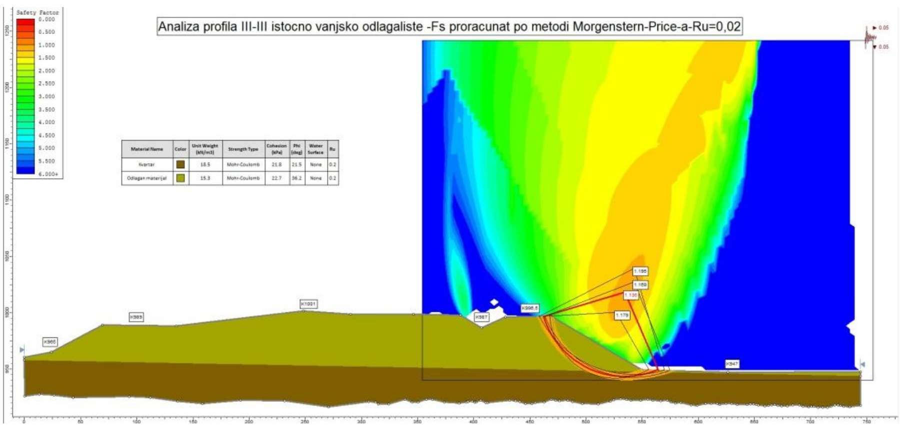
Sl. 7. *Analiza stabilnosti kosina po numeričkoj metodi Morgenstern-Price pri pornom pritisku r_u=0.0, Fs=1,441*



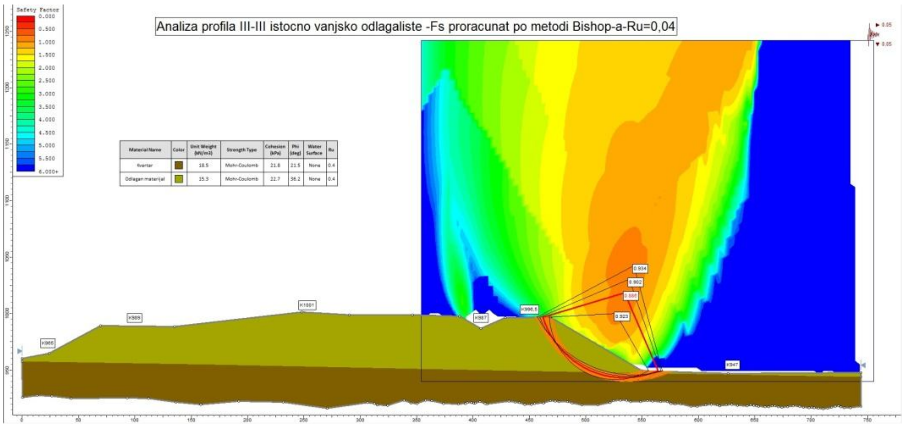
Sl. 8. *Analiza stabilnosti kosina po numeričkoj metodi Bishop pri pornom pritisku* r_u*=0.2, Fs=1,185*



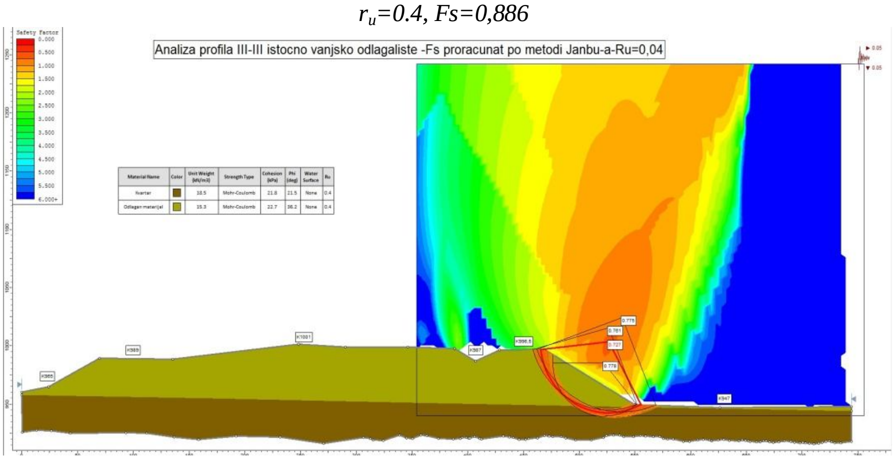
Sl. 9. *Analiza stabilnosti kosina po numeričkoj metodi Janbu pri pornom pritisku* r_u*=0.2, Fs=1,008*



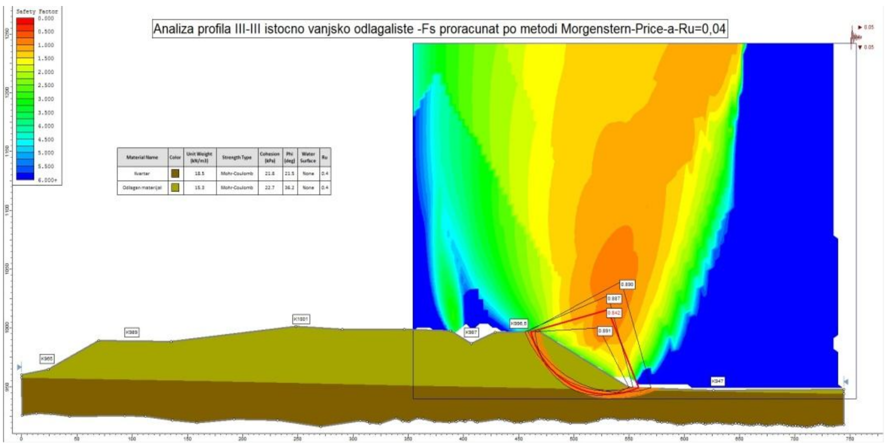
Sl. 10. *Analiza stabilnosti kosina po numeričkoj metodi Morgenstern-Price pri pornom pritisku* r_u*=0.2, Fs=1,136*



Sl. 11. *Analiza stabilnosti kosina po numeričkoj metodi Bishop pri pornom pritisku r_u=0.4, Fs=0,886*



Sl. 12. *Analiza stabilnosti kosina po numeričkoj metodi Janbu pri pornom pritisku r_u=0.4, Fs=0,787*

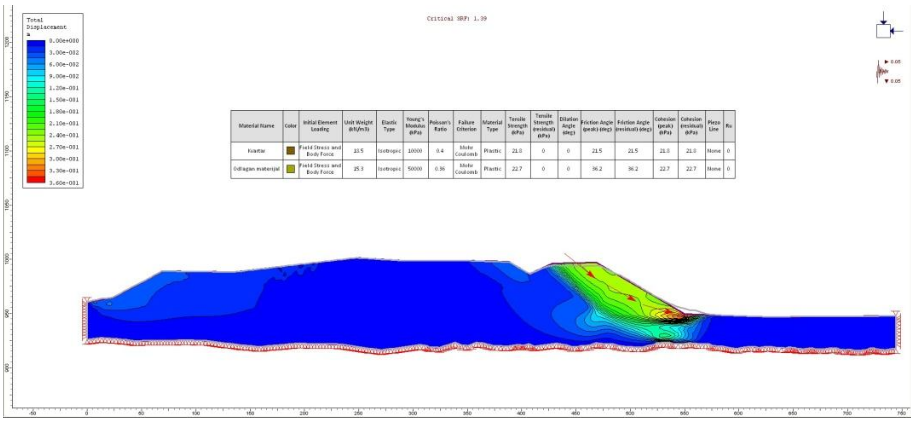


Sl. 13. *Analiza stabilnosti kosina po numeričkoj metodi Morgenstern-Price pri pornom pritisku r_u=0.4, Fs=0,842*

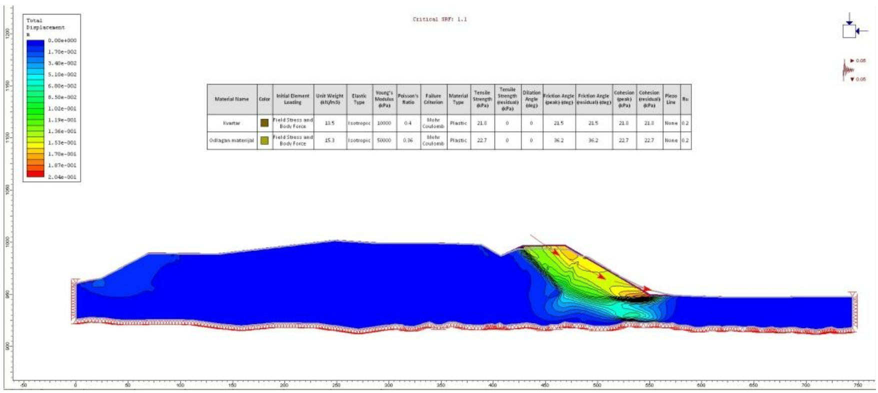
Na osnovu inženjersko-geološkog profila III - III' vanjskog *odlagališta* jalovine – Istočno odlagalište urađena je analiza stabilnosti pre*ma* matematičkom modelu *metodom konačnih elemenata sa promenom pornog pritiska* (r_u) *i* dobijeni su sledeći koeficijenti kritičnog naponskog stanja *(SRF)*:

Profil	**Koeficijent kritičnog naponskog stanja (SRF)**		
	Koeficijent pornog pritiska		
	$r_u = 0.0$	$r_u = 0.2$	$r_u = 0.4$
III – III`	1,39	1,10	0,78

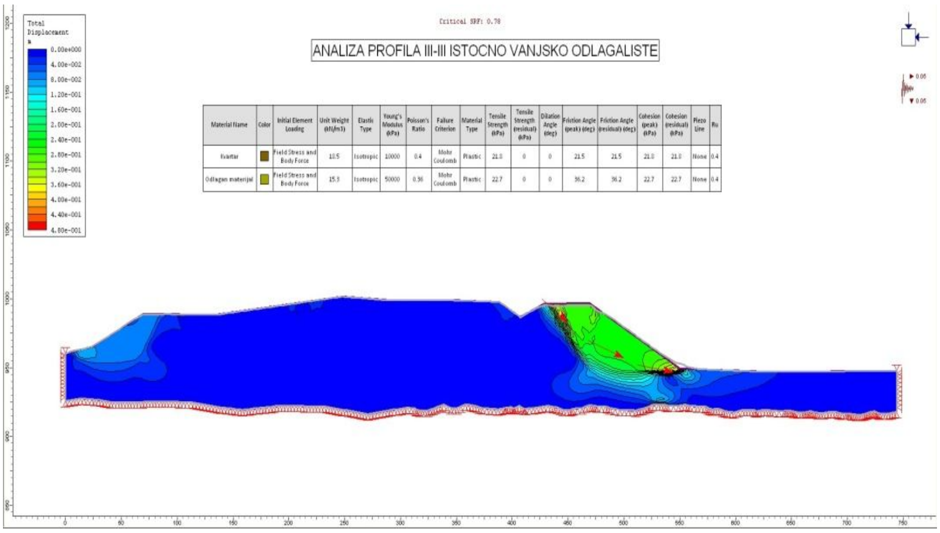
Grafički prikazane analize stabilnosti preko koeficijenta kritičnog naponskog stanja (SRF) sa promenom pornog pritiska (r_u) dati su na slikama od Sl. 14 do Sl. 16.



Sl. 14. *Analiza stabilnosti kosina preko naponskih stanja materijala pri pornom pritisku* $r_u=0.0$*, SRF=1,39*



Sl. 15. *Analiza stabilnosti kosina preko naponskih stanja materijala pri pornom pritisku* $r_u=0.2$*, SRF=1,10*



Sl. 16. *Analiza stabilnosti kosina preko naponskih stanja materijala pri pornom pritisku r_u=0.4, SRF=0,78*

ZAKLJUČAK

Analizom rezultata dobijenih pri proračunu za stabilnosti kosina pri pornim pritiscima r_u=0,0; r_u = 0,2 i r_u = 0,4, koristeći tri numeričke metode, po Bishop-u, Janbu i Morgenstern - Price-u kao i metodu konačnih elemenata za proračun naponskih stanja, može se konstatovati, da je koeficijent stabilnosti (F_s) i koeficijenta kritičnog naponskog stanja (SRF) samo u toj tački naponskog stanja skoro identičan.

Tom analizom smo potvrdili, da pored mogućnosti primene koeficijenta kritičnog naponskog stanja (SRF) u proveri stabilnosti teren u odnosu na naponska stanja koja se dešavaju unutar tla, može da bude i kontrola koeficijenta stabilnosti (F_s).

LITERATURA

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*Semir Fejzić**

PRESSURE CONDITION AROUND THE UNDERGROUND OPENING SUBSTRUCTURED BY ANCHORS IN MULTILAYERED DEPOSITS INVESTIGATED BY THE METHOD OF FINAL ELEMENTS

Abstract

Computer program ADINA is used for pressure analysis on a model of underground opening, semi-circular in shape, where there are the layers of lignite, and conducted pressure analysis, before, during and after the setting of three and five anchors. Theory on pressure distribution for secondary and tertiary pressure condition in the roof and board sides of the opening by setting anchors has been proven. In order to check the result, test of removing anchors from the roof and board sides of the opening was done. Testing and research, conducted at the level of obtained results, show the efficiency of setting underground opening using the anchors where there are multilayered deposits of lignite. The research results, provided in this paper, can be also used for other underground openings containing multilayered deposits.

Keywords: *pressure conditions, multilayered deposits, substructure, anchor, ADINA*

INTRODUCTION

In the process of substructure, it is necessary to make an assessment of substructures which include the adequate choice of rock mass classification, but also the other technical conditions that have to be explored in order to make a good project. In the applied rock mechanics, in the field of mining, planning includes the choice of specific objects and provides the investigation of rock mass behavior in modified condition using the equations of theoretical and applied rock mechanics. Analysis the primary pressure condition by numerical methods, and also analysis the secondary and tertiary pressure condition by the method of final elements, using the program package ADINA in conditions before, during and after the setting of anchors in the underground openings for multilayered deposits, give the useful, efficient and legitimate solutions. The primary research goal of this paper is a numerical justification of legitimacy and efficiency of the applied system model of setting the underground openings using the anchors where there are multilayered deposits in mining conditions of the lignite deposit Kreka. (3)

KREKA COAL BASIN

The coal basin Kreka is a part of the Tuzla tertiary basin, situated in the southwestern part of the town, between the southern slopes of the mountain Majevica and valley of the river Spreča (Figure 1), covering an area of 180 km^2. The whole basin is located in Tuzla Canton, and spreads to the areas of the municipalities Tuzla, Lukavac, Kalesija and Živinice.

* *BCC Tuzla Canton, Tuzla*

Figure 1 *Spatial position of the Kreka coal basin*

Five lignite layers were developed in this part of the basin of different economic significance and their development is shown in the geological - stratigraphic column, which completely coincides with lithostratographic development of overall Kreka basin in general. Coal layers are continuosly developed in the whole deposit, with the exception of roof layers in the Kovačevići syncline. Thickness of coal layers, including intercalations, varies in wide ranges (from 5 to 34 m). However, the coal layers almost never lose their productive thickness and quality.

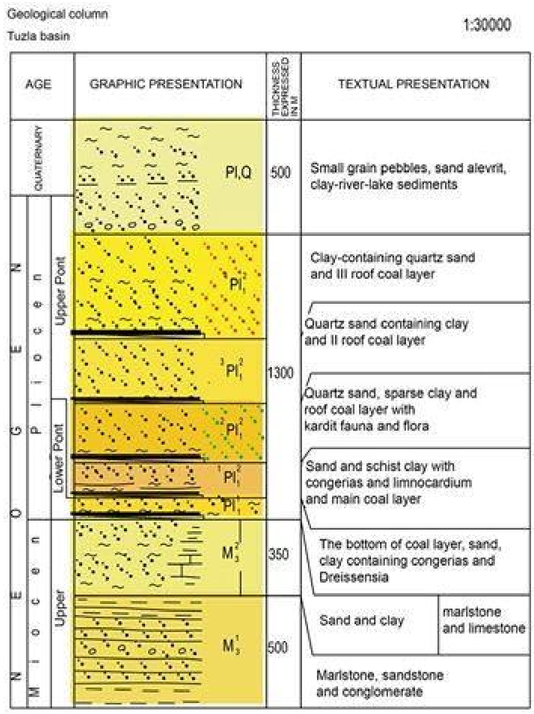


Figure 2 *Geological-stratigraphic column of the Kreka synclinorium*

ANALYSIS OF PRESSURE CONDITION AROUND UNDERGROUND OPENING IN A COAL LAYER BY THE METHOD OF FINAL ELEMENTS

Program package ADINA

ADINA (Automatic Dynamic Incremental Nonlinear Analysis) is a commercial finite element analysis program package which has widespread usage in the industry and academic community, since it is suitable for the analysis of pressure in solid rocks (2D and 3D models) of different structures. In this paper, 8.6 version is used, and it shows a difference in pressure rearrangement between the unsubstructured opening and substructured opening by anchors, i.e. it shows the secondary and tertiary pressure condition in the roof and board sides of the opening, which is the result of anchor setting. (1)

Input parameters of the work environment

Input parameters of the work environment include geomechanical characteristics of the work environment, lithological structure in the area of analyzed case, geometry of underground opening, unsubstructured or substructured by anchors.

Table 1 *Geomechanical characteristics*

TOP OF CLAY LAYER	COAL LAYER I	COAL LAYER II	COAL LAYER III	BOTTOM OF CLAY LAYER
γ = 21 kN/m^3	γ =12 kN/m^3	γ = 12 kN/m^3	Γ = 13kN/m^3	γ = 1.70 kN/m^3
υ = 0.40	υ = 0.21	υ = 0.22	Y = 0.22	υ = 0.35
C =0.07 MPa	C =3.5 Mpa	C =3.2 MPa	C =3.0 MPa	C =30 MPa
φ= 22^o	φ = 30^o	φ = 30^o	Φ = 30^o	φ = 35^o
σ_z =0.02 MPa	σ_z =1.4Mpa	σ_z =1.3 MPa	σ_z =1.20 MPa	σ_z =0 MPa
E = 25 MPa	E =600 Mpa	E = 600 MPa	E = 600 MPa	E = 300 MPa

Figure 3 gives a structure profile of coal layer, including the position, type and shape of underground opening which is in the focus of this research and substructure. There are also all necessary and available geomechanical characteristics of coal layer and accompanied deposits for the mining district Marići for the 16th floor (GDVH). These data are used in the paper as the base for all modeling. (2)

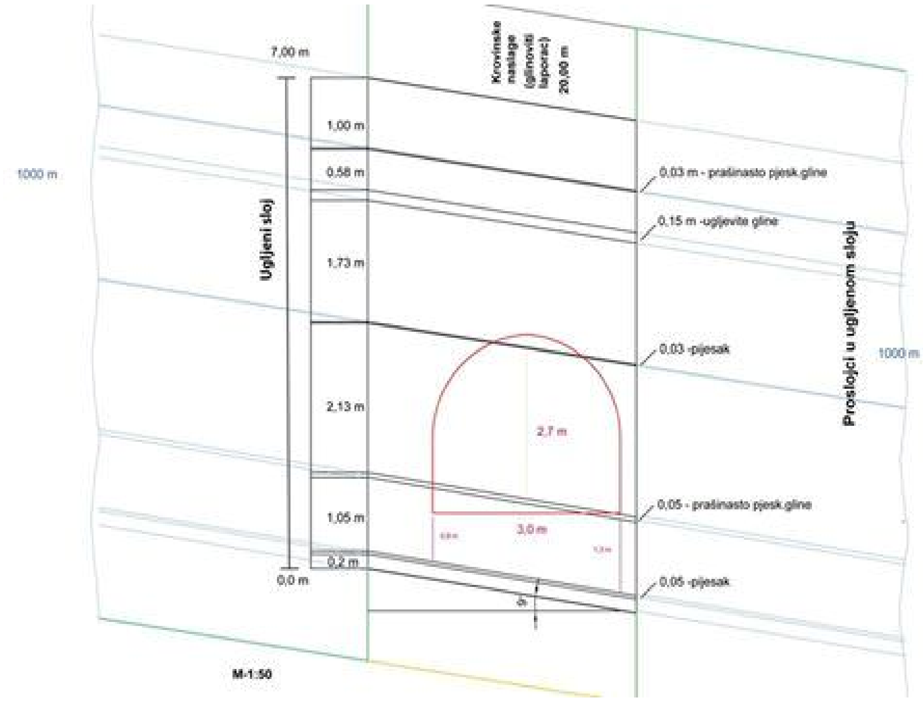
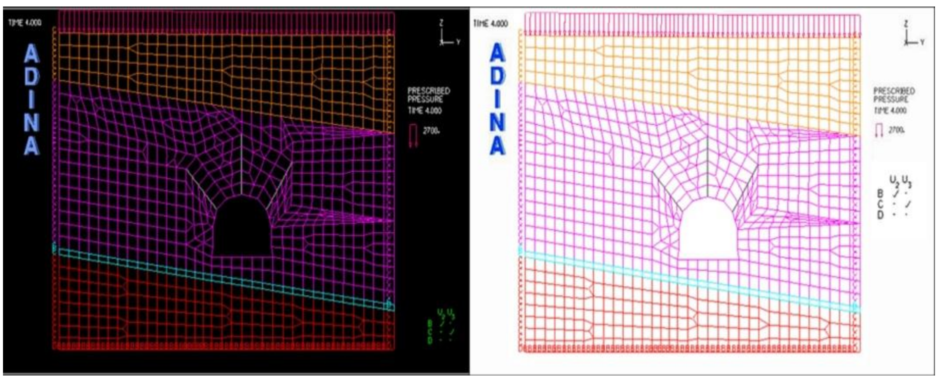


Figure 3 *Structure profile for the semi-circular shape of opening for (GDVH-16th floor)*

The analysis was conducted on two geologic cases. The first case is for substructure of opening by 3 anchors, and the second by 5 anchors.

CASE 1:

MKE model with the modified board side conditions and given load with three built-in anchors.



CASE 2:

MKE model with the specified board side conditions and given load with five built-in anchors.

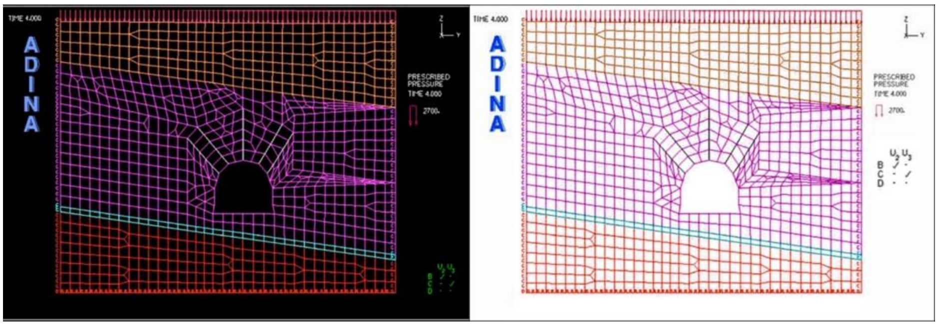


Figure shows in the first case the model of final elements for opening with semi-circular roof, built-in anchors, and the position of lithological members and overview the board side conditions. The model contains 3207 nodes, with five groups of elements, and anchors of 14 generalized line (truss) elements, while 2D elements which present coal, roof and material has 1044 quadrilateral elements with 8 Gauss integration points. In the second case, the model contains 3207 nodes with five groups of elements, and anchors of 24 generalized line (truss) elements of coal, roof and material, has 1044 quadrilateral elements with 8 Gauss integration points.

View of vertical pressure σz and axial forces in anchors

The condition of vertical pressure that is the range of intervals from minimum to maximum value of pressure is given in Figure 4 and expressed in kN/m^2. Negative sign means pressure (-), while plus sign (+) means tensioning.

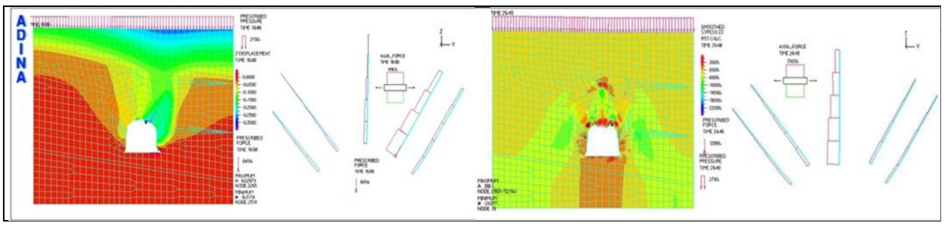


Figure 4 *Overview of pressure σ_z and axial forces in anchors after the excavation of profiles with 3 and 5 anchors*

Overview of vertical pressure around the opening highlights the pressure rearrangement in massif. The load in anchors suggests that the middle anchor has less force intensity, while board side anchors take higher load, and the expressed asymmetry is the consequence of position of layers. Also, a detailed overview of axial load affecting anchors is given. In the overview, the pressure is expressed on the upper side, while the bracing is given on the lower side and expressed in kN. In the case of 5 anchors, unlike the case where 3 anchors were set in opening, it can be noticed that the pressure load intensity is lower (by absolute value), but also that bracing load intensity is higher in the bottom part of opening. The load intensity in anchors is also higher.

Plastic deformations, vertical shift, plastic flag

The extent of plastic deformations is of less intensity around opening with built-in anchors. Plastic deformations are especially noticeable in the bottom right corner of opening, which is the consequence of litho logical composition and the shape of opening (there is sand in the bottom part), and also because the sharp corners cause high concentration of pressure. Plastic deformations are expressed in percentages (%). The extent of plastic deformations for opening without anchors is higher than for opening with anchors. It is also noticeable that the intensity of plastic deformations, in this case, is lower with 5 built-in anchors, than in the case of the same opening with 3 built-in anchors.

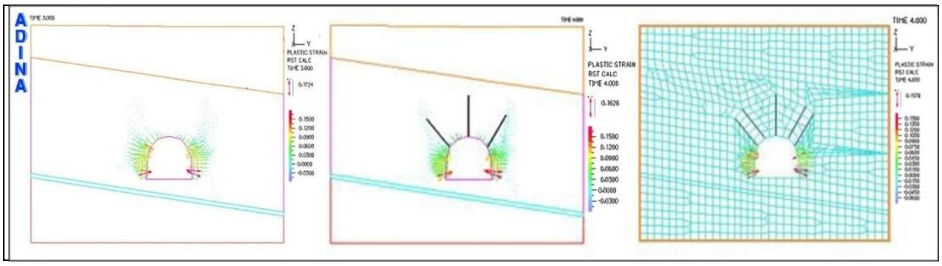


Figure 5 *Comparative overview of plastic deformations before and after mounting of 3 and 5 anchors*

Vertical shifts give an illustrative example when the usage of anchors is in case, since mounting of anchors in the short time after constructing the opening has a significant effect on height reduction of opening. It is noticeable from illustration that there is a change of scope of excavation to the secondary pressure condition in the massif, and the changes of secondary pressure conditions in the massif after mounting of anchors. The lines of vertical shift indicate that there is a significant change in rearrangement of vertical shifts with 5 built-in anchors. By comparison for the same conditions but for opening with only 3 built-in anchors, it is noticeable that the intensity of vertical shifts is lower.

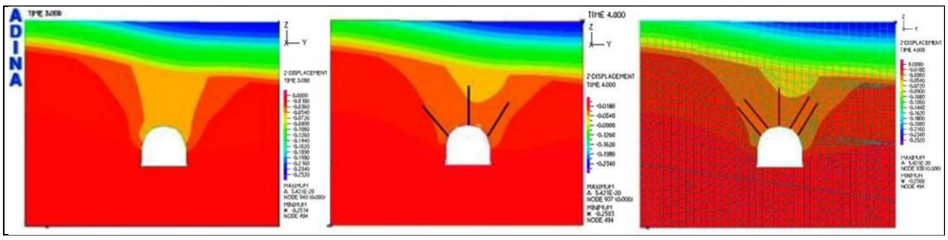


Figure 6 *Comparative overview of vertical shifts before and after mounting of 3 and 5 anchors*

Plastic flag is the indicator of emergence of plastic deformation in the Gauss points of elements. It indicates the zones and elements affected by plastic deformation. It is noticeable from the legend that plastification occurred as the conse quence of overflow the Mohr-Coulomb fracture condition. This zone is significantly more acute without anchors. Plastification for other conditions and criteria (pressure and bracing firmness) was not found. Also, the legend explains on which models the plastic deformation can or has to be expressed due to bracing or overflow the Mohr-Coulomb fracture condition and it also shows that there is an evident difference between the case with 3 and the case with 5 anchors.

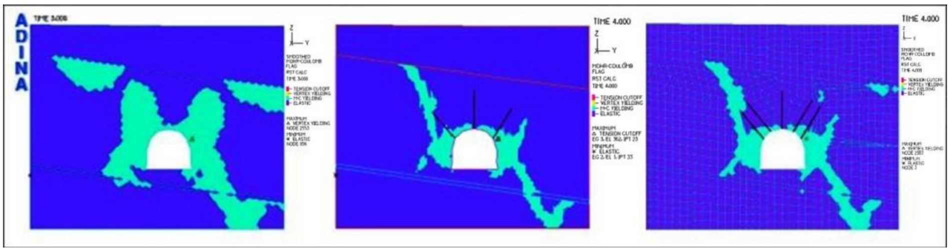


Figure 7 *Comparative overview of plastic flag during the period before and after mounting of 3 and 5 anchors*

Pull-out force

The results of pull-out force of anchors are considered and offered on the same model, but only from different positions of built-in anchor in a roof vertically, or in a board side of opening. The results consider the vertical shift and overview the force intensity. First, the pull-out force of the board side anchor was modeled, and then the pull-out force of the anchor set in a roof. The size of the forces and shifts is present and given in appropriate drawings and it is evident is that the pull-out force is higher in the case of set anchors in a roof.

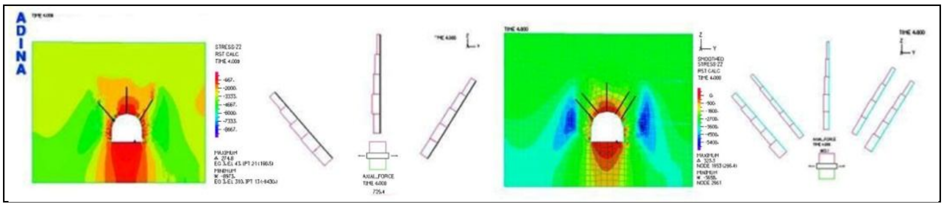


Figure 8 *Pull-out force of anchor set in a roof*

CONCLUSION

Based on the obtained results, it can be concluded that in the Mramor lignite mine, based on the analyzed profile of semi-circular roof of opening on the 16th floor (TOH-16), there is an evident difference in pressure rearrangement in case of substruc ture using three anchors and substructure using five anchors. Since the analysis of pressure condition around the underground openings is a safe method for the choice of substructuring underground openings by anchors, the pressure analysis was conducted by numerical methods using the licensed software ADINA, version 8.6 at the Faculty of Mining, Geology and Civil Engineering. Model ADINA in engineering terms gives reliable results offering reliable perspective on pressure and force of anchors. Through software analysis of pressure, the thesis on pressure rearrangement for the secondary and tertiary pressure condition in the roof and board sides of the opening by setting anchors was proved, which is supported by the obtained results. The pull-out force obtained from the modeled value has to be considerably lower than the force of practical pull-out, because in this case the support is formed with the support of pump and temporarily built-in support, which gives higher value of pull-out force than modeled force.

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*Semir Fejzić**

STANJE NAPONA OKO PODZEMNE PROSTORIJE PODGRAĐENE ANKERIMA U SLOJEVITIM LEŽIŠTIMA ISTRAŽENO METODOM KONAČNIH ELEMENATA

Izvod

Kompjuterski program ADINA korišten je za naponsku analizu na modelu podzemene prostorije polukružnog oblika u sloju lignita, urađenom naponskom analizom prije, za vrijeme, i poslije ugradnje tri i pet ankera. Dokazana je teza o preraspodjeli napona za sekundarno i tercijarno naponsko stanje u svodu i bokovima prostorije ugradnjom ankera. Za provjeru rezultatai urađen je test čupanja ankera iz stropa i boka prostorije. Provedena ispitivanja i istraživanja na ovom stepenu dosegnutih rezultata pokazuju efikasnost podgrađivanja podzemnih prostorija korištenjem ankera u uslovima slojevitih ležišta lignita. Rezultati istraživanja, dati u ovom radu, mogu biti primjenjivi i za druge podzemne građevine u uslovima slojevitih ležišta.

Ključne riječi: *naponska stanja, slojevita ležišta, podgrađivanje, anker, ADINA*

UVOD

Prilikom podgrađivanja potreban pristup za procjenu podgrade uključuje adekvatan odabir klasifikacije stijenskih masa, kao i drugih tehničkih uslova koji se moraju istražiti kako bi se napravio dobar projekat vezan za izbor podgrade. U primijenjenoj mehanici stijena, na područja rudarstva, projektovanje uključuje izbor određenih objekata i predviđa izučavanje ponašanja stijene u promijenjenim uslovima sekundarnog stanja napona, koristeći pri tome i jednačine teorijske i primijenjene mehanike stijena. Numeričkim metodama analizano primarno stanje napona, i analiza sekundarnog i tercijarnog naponskog stanja, metodom konačnih elemenata, koristeći programski paket ADINA u uslovima prije, za vrijeme i poslije ugradnje ankera u podzemnoj prostoriji, za slojevita ležišta, daju korisna, efikasna i opravdana rješenja. Primarni cilj istraživanja ovog rada je numerička potvrda opravdanosti i efikasnosti kod primjenjivog modela sistema podgrađivanja podzemnih prostorija, korištenjem ankera kod slojevitih ležišta u rudarskim uslovima krekanskog lignitnog ležišta. (3)

KREKANSKI UGLJENI BASEN

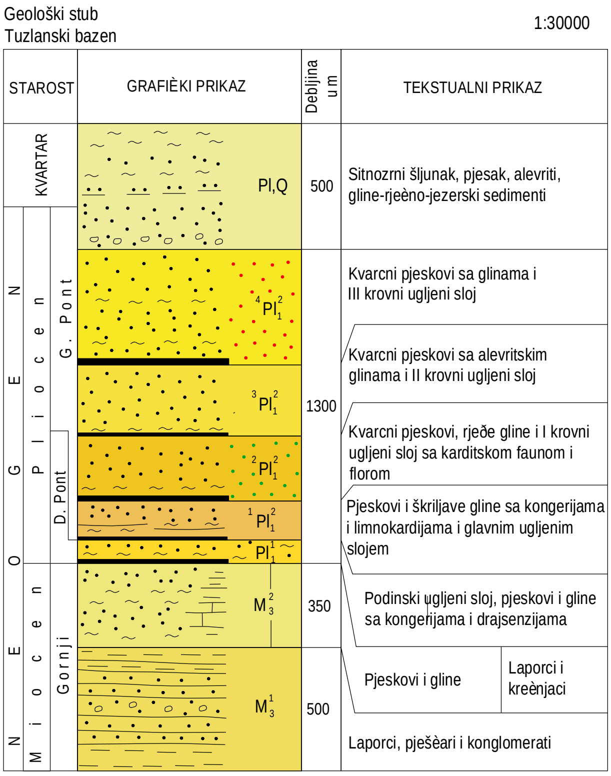
Krekanski ugljeni basen predstavlja jedan dio tuzlanskog tercijarnog basena, smješten u njegovim jugozapadnim dijelovima, između južnih padina planine Majevice i doline rijeke Spreče (slika 1.), na površini od oko 180 km^2.

Kompletan basen se nalazi u tuzlanskom kantonu, i zahvata dijelove općina: Tuzla, Lukavac, Kalesija i Živinice.

* *BKC TK Tuzla*

Sl. 1. *Prostorni položaj krekanskog ugljenog basena*

Na ovom dijelu basena razvijeno je pet lignitskih slojeva, različitog ekonomskog značaja, a njihov razvoj je dat na geološko –stratigrafskom stubu, koji se u potpunosti podudara sa opštim litostratigrafskim razvojem krekanskog basena u cjelini. Ugljeni slojevi su kontinuirano razvijeni na cijelom ležištu, izuzev krovnih slojeva u sinklinali „Kovačevići“. Debljina ugljenih slojeva, računajući i sve interkalacije, varira u dosta širokim granicama (od 5 do 34 m), ali ugljeni slojevi skoro nikada ne gube svoju produktivnu debljinu i kvalitet.



Sl. 2. *Geološki – stratigrafski stub krekanskog sinklinorijuma*

ANALIZA STANJA NAPONA OKO PODZEMNE PROSTORIJE U UGLJENOM SLOJU METODOM KONAČNIH ELEMENATA

Programski paket ADINA

ADINA (Automatsko Dinamičko Dodatna Nelinearna Analiza), je komercijalni programski paket za analizu metodom konačnih elemenata, koji, obzirom da je pogodan za analizu napona u čvrstim stijenama (2D i 3D model), te različitih struktura, ima široku primjenu u industriji i akademskoj zajednici. U radu je korištena verzija 8.6. kojom je pokazana razlika u preraspodjeli napona između nepodgrađene prostorije i prostorije podgrađene ankerima, odnosno prikazano je sekundarno i tercijarno naponsko stanje u svodu prostorije nastalo ugradnjom ankera. (1)

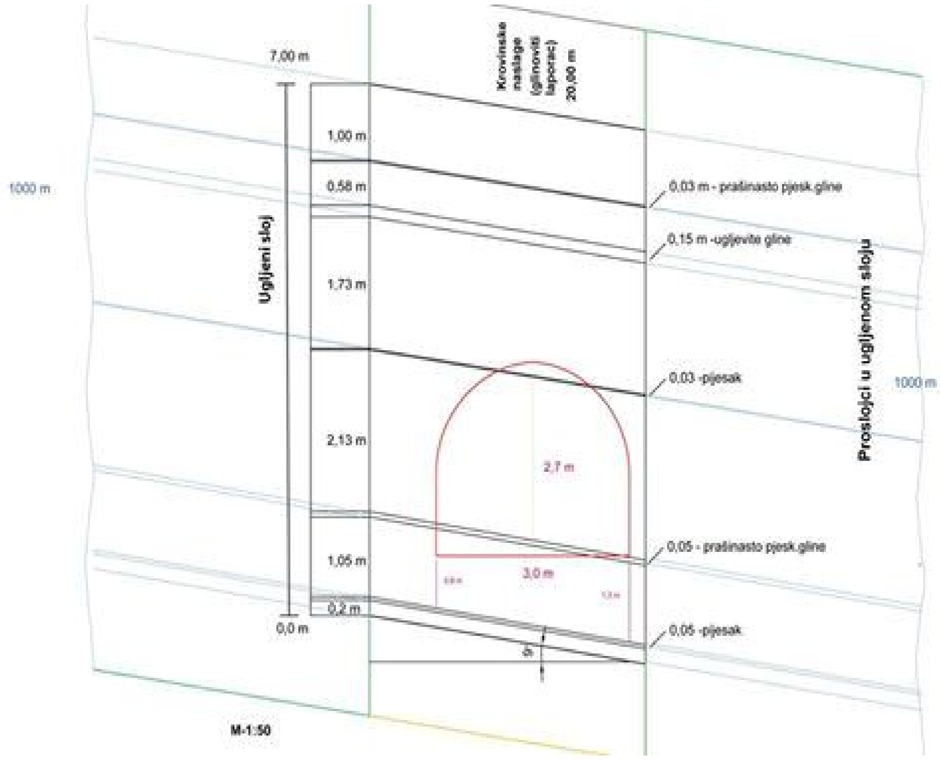
Ulazni parametri radne sredine

U ulazne parametre radne sredine spadaju geomehaničke karakteristike radne sredine, litološka građa u zoni analiziranog slučaja, geometrija podzemne prostorije nepodgrađene i podgrađene ankerima.

Tabela 1. *Geomehaničke karakteristike*

KROVINA GLINE	UGLJENI SLOJ I	UGLJENI SLOJ II	UGLJENI SLOJ III	PODINA PJESKA
γ = 21 kN/m^3	γ = 12 kN/m^3	γ = 12 kN/m^3	γ = 13kN/m^3	γ = 1,70 kN/m^3
υ = 0,40	υ = 0,21	υ = 0,22	υ = 0,22	υ = 0,35
C =0,07 MPa	C =3,5 MPa	C =3,2 MPa	C =3,0 MPa	C =30 MPa
φ= 22^o	φ = 30^o	φ = 30^o	φ = 30^o	φ = 35^o
σ_z =0,02 MPa	σ_z =1,4 MPa	σ_z =1,3 MPa	σ_z =1,20 MPa	σ_z =0 MPa
E = 25 MPa	E = 600 Pa	E = 600 MPa	E = 600 MPa	E = 300 MPa

Na slici 3. dat je strukturni profil ugljenog sloja sa položajem, vrstom i oblikom podzemne prostorije koja je predmet istraživanja i podgrađivanja. Takođe, date su i sve neophodne, a raspoložive, geomehaničke karakteristike ugljenog sloja i pratećih naslaga za revir „Marići“ za 16 sprat (GDVH). Ovi podaci se u radu koriste kao osnova za sva modeliranja. (2)

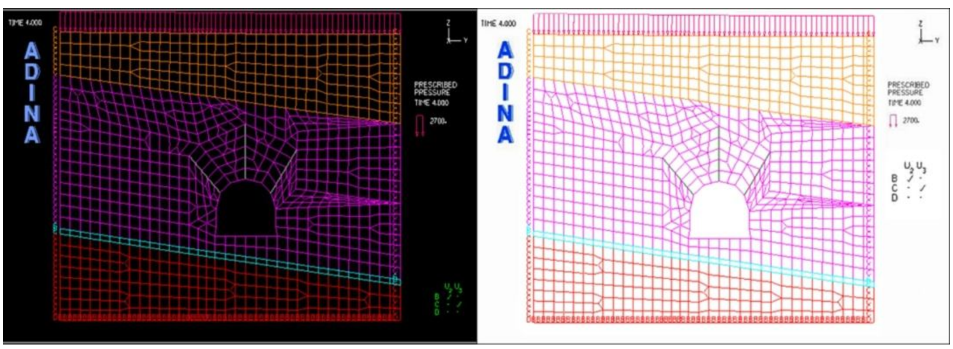


Sl. 3. *Strukturni profil za polukružni oblik prostorije za (GDVH- 16 sprat)*

Analiza je rađena u dva geološka slučaja, i to za podgrađivanje prostorije sa 3 ankera u prvom slučaju, i sa 5 ankera u drugom slučaju.

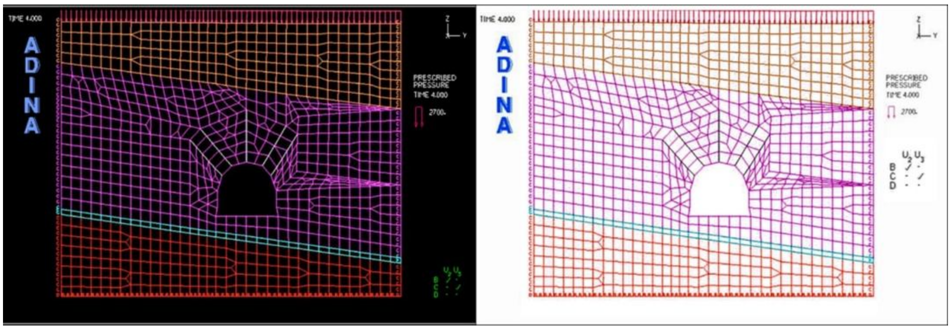
SLUČAJ 1:

MKE model sa naznačenim rubnim uslovima i zadanim opterećenjem sa ugrađenih 3 ankera.



SLUČAJ 2:

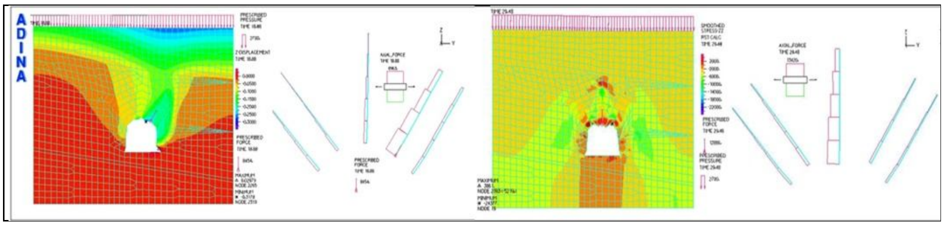
MKE model sa naznačenim rubnim uslovima i zadanim opterećenjem sa ugrađenih 5 ankera.



Na slici u prvom slučaju prikazan je model konačnih elemenata za prostoriju sa polukružnom svodom i ugrađenim ankerima, položajem litoloških članova i prikazom rubnih uslova. Model se sastoji od 3207 čvorova, sa pet grupa elemenata, a ankeri 14 generalisanih linijskih (*truss)* elementa. 2D elementi, koji predstavljaju ugalj, krovinu i materijal, sastoje se od 1044 kvadrilateralna elemenata sa 8 Gaussovih integracionih tačaka. U drugom slučaju model se sastoji od 3207 čvorova sa pet grupa elemenata a ankeri 24 generalisanih linijskih (*truss)* elementa, dok 2D elementi, koji predstavljaju ugalj, krovinu i materijal, od 1044 kvadrilaterala elementa sa 8 Gaussovih integracionih tačaka.

Prikaz vertikalnog napona σz i aksijalnih sila u ankerima

Stanje vertikalnih napona, odnosno raspon intervala od minimalne do maksimalne vrijednosti napona, dat je na slici i izražen je u kN/m^2. Negativan znak znači pritisak (-) dok pozitivan (+) zatezanje.

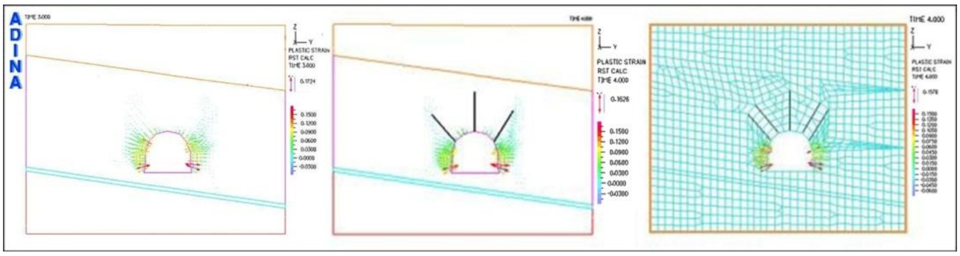


Sl. 4. *Prikaz napona σz i aksijalnih sila u ankerima nakon iskopa profila sa 3 i 5 ankera*

Prikaz vertikalnog napona oko prostorije ukazuje na pre raspodjelu napona u masivu. Sile u ankerima ukazuju da srednji anker ima manji intenzitet sile, dok bočni ankeri preuzimaju veća opterećenja a izražena nesimetrija je posljedica položaja slojeva. Također, na slici je dat detalj prikaza aksijalnih sila koje djeluju na ankerima na kome se s gornje strane označava pritisak a sa donje zatezanje, dato u kN. U slučaju 5 ankera, za razliku od slučaja kada je u prostoriji ugrađeno 3 ankera, može se uočiti da je intenzitet napona pritiska manji (po apsolutnoj vrijednosti), ali i da je intenzitet napona zatezanja nešto veći, i to u podinskom dijelu prostorije. Intenzitet sile u ankerima je također veći.

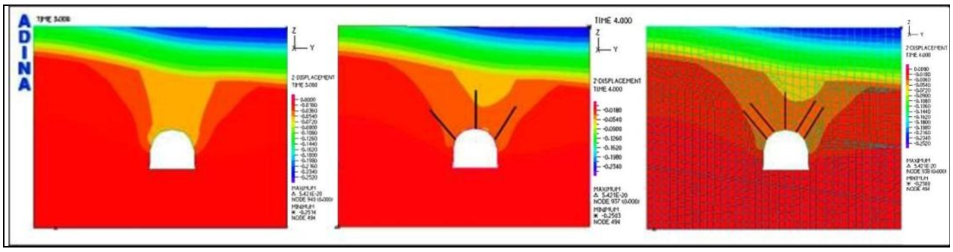
Plastične deformacije, vertikalni pomak, plastični flag

Veličine plastičnih deformacija su manjeg intenziteta oko prostorije sa ugrađenim ankerima. Plastične deformacije su naročito izražene u donjem desnom uglu prostorije, što je posljedica litološkog sastava i oblika prostorije (u podini je pijesak), te zato što oštri uglovi izazivaju visoke koncentracije napona. Plastične deformacije su izražene u procentima (%). Veličina plastičnih deformacija za prostoriju bez ankera je veća nego za prostoriju sa ankerima. Uočava se također da je intenzitet plastičnih deformacija, u ovom slučaju, manji sa 5, nego za slučaj iste prostorije sa ugrađena 3 ankera.



Sl. 5. *Uporedni prikaz plastičnih deformacija prije i nakon ugradnje 3 i 5 ankera*

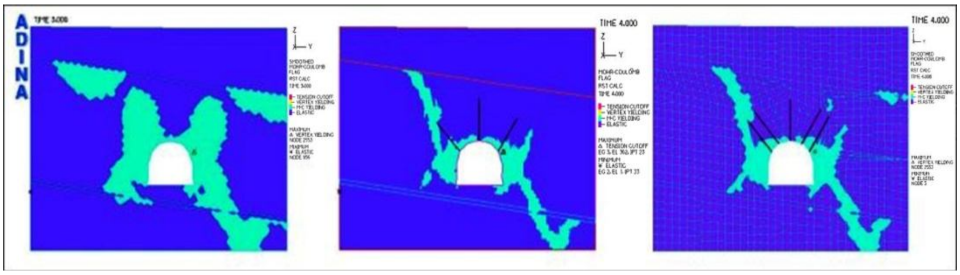
Vertikalni pomaci daju slikovit primjer kada je u pitanju primjena ankera, obzirom da ugradnja ankera u kratkom vremenu nakon izrade prostorije bitno utiče na smanjenje visine prostorije. Iz slike je jasno uočljivo da dolazi do promjene polja djelovanja iskopa na sekundarno naponsko stanje u masivu, i do promjena sekundarnog naponskog stanja u masivu nakon ugradnje ankera. Linije vertikalnog pomaka ukazuju da se bitno mijenja slika raspodjele vertikalnih pomaka sa ugrađenih 5 ankera. Uporeďivanjem za iste uslove, ali za prostoriju sa samo 3 ugrađena ankera vidljivo je da intenzitet vertikalnih pomaka manji.



Sl. 6. *Uporedni prikaz vertikalnih pomaka prije i nakon ugradnje 3 i 5 ankera*

Plastični flag je pokazatelj nastanka plastične deformacije u Gaussovim tačkama elemenata, te ukazuje na zone, elemente elemente, koji su pretrpjeli plastičnu deformaciju. Iz legende je uočljivo da je plastifikacija nastupila kao posljedica prekoračunja Mohr-Coulombovog uslova loma. Ova je zona znatno izraženija bez ankera. Nije uočena plastifikacija za ostale uslove i kriterije (čvrstoće na pritisak, zatezanje).

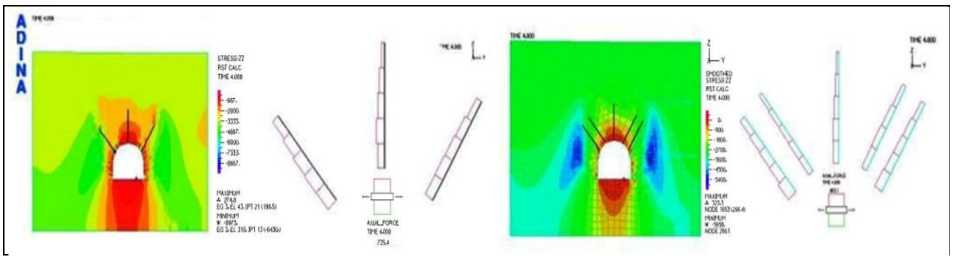
Također, u legendi dato je objašnjenje na koje modele može i mora biti izražena plastična deformacija zbog zatezanja, plastična deformacija zbog pritiska ili prekoračenja Mohr - Coulombovog uslova loma, a prikazano je da postoji evidentna razlika između slučaja sa 3 i 5 ankera.



Sl. 7. *Uporedni prikaz plastičnog flaga u vremenu prije u nakon ugradnje 3 i 5 ankera*

Sila čupanja ankera

Na istom modelu, samo iz različitih pozicija ugrađenih ankera u strop vertikalno, ili pod uglom, razmatranisu i dati rezultati sile čupanja ankera. U rezultatima se obrađuju vertikalni pomak i prikazuje intezitet sila. Modelirana je sila čupanja, prvo koso postavljenog ankera, a zatim i sila čupanja ankera direktno iz stropa. Veličine sila i pomaka su prezentirane i date na adekvatnim crtežima, a to što je evidentno jeste da je veća sila čupanja kod ankera ugrađenog direktno u strop.



Sl. 8. *Sila čupanja ankera iz stropa prostorije*

ZAKLJUČNA RAZMATRANJA

Na osnovu dobijenih rezultata može se zaključiti da u Rudniku lignita Mramor, na analiziranom profilu polukružnog svoda prostorije na 16-om spratu (TOH-16), postoji evidentna razlika u preraspodjeli napona kod podgrađivanja sa tri ankera i podgrađivanja sa pet ankera. Obzirom da je analiza stanja napona oko podzemnih prostorija u slojevitim ležištima sigurna metoda za izbor podgrađivanja podzemnih prostorija ankerima, numeričkim metodama izvedena je naponska analiza koristeći licencirani softver na RGGF-u Tuzla ADINA, verzija 8.6., s ciljem dobijanja što objektivnijih analiza i proračuna. Model ADINA, u inženjerskom smislu, daje pouzdane rezultate, u skladu s kojima se dobija pouzdana slika napona i sila u ankerima. Kroz softversku analizu napona dokazana je teza o preraspodjeli napona za sekundarno i tercijarno naponsko stanje u svodu i bokovima prostorije ugradnjom ankera, a što dokazuju dobijeni rezultati.

Dobijena sila čupanja iz modelirane vrijednosti mora biti bitno manja od sile praktičnog čupanja sa pumpom, iz razloga što se kod praktičnog čupanja stvara oslonac koji prave oslonac pumpe i privremeno ugrađena podgrada, te se time dobija veća vrijednost sile čupanja od modelirane vrijednosti.

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THEORETICAL ASSUMPTIONS IN DEVELOPMENT THE UNDERGROUD FACILITIES IN DIFFERENT GEOMECHANICAL CONDITIONS[**]

Abstract

The aim of this paper is to achieve a rational rates in development the underground facilities at the lowest costs of construction and possible maximum quality (in this case, under the quality is implied the satisfactory stability of contour of developed room and excavation profile as close to the shape and size of designed).

The applied research methods include analyzing development the underground facilities as a complex system with a significant number of maximum-dependent elements that are within this complex system, conditioned by the work environment, organization, mechanization, energy and other factors for achievement of this objective.

The results of these studies indicate that the construction process of development the underground facilities is functionally linked and depends on a whole range of interrelated factors. As the result, it is obtained that the corresponding mathematical models can define an optimal technology and organization of work for construction the underground facilities.

Keywords*: geomechanical conditions, production technology, underground rooms, systems, dependent elements, mathematical models*

1 INTRODUCTION

Design of underground facilities, regardless of the type of facilities it concerns (corridors, excavations, inclines, manholes, chambers, tunnels and rooms for other purposes), is a very complex system with a significant number of interdependent elements, which are conditioned within this complex system: working conditions, organization, equipment, energy and other factors of importance in achievement the overall objective, achieving a rational rate of construction the rooms, at the lowest costs of construction and possible maximum quality (*in this case, under the quality is implies a satisfactory stability contours of developed room and excavation profile as close to the shape and size of designed*).

By these very rigorous requirements, under the conditions of what is variable and often unknown rock mass, it is sometimes difficult to meet, for which there are many reasons: insufficient paying attention to the process of construction the underground facilities, insufficient knowledge on development conditions of facilities, inadequate technological manufacturing process, poor organization of work, equipment incompatibility with working conditions, lack of training of workers and many other factors. An objective assessment, if all the require-

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ments are met (the optimal rate of production, the lowest possible costs of manufacturing and quality of developed room), can be reached only after a detailed analysis, based on the large amount of information, which are reached by recording in the real working conditions of all elements in the technological system under the construction of facilities. Only, on the basis of an analysis of collected data, it is possible to assess the success of applied technology, equipment, organization and other elements that are a part of such system, to make closer the required amendments and supplements to the set requirements in respect of rationality and quality.

All complexity, related to the design of underground rooms is reflected through the independence of action and behavior of individual elements of the subsystems that are a part of technology development, as well as the large variability (in time and space) of working conditions and with these changes conditionality and changes of technological solutions, or individual ele-ments and parts of those subsystems. Also, the constant change of position of the work-place (head), working tools and workforce, are the reason for the changes of working conditions and efficiency of the process.

As the result of ongoing changes in the conditions of work, place of work and the efficiency of the operation, reduces the significance and reliability of the information gathered in one place to make decisions for work elsewhere, making it difficult, with frequent changes of working conditions, the definition of a unique technological solution of development and transport. The question of defining some unique technologies in these conditions is extremely complex. The production process becomes even more complex if the production of the observed object cannot be seen isolated from the system that surrounds it and with whom it is in the functional relationship. As an example, it can be noted that, the process of removing the mined material at the forefront of work site cannot be independent from the transport system and exports within the pit, the drilling process is not possible unless agreed with the possibility of supplying means for drilling with drive energy etc. All these examples show that the process of development the underground structure is functionally linked with the environment, and it depends on a whole series of interrelated factors, which can, for these purposes, be singled out as:

- working environment,
- organizational connections with the other technological processes in the system of pit,
- technological scheme of the pit,
- technological equipment of processes and
- importance of the underground facility for technological process of the pit as a whole.

All these factors directly affect the efficiency of technological process of the underground structure, and in particular must be studied. In view of complexity the construction process of underground faci-lities, and that the variability of factors influencing the process of design sometimes is significant, it is for assessments the design process or any of the elements of design, there is a need for a lot of information. Usually this information is obtained by direct recording of work processes and their elements and statistical analysis of the obtained data. Degree of their reliability is determined after that as well as finding, using mathematical methods, certain relationships and nature of their interdependence. Mathematically speaking, these relationships are usually stated in the form of dependency for required occurrence of one or more influential factors:

$$F = f(a, b, c, \dots). \qquad (1)$$

Technology construction analysis of underground spaces can be done in several different ways, from which is a system of complex study the problems of construction and determining the significance of influential factors in the technological process now found the most supporters. This system allows the technological process of construction to be split into several subsystems (the working operations), and subsystems on constituent elements and procedures, which completely independently of each other, and as a whole, using a logical, mathematical and organizational modeling allows, in terms of different aspects to require an assessment of speed advancement - effectiveness, efficiency coefficient of available time, utilization of available capacity, equipment and workforce, norms, the prices of construction, quality of construction and others. System of complex study of production technologies, or elements and subsystems applied or designed technological process, can be very well used in organizing or analyzing almost applied technological process.

2 METHODOLOGICAL APPROACH TO COMPLEX STUDY THE CONSTRUCTION TECHNOLOGY OF UNDERGROUND FACILITIES

The system of studying the complex construction technology of underground facilities or some parts of technological process allows more objective consideration of all factors that are active in the framework of design either the work processes or cycles designed or applied technology development. Thanks to this perception factors and their interdependence, it is possible to make the appropriate innovations and changes on the existing technological processes, and on the newly designed ones, already in the very beginning, to harmonize organizational and technological relationships, all with the aim that the technological process reach flawlessly organizational and technological functions, in order to achieve maximum efficiency and with minimum investments.

In the analysis of such a system, first it is necessary to make a partition of influential factors according to their nature as:

- input,
- desired,
- organizational, and
- random – uncontrolled parameters.

Schematic presentation of such model is shown in Figure 1. (A) indicates parameters related to: mining - geological conditions, technological characteristics of the rock mass, equipment, etc. (B) indicates desired results: construction rate of facilities, performance, price of construction, etc. (C) indicates parameters of organizational - technical nature: operation regime, organization, mechanizational degree of working operations, the drilling and mining parameters (in case when the method of mining for different rock mass is used), material, etc. (D) indicates random or applied parameters of technological processes and stability characteristics of rock mass, unscheduled downtime related to: lack of energy, auxiliary materials, various jams and others. It should be borne in mind that desired result of (B), in addition to the basic influences of (A), largely depends on conditions and parameters given in (C), although the impact factors of (D) cannot be ignored, because sometimes these impacts can have a significant impact on formation the final decision and achievement the end effects. Knowing all these facts, it is necessary to accept the events that occur within one such model, a significant proportion have all three factors, so that the final result represents their common synthesis, which allows the mathematical expression of required values to be expressed in the form as:

$$B = f\,(A.\ C.\ D). \qquad (2)$$

There is no doubt that such model can be dependent on a number of factors that, each individually, according to their impact on the ultimate outcomes can have different weights. Due to this this reason, and in order to rational and efficient solving the problem, it is necessary to highlight only those factors that have a significant impact on model behavior. Thus defined model allows that, according to the wishes and needs, find the best solutions (minimum or maximum values), but according to the character of occurrence and requested data. Figure 2 presents the scheme of model of technological systems in the field of construction related to the underground facilities.

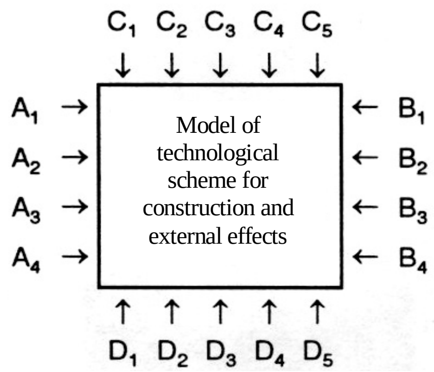

Figure 1 *Schematic models of technological systems in the field of construction of underground facilities*

Technological construction process of underground facilities (regardless of technological solutions), based on the dynamic plan development, represents a cyclic solution, in which in each cycle, constituent elements of the cycle are closely interlinked and carried out according to ahead established order, which enables this system to be observed as a stable system composed of several subsystems, which follow one another. Figure 2 shows a technological construction scheme, seen as a system composed of a number of independent subsystems.

Thus the formulated problem leads to the process of finding such alternative solutions, which, under the given conditions will provide the best results, not only of each subsystem, but the system as a whole. In solving these problems, it is necessary to perform an analysis from the following aspects: technological (real possibilities of application the analyzed solutions), organizational (possibility of organizing the implementation of analyzed solution) and time required to execute the scheduled job (selection of variants that are most favorable from the standpoint of time adaptation into the cycle and organizational scheme of the pit).

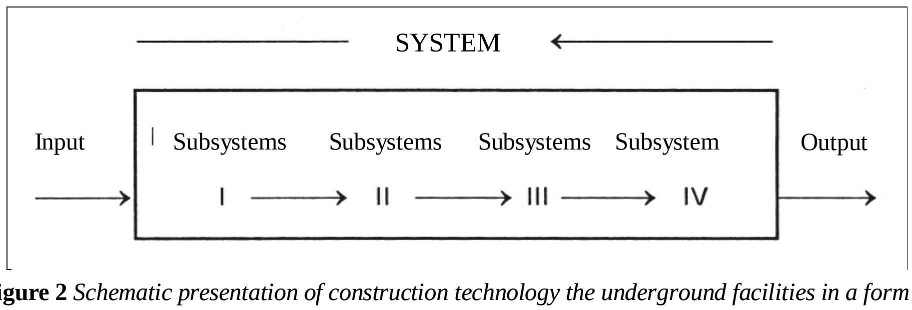

Figure 2 *Schematic presentation of construction technology the underground facilities in a form of independent system composed of several subsystems which are closely linked:*
I - Subsystem destruction of the rock mass; II - Ventilation subsystem of the worksite; III - Subsystem of loading and transportation the mined rock mass; IV - Subsystem of supporting facilities

Finding of criteria, based on which the optimal subsystems and systems will be determined, in terms of a large number of alternative solutions, represents a complex issue. Therefore, these studies show significantly more grateful finding the conditions of achieving the highest performance (in this case the highest advancement), with minimum of material costs (in this case the lowest price development). In mathematical theory, this procedure is known as the **theory of reciprocity**. This criterion is usually formed as the sum of individual criteria of occurrence (k), with a certain coefficient (f), which defines the signi-ficance of each of the observed occurrences:

$$U = f_1 \cdot k_1 + f_2 \cdot k_2 + f_n \cdot k_n \rightarrow \max (\min) \quad (3)$$

In analyzing the technological procedure of underground structure, in case of different optional solutions, most often the problem was considered from the standpoint of achieving the highest rate of construction (v) at the lowest cost of construction (c). This criterion is given in the form of linear relationship, as follows:

$$U = f \cdot (f_1 \cdot c + f_2 \cdot v), \quad (4)$$

where: $f_1 < 0$ i $f_2 > 0$ – are the coefficients of weight, taking into account the importance of indicators of costs and rate of construction

In solving the practical cases and tasks, there is no aspire to obtain the ideal values of selected criteria, considering that the results, obtained by field observations, are not fully adequate to imaginary model.

3 STRUCTURE OF SYSTEMS AND SUBSYSTEMS OF SELECTED CONSTRUCTION MODEL

As the method of development the facilities, in this case, the system with destruction the rock mass on the room face by blasting was adopted. This kind of system consists of several subsystems, among which the following stand out as the main:

- subsystem destruction of rock mass (I),
- ventilation subsystem (II),
- loading and transportation subsystem of blasted rock materials (Ill), and
- supporting subsystem (IV).

Other subsystems: coming from and going to the worksites, preparation the worksites, delivery of materials and auxiliary works (construction of water channels, extension of track, extension of tubes for compressed air, and pipes for water and separate ventilation), have been included in the organizational and regime works, and due to this reason will not be analyzed as separate subsystems, although they may have, in certain circumstances, a significant impact on final solution [2].

3.1 Structure of the subsystem destruction of rock mass

In this model, the followings occur as the input parameters:

f - coefficient of strength,
B - drilling of rocks,
g - resistence to destruction,
D - degree of cracking,
S - cross-section surface of the room, and
M - annual volume of works expressed in meters of constructed rooms.

As the output – desired parameters, the followings are adopted:

$l \cdot \eta$ - progression of room for one cycle,
Q - volume of blasted rock materials,
T - time of drilling, and
C - costs of drilling.

As the parameters that depend on technical and organizational conditions:

v - drilling rate and drilling and mining parameters of works:
q - specific consumption of explosives,
l - depth of bore holes,
N - number of bore holes,
d - diameter of bore holes,
A_{ex} - energy characteristics,
D - construction of mine, method of initiation and ignition,
Q_{org} - organization.

As variable and random sizes:

B - drilling of rocks,
O_t - interruption in work,
O_e - discontinuation due to a lack of energy, and
D_{dr} - other factors from this group.

Model of this subsystem is shown in Figure 3.

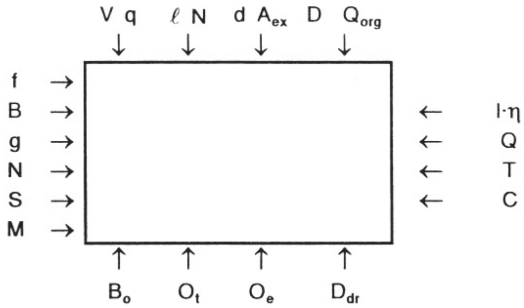

Figure 3 *Model structure of subsystem destruction of the rock mass*

Of all possible solutions and parameters, it is necessary to determine those solutions and those parameters that will provide the desired conditions with the least possible costs [3].

3.2 Structure of the subsystem ventilation

The input parameters are:

S - cross-section surface of room,
L - designed length,
H - depth of room,
Q_{ex} - consumption of explosive per cycle,
n_{rad} - number of emplyees at the worksite,

On the output side of the model, the desired parameters are:

h - required depression,
Q_{vaz} - the amount of air that should provide ventilation of facilities in time (t_{pr}) with economically justified costs (C_{prov}).

The organizational significant parameters are:

I - organization and ventilation scheme,
N - number of fans,
K - optimality of ventilation parameters and others.

The used random variables are:

P_{vent} - disruptions in fan operation,
P_{en} - lack of energy, and
D - other reasons.

From all these parameters, those should be chosen that will provide the required conditions and a stable system of ventilation. The model of this subsystem is shown in Figure 4.

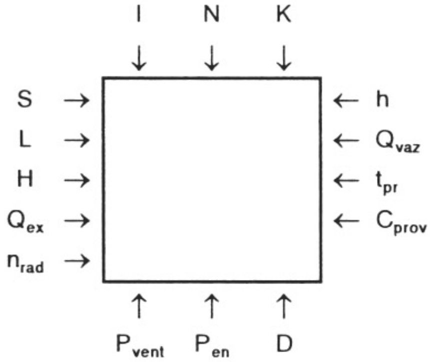

Figure 4 *Structure of the subsystem ventilation model*

3.3 Structure of the subsystem of loading and transport of blasted material

The main input parameters of this model are:

- S - cross-section surface of facilities,
- L - room length,
- Q - volume of blasted material, and
- M - annual volume of works on preparation.

The distinguished output parameters are:

- t - length of loading, and
- C_{tr} - costs of transport and loading.

The important organizational parameters are:

- E - way of loading and type of loading machine,
- F - way of wagon changing,
- P_{ut} - capacity of loader,
- O_{tr} - organization of transport and other parameters.

The important random parameters are:

- G - increase of non-dimensional pieces,
- Q_{tm} - failure of loader,
- P_e - interruption in power supply, and
- D - other reasons.

Optimum in this model for required conditions is achieved for the case when the loader operation is the shortest and costs are the lowest. Thus, the solution of this task (model) is led to the achievement of maximum loading capacity (Put $\rightarrow$ max), while the loading time is as short as possible (tut $\rightarrow$ min). The model of this subsystem is shown in Figure 5.

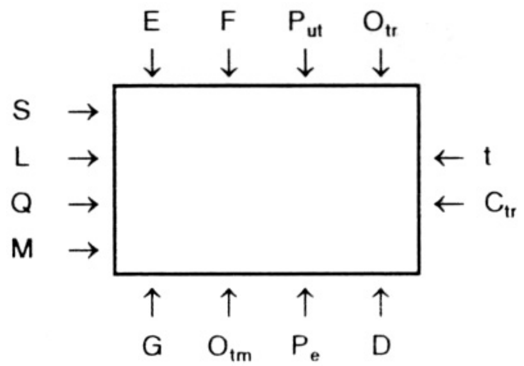

Figure 5 *Structure of subsystem loading and transport of blasted material*

3.4 Structure of the supporting subsystems

The main input parameters are:

- S – cross-section surface of facilities,
- H – depth of room,
- T –period (time) of room usage,
- f – coefficient of rock strength.

The important desired (output) data are:

- t_{pod} - lifetime of support,
- C_{pod} – cost of support, and
- F_{pod} – functionality of support.

Characteristic organizational parameters are:

- K_{pod} – applied economics of supporting construction,
- O_{pod} – designed parameter (volume) of supporting construction,
- P_{pod} – securing the necessary capacity of support,
- O_{org} – organization in support construction works.

The random variable parameters are:

f_0 - frequent and significant change the coefficient of rock mass strength,

X_{pod} – support damage, and

D_{pod} – other factors.

Model of this subsystem is shown in Figure. 6.

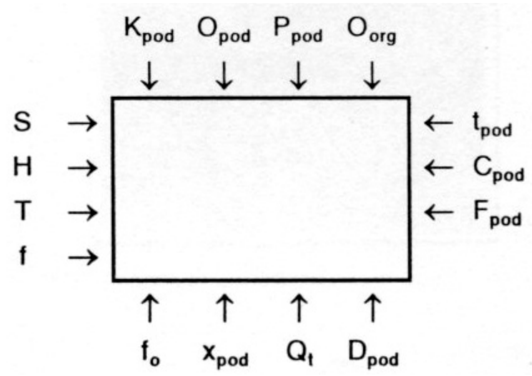

Figure 6 *Model structure of supporting subsystem*

CONCLUSION

Based on a detailed study of geomechanical conditions, technological processes and organization of work, it is possible to reach - from the standpoint of development the underground mine facilities, necessary data from which it is possible to design a new technology, organization of work, to carry out necessary industrial tests and checking, based on the obtained data - using the corresponding mathematical models, to define an optimal technology and work organization.

Based on the results obtained in natural conditions (optimal pits and different working environments) and their detailed analysis by the accepted mathematical methods and modern programs, the possibilities were created for comprehensive processing of problems by number and variety of data and obtaining the results that are verifiable in practice.

Based on all these processed elements, the possibilities were created for designing an optimal processing technology and work organization in which the problem of development rate and costs of construction are conditioned by techno-economic possibilities and requirements of this economic branch.

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TEOREТSKE POSTAVKE PRI IZRADI PODZEMNIH PROSTORIJA U RAZLIČITIM GEOMEHANIČKIM USLOVIMA**

Izvod

Cilj ovog rada je postizanje racionalne brzine izrade prostorije uz najniže troškove izgradnje i maksimalno mogući kvalitet (pod kvalitetom u ovom slučaju se podrazumeva zadovoljavajuća stabilnost konture izrađene prostorije i iskopni profil što bliži obliku i veličini projektovanog).

Primenjene metode istraživanja su analiza izrade podzemnih prostorija kao složenog sisitema sa znatnim brojem maksimalno zavisnimh elemenata koji su unutar ovog složenog sistema uslovljeni radnom sredinom, organizacijom, mehanizacijom, energijom i drugim činiocima za ostvarivanje ovog cilja.

Rezultati ovih istraživanja ukazuju da je proces izrade podzemnih prostorija funkcionalno vezan i da zavisi od čitavog niza međusobno povezanih činilaca. Kao rezultat dobijamo da sa odgovarajućim matematičkim modelima može se definisati optimalna tehnologija i organizacija rada na izradi podzemnih prostorija.

Ključne reči: *geomehanički uslovi, tehnologija izrade, porzemne prostorije, sistemi, zavisni elementi, matematički modeli*

1. UVOD

lzrada podzemnih prostorija, bez obzira o kojoj se vrsti prostorija radi, (hodnici, uskopi, niskopi, okna, komore, tuneli i prostorije druge namene), predstavlja veoma složen sistem sa znatnim brojem međusobno zavisnih elemenata, koji su unutar ovog složenog sistema uslovljeni: radnim uslovima, organizacijom, mehanizacijom. energijom i drugim činiocima od značaja za ostvarenje opšteg cilja, postizanje racionalne brzine izrade prostorije, uz najniže troškove izgradnje i maksimalno mogući kvalitet (*pod kvalitetom u ovom slučaju se podrazumeva zadovoljavajuća stabilnost konture izrađene prostorije i iskopni profil što bliži obliku i veličini projektovanog*).

Ovim i ovako veoma oštrim zahtevima, u uslovima kakva je promenljiva i često nepoznata stenska masa, ponekad je teško udovoljiti, za šta postoje mnogi razlozi: nedovoljno poklanjanje pažnje procesu izrade podzemnih prostorija, nedovoljno poznavanje uslova pod kojima će biti rađena prostorija, neodgovarajući tehnološki postupak izrade, loša organizacija rada, neusklađenost opreme sa radnim uslovima, neobučenost radnika i mnogi drugi činioci. Do objektivne procene, da li su svi postavljeni

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uslovi zadovoljeni (optimalna brzina izrade, najniži mogući troškovi izrade i kvalitet izrađene prostorije), moguće je doći samo posle detaljne analize zasnovane na velikom broju informacija, do kojih se dolazi snimanjem u realnim radnim uslovima svih elemenata u tehnološkom sistemu izrade prostorije. Tek na osnovu analize prikupljenih podataka moguće je proceniti uspešnost primenjene tehnologije, opreme, organizacije i drugih elemenata koji ulaze u sastav jednog ovakvog sistema, izvršiti potrebne dopune i izmene i približiti se postavljenim zahtevima u vezi racionalnosti i kvaliteta.

Sva složenost, vezana za izradu podzemnih prostorija, ogleda se kroz nezavisnost delovanja i ponašanja pojedinih elemenata podsistema koji ulaze u sastav tehnologije izrade, kao i velika promenljivost (u vremenu i prostoru) radnih uslova i sa ovim promenama uslovljavanje i izmene tehnološkog rešenja, ili pojedinih elemenata i delova ovih podsistema. Isto tako, i stalna promena položaja radnog mesta (čela), sredstava za rad i radne snage, razlog su izmenama uslova rada i efikasnosti samog procesa.

Kao posledica stalnih promena uslova rada, mesta rada i efikasnosti sredstava za rad, smanjuje se značaj i pouzdanost prikupljenih informacija na jednom mestu za donošenje odluka za rad na nekom drugom mestu, što otežava, kod čestih promena radnih uslova, definisanje jednog jedinstvenog tehnološkog rešenja izrade i transporta. Pitanje definisanja neke jedinstvene tehnologije u ovakvim uslovima je izuzetno složeno. Proces izrade postaje još složeniji, ako se izrada posmatranog objekta ne može posmatrati izolovano od sistema koji ga okružuje i sa kojim je on u funkcionalnoj povezanesti. Kao primer, može se istaći da, proces uklanjanja izminiranog materijala na čelu radilišta ne može biti nezavistan od sistema transporta i izvoza u okviru jame, proces bušenja nije moguć ukoliko nije usaglašen sa mogućnošću snabdevanja sredstava za bušenje pogonskom energijom itd. Svi ovi primeri ukazuju da je proces izrade podzemne prostorije funkcionalno vezan sa okruženjem, i da zavisi od čitavog niza međusobno povezanih činilaca, koji *se* mogu, za ove potrebe, izdvojiti kao:

- radna sredina,
- organizaciona povezanost sa ostalim tehnološkim procesima u sistemu jame,
- tehnološka šema jame,
- tehnološka opremljenost procesa i
- značaj podzemnog objekta za tehnološki proces jame kao celine.

Svi ovi činioci direktno utiču na efikasnost tehnološkog procesa izrade podzemne prostorije, i posebno se moraju izučavati. S obzirom na složenost procesa izrade podzemnih prostorija, i na to da je promenljivost činilaca koji utiču na proces izrade ponekad značajna, to je za donošenje ocene o procesu izrade ili nekog od elementa izrade, neophodno jako mnogo informacija. Obično se ove informacije dobijaju direktnim snimanjem radnih procesa i njihovih elemenata i statističkom obradom dobijenih podataka. Nakon toga se utvrđuje stepen njihove pouzdanosti i pronalaženje, pomoću matematičkih metoda, određenih veza i prirode njihove međuzavisnosti. Matematičkim jezikom rečeno, ove veze obično se iskazuju u obliku neke zavisnosti za traženu pojavu, od jednog ili više uticajnih činilaca:

$$F = f\,(a, b, c, \dots). \qquad (1)$$

Analiza tehnologije izrade podzemnih prostorija može biti izvršena na više različitih načina, od kojih je sistem kompleksnog izučavanja problematike izrade i utvrđivanja značaja uticajnih činilaca u tehnološkom procesu za sada našao najviše pristalica. Ovaj sistem omogućava da se tehnološki proces izrade razdvoji na više podsistema (radnih operacija), a podsistemi na sastavne elemente i zahvate, koji potpuno nezavisno jedan od drugog, a i kao celina, korišćenjem logičkog, matematičkog i organizacionog modeliranja omogućava, da se sa različitih aspekata da potrebna ocena brzine napredovanja – efikasnosti, stepena iskorišćenja raspoloživog vremena, iskorišćenja raspoloživih kapaciteta, opreme i radne snage, normativa, cene izrade, kvaliteta izrade i dr. Sistem kompleksnog izučavanja tehnologije izrade, ili elemenata i podsistema primenjenog ili projektovanog tehnološkog procesa, može veoma dobro da posluži prilikom organizovanja ili analize već primenjenog tehnološkog procesa.

2. METODOLOŠKI PRISTUP PRIMENI KOMPLEKSNOG IZUČAVANJA TEHNOLOGIJE IZRADE PODZEMNE PROSTORIJE

Sistem kompleksnog izučavanja tehnologije izrade podzemne prostorije, ili pojedinih delova tehnološkog procesa, omogućava objektivnije sagledavanje svih činilaca koji aktivno deluju u okviru zahvata, radnih procesa ili radnog ciklusa projektovane ili primenjene tehnologije izrade. Zahvaljujući ovakvom sagledavanju činilaca i njihovih međuzavisnosti, moguće je kod postojećih tehnoloških procesa izvršiti odgovarajuće inovacije i izmene, a kod novoprojektovanih, već u samom startu, organizaciono i tehnološki uskladiti međuodnose, sve sa ciljem da tehnološki proces besprekorno organizaciono i tehnološki funkcioniše, u funkciji postizanja maksimalne efikasnosti i uz najmanja ulaganja.

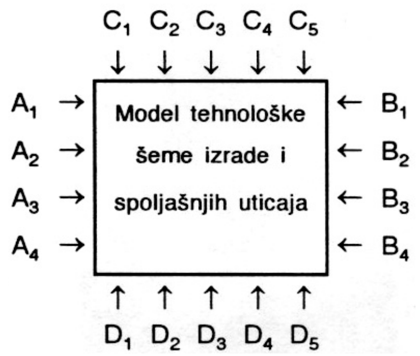
Prilikom analize jednog ovakvog sistema neophodno je prvo rasčlaniti uticajne činioce prema njihovoj prirodi na:

- ulazne,
- željene,
- organizacione i
- slučajne - nekontrolisane parametre.

Šematski prikaz ovakvog modela dat je na slici 1. Sa (A) su označeni parametri vezani za: rudarsko - geološke uslove, tehnološke karakteristike stenske mase, oprema i sl. Sa (B) su označeni željeni rezultati: brzina izrade prostorije, učinak, cena izrade i sl. Sa (C) su označeni parametri organizaciono - tehničke prirode: režim rada, organizacija, stepen mehanizovanosti radnih operacija, parametri bušenja i miniranja (za slučaj kada je korišćena metoda miniranja za razaranje stenske mase), materijal i sl. Sa (D) su označeni slučajni ili primenjivani parametri tehnološkog procesa i stabilnosnih karakteristika stenske mase, nepredviđeni prekidi u radu vezani za: nedostatak energije, pomoćnog materijala, razni zastoji i dr. Ovde treba imati u vidu da željeni rezultat (B), pored osnovnog uticaja (A), u najvećoj meri zavisi i od uslova i parametara datih pod (C), mada ni uticaj činilaca (D) ne sme biti zanemaren, jer ponekad ovi uticaji mogu imati značajan uticaj na formiranje konačnog rešenja i postizanje krajnjih efekata. Znajući sve ove činjenice, nužno je prihvatiti da na zbivanja koja *se* dešavaju unutar jednog ovakvog modela, značajan udeo imaju sva tri činioca, tako da konačan rezultat predstavlja njihovu zajedničku sintezu, što dozvoljava da se matematički izraz tražene vrednosti iskaže u obliku:

$$B = f\,(A.\ C.\ D). \qquad (2)$$

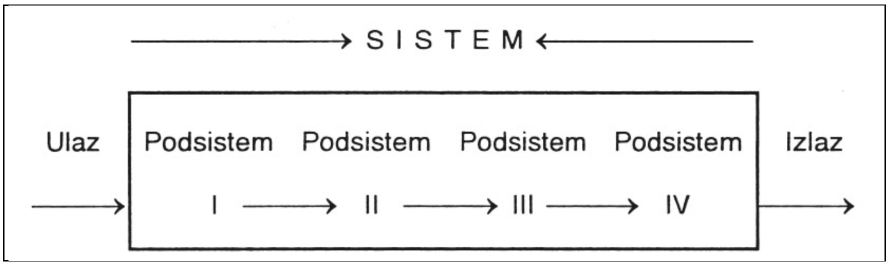
Nesumljivo da jedan ovakav model može biti zavistan od velikog broja činilaca, koji, svaki pojedinačno po svom uticaju na konačan rezultat, mogu imati različite težine. Iz ovog razloga, a u cilju racionalizacije i efikasnijeg rešavanja problema, potrebno je izdvojiti samo one činioce koji imaju značajniji uticaj na ponašanje modela. Ovako definisan model omogućava da se, prema želji i potrebama, nađu najpovoljnija rešenja (minimum ili maksimum vrednosti), već prema karakteru same pojave i traženog podatka. Na slici 2. prikazana je šema modela tehnološkog sistema u oblasti izrade podzemnih prostorija.



Sl. 1. *Šema modela tehnološkog sistema u oblasti izrade podzemnih prostorija*

Tehnološki proces izrade podzemnih prostorija (bez obzira na tehnološka rešenja), prema dinamičkom planu izrade, predstavlja ciklično rešenje, kod koga su u svakom ciklusu, sastavni elementi ciklusa tesno međusobno povezani i odvijaju se po napred utvrđenom redosledu, što omogućava da se ovakav sistem posmatra kao stabilan sistem sastavljen od više podsistema, koji slede jedan za drugim. Na slici 2. prikazana je jedna tehnološka šema izrade, posmatrana kao sistem sastavljen od većeg broja nezavisnih podsistema.

Ovako postavljen problem svodi se na postupak pronalaženja takvih varijantnih rešenja, koja će u datim uslovima obezbediti i najpovoljnije rezultate, ne samo svakog pojedinačnog podsistema, već i sistema kao celine. Kod rešavanja ovakvih problema neophodno je izvršiti analizu sa sledećih aspekata: tehnološkog (stvarne mogoćnosti primene analiziranog rešenja), organizacionog (mogućnost organizacionog sprovođenja analiziranog rešenja) i potrebnog vremena za izvršenje predviđenog posla (izbor varijanti koje su najpovoljnije sa stanovišta vremenskog uklapanja u ciklus i organizacione šeme jame).



Sl. 2. *Šematski prikaz tehnologlje izrade podzemne prostorije u obliku nezavisnog sistema sastavljenog od više podsistema koji su međusobno tesno povezani: I - Podsistem razaranja stenske mase; II - Podsistem provetravanja radilišta; III - Podsistem utovara i transporta izminiranog stenskog materijala; IV - Podsistem podgrađivanja prostorije*

Pronalaženje kriterijuma, na osnovu kojeg će biti utvrđivana optimalnost podsistema i sistema, s obzirom na veliki broj alternativnih rešenja, predstavlja složeno pitanje. Zato se kod ovakvih istraživanja pokazalo znatno zahvalnijim pronalaženje uslova pod kojim se postiže najveći učinak (u ovom slučaju najveće napredovanje), uz najmanje materijalne izdatke (u ovom slučaju najniža cena izrade). U matematičkoj teoriji, ovaj postupak poznat je kao **teorija uzajamnosti**. Ovakav kriterijum obično se obrazuje kao zbir proizvoda kriterijuma pojedinačnih pojava (k), sa nekim koeficijentom (f), koji definiše značaj svake od posmatranih pojava:

$$U = f_1 \cdot k_1 + f_2 \cdot k_2 + f_n \cdot k_n \rightarrow \max (\min) \quad (3)$$

Prilikom analize tehnološkog postupka izrade podzemne prostorije, za slučaj različitih varijantnih rešenja, najčešće se problem razmatra sa stanovišta postizanja najveće brzine izrade (v) uz najmanje troškove izrade (c). Ovaj kriterijum dat u obliku linearne veze, glasi:

$$U = f \cdot (f_1 \cdot c + f_2 \cdot v), \quad (4)$$

gde su: $f_1 < 0$ i $f_2 > 0$ - koeficijenti težine, koji uzimaju u obzir značaj pokazatelja troškova i brzine izrade.

Kod rešavanja praktičnih slučajeva i zadataka ne teži se dobijanju idealne vrednosti odabranog kriterijuma, s obzirom da rezultati, koji su dobijeni terenskim opažanjima nisu u potpunosti adekvatni zamišljenom modelu.

3. STRUKTURA SISTEMA I PODSISTEMA ODABRANOG MODELA IZRADE

Kao metoda izrade pozemnih prostorija, u ovom slučaju, usvojen je sistem sa razaranjem stenske mase na čeIu prostorije uz pomoć miniranja. Ovakav sistem sastoji se od više podsistema, među kojima se kao osnovni izdvajaju sledeći:

- podsistem razaranja stenske rnase (I),
- podsistem provetravanja (II),
- podsistem utovara i transporta miniranog stenskog materijala (Ill), i
- podsistem podgradivanja (IV).

Ostali podsistemi: dolazak i odlazak na i sa radilišta, priprema radilišta, doprema materijala i pomoćni radovi (izrada kanala za vodu, produženje koloseka, produženje cevi za sabijeni vazduh, cevi za vodu i cevi za separatno provetravanje), uvršćeni su u organizacione i režijske poslove, i iz tog razloga neće biti analizirani kao posebni podsistemi, iako oni mogu imati u određenim uslovima značajan uticaj na konačno rešenje [2].

3.1. Struktura podsistema razaranja stenske mase

Kod ovog modela kao ulazni parametri javljaju se:

- f - koeficijent čvrstoće,
- B - bušivost stene,
- g - otpor prema razaranju,
- D - stepen ispucalosti,
- S - površina poprečnog preseka prostorije i
- M - godišnji obim radova izražen u metrima izrađenih prostorija.

Kao izlazni - željeni parametri usvojeni su:

- $l \cdot \eta$ - napredovanje prostorije za jedan ciklus,
- Q - zapremina miniranog stenskog materijala,
- T - vreme bušenja i
- C - troškovi bušenja.

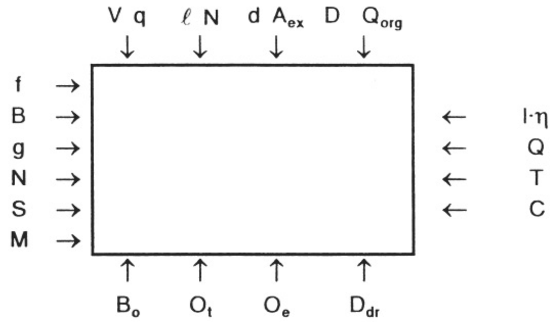
Kao parametri koji zavise od tehničko-organizacionih uslova:

- v - brzina bušenja i parametri bušačko-minerskih radova:
- q - specifična potrošnja eksploziva,
- l - dubina bušotina,
- N - broj bušotina,
- d - prečnik bušotine,
- A_{ex} - energetske karakteristike,
- D - konstrukcija mine, način iniciranja i paljenja,
- Q_{org} - organizacija.

Kao promenljive i slučajne veličine:

- B - bušivost stene,
- O_t - prekid u radu,
- O_e - prekid zbog nedostatka energije i
- D_{dr} - drugi činioci iz ove grupe.

Model ovog podsistema prikazan je na slici 3.



Sl. 3. *Struktura modela podsistema razaranja stenske mase*

Od svih mogućih varijantnih rešenja i parametara treba utvrditi ona rešenja i one parametre koji će obezbediti željene uslove uz najmanje moguće troškove [3].

3.2 Struktura podsistema provetravanja

Kao ulazni parametri definisani su:

S - površina poprečnog preseka prostorije,

L - projektovana dužina,

H - dubina prostorije,

Q_{ex} - utrošak eksploziva po ciklusu,

n_{rad} - broj zaposlenih na radilištu,

Na izlaznoj strani modela željeni parametri su:

h - potrebna depresija,

Q_{vaz} - količina vazduha koja treba da obezbedi provetravanje prostorije za vreme (t_{pr}) uz ekonomski opravdane troškove (C_{prov}).

Od organizacionih parametara značajni su:

I - organizacija i šema provetravanja,

N - broj ventilatora,

K - optimalnost parametara provetravanja i dr.

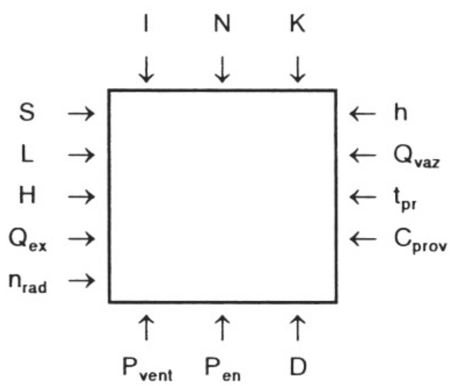
Kao slučajne promenjive korišćene su:

P_{vent} - prekidi u radu ventilatora,

P_{en} – nedostatak energije, i

D - drugi razlozi.

Od svih ovih parametara treba odabrati one koji će obezbediti tražene uslove i stabilan sistem provetravanja. Model ovog podsistema prikazan je na slici 4.



Sl. 4. *Struktura modela podsistema provetravanja*

3.3. Struktura podsistema utovara i transporta izminiranog materijala

Osnovni ulazni parametri kod ovog modela su:

S - površina poprečnog preseka prostorije,

L - dužina prostorije,

Q - zapremina miniranog materijala i

M - godišnji obim radova na izradi.

Kao izlazni parametri izdvajaju se:

t - dužina utovara i

C_{tr} - troškovi transporta i utovara.

Od organizacionoh parametara značajni su:

E - način utovara i tip mašine za utovar,

F - način izmene vagoneta,

P_{ut} - kapacitet utovarača,

O_{tr} - organizacija transporta i drugi parametri.

Od slučajnih parametara značajni su:

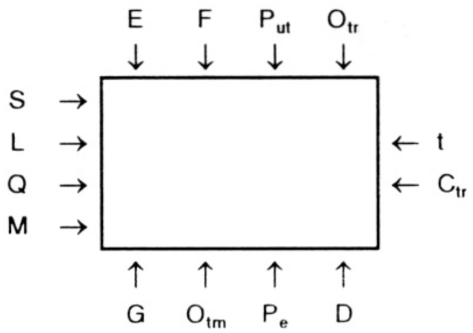
G - povećanje negabaritnih komada,

Q_{tm} - otkaz mašine za utovar,

P_e - prekid u dovodu energije i

D - drugi razlozi.

Za tražene uslove optimum se kod ovog modela postiže za slučaj kada je operacija utovara najkraća, a troškovi najniži. Prema tome, rešenje ovog zadatka (modela) svodi se na postizanje najvećeg mogućeg kapaciteta utovara ($P_{ut} \rightarrow max$), a da pri tome vreme utovara bude što kraće ($t_{ut} \rightarrow min$). Model ovog podsistema prikazan je na slici 5.



Sl. 5. *Struktura modela podsistema utovara i transporta izminiranog materijala*

3.4 Struktura podsistema podgrađivanja

Osnovni ulazni parametri su:

S - površina poprečnog preseka prostorije,

H - dubina prostorije,

T - period (vreme) korišćenja prostorije,

f - koeficijent čvrstoće stene.

Od željenih (izlaznih) podataka bitni su:

t_{pod} - vek trajanja podgrade,

C_{pod} - cena koštanja podgrade i

F_{pod} - funkcionalnost podgrade.

Od organizacionih parametara mogu se izdvojiti:

K_{pod} - ekonomičnost primenjene konstrukcije podgrade,

O_{pod} - projektovani parametar (obim) podgrade konstrukcije,

P_{pod} - obezbeđenje potrebne nosivosti podgrade,

O_{org} - organizacija pri izvođenju radova na podgrađivanju.

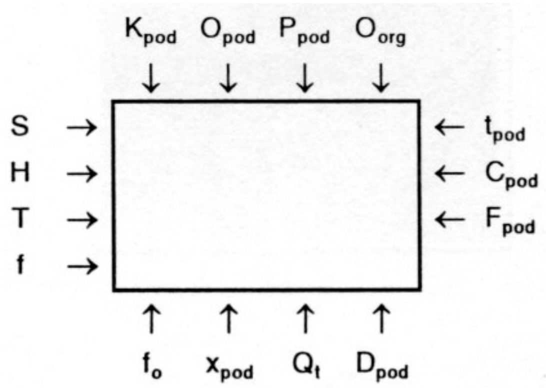
Od slučajnih promenljivih parametara prisutni su:

f_0 - česta i značajna promena koeficijenta čvrstoće stenske mase,

X_{pod} - oštećenje podgrade i

D_{pod} - drugi činioci.

Model ovog podsistema prikazan je na slici 6.



Sl. 6. *Struktura modela podsistema podgrađivanja*

ZAKLJUČAK

Na osnovu detaljnog izučavanja geomehaničkih uslova, tehnoloških procesa i organizacije rada moguće je doći do – sa stanovišta izrade jamskih prostorija, neophodnih podataka na osnovu kojih je moguće projektovanje nove tehnologije, organizacije rada, izvršiti potrebna industrijska ispitivanja i provera na osnovu ovako dobijenih podataka – koristeći se odgovarajućim matematičkim modelima, definistai optimalnu tehnologiju i organizaciju rada.

Na osnovu rezultata koji se dobijaju u prirodnim uslovima (optimalnim jamama i različitim radnim sredinama) i njihovom detaljnom analizom uz pomoć prihvaćenih matematičkih metoda i savremenih programa stvorene su mogućnosti da se ovako po broju i raznovrsnosti podataka složena problematika sveobuhvatno obradi i dobiju rezultati koji su u praksi proverljivi.

Na osnovu svih ovako obrađenih elemenata stvorene su mogućnosti za projektovanje optimalne tehnologije izrade i organizacije rada kod koje je problem brzine izrade i cene izrade uslovljena sa tehnoekonomskim mogućnostima i zahtevima ove privredne grane.

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NEW LEACHING METHOD ON THE ROCK SALT DEPOSIT „TETIMA“ NEAR TUZLA

Abstract

In the project documentation for rock salt deposit Tetima exploitation, two methods of exploitation are developed: method of lateral leaching with narrow footstep tubing as the main method applied on all drilled boreholes, and method of roof leaching with cemented protecting column as the alternative method, which will be applied in such parts of deposit where it has the advantage over the method of narrow footstep tubing.

Evaluation and decision on application the method of roof leaching with cemented protecting column will be made after ascertainment the above parameters in drilled borehole. This method has not been applied yet.

The main aim of this paper is to find an optimum for continous exploitation the existing boreholes through techno-economic analysis of previously applied method.

The analysis was carried out on an example of borehole B-67, and it has processed the regularity of chambers, "escaping" of the roof and balancing of isolant, and the all mentioned in correlation with the geological conditions. The Institute OBRGSChem. „CHEMKOP“ in Krakow has done a computer simulation of technology with lateral and roof leaching with two movable columns using the program WinUbroNet for borehole B-67 in two options: with partial isolation of roof and without isolation.

Keywords*: controlled leaching, exploitation method, isolant balancing, computer simulation*

1 INTRODUCTION

Salt production in each country has special meaning because salt and its products represent very important industrial raw material.

Salt exploitation in Bosnia and Herzegovina is related to Tuzla area, where the salt deposit “Tušanj“ is in exploitation for more than 100 years. The new deposit of rock salt “Tetima“ has intensified exploitation in the last ten years and represents a replacement capacity for the salt deposit ”Tušanj“.

Backing in 1971, long-year systematic geological explorations have started of the Dokanj syncline using geological and hydrochemical prospecting and thereafter continued with modern geological and geophysical methods which have indicated the potentiality of this structure.

Drilling in 1978 has confirmed a perspectivity of the deposit.

Exploration and contouring of the rock salt deposit was carried out in the next 6 years with 24 exploratory boreholes, out of which 17 boreholes have drilled a salt body.

The level of knowledge at that time on some important deposit characteristics and parameters (geological, hydrogeological, chemical-technological and others), which

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have a decisive influence in the selection of modes and methods of one salt deposit exploitation, were imposed to adopt, as an optimum solution, a concept by which the exploitation of this deposit will be performed using the controlled leaching of individual boreholes from surface.

In the project documentation, two methods of exploitation were developed: method of lateral leaching with narrow footstep tubing as the main method applied on all drilled boreholes, and the method of roof leaching with cemented protecting column as the alternative method which will be applied in parts of deposit where it has the advantage over the method of narrow footstep tubing.

This advantage is associated in the following cases:

- large or variable slope of layers in the roof of salt deposit, in parts of deposit with asserted lack of hermetic of rocks in the roof,
- identified large denivelations in the roof of salt deposit, formed as the result of salt karst,
- high content of insoluble components in lower part of deposit, especially in a number of continuous layers of insoluble rocks.

Evaluation and decision on application the method of cover leaching with cement casing will be taken after determining the above mentioned parameters in developed borehole. This method has not been applied yet.

Goal of this paper is try to find optimum during exploitation through techno-economic analysis of so far applied method, both on existing boreholes, as well as the ones that will be drilled in the future.

2 GEOLOGICAL INFORMATION ON THE ROCK SALT DEPOSIT TETIMA

The rock salt deposit Tetima is situated on the southern slopes of Majevica mountain, northeast of Tuzla at distance of 8 km.

The deposit is of the Middle Miocene, Lower Badenian age, occurring in the marine lagoon conditions of sedimentation, deposited in the Dokanj syncline. It is built of one single salt body of irregular shape and it has a complex structure. It is positioned in the roof part of banded series in the eastern frontal part of Dokanj syncline.

In a plan view, the deposit is of irregular oval shape, similar to the deposit in Tuzla. Longer axis is about 2000 m long, while shorter is about 1000 m. It is built of one salt body with layered- lenticular form, deposited in the Dokanj syncline with antiformic set of bottom in the northeast part of deposit. It lays in the northwest-southeast direction and falls to the west. The depth of this salt body, measured from surface. in the southeast is 400 m, and in the northwest is over 1000 m, which gives the average decline fall of 16^o.

Maximum thickness of the salt body is 150-200 m and goes parallel with longer axis, north of the center (longitudinal axis) of deposit, while toward the edges decreasing. In the southeastern part, the deposit thickness is reduced by antiformic structure of underlaying marl substratum within macro structure Dokanj syncline, while in the northwest turns into simpler lentoidal or layered form. The deposit form and especially inner tectonics, indicate the movement of salt masses to the shallower frontal part of syncline under the influence of tectonic forces, where the largest concentration of salt has occurred.

Salt body is mono-mineral with various forms of salt in the deposit. Quality of salt body is quite uniform with the average NaCl content of 91.9%.

Primarily, deposit was composed of crystalline halite aggregates, with coarse crystal structure of salt (millimeter-centimeter-sized grains), white and gray colored, with rare layers of marl and improperly deployed grains of anhydrite.

Tectonic processes have caused the change from primarily crystalline form of salt in the deposit into small, medium and coarse-grained form.

Bottom of the salt body is built of laminated dolomicrites which end with 8-10 cm thick interbeds of strip anhydrite. Very steep and often vertical layers indicate significant folding of bottom. Those are very often the meter-decimeter folds, probably inter layered.

The roof begins with well stratified anhydrite - marly breccia consisting of fragments of belt marl, anhydrite, marly limestone, tuffites and as a binder - dark gray marl of the Lower Badenian.

Breccia was formed after short emersion, and drying crack occurred at that time, both in clay-carbonate sludge and gypsum-anhydrite sediments. Short-term transport and binding of fragments occurred during the Lower Badenian transgression. The resulting breccia layer has a thickness of 5-40 m. Higher and high overlaying is made of marl and sandy - marl rocks of the Badenian and Sarmatian.

Hydrogeological situation is quite unfavorable.

On the contact of Lower Badenian marls and overlying breccias, the aggressive water was found with different degrees of mineralization. In the northeastern and eastern edge of the deposits, this water came in contact with a salt body causing occurrence of leaching.

In the bottom of salt body, presented with strip dolomicrites, in the tectonically damaged zone 10-30 meters below the salt body, the water body is developed with different mineralized and aggressive water.

In high roof layers, the water in the Baden and Sarmatian were identified. The Sarmatian water is of artesian character while others are sub artesian.

3 APPLICATION OF LATERAL LEACHING METHOD WITH CLOSE FOOTSTEPS OF TUBES

Techno-economic analysis of application the lateral leaching method with close footsteps of tubes is based on the example of borehole B-78, which ended its exploitation due to representativeness of data.

The analysis has primarily processed the regularity of chamber, "escaping" of the roof, balancing of isolator, and all in correlation with geological conditions.

3.1 Borehole B-78

The borehole was drilled in 1989, according to the Main Mining Project on Exploitation - Technical Project of Drilling and Completion of Boreholes for Exploitation the Rock Salt Tetima.

It is located in the newly formed cross section VI.

Basic data:

- Depth to the roof of salt body .... 455.80 m
- Depth to the bottom of salt body .... 589.29 m
- Thickness of salt body .... 133.49 m
- Dip of roof layer 22º
- Dip of bottom 30º

Data about quality:

- Content of salt in the salt body.......................................96.47 %
- Content of NaCl in salt ...... 95.59 %
- Content of NaCl in the salt body .... 91.26 %

3.2 Analysis of applied method

Real time of leaching in phases was approximately to the designed, capacities were slightly lower and concentrations were slightly higher than designed. During this period, six series of echo location measurements were done wherein it can be concluded that the sixth series resulted in exceeding the radius for 1.34 m at depth of 570 m in azimuth of 70°.

Maximum values of diameter and radius at the same depth are in the second (575 m) and the fourth series of measurements (577 m), wherein the hydro notch is eccentric, so that maximum radius has about 2/3 value of diameter. The general direction of hydro notch development is the east-southeast.

The final diameter of hydro notch is lower by 1.75 m than designed. The phenomenon of roof "escaping" was not observed. There was regularly thrown projected amounts of isolator in borehole. Temperatures of technological and salt water were dependent on the outside temperature or season.

3.2.1 Salt water production

During this period, five series of echo location measurement were carried out where the chamber continued to follow the started developing trend towards the northeast. In the eighth series of echo location measurement, exceeding of radius for 1.73 meters at depth of 534 m was observed by azimuth of 60°, while maximum diameter was less 10 m than designed. This trend of development chamber have continued until echo location measurement in the eleventh series exceeding radius for 21.77 m and diameter for 13.99 m at depth of 510 m in azimuth of 60° (Figure 1).

It can be conclude here that in the ninth, tenth and eleventh series of echo location measurements, maximal exceeding of diameter and radius is at the same depth, and that the radius is approximately 2/3 of diameter. Exceedences of radius are at depth of 474-488 m as well as on depth of 500-520 m as shown in Figure 2.

With the last series of echo location measurement, a vertical movement of chamber roof was observed (from the level of 475.00 m to the level 463.00 m). This practically means that the level of chamber roof is 12 m above footstep of technical tubing with diameter 9 ⅝ ". By this way, the majority of salt roof shelf was leached. On 15/10/2009, 17.00 m^3 of isolator (7.00 m^3 in the annular space and 10.00 in m^3 the roof of the chamber) were pumped in the borehole and roof of leachable chamber.

The borehole is excluded from process of salt water production on 30/09/2009.

During exploitation of the borehole, 448,142.61 t of salt was produced from 620,745 t of industrial reserves or the recovery of this chamber is about 72.19%.

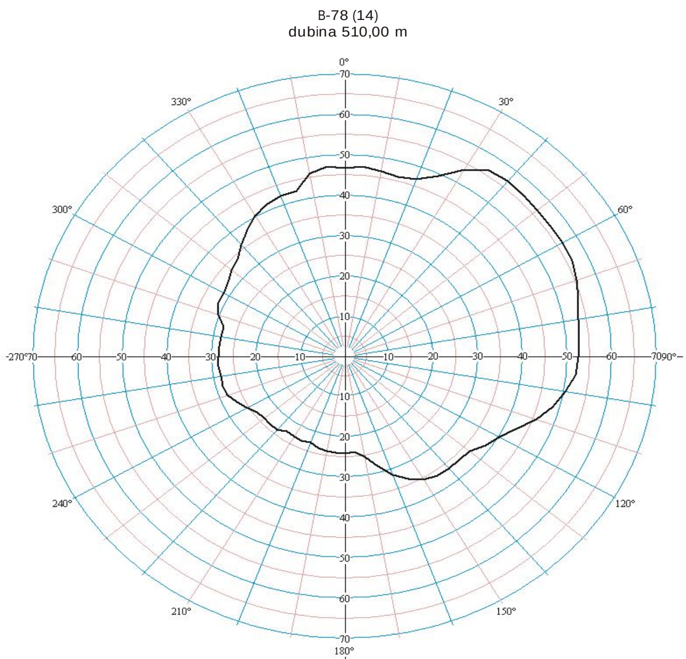

Figure 1 *Horizontal recording on the borehole B-78, depth 510.00 m*

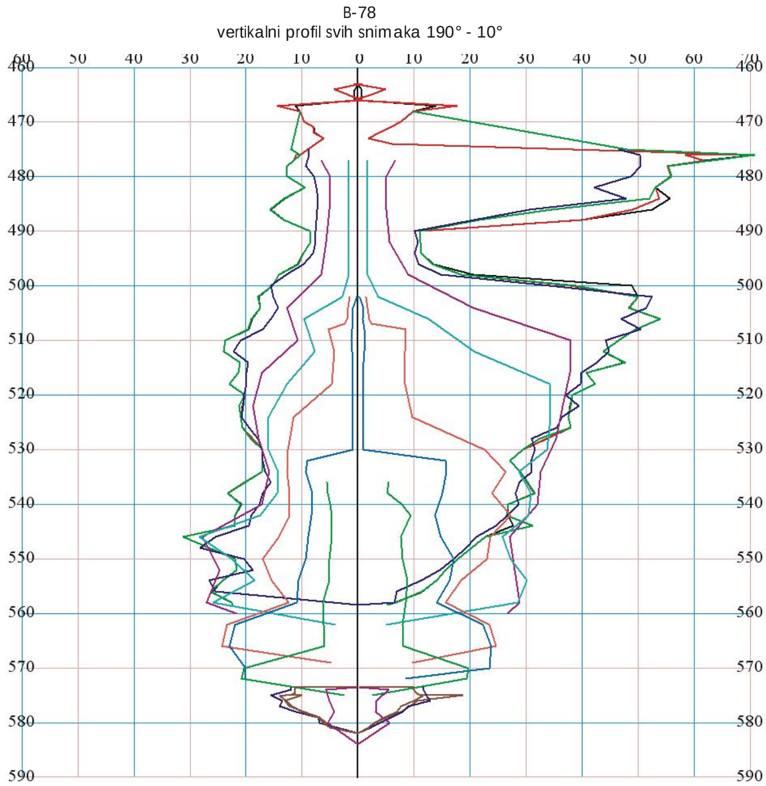

Figure 2 *Vertical cross section of all echo recordings on B-78, azimuth 190º -10º*

Three boreholes, namely B-87, B-84 and B-86, have completed their exploitation lifetime, in addition to the borehole B-78. Analyzing all four aforementioned boreholes, the following can be concluded:

- Hydro notches have got the irregular shapes, or mostly got eccentric form in the direction east-northeast, while the blockage of development is registered on the western side. In all hydro notches, maximum radius is approximately 2/3 of diameter. This can be also concluded for all other currently active boreholes.
- During production of salt water with industrial concentration in the boreholes B-87, B-86 and B-78, an exceeding of radius and diameter was registered, which was the highest in the borehole B-87. Also, in these boreholes, the general development direction is the east-northeast. An exceeding of radius was registered in the borehole B-84, while diameter was smaller than designed
- “Escaping" of the chamber roof is registered in B-86 (0.5 m), B-78 (1.5 m and 12.0 m), B-84 (1.7 m, 0.4 m and 0.7 m), while this phenomena is not registered in B-87.

Maximum value of "escaping" is in the borehole B-78, where the last series of echo location measurements have observed a vertical movement of the chamber roof (from the level of 475.00 m to the level 463.00 m). This practically means that the level of chamber roof is 12 m above the footstep of technical tubing with diameter 9⅝ ". By this way, a larger part of roof salt shelf was leached.

Balancing of isolator is extremely unfavorable. Considering that for some boreholes there are no data on isolator removal in the phase of hydro notch construction, total amounts are analyzed total amounts for which there are no data.

In the borehole B-84, from 313.5 m^3 of inserted isolator, 111.8 m^3 was obtained outside (“left“ in chamber 201.7 m^3).

In the borehole B-87, from 440.5 m^3 of inserted isolator, 418.2 m^3 was obtained outside (“left“ in chamber 22.3 m^3).

In the borehole B-78, from 242.7 m^3 of inserted isolator, 88.4 m^3 was obtained outside (“left“ in chamber 154.3 m^3).

In the borehole B-86, from 129.0 m^3 of inserted isolator, 42.1 m^3 was obtained outside (“left“ in chamber 86.9 m^3).

4 MAIN REASONS FOR CHANGING THE CURRENT METHOD

Variants for further leaching technologies are made primarily due to:

- Adaptation to the leaching in variable mining and geological conditions in the cross-section chamber,
- Limitations of isolator quantity used during leaching (to reduce losses)
- Higher efficiency of reserves

Limitation of isolator amount used during leaching will be realized through reduction in diameter of hydro notch, which will result in a more favorable balance of removed isolator below the roof of hydro notch and shortening the introductory period of leaching. In addition, the lower boundary of deposit with marls in bottom is tectonically very disturbed, there are blocks with cracked water bearing marls that are embedded in dozen meters in salt body, which supports the theory where diameter of hydro notch should be smaller, because there is a latent risk that during development of hydro notch it can make contact with the mentioned marls.

After the introductory leaching, exploitation could be conducted without isolation of the roof or with partial isolation.

In case when in the vertical profile of borehole (deposit) there are variable mining-geological conditions, the technology of roof or roof-lateral leaching offers the possibility of higher utilization of rock salt reserves compared to lateral leaching technology.

In lateral-roof leaching technology at the beginning of leaching, the hydro notch is much smaller than the current hydro notch. Leaching is much shorter because the roof leaching is faster than lateral, and it is possible to obtain saturated salt water earlier.

5 PROPOSAL FOR A NEW METHOD OF LEACHING

Based on the above, and based on the past experiences, a new method of exploitation is proposed, called the "Method of lateral and roof leaching without cemented protecting column".

According to this proposal, the Institut OBRGSChem. “CHEMKOP“ in Krakow has developed a computer simulation of lateral and roof leaching technology without cemented protecting column using the program *WinUbroNet* for borehole B-67 in two solutions: with partial roof isolation and without roof isolation.

After completion the preliminary leaching, the production of salt water starts with industrial concentrations, wherein two options are possible:

- Variant with partial isolation of the roof (radius not exceeding 4 m) with the achieved rising of the roof through rising the level of isolant in steps of 5.0 and 7.0 m. After the roof rising (at every step), the appropriate amount of isolator will be pumped into the borehole. Parallel to increasing the isolator level, column 4½" is raised. This technology is based on the lateral-roof leaching, where the chamber roof becomes domed, what is much more favorable in geomechanical terms.
- Variant without roof isolation, where at the same time with roof rising, the

appropriate amount of isolator is removed from borehole. It has to be done precisely, taking into account the possibility of roof "escaping" in the case of isolator loss, or leakage of isolator behind the cement stone of embedded column. This technology is also based on lateral-roof leaching and creates a domed shape of chamber.

To improve the level isolator control, an expansion of borehole channel is proposed in the area of exploitation to radius of 0.5 m. ("high narrow chamber").

6 BASIC ASSUMPTIONS FOR SIMULATION

In the cross-section of borehole B-67, the rock salt is located the depth from 530.65 to 654.42 m. At depth from 602.35 to 605.18 m, there is inter layer of massive marl in salt. At many places in rock salt, there are located inter layers of stripped marl whose thickness range from a few cm to ten cm. Angle of these marl inter layers is about 10^o - 50^o.

Based on previous experiences, thicker layers of massive marl are cracked and will not interfere in technology of lateral - roof leaching, or will not present a certain barrier. It also can be considered for thin inter layers. These inter layers may only cause local irregularities of chamber's shape. Technical column 9 5/8" is located and cemented up to depth of 30 m in the salt body, respectively to depth of 560.65 m. Computer simulation has encompassed the interval of salt body at depth of 654-560 m.

The other assumptions for simulation or computer modeling:

- average temperature in chamber .... 25^oC
- depth step for za model .... 0.5 m
- number of sectors in a circle with different leaching rates 16
- limit angle of leaching .... 15^0
- coefficient of widespread insoluble residue 1.5
- maximum chamber diameter ....70 m

Leaching of hydro notch in the borehole B-67 started on 15/12/2011, where column 7" was at position 636.42 m, column 4 ½" at position 651.42 m.

Level of isolation was at depth of column 7" foot (636.42 m), while the flow of technological water was in a direct circulation.

The first measurement of chamber B-67 with echo transducer was finished on 18/01/2012.

Measurement showed the following:

- roof of chamber .... 637.4 m
- bottom of chamber .... 649.0 m
- column 7" foot depth .... 637.4 m
- volume of chamber .... 861.7 m^3.

Equivalent [average] radius of the chamber below the roof was 5.23 m, with maximum radius of 7.22 m, and minimum radius of 4.06 m, which indicates that the hydro notch is quite irregular. The biggest irregularity is recorded in the interval 647-645 m, by privileged azimuth 100^o – 140^o. At depth of 646.0 m, the average radius of hydro notch was 4.65 m, maximum radius was 8.45 m, while minimum was 3.74 m. In the interval from 641.0 to 637.4 m, the hydro notch had generally the uniform leaching.

The second stage of hydro notch leaching was guided on the same position of the column 7", at the same depth of isolation level, while column 4 ½" was positioned one meter from residue.

The other measurement hydro notch form has showed the following:

- roof of chamber .... 636.7 m
- bottom of chamber .... 646.5 m
- column 7" foot depth ...... 637.4 m
- volume of hydro notch .... 3773.5 m^3

Equivalent [average] radius of the chamber below the roof was 11.05 m, at maximum radius of 14.03 m and minimum 9.07 m.

The results of this measurement have showed more regularity in hydro notch leaching compared to the results from the first measurement.

Still, practically on entire height of hydro notch, there is a privileged direction in azimuth $90^o – 180^o$, in which leaching is faster. In the interval from 638.0 to 636.7 m, the form of hydro notch is quite regular.

7 DETERMINING THE PARAMETERS FOR SIMULATION OF FURTHER CHAMBER LEACHING

In the laboratory, on real samples of salt from borehole B-67, the rate of lateral [horizontal] leaching of salt for the zone hydro notch was determined, which amounts to 6.8 m /h, while that rate is 7.5 mm/h for lower part of the deposit. These rates are determined on the basis of hydrostatic condition of the solvent (water) and do not match a dynamic state what is in the chamber and which depends on the flow rate of solvent, size and shape of the chamber, as well as the other factors.

If this value of lateral leaching rate would be taken for simulation for the period up to the first measurement with echo transducer, the hydro notch with volume of 585.7 m^3 will be obtained from modeling, while the sum of produced salt would be to 1182 t. The real amount of salt is 1582 t, and it is higher than calculated value for 33.8%.

In order to determine the rate of lateral leaching which corresponds to the actual leaching conditions (up to the first measurement), the model *WinUbro/Korlog* was applied.

Taking this rate as the base by special program ScenStages, two scenarios are considered: the first for the period up to the first measurement with echo transducer, and the second for the period from the first measurement to the second measurement.

From simulation of the first period of leaching by the program Korlog (flow 1-0) the following data are obtained:

- Amount of extracted salt (borehole) ....1,582 t
- Amount of extracted salt (simul.) .... 1,509 t
- Volume of extracted salt .... 825 m^3
- Volume measured with echo transducer .... 862 m^3
- Volume from simulation .... 777 m^3

The form of chamber was taken for the next period of leaching, measured with echo transducer, decreased approximately 3%, with volume 860 m^3, with different coefficients of leaching rate by sectors, obtained on the basis of program Korlog.

The highest values of leaching rate coefficients (1.58 times higher) were located in sector 5 (azimuth 90°-112.5°) in the interval 642.5-645.5 m.

The lowest values (0.64 times lower) in sectors 8-12 (azimuth 157.5°-225°) in the interval 647.0-649.0 m.

From t depth of 642.0 m and upward, differences decrease and are within the limits of 0.88 to 1.22 compared to the nominal value.

After simulation the second period of leaching by the program Korlog (flow 2-1) the following data are obtained:

- amount of extracted salt (borehole) .... 6,874 t
- amount of extracted salt (simul.) .... 6,475 t
- volume of extracted salt ..... 3,473 m^3
- volume measured with echo transducer .... 3,804 m^3
- volume from simulation .... 3,310 m^3

The highest values of leaching rate coefficient (2.82 times more) were located in sector 7 (azimuth 135°-157.5°) in the interval 641.5-646 m.

The lowest values (0.29 times lower) were in sectors 12 and 14 (azimuth 247.5°-270° and 292.5°-315°) in the interval 645.0 – 646.5.

From depth of 642.0 m upward, the difference is reduced staying within the limits of 0.75 to 1.73 of the nominal value.

This shows that, if differences are higher, the results are not representative.

Due to this, another simulation was done. The first period of leaching to the first measurement with echo transducer was simulated without modification After the first Korloga, it was applied for further simulation, only form of the chamber from the first measurement with echo transducer was reduced.

For further simulations one leaching rate value (11 mm/h) was taken.

After simulation the second period of leaching by the program Korlog (flow 2-0), the following data are obtained:

- Extracted amount of salt (borehole) ....6,874 t
- Extracted amount of salt (simul.) ....6,139 t
- Volume of extracted salt ....3,466 m^3 *(slightly lower than flow 2-1, due to lower salt water concentration inside the chamber)*
- Volume measured with echo transducer ....3,774 m^3
- Volume from simulation ....3,63 m^3

Difference between coefficients are mainly found between the flows of *Korloga* 1-0 and 2-1.

Maximum (1.7 of nominal value) is pointed in sector 7 (azimuth 135°-157.5°), at depth of 642.25 m.

Minimum (0.45 of nominal value) is pointed in sector 12 (azimuth 247.5°-270°), at depth of 645.25 m.

From depth of 642.0 meter and upwards, the differences are reduced and remain within the range from 0.81 to 1.52 of nominal value.

After the analysis of simulation results in the borehole B-67, it can be concluded:

- slightly reduced form of chamber is from the second measurement by echo transducer with capacity of 3560 m^3,
- nominal rate of lateral leaching is increased up to 13 mm/h,
- nominal rate of roof leaching is 16.9 mm/h (laboratory data),
- for further calculation in all directions, the leaching of 13 mm/h is taken.

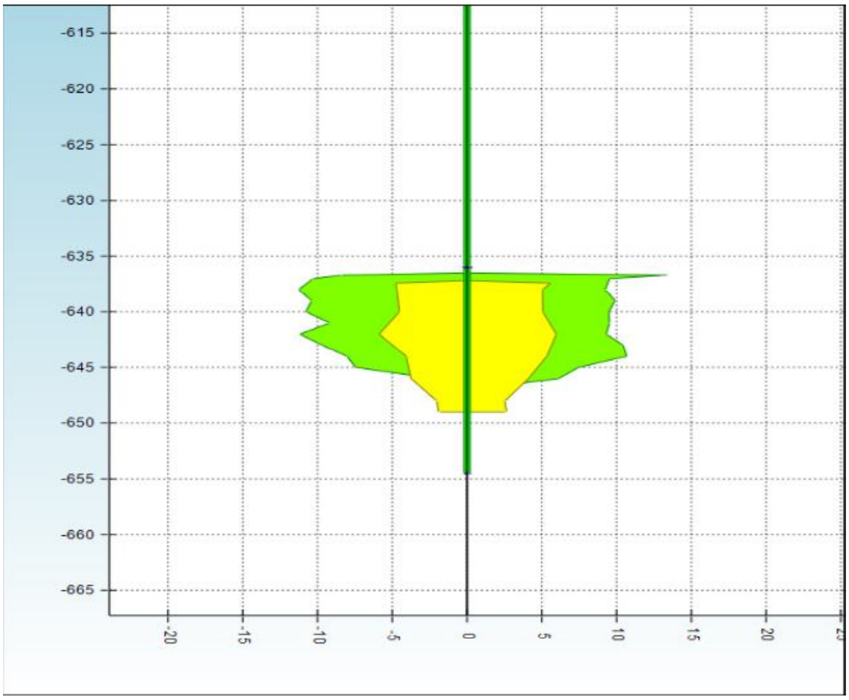

Figure 3 *Initial shape for simulation*

8 REVIEW OF SIMULATION FOR LEACHING TECHNOLOGY WITH PARTIAL ROOF ISOLATION

8.1 Phase I – leaching of introductory column

After creating a shortened hydro notch [up to the II measure by echo transducer], the movable columns are positioned at the following depths:

7" at 629 m, and 4½" at 644.5 m.

The isolation level will be retained on the foot of column 7", or at depth 629.0 m.

Leaching at this stage keep in direct circulation for a period of 8 days, with a flow rate of solvent ~ 10 m^3/h (up to the amount of salt 450 t), for the purpose of isolator removal below the roof.

After that, leach in the next 103 days, in direct circulation, with flow rates of 20 m^3/h (up to the amount of salt 17,450 t).

It follows from simulation that the average concentration of salt water is about 245 kg/m^3. Residue on the bottom of chamber at the end of phase will be at depth of 644.5 m. At the end of phase, the chamber radius will be ~ 5 m, when the echo measurement is predicted.

In order to provide a layer of isolator of 3 cm below the roof, it is necessary to do pumping every seven days in "portions" of 0.1-0.3 m^3.

8.2 Phase II – leaching of ”narrow high chamber“

Leaching of “narrow high chamber“ is divided on two intervals because an inter layer of massive marl (602.35 to 605.18 m) is located in the chamber profile, as follows:

- lower interval (606.0 – 629.0 m) and
- upper interval (560.0 – 606.0 m).

Leaching of lower interval of "narrow high" chamber:

- Depth of column: 7" (606 m), and 4½" (628.5 m or 0.5 m above the roof of chamber);
- Level of isolator 606 m (overflow with accurate measurement of volume);
- Flow of solvent ....40 m^3/h (in indirect circulation), or 20 m^3/h (in direct circu-lation);
- Amount of salt that will be obtained ~54 t (in indirect circulation about 18 t, in direct circulation about 36 t);
- Duration of leaching .... 1.5 days;
- Radius bellow the roof ...... 0.5 m;
- Depth of residue .... 644.4 m.

After completion the "narrow high chamber" drain isolator and precisely measure its amount (V1). Lower the column 7" at depth of 628.5 m, and set the column 4½" half a meter above the filling-residue. Again pump oil (isolator) into the borehole, on the overflow over the column 7", and measure precisely its amount (V2). Difference between these two amounts DV is the actual volume of narrow high chamber, which is very important in the lateral-roof leaching technology.

When the volume of "narrow high chamber" (DV) is divided with its height (22.5 m), the volume of one longitudinal meter of narrow high chamber (dV) is obtained.

Theoretically, this volume is 0.760 m^3 and it is very important in rising of chamber through the discharge of certain amounts of isolator.

8.3. Phase III - continuation of initial chamber leaching

- Depth of isolator: 7" (633 m), and 4½" (644 m);
- Level of isolator ....624 m; (quantity of isolator is calculated from formula V2 – dV (628-624) m^3);
- Water flow ....10 m^3/h (indirect circulation);
- Amount of salt that will be obtained .... ~ 2050 t;

- Duration of leaching ....30 days;
- Radius bellow roof of chamber 1.3 m;
- Average concentration ~299 kg/m^3;
- Depth of residue ....644.4 m.

In order to provide a layer of isolator three cm below roof, it is necessary to do pumping every seven days, in "portions" of 0.1 - 0.3 m^3.

After this phase it is completed introductory leaching. The next phase is production of salt water with industrial concentrations.

8.4 Phase IV until the end of salt water production

- Depth of column: 7" (633 m), and 4½" (643 m);
- Level of isolator ....624 m;
- Flow 15 m^3/h (indirect circulation);
- Amount of salt that will be obtained ....~ 5400 t;
- Duration of phase IV ....51 days;
- Radius of chamber bellow the roof ....3.0 m;
- Average concentration ....~ 307 g/l;
- Depth of residue .... 653.9 m.

In order to provide a layer of isolator 3 cm below roof, it is necessary to do pumping every seven days, in "portions" of 0.1-0.3 m^3.

Further leaching will be done in phases that last between 100 and 120 days, with successive lifting of isolation level of 5 m. After reaching isolation level of 606 meters, leaching of second high chamber (as already described) should be done in belt of 606-561 m, with successive lifting of isolation level of 5 m to the level 561 m (Figure 4).

After this phase, the upper part of the chamber above 561 m still can be in exploitation without use of isolation materials, except that must have a certain thickness of roof protection.

In this case, since column $9^5/_8$" is located about 30 m in salt, it can be in exploitation for another ten meters above the level of 561 m, but it is recommended to obtain a domed shape roof as the final form of roof.

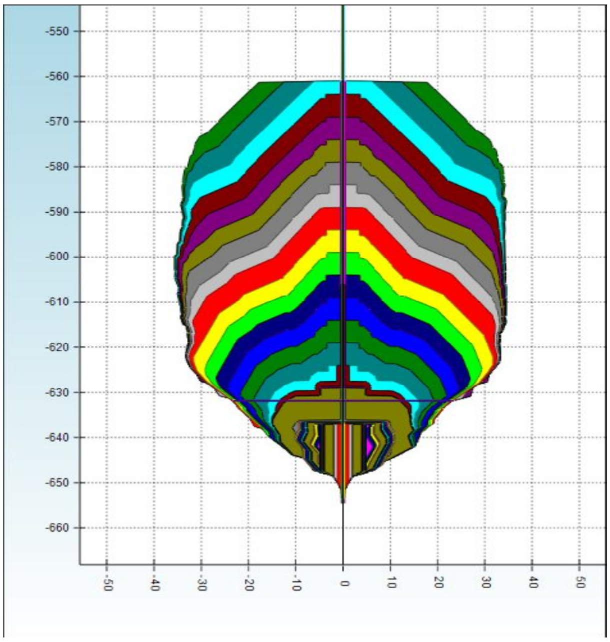

Figure 4 *Final shape of chamber with domed shape roof*

9 DISCUSSION

Borehole B-67 was put into introductory leaching on 15/12/2011. As it was described above, after the second series of echo location measurements and after simulation by computer programs Win Ubro NET with the procedure Korlog, moving of columns are finished and borehole “works“ by the new technology of leaching. Thereafter, one echo location measurement was done.

At this phase, the borehole completely worked following according to the predicted simulation, what can be seen in Table 1:

- Depth of column for leaching:
  column 7" ....633.0 m
  column 4½" ....644.0 m
- Level of isolant ....624 m; (quantity of isolant is calculated from formula V2-dV · (628-624) m^3);
- Water flow ....10 m^3/h (indirect circulation);
- Amount of salt that will be obtained ....2050 t;
- Leaching time of this phase 30 days;
- Radius bellow roof of chamber ....1.3 m;
- Average concentration ....~299 kg/m^3;
- Depth of residue ....644.4 m

Table 1 *Review the results obtained by simulation compared to the real situation in the borehole B-67*

Parameter	Simulation	Real situation
Tubing of column 7" (m)	633	633
Tubing of column 4½" (m)	644	644
Level of isolant (m)	624	624
Flow ratio (m^3/h)	10,0	10,51
Salt amount (t)	2,050	2,253
Leaching time (day)	30	30.5
Radius (m)	1.3	2.00
Average concentration (kg/m^3)	299	297
Balance of isolator (m^3)	21.7	23.7

It can be seen from Table 1 that columns are positioned according to the simulation, the level of isolant is retained at a given position, the average flow rate was slightly higher resulting in higher quantities of salt and larger radius of the roof chamber, and that the prognostic average concentration is approximate to the realized one.

In addition, it is important to point out that the balance isolant is higher by 2.0 m^3 which means that the "captured" isolant from hydro cuts started to go out, and that in the future the appearance of the other trapped amounts should be expected.

Recorded developed form of the chamber (Figure 5) is approximately equal to the predicted or simulated, which is besides the balance of isolant, certainly the most important fact.

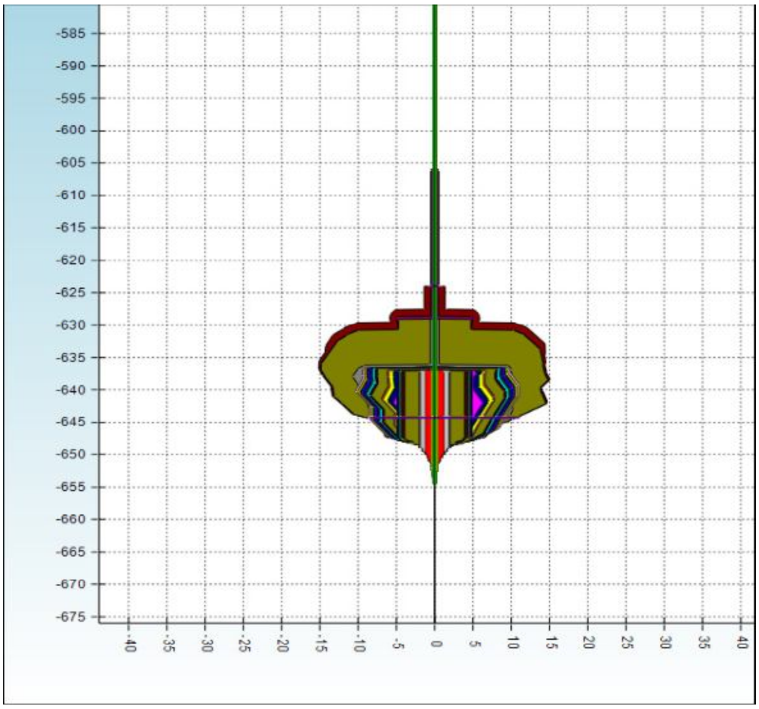

Figure 5 *Recorded shape of chamber B-67 by azimuth 0°-180°*

CONCLUSION

Due to negative experiences in balance of isolation materials, the method of lateral-roof leaching without cemented casing has a great advantage over the existing method. Limit of isolant amount in the introductory leaching will be realized through the reduction of hydro notches diameter, which will result in more favorable balance of removed isolator, while in continuation of exploitation leaching will lead with the partial isolation of the roof, what requires small amount of isolant under the roof (maximum 10 m^3). Technology of lateral-roof leaching without cemented casing provides decrease of the chamber roof surface of its domed shape which indicates that the losses of isolant will be much smaller or none.

Sum of salt obtained by the method of lateral-roof leaching without cemented casing, observing thr analyzed borehole B-67, is 474,400 t; whereby the chamber has a domed roof, while in the case of continuing exploitation when the roof is horizontal, the sum of resulting salt would be 563,300 t. Calculating sum of the salt obtained by designed method of lateral leaching with narrow footstep of tubs is 467,124 t. In both cases, by the method of lateral-roof leaching without cemented casing, a higher utilization is realized.

Simulation technology of lateral-roof leaching without cemented column should be seen as a basis. Based on previous experiences, it can be concluded that deposit of rock salt „Tetima" is very inhomogeneous; it is not uniform, as evidenced by determination of geological exploration and leaching rate. This resulted in the irregular development of chambers, as it can be seen above all from the echo location recordings. Due to these reasons, it is not possible to create a very accurate forecast for entire thickness of salt layer. Precise prognosis can be made after each phase (after echo measurements) for the next phase, for which is necessary to own and use the computer program Win UBRO NET with the procedure Korlog.

After each phase and completed echo measurements, based on actual achieved data (actual shape of the chamber), it is necessary to correct positioning of free hanging columns, level of isolant, insulation materials as pumping dynamics of isolant pumping and duration of a new phase.

The obtained simulations of current hydro notch leaching indicate that the actual rate of lateral leaching is considerably higher than the rateobtained from laboratory tests, due to hydrodynamics of liquid in the chamber influence. During leaching of hydro notch, there was no possibility of correction the roof rate of leaching. This should be done after leaching of introductory chamber (after measuring with echo transducer) using programme Korlog.

Computer model WinUbroNet, in simulations slightly reduces the concentration of salt water (near saturation). Keeping this in mind, in the simulation results, the concentration of ~ 305 g/l for a minimum concentration of industrial salt water was taken into account.

Quantities of isolant (shown in Table 1) for the isolation of chamber roof and borehole channel are based on the full of salt body an imperviousness of cement stone columns behind column $9^{5}/_{8}$". If the loss of isolant is observed, its quantity must be corrected.

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NOVA METODA IZLUŽIVANJA NA LEŽIŠTU KAMENE SOLI „TETIMA“ KOD TUZLE

Izvod

U projektnoj dokumentaciji eksploatacije ležišta kamene soli Tetima razrađene su dvije metode eksploatacije: metoda bočnog izluživanja sa bliskim stopama cijevi kao osnovna metoda koja se i primjenjuje na svim do sad izbušenim bušotinama, i metoda stropnog izluživanja sa cementiranom zaštitnom kolonom, kao alternativna metoda, koja će se primjenjivati u takvim dijelovima ležišta gdje ima prednost nad metodom bliskih stopa cijevi.

Ocjena i odluka o primjeni metode stropnog izluživanja sa cementiranom zaštitnom kolonom donosti će se nakon konstatovanja navedenih parametara u izbušenoj bušotini. Ova metoda se do sada nije primjenjivala.

Cilj ovog rada ja da se kroz tehno-ekonomsku analizu do sada primjenjivane metode pokuša iznaći optimum za nastavak eksploatacije na već postojećim bušotinama.

Analiza je rađena na primjeru bušotina B-67, a obradila je regularnost komora, „bježanje“ stropa i bilansiranje izolanta, a sve u korelaciji sa geološkim prilikama. U Institutu OBRGSChem. „CHEMKOP“ u Krakovu urađena je kompjuterska simulacija tehnologije bočno-stropnog izluživanja sa dvije pokretne kolone korištenjem programa WinUbroNet za bušotinu B-67 u dvije varijante: sa djelimičnom izolacijom stropa i bez izolacije stropa.

Ključne riječi: *kontrolisano izluživanje, metoda eksploatacije, bilansiranje izolanta, kompjuterska simulacija*

1. UVOD

Proizvodnja soli u svakoj zemlji ima posebno značenje, jer so ili proizvodi njene pretvorbe predstavljaju značajnu industrijsku sirovinu.

Eksploatacija soli u Bosni i Hercegovini vezana je za tuzlansko područje, i to za ležište kamene soli u Tuzli, na kome se industrijska eksploatacija soli vršila više od 100 godina, ali i novo ležište kamene soli "Tetima", koje u zadnjih desetak godina intenzivira eksploataciju, i koje predstavlja zamjenski kapacitet za tuzlansko sono ležište.

Davne 1971. godine započeta su višegodišnja sistematska geološka istraživanja dokanjske sinklinale, geološkom i hidrohemijskom prospekcijom, da bi bila nastavljena savremenim geološko-geofizičkim metodama koja su i ukazala na potencijalnost ove strukture.

Bušenjem 1978. godine perspektivnost je potvrđena.

Istraživanje i okonturenje ležišta vršeno je narednih 6 godina sa 24 istražne bušotine, od kojih su 17 nabušile sono tijelo.

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Tadašnji stepen poznavanja nekih bitnih ležišnih karakteristika i parametara (geoloških, hidrogeoloških, hemijsko-tehnoloških i drugih), a koji imaju odlučujući uticaj kod izbora načina i metode eksploatacije jednog sonog ležišta, nametali su da se kao optimalno rješenje usvoji koncept po kome će se eksploatacija ovog ležišta vršiti kontrolisanim izluživanjem pojedinačnim bušotinama sa površine terena.

U projektnoj dokumentaciji razrađene su dvije metode eksploatacije: metoda bočnog izluživanja sa bliskim stopama cijevi, kao osnovna metoda, koja se i primjenjuje na svim do sad izbušenim bušotinama, i metoda stropnog izluživanja sa cementiranom zaštitnom kolonom, kao alternativna metoda, koja će se primjenjivati u takvim dijelovima ležišta gdje ima prednost nad metodom bliskih stopa cijevi. Ova prednost se ogleda u sledećim slučajevima:

- velikog ili promjenljivog nagiba slojeva u krovini ležišta soli u dijelovima ležišta sa konstatovanim nedostatkom hermetičnosti stijena u krovini ležišta,
- konstatovanih velikih denivelacija u krovini sonog ležišta, nastalih kao rezultat sonog karsta,
- visokog sadržaja nerastvornih dijelova u donjem dijelu ležišta, a posebno kod brojnih kontinuiranih proslojaka nearstvornih stijena.

Ocjena i odluka o primjeni metode stropnog izluživanja sa cementiranom zaštitnom kolonom donosit će se nakon konstatovanja navedenih parametara u izradjenoj bušotini. Ova metoda se do sada nije primjenjivala.

Cilj ovog rada ja da se kroz tehno-ekonomsku analizu do sada primjenjivane metode pokuša iznaći optimum pri eksploataciji, kako na već postojećim bušotinama, tako i na onima koje će se izgrađivati u budućnosti.

2. GEOLOŠKI PODACI O LEŽIŠTU KAMENE SOLI TETIMA

Na južnim obroncima Majevice, sjeveroistočno od Tuzle na rastojanju od 8 km, smješteno je ležište kamene soli Tetima.

Ležište je srednjemiocenske, donje badenske starosti, nastalo u marinskim - lagunskim uslovima sedimentacije, deponovao u dokanjskoj sinklinali a izgrađeno je od jednog sonog tijela nepravilnog slojevito-sočivastog oblika i složene građe. Pozicionirano je u krovinskom dijelu trakaste serije u istočnom-čeonom dijelu dokanjske sinklinale.

U planu, ležište ima nepravilno elipsast oblik, slično ležištu u Tuzli, sa dužom osom preko 2000 m i kraćom oko 1000 m. Izgrađeno je od jednog sonog tijela slojevito-sočivaste forme, deponovanog u dokanjskoj sinklinali sa antiformnim naborom podine u sjeveroistočnom dijelu ležišta. Ima pružanje sjeverozapad - jugoistok i pad prema zapadu. Dubina zalijeganja na jugoistoku iznosi 400 m, a na sjeverozapadu preko 1000 m, što daje prosječan pad po pružanju od 16^{o}. Međutim, pad sonog tijela upravno na pružanje iznosi i do 30°.

Maksimalna debljina sonog tijela je 150-200 m i ide paralelno sa dužom osom, sjeverno od centra (podužne ose) ležišta, dok prema rubovima opada. U jugoistočnom dijelu moćnost ležišta je redukovana antiformnom strukturom podinskih laporaca unutar makro strukture dokanjske sinklinale dok prema sjeverozapadu prelazi u jednostavniju sočivasto slojevitu formu. Forma ležišta, a posebno unutrašnja tektonika, ukazuju na kretanje sone mase pod uticajem tektonskih sila prema plićem čeonom dijelu sinklinale, gdje je došlo do najveće koncentracije soli.

Sono tijelo je monomineralno s raznovrsnim formama soli u ležištu. Kvalitet sonog tijela je dosta ujednačen sa prosječnim sadržajem NaCl u sonom tijelu od 91,9 %.

Primarno, ležište je bilo izgrađeno od kristalastih agregata halita, krupnokristalne strukture soli (milimetarsko-centimetarske veličine zrna), bijele i sive boje sa rijetkim proslojcima laporaca i nepravilno razmještenim zrnima anhidrita.

Tektonskim procesima došlo je do promjene primarno kristalne i kristalaste forme pojavljivanja soli u ležištu u sitno, srednje i krupnozrne forme.

Podinu sonog tijela grade laminirani dolomikriti, koji završavaju sa 8-10 cm debelim proslojkom trakastog anhidrita. Veoma strmi, a često i vertikalni slojevi ukazuju na značajno ubiranje podine. To su najčešće metarsko-decimetarski nabori, najvjerovatnije međuslojni.

Krovina počinje dobro stratifikovanim anhidritsko - laporovitim brečama u čiji sastav, pored odlomaka trakastih laporaca, ulaze: anhidriti, laporoviti krečnjak, tufit i kao vezivo - tamnosivi donjebadenski laporac.

Breča je nastala nakon kratkotrajne emerzije, kojom prilikom su nastale pukotine isušivanja, kako u glinovito-karbonatnom mulju, tako i u gipsno-anhidritskim sedimentima. Kratkotrajni transport i povezivanje odlomaka nastupa u vrijeme donjebadenske transgresije. Tako nastao sloj breča ima debljinu od 5-40 m. Višu i visoku krovinu čine laporci i pjeskovito-laporovite stijene badena i sarmata.

Hidrogeološka slika je dosta nepovoljna.

Na kontaktu donjebadenskih laporaca i krovinskih breča konstatovana je podzemna agresivna voda sa različitim stepenom mineralizacije. Uz sjeveroistočni i istočni obod ležišta, ove vode su došle u kontakt sa sonim tijelom uslijed čega je nastupilo izluživanje.

U podinskim trakastim dolomikritima, u zoni tektonske oštećenosti, na 10-30 metara ispod sonog tijela, razvijena je pukotinska izdan sa različito mineralizovanim i agresivnim vodama.

U visokoj krovini konstatovane su vode u badenu i sarmatu. Sarmatska izdan je arteška, a ostale su subarteške.

3. PRIMJENA METODE BOČNOG IZLUŽIVANJA SA BLISKIM STOPAMA CIJEVI

Tehno-ekonomska analiza primjene metode bočnog izluživanja sa bliskim stopama cijevi rađena je na primjeru bušotine B-78, koja je završila svoj eksploatacioni vijek, i to zbog reprezentativnosti samih podataka.

Analiza je, prije svega, obradila regularnost komore, „bježanje“ stropa, bilansiranje izolanta, a sve u korelaciji sa geološkim prilikama.

3.1. Bušotina B-78

Bušotina je izvedena 1989. godine, u skladu sa Glavnim rudarskim projektom eksploatacije - Tehničkim projektom bušenja i opremanja eksploatacionih bušotina za eksploataciju kamene soli Tetima.

Locirana je na novoformiranom obračunskom profilu VI.

Osnovni podaci:

- Dubina krovine sonog tijela 455,80 m
- Dubina podine sonog tijela 589,29 m
- Debljina sonog tijela .... 133,49 m
- Ugao pada krovine .... 22^o
- Ugao pada podine .... 30 ^{o}

Podaci o kvalitetu :

- Sadržaj soli u sonom tijelu ....96,47 %
- Sadržaj NaCl u soli ....95,59 %
- Sadržaj NaCl u sonom tijelu .91,26 %

3.2. Analiza primjene metode

Stvarno vrijeme izluživanja po etapama je bilo približno projektovanom, kapaciteti su bili nešto manji a analogno tome koncentracije su bile nešto veće u odnosu na projektovane. U ovom periodu je obavljeno šest serija eholokacijskih mjerenja pri čemu se može konstatovati da je u šestoj seriji došlo do prekoračenja poluprečnika za 1,34 m na dubini 570 m po azimutu 70^o.

Maksimalne vrijednosti prečnika i poluprečnika na istoj dubini su u drugoj (575 m) i četvrtoj seriji mjerenja (577 m), pri čemu je hidrousjek ekscentričan, tako da maksimalni poluprečnik ima približno 2/3 vrijednosti prečnika. Generalni pravac razvoja hidrousjeka je istok-jugoistok.

Konačni prečnik hidrousjeka je manji za 1,75 m od projektovanog. Pojave „bježanja“ stropa nije bilo. Redovno su ubacivane projektovane količine izolanta u bušotinu. Temperature tehnološke i slane vode su bile u ovisnosti od vanjske temperature odnosno od godišnjeg doba.

3.2.1. Proizvodnja slane vode

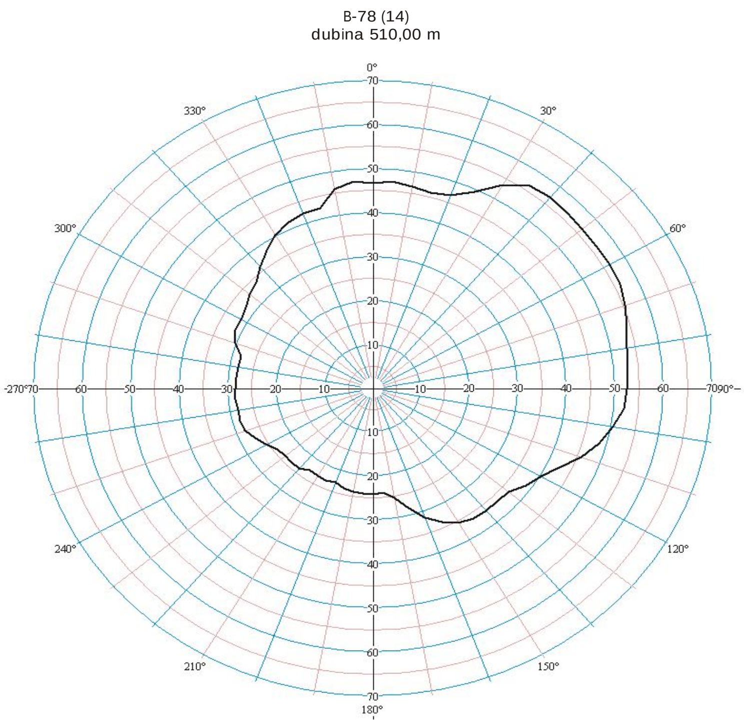
U ovom periodu je obavljeno pet serija eholokacijskih mjerenja pri čemu je komora nastavila započeti trend razvoja prema sjeveroistoku. U osmoj seriji eholokacijskih mjerenja konstatovano je prekoračenje poluprečnika za 1,73 metra na dubini 534 metra po azimutu 60^o, dok je maksimalni prečnik manji od projektovanog za 10 metara. Ovakav trend razvoja komora je i dalje nastavila da bi u jedanaestoj seriji eholokacijskih mjerenja konstatovano prekoračenje i poluprečnika (21,77 m) i prečnika (13,99 m) na dubini 510 metara po azimutu 60^o (slika 1).

I ovdje se može konstatovati da su u devetoj, desetoj i jedanaestoj seriji eholokacijskih mjerenja maksimalna prekoračenja i prečnika i poluprečnika na istim dubinama te da poluprečnik iznosi približno 2/3 prečnika. Prekoračenja poluprečnika su na dubinama od 474-488 metara kao i na dubinama 500-520 metara, što je vidljivo na slici 2.

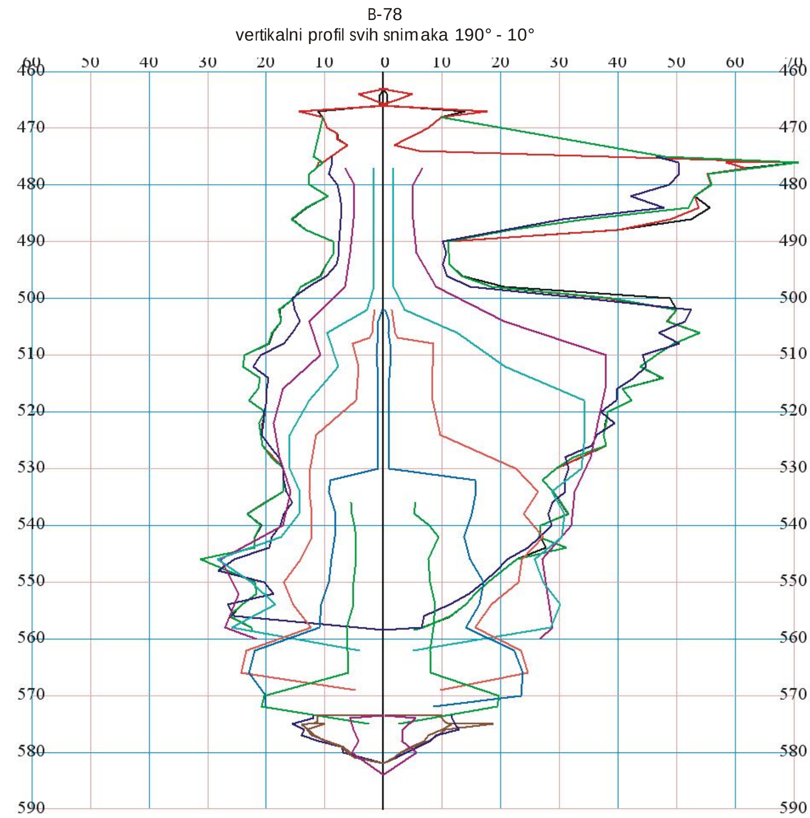
Sa zadnjom serijom eholokacijskih mjerenja konstatovano je pomjeranje stropa komore po vertikali (sa nivoa 475,00 m na nivo 463,00 m). Ovo praktički znači da je nivo stropa komore 12 metara iznad stope tehničke kolone Ø 9⅝". Na taj način je izlužen veći dio stropne sone police. Dana 15. 10. 2009. godine u bušotinu i pod strop izlužene komore upumpano je 17,00 m^3 izolanta (7,00 m^3 u prstenasti prostor i 10,00 m^3 pod strop komore).

Bušotina je isključena iz procesa proizvodnje slane vode 30.09.2009. godine.

Za vrijeme eksploatacije na bušotini je proizvedeno 448.142,61 t soli od 620.745 t industrijskih rezervi odnosno iskorištenje na ovoj komori iznosi 72,19 %.



Sl. 1. *Horizontalni snimak na bušotini B-78, dubina 510,00 m*



Sl. 2. *Vertikalni presjek svih ehosnimaka na B-78, azimut 190° -10°*

Eksploatacioni vijek su, do sada, pored bušotine B-78, završile još tri bušotine, i to: B-87, B-84 i B-86. Analizirajući sve četiri pomenute bušotine može se zaključiti:

- Hidrousjeci su zadobili neregularan oblik, odnosno mahom su dobili ekscentričnu formu u pravcu istok-sjeveroistok, dok je blokada razvoja registrovana na zapadnoj strani. Kod svih hidrousjeka maksimalni poluprečnik iznosi približno 2/3 prečnika. Ovo se također može konstatovati i za sve ostale trenutno aktivne bušotine.
- Tokom proizvodnje slane vode industrijske koncentracije, na bušotinama B-87, B-86 i B-78 registrovano je prekoračenje i poluprečnika i prečnika koje najviše iznosi na B-87. Ujedno, na ovim bušotinama, generalni pravac razvoja je istok-sjeveroistok. Na bušotini B-84 registrovano je prekoračenje poluprečnika, dok je prečnik manji od projektovanog.
- „Bježanje" stropa komore je registrovano na B-86 (0,5 m), B-78 (1,5 m i 12,0 m), B-84 (1,7 m, 0,4 m i 0,7 m), dok na B-87 ova pojava nije registrovana.

Najveća vrijednost „bježanja“ je na bušotini B-78, gdje je sa zadnjom serijom eholokacijskih mjerenja konstatovano pomjeranje stropa komore po vertikali (sa nivoa 475,00 m na nivo 463,00 m). Ovo praktički znači da je nivo stropa komore na 12 m iznad stope tehničke kolone Ø 9⅝". Na taj način je izlužen veći dio stropne sone police.

Bilansiranje izolanta je izuzetno nepovoljno. Obzirom da za neke bušotine nema podataka o vađenju izolanta u fazi izrade hidrousjeka, ovdje su analizirane ukupne količine za koje su evidentirani podaci o sumi izolanta.

Na bušotini B-84, od 313,5 m^3 ubačenog izolanta, vani je dobiveno 111,8 m^3(„ostalo“ u komori 201,7 m^3).

Na bušotini B-87, od 440,5 m^3 ubačenog izolanta vani je dobiveno 418,2 m^3 („ostalo“ u komori 22,3 m^3).

Na bušotini B-78, od 242,7 m^3 ubačenog izolanta vani je dobiveno 88,4 m^3 („ostalo“ u komori 154,3 m^3).

Na bušotini B-86, od 129,0 m^3 ubačenog izolanta vani je dobiveno 42,1 m^3(„ostalo“ u komori 86,9 m^3).

4. OSNOVNI RAZLOZI ZA IZMJENU POSTOJEĆE METODE

Varijante dalje tehnologije izluživanja su izrađene prije svega zbog:

- prilagođavanja načina izluživanja za promjenljive rudarsko-geološke uslove u profilu komore,
- ograničenja količina izolanta korištenog u toku izluživanja (u cilju smanjenja gubitaka),
- većeg iskorištenja rezervi

Ograničenje količina izolanta korištenog u toku izluživanja realizovaće se preko smanjenja prečnika hidrousjeka, što će prouzrokovati povoljniji bilans izvađenog izolanta ispod stropa hidrousijeka i skraćenje perioda uvodnog izluživanja. Pored ovoga, granica podine ležišta sa podinskim laporcima je tektonski vrlo poremećena, postoje blokovi sa ispucanim vodonosnim laporcima koji su utisnuti na nekoliko desetina metara u sono tijelo, što ide u prilog tezi da bi prečnik hidrousjeka trebao biti manji, jer postoji latentna opasnost da se tokom njegovog razvoja ostvari kontakt hidrousjeka sa pomenutim laporcima.

Nakon uvodnog izluživanja, eksploatacija bi se vodila bez izolacije stropa ili sa djelimičnom izolacijom.

U slučaju kada u vertikalnom profilu bušotine (ležišta) postoje promjenljivi rudarsko-geološki uslovi, tehnologija stropnog ili bočno-stropnog izluživanja omogućava veće iskorištenje rezervi soli u odnosu na tehnologiju bočnog izluživanja.

Pri bočno-stropnoj tehnologiji izluživanja, na početku izluživanja hidrousjek je puno manji od dosadašnjeg hidrousjeka. Izluživanje je puno kraće jer je stropno izluživanje brže od bočnog i ranije je moguće dobiti zasićenu slanu vodu.

5. PRIJEDLOG NOVE METODE IZLUŽIVANJA

Na osnovu svega navedenog, kao i na osnovu dosadašnjih iskustava, predložena je nova metoda eksploatacije pod nazivom "Metoda bočno-stropnog izluživanja bez cementirane zaštitne kolone".

Prema ovom prijedlogu, u Institutu OBRGSChem. „CHEMKOP“ u Krakovu, urađena je kompjuterska simulacija tehnologije bočno-stropnog izluživanja bez cementirane zaštitne kolone korištenjem programa *WinUbroNet* za bušotinu B-67 u dvije varijante: sa djelimičnom izolacijom stropa i bez izolacije stropa.

Poslije završetka uvodnog izluživanja započinje proizvodnja slane vode industrijske koncentracije, pri čemu su moguće dvije varijante:

- Varijanta sa djelimičnom izolacijom stropa (poluprečnik koji ne prelazi 4 m), pri čemu se podizanje stropa ostvaruje preko podizanja nivoa izolanta u koracima od po 5,0 m i 7,0 m. Poslije podizanja stropa (po svakom koraku), upumpava se u bušotinu odgovarajuća količina izolanta. Istovremeno sa podizanjem nivoa izolanta, podiže se i kolona 4½". Ova tehnologija se zasniva na bočno-stropnom izluživanju, a strop komore postaje kupolast, što je puno povoljnije u geomehaničkom smislu.
- Varijanta bez izolacije stropa, u kojoj se istovremeno sa podizanjem

stropa vadi iz kanala bušotine odgovarajuća količina izolanta. To se mora raditi precizno, imajući u vidu mogućnost bježanja stropa u slučaju gubitka izolanta, odnosno propuštanja izolanta iza cementnog kamena ugrađene kolone 9⅝". Ova tehnologija se, takođe, zasniva na bočnostropnom izluživanju i stvara kupolast oblik komore.

Radi poboljšanja kontrole nivoa izolanta predlaže sa proširenje kanala bušotine u zoni eksploatacije do poluprečnika 0,5 m ("visoka uska komora").

6. OSNOVNE PRETPOSTAVKE ZA SIMULACIJU

U profilu bušotine B-67 so se nalazi na dubini od 530,65 - 654,42 m. Na dubini 602,35 – 605,18 m, u soli, nalazi se proslojak masivnog laporca. Na mnogim mjestima u soli nalaze se proslojci trakastog laporca debljine od nekoliko centimetara do desetak centimetara. Nagib ovih proslojaka je od 10^o do oko 50^o.

Na osnovu dosadašnjih iskustava, deblji proslojci masivnog laporca su ispucani i neće smetati pri tehnologiji bočno – stropnog izluživanja, odnosno neće predstavljati barijeru, što se može konstatovati i za tanke proslojke. Ovi proslojci mogu izazivati samo lokalne neregularnosti oblika komore. Thenička kolona 9⅝" ' je locirana i cementirana do dubine oko 30 metara u sono tijelo, tj. 560,65 metara. Kompjuterska simulacija je obuhvatila interval sonog tijela na dubini od 654 - 560 metara.

Ostale pretpostavke za simulaciju odnosno kompjutersko modeliranje:

- prosječna temperatura u komori .... 25^oC
- dubinski korak za model .... 0,5 m
- broj sektora na krugu koji imaju različite brzine izluživanja 16
- granični ugao izluživanja .... 15^0
- koeficijent rasprostranjenja nerastvornog ostatka 1,5
- maksimalan prečnik komore ......70 m

Izluživanje hidrousjeka u bušotini B-67 započelo je 15.12.2011. god., pri položaju kolona: 7" na 636,42 m, 4½" na 651,42 m.

Nivo izolacije je bio na dubini pete kolone 7" (636,42 m), dok je protok tehnološke vode bio u direktnoj cirkulaciji.

Prvo mjerenje komore B-67 ehosondom je izvršeno 18.01.2012. god.

Mjerenje je pokazalo sledeće:

- strop komore ....637,4 m
- podina komore ....649,0 m
- dubina pete kolone 7" ....637,4 m
- zapremina komore ....861,7 m^3.

Ekvivalentan [prosječan] poluprečnik komore pod stropom je iznosio 5,23 m, pri maksimalnom poluprečniku od 7,22 m, kao i minimalnom (4,06 m), iz čega proizilazi da je hidrousjek dosta neregularan. Najveća neregularnost se registruje u intervalu 647 – 645 m, po privilegovanom azimutu 100^o – 140^o. Na dubini 646,0 m, prosječan poluprečnik hidrousijeka je iznosio 4,65 m, maksimalni poluprečnik je 8,45 m, dok je minimalni 3,74 m. U intervalu 641,0 – 637,4 m hidrousjek je imao, generalno, ravnomjerno izluživanje.

Druga etapa izluživanja hidrousjeka vođena je pri istoj poziciji kolone 7" i pri istoj dubini nivoa izolacije, dok je kolona 4½" pozicionirana 1 metar od taloga.

Drugo mjerenje oblika hidrousijeka pokazalo je slijedeće:

- strop komore ....636,7 m
- podina komore ....646,5 m
- dubina pete kolone 7” ....637,4 m
- zapremina hidrousjeka ....3773,5 m^3

Ekvivalentan [prosječan] poluprečnik komore pod stropom je iznosio 11,05 m, pri maksimalnom poluprečniku 14,03 m i minimalnom 9,07 m.

Rezultati ovog mjerenja su pokazali više regularnosti u izluživanju hidrousjeka u odnosu na rezultate iz prvog mjerenja.

Ipak, i dalje praktično na čitavoj visini hidrousjeka, postoji privilegovan smjer po azimutu 90^o – 180^o, u kojem je izluživanje brže. U intervalu 638,0 – 636,7 m, oblik hidrousjeka je dosta regularan.

7. ODREĐIVANJE PARAMETARA ZA SIMULACIJU DALJEG IZLUŽIVANJA KOMORE

U laboratoriji, na stvarnim uzorcima soli iz bušotine B-67, određena je brzina bočnog [horizontalnog] izluživanja soli za zonu hidrousjeka, koja iznosi 6,8 mm/h, dok za donji dio ležišta ta brzina iznosi 7,5 mm/h. Ove brzine su određene na osnovu hidrostatičkog stanja rastvarača (vode) i ne odgovaraju dinamičkom stanju koje je u komori, a koje zavisi od protoka, rastvarača, veličine i oblika komore, kao i drugih faktora.

Kada bi se za simulaciju uzela ova vrijednost brzine bočnog izluživanja, i to za period do prvog mjerenja ehosondom, iz modeliranja bi proizašao hidrousjek zapremine 585,7 m^3, dok bi suma proizvedene soli iznosila 1182 t. Stvarno dobivena suma soli iznosi 1582 t, i veća je od računske vrijednosti za 33,8 %.

U cilju određivanja brzine bočnog izluživanja koja odgovara stvarnim uslovima (do prvog mjerenja), primjenjen je model *WinUbro/Korlog*.

Nakon prvih probnih simulacija za nominalnu brzinu bočnog izluživanja uzeta je vrijednost od 11 mm/h. Uzimajući kao osnovu ovu brzinu, posebnim programom *ScenStages* razmotrena su dva scenarija: prvi za period do prvog mjerenja ehosondom i drugi za period od prvog mjerenja do drugog mjerenja.

Iz simulacije prvog perioda izluživanja po programu *Korlog* (tok 1-0), dobiveni su sledeći podaci:

- izvađena količina soli (bušotina) .... 1.582 t
- izvađena količina soli (simul.) .... 1.509 t
- zapremina izvađene soli .... 825 m^3
- zapremina izmjerena ehosondom .... 862 m^3
- zapremina iz simulacije .... 777 m^3

Za sledeći period izluživanja uzet je oblik komore izmjeren ehosondom, smanjen oko 3%, zapremine 860 m^3, sa različitim koeficijentima brzina izluživanja po sektorima koji su dobiveni na osnovu programa *Korlog*.

Najviše vrijednosti koeficijenta brzine izluživanja (1,58 puta više) nalazile su se u sektoru 5 (azimut 90°-112,5°), u intervalu dubine 642,5-645,5 m.

Najniže vrijednosti (0,64 puta niže) u sektorima 8-12 (azimut 157,5°-225°), u intervalu dubine 647,0-649,0 m.

Od dubine 642,0 m pa na gore, razlike se smanjuju i nalaze u granicama 0,88-1,22 u odnosu na nominalnu vrijednost.

Poslije simulacije drugog perioda izluživanja po programu *Korlog* (tok 2-1), dobiveni su slijedeći podaci:

- izvađena količina soli (bušotina) .... 6.874 t
- izvađena količina soli (simul.) .... 6.475 t
- zapremina iz izvađene soli ..3.473 m^3
- zapr. izmjerena ehosondom .... 3.804 m^3
- zapremina iz simulacije .. 3.310 m^3

Najviše vrijednosti koeficijenta brzine izluživanja (2,82 puta više) nalazile su se u sektoru 7 (azimut 135°-157,5°), u intervalu dubine 641,5-646 m.

Najniže vrijednosti (0,29 puta niže) nalazile su se u sektorima 12 i 14 (azimuti 247,5°-270° i 292,5°-315°), u intervalu dubine 645,0 - 646,5.

Od dubine 642,0 m, prema gore, razlika se smanjuje, ostajući u granicama 0,75-1,73 od nominalne vrijednosti.

Iz ovoga se vidi da, ako imamo veće razlike, rezultati nisu reprezentativni.

Zbog toga je izrađena još jedna simulacija. Prvi period izluživanja do prvog mjerenja ehosondom simuliran je bez izmjena. Poslije prvog *Korloga*, primijenjeno za dalju simulaciju, jedino je smanjen oblik komore iz prvog mjerenja ehosondom.

Za dalje simulacije uzeta je jedna vrijednost brzine izluživanja (11 mm/h).

Poslije simulacije drugog perioda izluživanja po programu *Korlog* (tok 2-0), dobiveni su sledeći podaci:

- izvađena količina soli (bušotine) .... 6.874 t
- izvađena količina soli (simul.) .... 6.139 t
- zapremina iz izvađene soli 3.466 m^3 *(nešto manja od toka 2-1, zbog manje koncentracije slane vode u komori)*
- zapremina izmjerena ehosondom .... 3.774 m^3
- zapremina iz simulacije .... 3.263 m^3

Razlike koeficijenata se, uglavnom, nalaze između tokova *Korloga* 1-0 i 2-1.

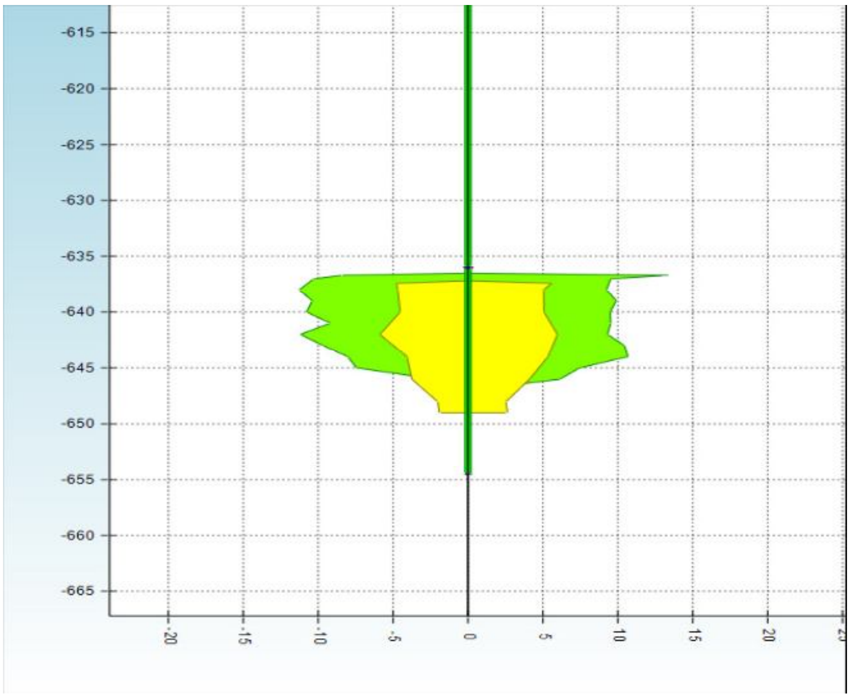
Maksimum (1,7 nominalne vrijednosti) nalazi se u sektoru 7 (azimut 135°-157,5°), na dubini 642,25 m.

Minimum (0,45 nominalne vrijednosti) nalazi se u sektoru 12 (azimut 247,5°-270°), na dubini 645,25 m.

Od dubine 642,0 m, pa na gore, razlike se smanjuju i ostaju u granicama 0,81-1,52 nominalne vrijednosti.

Poslije analize rezultata simulacije daljeg izluživanja u bušotini B-67 može se konstatovati:

- nešto smanjeni oblik komore iz drugog mjerjenja ehosondom, sa zapreminom 3.560 m^3,
- nominalna brzina bočnog izluživanja je povećana do 13 mm/h,
- nominalna brzina stropnog izluživanja je 16,9 mm/h (laboratorijski podatak),
- za dalje račune u svim pravcima uzeta je brzina izluživanja koja iznosi 13 mm/h.



Sl. 3. *Početni oblik za simulaciju*

8. PRIKAZ SIMULACIJE ZA TEHNOLOGIJU IZLUŽIVANJA SA DJELIMIČNOM IZOLACIJOM STROPA

8.1. Faza I - izluživanje uvodne komore

Nakon izrade skraćenog hidrousjeka [do II mjerenja ehosondom] pokretne kolone pozicionirati na slijedeće dubine:

7" na 629 m, a 4½" na 644,5 m.

Nivo izolacije zadržati na peti kolone 7" odnosno na dubini 629,0 m.

Izluživanje u ovoj fazi voditi u direktnoj cirkulaciji, u trajanju od 8 dana sa protokom rastvarača ~10 m^3/h (do sume soli od 450 t), u cilju vađenja izolanta ispod stropa.

Nakona toga izluživanje voditi u naredna 103 dana, u direktnoj cirkulaciji, sa protokom 20 m^3/h (do sume soli od 17.450 t).

Iz simulacije proizilazi da će prosječna koncentracija slane vode iznositi oko 245 kg/m^3. Talog na dnu komore pri kraju faze nalazit će se na dubini 644,5 m. Na završetku faze poluprečnik komore iznosit će ~5 m, kada je predviđeno i ehomjerenje.

U cilju obezbjeđenja sloja izolanta od 3 cm pod stropom, upumpavanje je neophodno vršiti svakih sedam dana, u "porcijama" od 0,1-0,3 m^3.

8.2. Faza II - izluživanje „uske visoke komore“

Izluživanje „uske visoke komore“ podijeljeno je na dva intervala, zbog toga što se u profilu komore nalazi proslojak masivnog laporca (602,35-605,18 m), i to:

- donji interval (606,0 – 629,0 m) i
- gornji interval (560,0 – 606,0 m).

Izluživanje donjeg intervala „uske visoke komore“:

- Dubina kolona cijevi: 7" (606 m), a 4½" (628,5 m, tj. 0,5 m iznad stropa komore);
- Nivo izolanta ... 606 m (preliv sa tačnim mjerenjem zapremine);
- Protok rastvarača .... 40 m^3/h (u indirektnoj cirkulaciji), odnosno 20 m^3/h (u direktnoj cirkulaciji);
- Količina soli koja će se dobiti ~54 t (u indirektonoj cirkulaciji oko 18 t, a u direktnoj cirkulaciji oko 36 t);
- Vrijeme trajanja izluživanja 1,5 dana;
- Poluprečnik ispod stropa ......0,5 m;
- Nivo taloga .... 644,4 m.

Poslije završetka „uske visoke komore“ ispustiti izolant i precizno izmjeriti njegovu količinu (V_1). Spustiti kolonu 7" na dubinu 628,5 a kolonu 4½" postaviti pola metra iznad zasipa-taloga. Upumpati ponovo ulje (izolant) u bušotinu, na preliv preko kolone 7", i izmjeriti precizno njegovu količinu (V_2). Razlika između ove dvije količine DV je stvarna zapremina uske visoke komore, koja je vrlo važna u bočno-stropnoj tehnologiji izluživanja.

Kada se podijeli zapremina „uske visoke komore“ (DV) sa njenom visinom (22,5 m) dobija se zapremina jednog dužnog metra uske visoke komore (dV).

Iz teoretskog računa, ova zapremina iznosi 0,760 m^3 i vrlo je važna pri podizanju stropa komore putem ispuštanja određene količine izolanta.

8.3. Faza III - nastavak izluživanja uvodne komore

- Dubina kolona cijevi: 7" (633 m), a 4½" (644 m);
- Nivo izolanta .... 624 m (količina izolana izračunata je iz obrasca $V_2 – dV \cdot (628\text{-}624)$ ..[m^3]);
- Protok vode .... 10 m^3/h (indirektna cirkulacija);
- Količina soli koja će se dobiti ~ 2050 t

- Vrijeme trajanja izluživanja-30 dana;
- Poluprečnik ispod stropa komore 1,3 m;
- Prosječna koncentracija ~299 kg/m^3;
- Dubina taloga .... 644,4 m.

U cilju obezbjeđenja sloja izolanta od 3 cm pod stropom, upumpavanje je neophodno vršiti svakih sedam dana, u "porcijama" od 0,1-0,3 m^3.

Nakon ove faze završeno je uvodno izluživanje. Slijedeće faze pripadaju proizvodnji slane vode industrijske koncentacije.

8.4. Faza IV do kraja – proizvodnja slane vode

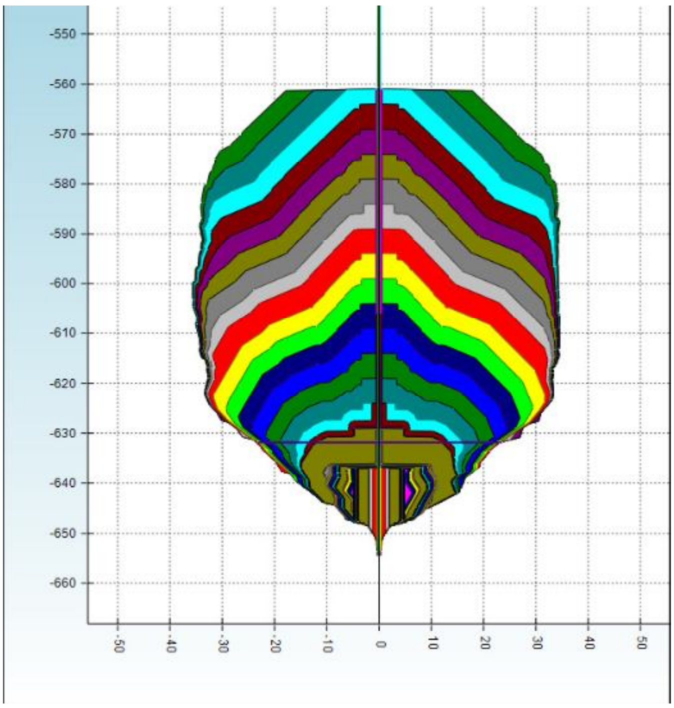
- Dubina kolona cijevi: 7" (633 m), a 4½" (643 m);
- Nivo izolanta ....624 m;
- Protok 15 m^3/h (indirektna cirkulacija);
- Količina soli koja će se dobiti 5400 t;
- Vrijeme trajanja IV faze …. 51 dan;
- Poluprečnik komore ispod stropa ....3,0 m;
- Prosječna koncentracija ~ 307 g/l;
- Dubina taloga 653,9 m.

U cilju obezbjeđenja sloja izolanta od 3 cm pod stropom, upumpavanje je neophodno vršiti svakih sedam dana, u "porcijama" od 0,1-0,3 m^3.

Dalje izluživanje se vrši u fazama koje traju od 100 do 120 dana, sa sukcesivnim zadizanjem nivoa izolacije po 5 m. Nakon dostizanja nivoa izolacije od 606 metara vrši se, na već opisan način, izluživanje druge visoke komore, u pojasu od 606-561 metar, sa sukcesivnim zadizanjem nivoa izolacije po pet metara do nivoa 561 m (slika 4).

Poslije ove faze, gornji dio komore, iznad 561 m, može se eksploatisati dalje bez korištenja izolanta, s tim što se mora ostaviti određena debljina stropne zaštitne police.

U ovom slučaju, pošto je kolona $9^5/_8$" locirana oko 30 metara u so, može se eksploatisati još desetak metara iznad nivoa 561 m, s tim što se preporučuje ostaviti kupolast završni oblik stropa.



Sl. 4. *Završni oblik komore sa kupolastim stropom*

9. DISKUSIJA

Bušotina B-67 je puštena u uvodno izluživanje 15. 12. 2011. godine. Kako je već opisano, nakon druge serije eholokacijskih mjerenja i urađene simulacije po kompjuterskim programima *Win Ubro NET* sa procedurom *Korlog*, izvršena su prepozicioniranja kolona i bušotina se vodi po novoj tehnologiji izluživanja. Nakon toga je uzvršeno jedno eholokacijsko mjerenje.

U ovoj fazi rada bušotina je u potpunosti radila po predviđenoj simulaciji što se vidi iz tabele 1:

- Dubina kolona cijevi za izluživanje:
  kolona 7" ....633 m
  kolona 4½" ....644 m
- Nivo izolanta ....624m; (količina izolana izračunata je iz obrasca V_2-dV · (628-624) [m^3]);
- Protok vode ....10 m^3/h (indirektna cirkulacija);
- Količina soli koja će se dobiti ... 2050 t;
- Vrijeme izluživanja ove faze .. 30 dana;
- Poluprečnik ispod stropa komore 1,3 m;
- Prosječna koncentracija .... ~299 kg/m^3;
- Dubina taloga ....644,4 m.

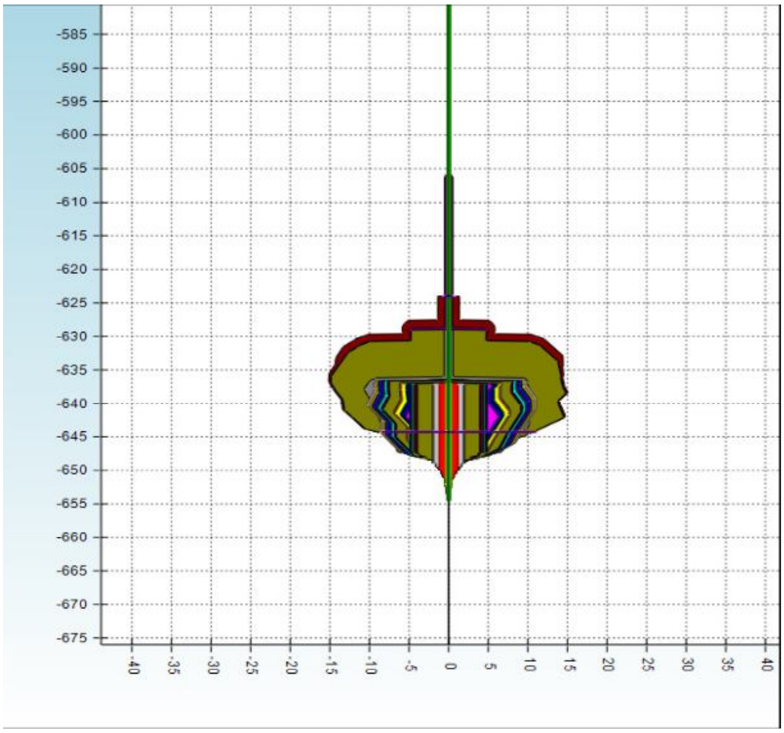
Tabela 1. *Prikaz rezultata dobijenih simulacijom, u odnosu na stvarno stanje u bušotini B-67*

Parametar	Simulacija	Stvarno stanje
Pocjevljenje kolone 7" (m)	633	633
Pocjevljenje kolone 4½" (m)	644	644
Nivo izolanta (m)	624	624
Protok (m^3/h)	10,0	10,51
Količina soli (t)	2.050	2.253
Vrijeme izluživanja (dan)	30	30,5
Poluprečnik (m)	1,3	2,00
Prosječna koncentracija (kg/m^3)	299	297
Bilans izolanta (m^3)	21,7	23,7

Iz tabele 1 se vidi da su kolone pozicionirane po simulaciji, da je nivo izolanta zadržan na zadatoj poziciji, da je prosječni protok bio nešto veći, što je rezultiralo većom ostvarenom količinom soli i većim poluprečnikom komore pri stropu, te da je prognozna prosječna koncentracija približna ostvarenoj.

Pored ovoga, bitno je istaći da je bilans izolanta veći za 2,0 m^3, iz čega proizilazi da je „zarobljeni“ izolant iz hidrousjeka počeo izlaziti, te da u narednom periodu treba očekivati pojavu i ostale zarobljene količine.

Snimljeni razvojni oblik komore (slika 5), približno je jednak predviđenom, odnosno simuliranom, što je zasigurno, pored bilansa izolanta, najvažnija činjenica.



Sl. 5. *Snimljeni oblik komore B-67 po azimutu 0°-180°*

ZAKLJUČCI

Obzirom na negativna iskustva u pogledu bilansa izolanta, metoda bočno-stropnog izluživanja bez cementirane zaštitne kolone ima veliku prednost u odnosu na postojeću metodu. Ograničenje količina izolanta u uvodnom izluživanju realizovaće se preko smanjenja prečnika hidrousjeka, što će prouzrokovati povoljniji bilans izvađenog izolanta, dok će se u nastavku eksploatacije izluživanje voditi sa djelimičnom izolacijom stropa, što zahtijeva male količine izolanta pod stropom (maksimalno 10 m^3). Sama tehnologija bočno-stropnog izluživanja bez cementirane zaštitne kolone omogućava smanjenje površine stropa komore kao i njegov kupolast oblik iz čega proizilazi da će gubici izolanta biti mnogo manji ili ih neće biti.

Suma dobivene soli po metodi bočno-stropnog izluživanja bez cementirane zaštitne kolone, posmatrajući analiziranu bušotinu B-67, iznosi 474.400 t, pri čemu komora ima kupolast strop, dok bi u slučaju nastavka eksploatacije, kada bi strop bio horizontalan, suma dobivene soli iznosila 563.300 t. Računajući sumu dobivene soli po projektovanoj metodi bočnog izluživanja sa bliskim stopama cijevi ona iznosi 467.124 t. U oba slučaja, po metodi bočno-stropnog izluživanja bez cementirane zaštitne kolone imamo veće iskorištenje.

Simulaciju tehnologije bočno-stropnog izluživanja bez cementirane zaštitne kolone treba posmatrati kao okvirnu (baznu). Na osnovu dosadašnjih iskustava može se konstatovati da je ležište kamene soli

"Tetima" vrlo nehomogeno, odnosno nejednorodno, što se vidi iz geoloških determinacija i istraživanja brzina izluživanja. Ovo je za posljedicu imalo neregularan razvoj komora, a što se vidi prije svega iz eholokacijskih snimaka. Iz ovih razloga nije moguće izraditi vrlo preciznu prognozu za čitavu moćnost sloja soli. Precizna prognoza može se izraditi poslije svake faze (poslije ehomjerenja) za narednu fazu, za što je neophodno posjedovati i koristiti kompjuterski program *Win Ubro NET* sa procedurom *Korlog.*

Poslije svake faze i odrađenog ehomjerenja na bazi stvarnih postignutih podataka (aktuelni oblik komore), neophodno je korigovati pozicioniranje slobodnovisećih kolona, nivo izolanta, dinamiku upumpavanja izolanta kao i dužinu trajanja nove faze.

Izrađene simulacije dosadašneg izluživanja hidrousjeka pokazuju da su stvarne brzine bočnog izluživanja znatno veće od brzina dobivenih laboratorijskim testovima, zbog uticaja hidrodinamike tečnosti u komori. Za vrijeme izluživanja hidrousjeka nije bilo mogućnosti korekcije stropne brzine izluživanja. Ovo treba uraditi nakon izluživanja uvodne komore (poslije mjerenja ehosondom) koristeći program *Korlog.*

Kompjuterski model *WinUbroNet*, u simulacijama, donekle smanjuje koncentraciju slane vode (u blizini zasićenja). Imajući to u vidu, u rezlutatima simulacije uzeta je koncentacija ~ 305 g/l za minimalnu koncentraciju industrijske slane vode.

Količine izolanta (prikazane u tabeli 1) za izolaciju stropa komore i kanala bušotine, zasnivaju se na potpunoj hermetičnosti sonog tijela i cementnog kamena iza kolone $9^5/_8$". Ukoliko se primijeti gubitak izolanta, njegova količina se mora korigovati.

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ANALYTIC USE OF MACROECONOMIC AGGREGATES

Abstract

Economic science has developed the whole system of so called macroeconomic aggregates – the system of a certain global and synthetic indicators which express the basic contents, dynamics and structure as well as the results of economic activity in some state or social community. The aim of this paper is to analyze the possible use of macroeconomic aggregates in the industries such as mining and metallurgy which support economic and social development of the north region of Kosovo and Metohija. The aggregate results of social production are indicators of volume, production and value structure of social production. Some aggregates like the national product and national income are used for recognition the dynamics and basic tendencies of economic development and total changes in national economy. Their absolute dimensions give the information on strength of national community economy, the same as possibility of its economic development. Focus of research will be directed on macroeconomic aggregates which are the expression of the social reproduction result that are the gross domestic product, national product and national income. These aggregates, together with unemployment, inflation and balance of payments are in the center of attention of macroeconomic analysis. Macroeconomic aggregates represent the important analytic categories because they provide an overview of structural elements of social reproduction, showing the direction of economic trends.

Keywords: *economy, macroeconomic aggregates, national product, gross national income*

INTRODUCTION

In order to estimate the result of some enterprise work, its incomes and expenses are compared or their difference – profit or loss. If the enterprise has earned a profit then it can be argued that the result of its operations is more or less good, depending on the profit amount and depending on the other indicators of successful business. Microeconomics deals with the result of analysis of a single enterprise.

A large number of various products are produced in an economy in a year, different kinds of goods are traded and the most various services are given, so a question can be asked how to determine a prosperity of the results which is achieved by a whole economic system in a certain year. To include values and quantity of all those results of economic science production, macroeconomics as its part has developed the whole system of so called macroeconomic aggregates – the system of a certain global and synthetic indicator which expresses the basic contents, dynamics and structure as well as the results of economic activity in some state or social community.

Aggregate results of social production are indicators of volume, production and value structure of social production. They can be recognized from the standpoint of sector structure according to which it is known what is the contribution of achieved

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results in operating of the primary, secondary, third and other economy sectors, what is a contribution of agriculture, industry, mining and others. If the certain economic aggregates are presented per capita or if they are calculated according to the structure of intended distribution of domestic product or national income, they can precisely express the level of economic development, as well as the level of living standard, and socio-economic prosperity of people.

Some of presently used macroeconomic aggregates were already mentioned in the XVII century. Their more significant use in macroeconomic analysis started only in a period after the Great economic crisis. These aggregates, together with unemployment, inflation and balance of payment are in the center of attention of macroeconomic analysis. Macroeconomic aggregates represent the important analytic categories, because they provide an overview of structural elements of social reproduction, showing the direction of economic trends.

Considering the above mentioned, this paper has been systematized in three chapters. The first chapter of paper places the emphasis on the most comprehensive indicator, gross domestic product, factors which determine it considering its structure. The next chapter is focused on the national product and national income as two more accurate indicators of economy development as well as the certain social community. In the end, it is stressed where the macroeconomic aggregates can be met and due to that it is realized that they have a great significance for socio-economic planning, economic policy of a modern state and international comparison of national economies.

GROSS DOMESTIC PRODUCT

For the needs of its analysis, the macroeconomics has developed a great number of macroeconomic aggregates, and each of them, depending on the way of calculating and its structure, represents an indicator of the result or structure of the result of economic system. Nevertheless, the most used macroeconomic aggregate, either in economic analysis of concrete economy or in its comparison with the other economies is a gross domestic product and it is the most comprehensive indicator of the social production result of a certain national community.

Gross domestic product is the expression of total amount of produced goods and services which are produced in a certain national community during a year. To understand completely the essence of gross domestic product, it is necessary to have in mind: gross domestic product presents market value of all products and services produced in one state in a period of a year, which means that the market prices of goods and services are used for its calculation; the value of so called interphase products gets in calculating of this aggregate because its value has been calculated in the value of final production products (e.g. jewellery production is associated with the primary production of gold and silver, and its processing, wholesale and retail); gross domestic product includes only the products which are produced during an accounting year; calculation the gross domestic product includes only goods and services which are legally sold during a year meaning that this macroeconomic aggregate does not calculate the transactions on the black market; gross domestic product of domestic state including the goods and services, produced on its territory by the foreign companies or foreign citizens [1].

It is, also, necessary to stress the fact that the gross domestic product is macroeconomic aggregate which at the same time expresses two sizes – total income of economic subjects and total costs of all goods and services in a certain economy. It means that total income is always equal to total cost. The essence of this equality is in that if, let's say, one citizen of Serbia pays for the repair of electrical installation, that transaction is an expense for him. For the electrician who has done the repair work that transaction is an income. On that way, total income and total expense are really equal within one economy.

If one wants to understand what determines demand for goods and services, it is necessary to split the gross domestic product on integral parts, considering that there are different buyers of those goods. In the context of such analysis, the gross domestic product consists of: consumption (C), investment (I), government purchasing – state consumption (G), export net (NX) and investment in reserve (IZ) [2].

In the following lines, the above mentioned integral parts will be briefly explained: consumption consists of goods and services bought by individual buyer, or household, except a housing space; investment consists of bought goods for future production while the economists under investing foresee production of permanent capital goods (it means that if one deposits 5000euros from aid fund into a bank or buy government bonds, according to the economists no investment has happened, only one shape of financial property has been replaced with the other); state consumption includes purchasing of goods like: roads, airports, army, police, health institution, pension funds, etc. Within state expenses transfer payments should be excluded (e.g. payments for unemployment insurance, payments for war veterans, payments for elderly and disabled, health and social insurance, etc.); net export or foreign trade balance represents difference between the export and import of goods and services; the reserves are included because there are interests in total production and total sales transaction of any national economy, and if it is not a case, there is a difference between the produced and sold goods in a year and as a matter of fact it is investment in reserve.

Factors which determine a volume of gross domestic product are: *natural resources* (the main condition of every production are natural resources. Natural resources include the state and everything that comes along. Production process is in the essence changing and adapting the nature to human needs. To use natural resources properly, the production means must be developed. This is particularly evident in the mining and metallurgical industry where technology and degree of capacity utilization play a key role. Natural resources are just potential factor which has influence on a volume of gross domestic product); *development of production means* (people may live poor in naturally rich surroundings if they have no proper means, knowledge and capability to use them by the proper way and transform them in natural resources. Natural resources is defined as the all accumulated material goods which are owned by one society and present the work products of the past and present generations); *population* (population is permanent resource of labor without which the production process cannot be imagined. Number and structure of population in one state influence the volume and structure of consumption. The volume of gross domestic product will be bigger if that community has larger number of productively active population); *labor productivity* (labor productivity expresses productive powers of labor to produce larger or smaller amount of material goods for certain period of time. If the productive powers of labor is larger, manufacturer who owns it will be able to produce larger amount of products for the same time or one product for shorter time comparing with another manufacturer. Increased labor productivity is achieved if the certain material goods are produced in less time or if within the same time a larger quantity of material goods is produced. Labor productivity can be calculated as follows [13]:

Model 1 Labor Productivity

$$Pr = \frac{Q}{T} \qquad (1)$$

Q – production volume, T– time,
Pr – labor productivity.

The most important factors of productivity can be defined as: technical production process, organizational, personal factor of labor, socio institutional; *intensity of labor* (represents a degree of wear of human labor per time unit) [14]; *social relations* (social relations have important influence on the way and degree of use of all available human and material factors of production. If social relations are better, the manufacturer will have higher economic interest to enlarge the production volume [3].

The structure of gross domestic product can be considered from: natural and valuable (financial) aspect. When the gross domestic product is considered from the natural aspect then it presents a large number of qualitative different products and services. The gross domestic product considered from the natural aspect can be divided on products which are foreseen for production consumption, i.e. remanufacturing, and products that are intended for the final consumption. But, calculating the gross domestic product considered naturally would represent very complicated arithmetical operation, either due to a fact that different products are expressed in different measurement units (kilograms, centimeters, liters), or due to the fact that gathering of their data would be too big work .

Due to this, the goods considered in calculation of gross domestic product are calculated by their market prices which express what all goods and services have in common, and that is that they have a certain value. Expressing the gross domestic product by value, i.e. price indicators, is incomparable easier, considering that its total value is obtained multiplying the achieved production volume and provided services of all kinds multiplied with certain prices and then respective multiplicands are added. However, calculation of goods and services by their market prices brings another problem – problem of unstable prices. Market prices change under different factors: variable relation of supply and demand, variable value of goods and services but variable money value (inflation, deflation, devaluation, revaluation).

Material (natural) structure of gross domestic product

Products of human labor satisfy different social needs. Some serve to the production consumption, i.e. they are used in production the new material goods, and the others are for personal consumption. Due to this, from this aspect, it can be said that natural structure of gross domestic product consists of all produced means for production (means for work and work objects) and consumption means.[4] Production means serve for satisfying the needs of production consumption while consumption means (disposable goods) are used for satisfying the needs of non-production or real consumption. Natural structure of gross natural product is presented with the model [11]:

Model 2 Natural Structure of Gross Domestic Product

$$DBP = SPR + SP \qquad (2)$$

DBP denotes the gross domestic product, SPR stands for means for production and SP denotes means for consumption. This division itself is conditional, because there is no sharp distinction between these two kinds of material goods, considering that many products can be used either in productive or non-productive consumption.

Value structure of gross domestic product

Considering that domestic product is the result of one social community work during a certain period of time, the results in that the labor appears as the creator and common denominator of social product. Considering a man taking a part in production process, with his production experience and working habits, and production means, the live or current labor is differ entiated which invest a man in the production process, and the past labor which is contained in the production means. Live or current labor creates so called a newly created value which is added in the production process and as such increases the national wealth, and a transferred value is formed is formed within consumption.

Due to the heterogeneous parts of natural structure of gross domestic product, it is difficult to quantify it and collectively express. This is all because there is no appropriate measurement unit for settling the different goods on unique common quantitative indicator. Problem is solved examining a common content of all different use values which make the spent labor, which results in an idea of value structure presented by the following model [11]:

Model 3 Value Structure of Gross Domestic Product

$$DBP = PB + NB \quad (3)$$

Considering this,I t can be concluded that total value of gross domestic product (GDP) is equal to the addition of transmitted value (PV) and new created value (NV). It is necessary to stress that transmitted value consists of two elements: material costs of production and amortization [5]. A newly created value is a part of the value of gross domestic product, which size is determined by the quantity of spent newly added labor.

Prosperity and factors which are not foreseen in BDP calculation

Gross domestic product is not an incontestable indicator of economic and social prosperity of the people of a certain community. Prosperity of a society understood as a level of living trend (personal consumption and social standard), like the average consumption level (like products for food, clothes, shoes, living conditions and similar), measured by responsible amount of goods which include certain needs of collective consumption (education, health care, culture and similar) in an important part depend on gross domestic production level. That amount of goods and services which objectively enables a certain level of BDP do not have to mean to coincide with the level of economic prosperity of people and due to this reason that is difficult to imagine a possibility of equal distribution of that economical welfare to the individuals. According that, it is necessary to remember that BDP do not contain answer on a question who gets the products and uses the services which he is made of. Classical relations and especially relations in BDP distribution as well as politics of economic development and economical politics of national community in a certain period of time can significantly differ among states in spite of equality of their BDP per capita. Those are the reasons why the level of economical welfare of people and distribution of economical welfare among individuals differ in conditions of equality BDP of two national communities.

It is necessary to have in mind that needs structure of people of a certain national community, differentiated on a class basis, brings about also the production structure of BDP, which also influence the economic prosperity of people. Considering that calculation of BDP does not contain relations in distribution among individuals, so it cannot express their level of prosperity.

Socio-economic welfare of people of certain national communities can be different from a few factors which influence the life quality of individuals of national community and which are not calculated within the gross domestic product. The factors will be listed and explained briefly: there are products and services which do not appear on the market, fast scientific – technological changes which do not cause appearance of the product which are used for the same use (cars, computer, etc.) and which are of better quality than previously produced, and improving the quality is important for the level of economic prosperity and cannot express BDP considering that BDP is quantitative but not qualitative indicator and the whole row of other factors , which are not foreseen by BDP [6].

NATIONAL PRODUCT AND NATIONAL INCOME

The above mentioned shortage of gross domestic product caused the need to consolidate the indicator which will state the size of value of final goods and services of national community realized in a stated time (a year). That indicator is named a national product. National product includes all final goods and services which are not used as objects of labor in the next phase of labor process and business. As the financial indicator of production results, it is contained in depreciation (AM) as the financial expression of consumed means of labor and new realized value or national income (ND), produced in a certain period, which will be presented in a following way [6]:

Model 4 National Product

$$DP = Am + ND \quad (4)$$

In other words, that is an indicator of financial amount of market realization the products and services which volume differentiate of the gross domestic product for the amount of transferred value on behalf of spent labor objects (interphase of consumption) . This leads to the conclusion that domestic product appears as a positive difference between the gross domestic product (GDP) and value of consumed labor objects (material costs), shown as [6]:

Model 5. National Product

$$DP = DBP - MTr \quad (5)$$

National product is often called the gross additional value, because it contains what producers of final products and services add through their own activities by the production of those products and delivering those services.

It is a material base of all types of final consumption, personal consumption, state or public and investment consumption. In the conditions when domestic community has a business with foreign communities, the size of values of final products and services, which appear as the positive or negative difference between the value of export and import of goods and services, will be included.

In statistics of industrial developed countries, according to methodology of the UN, the national product appears in two its shapes: gross domestic product or gross additional value and gross national product or gross national income.

Gross domestic product presents the collective expression values of final goods and services produced in a year or a quarter of a year within the borders i.e. the territory of one country (Table 1 gives an overview of this aggregate movement in a given period of time as the same of movement projections). *Gross domestic product* is a value of final goods and services whose sale brings incomes to home residents, independently if production was realized in the country or out of its borders [7]. In the other words, the gross national product is the gross domestic product increased by incomes that national residents have gained from the economic activity or based on the ownership in foreign countries, and reduced for incomes which are paid to non-resident business entities. Difference between the gross national product and gross domestic product is called the net income from economical activities and ownership in foreign countries. According to the above mentioned about these two indicators, it can be said that they will be qualitative equal if domestic residents have no activities in foreign countries as well as if foreign businesses have no involvement in a given community.

Table 1 *BDP and growth rate for the period 2005-2014 as well as projection of growth rate of domestic financial institution for 2015 and 2016 [8].*

Year	GDP (billions USD)	GDP growth rate
2005	25.06	+ 5.4
2006	29.33	+ 3.6
2007	39.16	+ 5.4
2008	47.67	+ 3.8
2009	40.24	- 3.5
2010	36.38	+ 1.0
2011	43.77	+ 1.6
2012	38.09	- 1.5
2013	42.49	+ 2.6
2014	42.65	- 0.6
2015	/	+ 1.8
2016	/	+ 2.0[9]

National product, as all other value expressed macroeconomic aggregates, is total amount of produced goods and services multiplied with the unit price of product or service, as it is known, it is impossible to use the natural indicators. Depending on the price, the calculation is used in differentiate: nominal and real national product.

Nominal national product presents the national product which is calculated according to the current prices, i.e. prices of products and services which were current at the moment of calculation (problem is that the prices can change even in a short period of time). The real national product is obtained if the influence of price changing is excluded from the nominal national product (it is calculated according to the stable prices).

National income is macroeconomic aggregate which expresses total quantity of newly created value in the area of material production produced by the national community in a given period of time (usually a year). Thus observed as the value expression, this indicator is presented as difference between the total size of national production value (GDP) and transferred value (PV) which is [6]:

Model 6 National Income

$$ND = DBP - PB \qquad (6)$$

It can be calculated as difference between national product (DP) and depreciation (Am), that is if the amount of transferred value is subtracted from national product for spent labor means, as follows [12]:

Model 7 National Income

$$DP - Am = ND \qquad (7)$$

As a new created value created by current labor in economy during the observed period, the national income is maximum value that the country can spend without any fear that it can endanger its own survival. It is important to point out that the level of living trend of population depends on national income amount as well as the level and possibility of economical development of a certain social community. Absolute size and growth rate of this macroeconomic aggregate is used as the indicator of economy development degree. It expresses a development degree by very special way that is the same as a possibility of further development if it is expressed like a value size compared with the number of population of a certain national community. The national income per capita is obtained by this way.

National income per capita shows which part of total gross national product of a country would belong to every individual if it is distributed equally. It shows the general level of living standard of average inhabitant in one country. It is connected with the other instruments which show the social, economical and other welfare of a country and its inhabitants.

It can be said that the national income is equal to total wages, profits and rents, i.e. the sum of values of primary incomes of all institutional sectors. Only national income can be used for satisfying the needs of inhabitants and investments, while the transferred value of production factors must be back in a function of production. That is the way to compensate what existed before it was consumed in the production of the new material goods [6].

The national income is divided into 5 components, and those are: salaries of employees, owner income, private lease incomes from rents, corporation profits and net participation. These five categories can be expressed in the approximate percentage figures. It will be seen that the salaries take 70%, ownership income 9%, rents 2, profits of companies 12% and net participation 7%. It is important to point out that this division was done according to the way of acquiring the income [10].

ANALYTIC USE OF AGGREGATE PRODUCTION EXPRESSION

Considering that three different sizes were stressed for marking the volume of material production, their analytic use and usefulness will be shortly analyzed. All three sizes have its sense and place either in theoretical or quantitative analysis but it is controversial which one has priority and greater importance. A certain number of economists consider that importance belongs to the gross domestic product because it deals with a large number of observable facts. The gross domestic product represents really an irreplaceable size in all analysis directed at exploring the inter-sectoral linkages and changes occurring in the structure of material production especially in relations between its basic sections. Beside that, it shows total domestic turnover of product, total amount of goods which should be exchanged in the economy and in a given period of time. In its structure, there are two additional components which have influence on creation and movements of other two sizes.

Two characteristics of gross domestic product should not be forgotten. The first, one part of gross domestic product that is transferred value of consumed raw material is a product of the past period or previous year which is only repeated in a new product. Society cannot utilize it, considering it has already been consumed, so it cannot subsequently be used for different purposes in economy. The second, in the gross domestic product expression, there are multiple repetitions of values of labor means that pass through many successive stages of processing. If there are more phases, if labor division is more developed and if there is the jagged state of economy then the number of these repetitions is higher as well. In that way, the gross domestic product expresses not just the real changes in production volume but, at the same time, all changes in organizational structure of economy and in social labor division. Its size can be influenced significantly by different organizational reorganization of production, higher or smaller degree of integration between the production units, regardless if there were the real changes at the level of material production.

These two reasons show that the gross domestic product is not the most appropriate size for expressing the real production volume and the pace of its changes in time, regardless from what particularly great difficulty inflicts its expression in constant prices, its conversion from current to constant prices. The above mentioned difficulties are such that practically disable the use of gross domestic product in the economic microanalysis which explores a longer time period. This, of course, does not reduce the mentioned analytical characteristics, which among others have a role to present very complex conditions in which production is done.

There are no multiple calculations in the gross domestic product and income and due to that it is possible to calculate the real production volume and achieved level and the pace of economic development, more effectively. The ability of production expansion and the level of satisfying and developing different social needs depend on their size.

According to all of that, it should be borne in mind the difference between these two sizes. Category of national income has only the net investments, and they are not enough, especially in one dynamic economy to express all real possibilities of expanded reproduction, considering that in such economy the depreciation also serve with its big part, in capital expansion and acceleration of economical growth. While exploring influence of investment on economical growth, it is necessary to consider total investments, i.e. investments which include depreciation. The national product which, beside national income, contains the depreciation, gives that wider opportunity for connecting and establishing the effects of total investments on production growth. In that sense, it can be considered as wider and more appropriate size in examining the basic interdependence which characterizes the process of economic growth.

Having in mind the analytic use of aggregate production expression, it can be concluded that every mentioned indicator has its own place in expressing the economical results. Depending on the “depth” and requirements of analysis, their use is different.

CONCLUSION

As it was seen, the gross domestic product is presented in global and short characteristics, as well as its distribution and shortcoming is stressed expressing as the most comprehensive aggregate. Namely, due to this multiple calculation the values of spent labor subjects; the gross domestic product inadequately expresses the size of total production value. At present, no matter on all that is used in macroeconomic analysis; it scrutinizes economical trends and has a great importance for the theory and practice in planning the development of one country, i.e. its economy.

The above mentioned shortcoming has conditioned the need to establish another indicator, national product and it entails all goods and services which are not used in the next phase as labor subjects. It is necessary to remind that the national product of a certain national economy, regardless it expressed through gross domestic or gross national product; it differs from the gross social product, total value of social production by the way that it does not contain the material costs, which appear depending on a number of market transactions of reproductive connected commodity producers. It can be concluded that the size of gross domestic product would not differ from national product but only in the case that economy is organized as one enterprise and, in that case, the size of values of all final products and services would determine the both indicators. Hence, it is not the case in market economy, these two economy aggregates differentiate very much.

For better overview the macroeconomic activity, the national income is very often used. It is very complex to determine this size. Depending on its size - dynamic of growth, i.e. whether it declines or grows, the economical progress of society and living standard of population can be followed. Its special significance reflects in the international comparison of national product height per capita among certain countries. At present, in every and especially in developed countries, there is a systematic system to follow national income trends and its integral parts and there are necessary actions to provide necessary level of national income growth from year to year. Thus, the national income represents the most important indicator of direction the economical development and providing conditions for increasing the satisfaction of individual and collective needs of society that is constantly increasing.

Although, it is here pointed out their large application, it should not be forgotten that these are the most global aggregates which, however, cannot be the basis for a more detailed economic analysis. Since there is a need for such analyzes, such demands cannot be met thanks to the system of social accounting or macroeconomic balances.

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ANALITIČKA UPOTREBA MAKROEKONOMSKIH AGREGATA

Izvod

Ekonomska nauka je razvila čitav sistem takozvanih makroekonomskih agregata - sistem određenih globalnih i sintetičkih pokazatelja kojima se izražavaju osnovni sadržaji, dinamika i struktura, kao i rezultati ekonomske aktivnosti u nekoj državi odnosno društvenoj zajednici. Cilj ovog rada je da sagleda mogućnosti upotrebe makroekonomskih agregata u privrednim granama kao što su rudarstvo i metalurgija koji predstavljaju oslonac privrednog i društvenog razvoja regije severnog dela Kosova i Metohije. Agregati rezultata društvene proizvodnje su pokazatelji obima, proizvodne i vrednosne strukture društvene proizvodnje. Pojedini agregati kao što su društveni proizvod i nacionalni dohodak koriste se za sagledavanje dinamike i osnovnih tendencija privrednog razvoja i ukupnih promena u nacionalnoj privredi. Njihove apsolutne veličine pružaju informacije o snazi privrede nacionalne zajednice kao i o mogućnostima njenog privrednog razvoja. Fokus istraživanja biće uperen na makro-ekonomske agregate koji su izraz rezultata društvene reprodukcije, a to su društveni bruto proizvod, društveni proizvod i nacionalni dohodak. Ovi agregati zajedno sa nezaposlenošću, inflacijom i platnim bilansom nalaze se u centru pažnje makroekonomske analize. Makroekonomski agregati predstavljaju važne analitičke kategorije, jer pružaju pregled strukturnih elemenata društvene reprodukcije, pokazujući pravac privrednih kretanja.

Ključne reči: *privreda, makroekonomski agregati, društveni proizvod, nacionalni dohodak*

UVOD

Da bi se izmerio rezultat poslovanja određenog preduzeća porede se njegovi prihodi i rashodi odnosno njihova razlika - dobit ili gubitak. Ako je preduzeće ostvarilo dobit onda možemo tvrditi da je rezultat njegovog poslovanja manje ili više dobar, zavisno od visine dobiti i zavisno od ostalih pokazatelja uspešnosti poslovanja. Analizom rezultata pojedinačnog preduzeća bavi se mikroekonomija.

U jednoj privredi se u toku godine proizvede mnoštvo najrazličitijih proizvoda, trguje se različitim vrstama robe i pružaju se najraznovrsnije usluge, pa možemo postaviti pitanje kako odrediti uspešnost rezultata koji u određenoj godini ostvaruje čitav ekonomski sistem. Da bi se vrednosno i količinski obuhvatili svi ti rezultati proizvodnje ekonomska nauka, odnosno makroekonomija kao njen deo, razvila je čitav sistem takozvanih makroekonomskih agregata-sistem određenih globalnih i sintetičkih pokazatelja kojima se izražavaju osnovni sadržaji, dinamika i struktura, kao i rezultati ekonomske aktivnosti u nekoj državi odnosno društvenoj zajednici.

Agregati rezultata društvene proizvodnje su pokazatelji obima, proizvodne i vrednosne strukture društvene proizvodnje. Mogu se sagledavati sa stanovišta sektorske

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strukture na osnovu koje se saznaje o tome koliki je doprinos ostvarenim rezultatima privređivanja primarnog, sekundarnog, tercijalnog i drugih sektora privrede, koliki je udeo poljuprivrede, industrije, rudarstva i drugih. Ukoliko se određeni privredni agregati predstavljaju po glavi stanovnika ili ukoliko se obračunavaju na osnovu strukture namenske raspodele društvenog proizvoda ili nacionalnog dohodka mogu precizno izraziti nivo ekonomske razvijenosti, kao i nivo životnog standarda, odnosno ekonomskog i društvenog blagostanja ljudi.

Neki se od danas korišćenih makroekonomskih agregata pominju još u XVII veku. Njihovo značajnije korišćenje u makroekonomskoj analizi započinje tek u periodu posle Velike ekonomske krize. Ovi agregati zajedno sa nezaposlenošću, inflacijom i platnim bilansom nalaze se u centru pažnje makroekonomske analize. Makroekonomski agregati predstavljaju važne analitičke kategorije, jer pružaju pregled strukturnih elemenata društvene reprodukcije, pokazujući pravac privrednih kretanja.

Polazeći od svega navedenog, ovaj rad je sistematizovan u tri poglavlja. Prvo poglavlje rada akcenat stavlja na najobuhvatniji pokazatelj, bruto društveni proizvod, faktore koji ga određuju uz osvrt na njegovu strukturu. U narednom poglavlju fokusirali smo se na društveni proizvod i nacionalni dohodak kao dva realnija pokazatelja razvijenosti privrede a samim tim i određene društvene zajednice. Na kraju smo istakli gde se sve možemo sresti sa makroekonomskim agregatima i samim tim videli da oni imaju ogroman značaj za društveno planiranje, ekonomsku politiku savremene države i međunarodna poređenja nacionalnih ekonomija.

DRUŠTVENI BRUTO PROIZVOD

Makroekonomija je za potrebe svoje analize razvila veliki broj makroekonomskih agregata, a svaki od njih, zavisno od načina izračunavanja i svoje strukture, predstavlja pokazatelj rezultata ili strukture rezultata ekonomskog sistema. Ipak, najkorišćeniji makroekonomski agregat, kako u ekonomskim analizama konkretne privrede, tako i u njenom poređenju sa drugim privredama je društveni bruto proizvod i on je najsveobuhvatniji pokazatelj rezultata društvene proizvodnje određene nacionalne zajednice.

Društveni bruto proizvod je izraz ukupne veličine proizvedenih dobara i usluga koje se proizvode u određenoj nacionalnoj zajednici u toku jedne godine. Kako bi se u potpunosti razumela suština bruto društvenog proizvoda potrebno je imati u vidu: da bruto društveni proizvod predstavlja tržišnu vrednost svih proizvoda i usluga proizvedenih u jednoj zemlji u periodu od godinu dana to znači da se za njegovo izračunavanje koriste tržišne cene dobara i usluga; u obračun ovog agregata ulazi vrednost takozvanih međufaznih proizvoda jer je njihova vrednost obračunata i u vrednosti finalnih proizvoda proizvodnje (npr. proizvodnja nakita, povezana sa primarnom proizvodnjom zlata i srebra, a zatim njegovom preradom, trgovinom na veliko i na malo); bruto društveni proizvod uključuje samo proizvode koji su proizvedeni u toku obračunske godine; u obračun bruto društvenog proizvoda ulaze samo dobra i usluge koje su legalno prodate u toku godine što znači da ovaj makroekonomski agregat ne obračunava transakcije koje su izvršene u okviru sive ekonomije; u obračun bruto društvenog proizvoda domaće zemlje ulaze i roba i usluge koje su na teritoriji domaće zemlje proizvele strane kompanije odnosno strani građani [1].

Treba, takođe, istaći i činjenicu da je bruto društveni proizvod makroekonomski agregat koji istovremeno izražava dve veličine - ukupan dohodak privrednih subjekata i ukupne troškove svih roba i usluga u određenoj privredi. To znači da je ukupan dohodak uvek jednak ukupnom trošku. Suština ove jednakosti je u tome što ako, recimo, jedan građanin Srbije plati popravku elektroinstalacije za njega će ta transakcija predstavljati trošak. Za električara koji je popravku izvršio ta transakcija će predstavljati dohodak. Na taj način su u okviru jedne privrede ukupan dohodak i ukupni troškovi zaista jednaki.

Ako želimo da razumemo šta određuje tražnju za dobrima i uslugama, neophodno je rastaviti bruto domaći proizvod na sastavne delove, pošto imamo različite kupce tih dobara. U kontekstu ovakve analize bruto društveni proizvod se sastoji od: potrošnje (C), investicija (I), vladinih kupovina – državna potrošnja (G), neto izvoza (NX) i investicija u zalihe (IZ) [2].

U daljem radu, kratko ćemo objasniti gore navedene sastavne delove: potrošnja se sastoji od roba i usluga kupljenih od strane pojedinca, odnosno domaćinstava, izuzev stambenog prostora; investicije se sastoje od kupljenih dobara za buduću proizvodnju, dok ekonomisti pod investiranjem podrazumevaju proizvodnju trajnih kapitalnih dobara (to znači da ako pet hiljada eura iz blagajne stavimo u banku ili kupimo državne obveznice, prema ekonomistima nikakva se investicija nije dogodila, zamenio se samo jedan sa drugim oblikom finansiske imovine); državna potrošnja uključuju kupovinu dobara kao što su: putevi, aerodromi, vojska, policija, zdravstvo, penzioni fondovi itd., i kod državnih rashoda treba isključiti transferna plaćanja (npr: plaćanja za osiguranja od nezaposlenosti, primanja ratnih boraca, primanja starih i iznemoglih, zdravstveno i socijalno osiguranje itd.); neto izvoz ili spoljnotrgovinski bilans predstavlja razliku između izvoza i uvoza dobara i usluga; zalihe smo uključili, jer nas zanima ukupna proizvodnja, odnosno ukupne kupoprodajne transakcije bilo koje nacionalne ekonomije, a ukoliko to nije slučaj dolazi do razlike između proizvedenih i prodatih dobara u tekućoj godini i to je ustvari investicija u zalihe.

Faktori koji određuju obim društvenog bruto proizvoda su: *prirodno bogatstvo* (uslov svake proizvodnje predstavlja prirodno bogatstvo. U prirodno bogatstvo spada zemlja i sve što se u njoj nalazi. Proces proizvodnje je u suštini menjanje i prilagođavanje prirode ljudskim potreba. Da bi se prirodna bogatstva mogla koristiti moraju da budu razvijena sredstva za proizvodnju. Ovo posebno dolazi do izražaja u rudarstvu i metalurgiji gde tehnologija i stepen iskorišćenosti kapaciteta igraju ključnu ulogu. Prirodna bogatstva su samo potencijalni faktor koji utiče na obim društvenog bruto proizvoda); *razvijenost sredstava za proizvodnju* (ljudi mogu da žive vrlo siromašno u prirodno bogatom podneblju ako nemaju odgovarajuća sredstva, znanja i sposobnosti da ih iskoriste na pravi način te tako pretvore u društveno bogatstvo. Društveno bogatstvo se definiše kao sva nagomilana materijalna dobra kojima raspolaže jedno društvno a proizvodi su rada prošlih i sadašnjih generacija); *stanovništvo* (stanovništvo je trajni izvor radne snage bez koga se ne može zamisliti proces proizvodnje. Broj i struktura stanovništva u jednoj zemlji utiču na obim i strukturu potrošnje. Obim društvnog bruto proizvoda biće veći ukoliko ta zajednica raspoleže većim brojem proizvodno aktivnog stanovništva); *produktivnost rada* (produktivnost rada izražava proizvodnu snagu rada da se za određeno vreme proizvodi veća ili manja količina materijalnih dobara. Ukoliko je proizvodna snaga rada veća, proizvođač koji je poseduje biće u stanju da za isto vreme proizvede veću količinu proizvoda ili jedan proizvod za kraće vreme u odnosu na drugog proizvođača. Veća produktivnost rada ostvaruje se ukoliko se određeno materijalno dobro proizvede za kraće vreme ili ukoliko se za isto vreme proizvede veća količina materijalnih dobara. Produktivnost rada se može izračunati kao [13]:

Obrazac 1. Produktivnost rada

$$P_r = \frac{Q}{T} \qquad (1)$$

Q - obim proizvodnje, T – vreme,
Pr - pro-duktivnost rada.

Najvažniji faktori produktivnosti mogu se definisati kao: tehničko-tehnološki, organizacioni, lični faktor radne snage, društveno institucionalni); *intenzivnost rada* (predstavlja stepen trošenja ljudske radne snage u jedinici vremena) [14]; *društveni odnosi* (društveni odnosi imaju značajan uticaj na način i stepen korišćenja svih raspoloživih ljudskih i materijalnih činilaca proizvodnje. Što su društveni odnosi povoljniji za proizvođače, proizvođači će imati veći ekonomski interes da povećaju obim proizvodnje) [3].

Struktura bruto društvenog proizvoda se može posmatrati sa: naturalnog i sa vrednosnog (finansijskog) aspekta. Kada se bruto društveni proizvod posmatra sa naturalnog aspekta onda on predstavlja skup velikog broja kvalitativno različitih proizvoda i usluga. Bruto društveni proizvod posmatran sa naturalnog aspekta može se podeliti na proizvode koji su namenjeni proizvodnoj potrošnji odnosno ponovnoj proizvodnji i proizvode koji su namenjeni finalnoj potrošnji. Međutim, izračunavanje bruto društvenog proizvoda izraženog naturalno predstavljalo bi veoma komplikovanu računsku operaciju, kako zbog toga što se različiti proizvodi izražavaju u različitim jedinicama mere (kilogrami, centimetri, litri), tako i zbog toga što bi prikupljanje podataka o njima predstavljalo preobiman posao.

Zbog toga se dobra koja ulaze u obračun bruto društvenog proizvoda obračunavaju preko njihovih tržišnih cena koje izražavaju ono što je svim dobrima i uslugama zajedničko, a to je da imaju određenu vrednost. Izražavanje društvenog bruto proizvoda vrednosnim odnosno cenovnim pokazateljima je neuporedivo lakše, pošto se njegova ukupna vrednost dobija tako što se ostvareni obim proizvodnje i usluga svake vrste pomnoži najpre odgovarajućim cenama a potom pojedinačni umnošci saberu. Obračunavanje dobara i usluga po njihovim tržišnim cenama, međutim, nosi sa sobom drugi problem - problem promenljivosti cena. Tržišne cene se menjaju pod dejstvom različitih faktora: promene odnosa ponude i tražnje, promena same vrednosti dobara i usluga, ali i promena vrednosti novca (inflacija, deflacija, devalvacija, revalvacija).

Materijalna (naturalna) struktura društvenog bruto proizvoda

Proizvodi ljudskog rada zadovoljavaju različite društvene potrebe. Jedni služe proizvodnoj potrošnji, tj. koriste se u proizvodnji novih materijalnih dobara, a drugi su namenjeni ličnoj potrošnji. Zbog toga, sa ovog stanovišta, možemo reći da naturalnu strukturu društvenog bruto proizvoda čine sva proizvedena sredstva za proizvodnju (sredstva za rad i predmeti rada) i sredstva za potrošnju [4]. Sredstva za proizvodnju služe za zadovoljavanje potrebe proizvodne potrošnje dok se sredstava za potrošnju (potrošna dobra) koriste za podmirivanje potreba neproizvodne ili prave potrošnje. Naturalna struktura društvenog bruto proizvoda se predstavlja sledećim obrazcem [11]:

Obrazac 2. Naturalna struktura društvenog bruto proizvoda

$$DBP = SPR + SP \qquad (2)$$

DBP označava društveni bruto proizvod, SPR označava sredstva za proizvodnju, a SP sredstva za potrošnju. Sama ova podela je uslovne prirode, jer ne postoji oštra granica između ove dve vrste materijalnih dobara, pošto se mnogi proizvodi mogu koristiti i u proizvodnoj i u neproizvodnoj potrošnji.

Vrednosna struktura društvenog bruto proizvoda

Pošto je društveni proizvod rezultat rada jedne društvene zajednice u toku određenog vremena to se rad javlja kao tvorac i zajednički imenitelj društvenog proizvoda. Budući da u procesu proizvodnje učestvuje i čovek, sa svojim proizvodnim iskustvom i radnim navikama, i sredstva za proizvodnju, razlikujemo živi ili tekući rad, koji ulaže čovek u toku datog procesa proizvodnje, i preneti, minuli rad koji je sadržan u sredstvima za proizvodnju. Živi ili tekući rad stvara tzv. novostvorenu vrednost koja se dodaje u procesu proizvodnje i tako uvećava društveno bogatstvo, a utroškom minulog ili prenetog rada formira se preneta vrednost.

Zbog heterogenosti delova naturalne strukture društvenog bruto proizvoda teško ga je količinski zbirno izraziti. Sve ovo zbog toga što ne postoji prikladna jedinica mere za svođenje različitih dobara na jedinstven količinski zajednički pokazatelj. Problem se rešava posmatranjem zajedničkog sadržaja svih različitih upotrebnih vrednosti koji čine utrošen rad, čime se dolazi do pojma vrednosne strukture, koju možemo predstaviti sledećim obrascem:[11]

Obrazac 3. Vrednosna struktura društvenog bruto proizvoda

$$DBP = PV + NV \qquad (3)$$

Iz ovog zaključujemo da je ukupna vrednost društvenog bruto proizvoda (DBP) jednaka zbiru prenete vrednosti (PV) i novostvorene vrednosti (NV). Potrebno je naglasiti da prenetu vrednost čine dva elementa: materijalni troškovi proizvodnje i amortizacija [5]. Novostvorena vrednost je onaj deo vrednosti društvenog bruto proizvoda, čija je veličina određena količinom utrošenog novododatog rada.

Blagostanje i faktori koji se ne obuhvataju u obračunu BDP

Bruto društveni proizvod nije pouzdan pokazatelj ekonomskog i društvenog blagostanja ljudi određene nacionalne zajednice. Blagostanje društva shvaćeno kao nivo životnog standarda (lične potrošnje i društvenog standarda), kao prosečan nivo potrošnje (kao što su proizvodi za ishranu, odevanje, oduvanje, stambeni uslovi i sl.) mereno odgovarajućom korpom dobara koje uključuje i određene potrebe kolektivne potrošnje (obrazovanje, zdravstvo, kultura i sl.) u značajnoj meri zavise od nivoa bruto društvenog proizvoda. Ta korpa dobara i usluga koju objektivno omogućuje određeni nivo BDP ne mora da znači da se podudara sa nivoom ekonomskog blagostanja ljudi i to iz prostog razloga što je teško zamisliti mogućnost ravnopravne raspodele tog ekonomskog blagostanja na pojedince. Pri tome treba imati u vidu da BDP ne sadrži odgovor na pitanje ko prisvaja proizvode i koristi usluge koje ga sačinjavaju. Klasni odnosi i posebno odnosi u raspodeli BDP, kao i politika privrednog razvoja i ekonomska politika nacionalne zajednice u određenom vremenu mogu se značajno razlikovati između zemalja i pored jednakosti njihovog BDP per capita. To su i razlozi što se po pravilu razlikuje nivo ekonomskog blagostanja ljudi odnosno raspodela ekonomskog blagostanja između pojedinaca u uslovima jednakosti BDP – a dve nacionalne zajednice.

Potrebno je imati u vidu da stuktura potreba ljudi određene nacionalne zajednice, klasno izdiferencirane, uslovljava i strukturu proizvodnje BDP - a, što itekako utiče na ekonomsko blagostanje ljudi. Pošto obračun BDP - a ne sadrži odnose u raspodeli između pojedinaca, to on ne može da izrazi ni njihov nivo blagostanja.

Ekonomsko i društveno blagostanje ljudi određenih nacionalnih zajednica može biti različito iz čitavog niza faktora koji itekako utiču na kvalitet života pojedinca nacionalne zajednice, a koji se ne obračunavaju u okvirima bruto domaćeg proizvoda.

Nabrojaćemo faktore i ukratko objasniti: tu spadaju proizvodi i usluge koje se ne pojavljuju na tržištu, brze naučno – tehnološke promene koje uslovljavaju pojavu proizvoda koji služe istoj upotrebi (automobil, kompjuter i dr.) koji su kvalitetniji od primeraka predhodno proizvedenih, a to poboljšanje kvaliteta od značaja za nivo ekonomskog blagostanja ne može da izrazi BDP iz razloga što je on količinski, a ne kvalitativni pokazatelj i čitav niz drugih faktora koji nisu obuhvaćeni BDP – om [6].

DRUŠTVENI PROIZVOD I NACIONALNI DOHODAK

Navedeni nedostatak društvenog bruto proizvoda uslovio je potrebu da se utvrdi pokazatelj kojim će se iskazati veličina vrednosti finalnih dobara i usluga nacionalne zajednice ostvarenih u određenom vremenu (godinu dana). Taj pokazatelj naziva se društveni proizvod. Društvenim proizvodom se obuhvataju sva finalna dobra i usluge koji se ne koriste kao predmeti rada u naredenoj fazi procesa rada i poslovanja. Kao vrednosni pokazatelj rezultata proizvodnje sadrži se iz amortizacije (Am) kao vrednosnog izraza utrošenih sredstava rada i novostvorene vrednosti ili nacionalnog dohotka (ND) koja se proizvodi u određenom periodu, što ćemo prikazati na sledeći način [6]:

Obrazac 4. Društveni proizvod

$$DP = Am + ND \quad (4)$$

Drugim rečima, to je pokazatelj veličine vrednosti tržišne realizacije proizvoda i usluga čiji se obim razlikuje od društvenog bruto proizvoda za iznos prenete vrednosti na ime utrošenih predmeta rada (međufazne potrošnje). Iz ovog zaključujemo da se društveni proizvod pojavljuje kao pozitivna razlika između društvenog bruto proizvoda (DBP) i vrednosti utrošenih predmeta rada (materijalni troškovi), i ovo prikazujemo [6]:

Obrazac 5. Društveni proizvod

$$DP = DBP - MTr \quad (5)$$

Društveni proizvod često i nazivamo bruto dodatna vrednost, jer sadrži ono što proizvođači finalnih proizvoda i usluga dodaju svojom aktivnošću baveći se proizvodnjom tih proizvoda i vršenjem tih usluga.

On je materijalna osnova svih oblika finalne potrošnje, lične potrošnje, državne ili javne i investicione potrošnje. U uslovima poslovanja domaće zajednice sa inostranstvom obuhvatiće i veličinu vrednosti finalnih proizvoda i usluga koji se pojavljuju kao pozitivna ili negativna razlika između vrednosti izvoza i uvoza roba i usluga.

Društveni proizvod se u statistici industrijski visoko razvijenih zemalja, kao i po metodologiji UN pojavljuje u svoja dva oblika: bruto domaćeg proizvoda ili bruto dodatne vrednosti i bruto nacionalnog proizvoda ili bruto nacionalnog dohotka.

Bruto domaći proizvod predstavlja zbirni izraz vrednosti finalnih dobara i usluga proizvedenih u toku jedne godine ili jednog tromesečija u godini u granicama odnosno na teritoriji jedne zemlje (u tabeli 1. dat je prikaz kretanja ovog agregata u određenom periodu, kao i projekcije kretanja). *Bruto nacionalni proizvod* je vrednost finalnih dobara i usluga čijom prodajom domaći rezidenti stiču dohotke nezavisno od toga da li je proizvodnja ostvarena unutar ili van granica sopstvene zemlje [7]. Drugačije rečeno bruto nacionalni proizvod je bruto domaći proizvod uvećan za dohotke koje su nacionalni rezidenti ostvarili od ekonomske aktivnosti ili po osnovu svojine u inostranstvu, a umanjen za dohotke koji se isplaćuju poslovnim jedinicama nerezidentima. Razlika između bruto nacinalnog proizvoda i bruto domaćeg proizvoda naziva se neto dohodak od ekonomskih aktivnosti i od svojine iz inostranstva. Na osnovu izloženog o ova dva pokazatelja možemo reći da će oni biti kvantitativno jednaki ukoliko domaći rezidenti nemaju nikakvih aktivnosti u inostranstvu, odnosno ukoliko takođe strani poslovni subjekti nemaju nikakvog angažovanja u toj zajednici.

Tabela 1. *BDP i stopa rasta za period 2005-2014, kao i projekcija stope rasta domaće finansijske institucije za 2015. i 2016. [8]*

Godina	BDP (usd billions)	Stopa rasta BDP
2005	25.06	+ 5.4
2006	29.33	+ 3.6
2007	39.16	+ 5.4
2008	47.67	+ 3.8
2009	40.24	- 3.5
2010	36.38	+ 1.0
2011	43.77	+ 1.6
2012	38.09	- 1.5
2013	42.49	+ 2.6
2014	42.65	- 0.6
2015	/	+ 1.8
2016	/	+ 2.0 [9]

Društveni proizvod se, kao i svi ostali makroekonomski agregati izražava vrednosno, odnosno ukupna količina proizvedenih dobara i usluga se množi sa cenom po jedinici proizvoda ili usluge, jer je iz već poznatih razloga nemoguće koristiti naturalne pokazatelje. U zavisnosti od toga koje cene koristimo prolikom izračunavanja razlikujemo: nominalni i realni društveni proizvod.

Nominalni društveni proizvod predstavlja društveni proizvod koji je izračunat po tekućim cenama, odnosno cenama proizvoda i usluga koje su bile aktuelne u trenutku njegovog izračunavanja (problem je što se te cene mogu menjati i u kratkom vremenskom periodu). Realni društveni proizvod dobijamo ako iz nominalnog društvenog proizvoda isključimo uticaj kretanja cena (on se izračunava na osnovu stalnih cena). U ovom slučaju društveni proizvod, odnosno cena iz nekog baznog perioda.

Nacionalni dohodak je makroekonomski agregat koji izražava ukupnu veličinu novostvorene vrednosti u oblasti materijalne proizvodnje koju je proizvela nacionalna zajednica u određenom vremenu (obično se uzima godinu dana). Tako posmatran, kao vrednosni izraz ovaj pokazatelj se predstavlja kao razlika između ukupne veličine vrednosti društvene proizvodnje (DBP) i prenete vrednosti (PV) što izgleda [6]:

Obrazac 6. Nacionalni dohodak

$$ND = DBP - PV \qquad (6)$$

Može se dobiti i kao razlika između društvenog proizvoda (DP) i amortizacije (Am), odnosno ukoliko se od društvenog proizvoda oduzme iznos prenete vrednosti na ime utrošenih sredstava za rad, odnosno [12]:

Obrazac 7. Nacionalni dohodak

$$DP - Am = ND \qquad (7)$$

Kao novostvorena vrednost stvorena tekućim radom u privredi tokom posmatranog perioda, nacionalni dohodak je maksimalna vrednost koju konkretna zemlja može trošiti bez straha da može ugroziti vlastiti opstanak. Bitno je naglasiti da od veličine nacionalnog dohodka zavisi nivo životnog standarda stanovništva kao i nivo i mogućnost privrednog razvoja određene društvene zajednice. Apsolutna veličina i stopa rasta ovog makroekonomskog agregata koristi se kao pokazatelj stepena razvijenosti privrede. On posebno pregledno izražava stepen razvijenosti i mogućnost daljeg razvoja ukoliko se izražava kao vrednosna veličina stavljena u odnosu sa brojem stanovnika određene nacionalne zajednice. Tako dolazimo do nacionalnog dohodka po glavi stanovnika ili nacionalnog dohodka per capita.

Nacionalni dohodak po glavi stanovnika pokazuje koji deo ukupnog bruto nacionalnog proizvoda zemlje bi pripadao svakom pojedincu ukoliko bi on bio ravnomerno raspoređen. On pokazuje opšti nivo životnog standarda prosečnog stanovnika jedne zemlje. On je povezan sa drugim instrumentima koji pokazuju društveno, ekonomsko i svako drugo blagostanje zemlje i njenog stanovništva.

Možemo reći da je nacionalni dohodak jednak ukupnim nadnicama, profitima i rentama, odnosno to je zbir vrednosti primarnih dohodaka svih institucionalnih sektora. Samo se nacionalni dohodak može upotrebiti za podmirenje potreba stanovništva i investicije, dok se prenesena vrednost faktora proizvodnje mora ponovo vratiti u funkciju proizvodnje. Time se nadoknađuje ono što je postojalo, a utrošeno je u stvaranju novih materijalnih dobara [6].

Nacionalni dohodak se deli na pet komponenti, a to su: zarade zaposlenima, vlasnički dohodak, privatni zakupni dohodak od rente, profiti korporacija i neto učešće. Ovih pet kategorija možemo iskazati i u aproksimiranim procentualnim iznosima. Videćemo da na zarade odlazi 70%, na vlasnicki dohodak 9%, na zakupnine od renti 2%, profit firme 12% i na neto učešće 7%. Bitno je napomenuti da je ova podela izvršena u zavisnosti od načina sticanja dohotka [10].

ANALITIČKA UPOTREBA AGREGATNIH IZRAZA PROIZVODNJE

Pošto smo naveli tri različite veličine za obeležavanje obima materijalne proizvodnje, valja se kratko pozabaviti njihovom analitičkom upotrebom i svrsishodnošću. Sve tri veličine imaju svoj smisao i mesto kako u teorijskoj tako i kvantitativnoj analizi, mada je sporno kojoj od njih treba pridati prvenstveni i najveći značaj. Jedan broj ekonomista taj značaj pripisuje društvenom bruto proizvodu zbog širine tokova koje obuhvata. Društveni bruto proizvod predstavlja zaista nezamenljivu veličinu u svim analizama koje su upravljene na istraživanje međugranskih povezanosti i promena koje nastaju u strukturi materijalne proizvodnje, a posebno u odnosima između njenih osnovnih odeljaka. On, sem toga, pokazuje ukupan društveni obrt proizvoda, ukupnu veličinu dobara koju valja razmeniti u datoj privredi i datom vremenskom periodu. U svojoj strukturi sadrži takve dodatne komponente koje su od uticaja na formiranje i kretanje drugih dveju veličina.

Ne treba, međutim, izgubiti iz vida dve osobenosti društvenog bruto proizvoda. Prvo, jedan deo društvenog bruto proizvoda, tj. prenesena vrednost utrošenih sirovina, predstavlja proizvod prethodnog razdoblja ili prethodne godine koji se samo ponavlja u novom proizvodu. Njime društvo ne može raspolagati, budući da je već utrošen, te se ne može naknadno koristiti za različite svrhe u privredi. Drugo, u izrazu društvenog bruto proizvoda dolazi do višestrukog ponavljanja vrednosti predmeta rada koji prolaze kroz brojne uzastopne faze prerade. Ukoliko je broj tih faza veći, ukoliko je više razvijena podela rada i veća razuđenost privrede, utoliko je i broj ovih ponavljanja veći. Društveni bruto proizvod na taj način izražava ne samo stvarne promene u obimu proizvodnje, nego istovremeno i sve promene u organizacionoj strukturi privrede, u društvenoj podeli rada. Na njegovu veličinu mogu bitno uticati različita organizaciona preustrojstva proizvodnje, veći ili manji stepen integrisanosti proizvodnih jedinica, nezavisno od toga da li je došlo do stvarnih promena u nivou materijalne proizvodnje.

Iz oba navedena razloga društveni bruto proizvod nije najprikladnija veličina za izražavanje stvarnog obima proizvodnje i tempa njenih promena u vremenu, nezavisno od toga što naročito velike teškoće zadaje njegovo izražavanje u stalnim cenama, njegova konverzija sa tekućih na stalne cene. Navedene teškoće su takve prirode da praktično onemogućavaju upotrebu društvenog bruto proizvoda u ekonomskim makroanalizama koje se tiču dužih vremenskih razdoblja. Time se naravno ne umanjuju njegova ranije pomenuta analitička svojstva, koja se između ostalog sastoje u pružanju slike o veoma složenim uslovima u kojima se proizvodnja obavlja.

U društvenom proizvodu i nacionalnom dohotku nema ovog višestrukog obračunavanja i zato se pomoću njih adekvatnije može da izražava stvarni obim proizvodnje, dostignuti nivo i tempo privrednog razvoja. Od njihove veličine u krajnjoj liniji zavisi mogućnost proširivanja proizvodnje i stepen zadovoljavanja i razvijanja različitih društvenih potreba.

Treba pri svemu tome imati u vidu razliku između ove dve veličine. Kategorija nacionalnog dohotka sadrži samo neto investicije, a one nisu dovoljne, naročito u jednoj dinamičnoj privredi, da izraze sve stvarne mogućnosti proširene reprodukcije, pošto u takvoj privredi i amortizacija znatnim svojim delom služi uvećanju kapitala i ubrzanju privrednog rasta. U posmatranju uticaja investicija na privredni rast nužno je uzimati u obzir ukupne investicije, dakle, investicije koje u sebi sadrže i amortizaciju. Društveni proizvod kojim je pored nacionalnog dohotka obuhvaćena i amortizacija, pruža tu širu mogućnost za povezivanje i utvrđivanje efekata ukupnih investicija na rast proizvodnje. U tom smislu on se može smatrati širom i pogodnijom veličinom u posmatranju osnovnih međuzavisnosti koje karakterišu procese privrednog rasta.

Imajući u vidu analitičku upotrebu agregatnih izraza proizvodnje, možemo zaključiti da svaki od navedenih indikatora ima svoje mesto u iskazivanju privrednih rezultata. Različita je njihova upotreba u zavisnosti od „širine" i potreba analize.

ZAKLJUČAK

Prikazani su, kao što smo videli u globalu i kraćim crtama društveni bruto proizvod, njegova raspodela i istakli smo njegove nedostatke koje ispoljava kao najsveobuhvatniji agregat. Uprabo zbog tog višestrukog obračunavanja vrednosti utrošenih predmeta rada društveni bruto proizvod neadekvatno iskazuje veličinu vrednosti ukupne proizvodnje. Danas se bez obzira na sve to on koristi u makroekonomskoj analizi, sagledava privredna kretanja i od velikog je značaja za teoriju i praksu planiranja razvoja jedne zemlje, odnosno njene privrede.

Navedeni nedostatak uslovio je potrebu da se utvrdi drugi pokazatelj, društveni proizvod i on obuhvata sva dobra u usluge koja se ne koriste u narednoj fazi kao predmeti rada. Potrebno je podsetiti da se društveni proizvod određene nacionalne privrede, bilo da se izražava preko bruto domaćeg ili bruto nacionalnog proizvoda razlikuje od društvenog bruto proizvoda, ukupne vrednosti društvene proizvodnje, utoliko što ne sadrži materijalne troškove, koji se pojavljuju zavisno od broja tržišnih transakcija reprodukciono povezanih robnih proizvođača. Možemo zaključiti da se veličina društvenog bruto proizvoda ne bi razlikovala od društvenog proizvoda samo ukoliko bi se privreda organizovala kao jedno preduzeće jer bi u tom slučaju veličina vrednosti svih finalnih proizvoda i usluga određivala oba pokazatelja. Pošto to u tržišnoj privredi nije slučaj, to se bitno razlikuju ova dva privredna agregata.

Radi boljeg sagledavanja makroekonomskih aktivnosti, često je u upotrebi nacionalni dohodak. Složeno je utvrđivanje ove veličine. U zavisnosti od njegove veličine odnosno dinamike rasta tj. da li on opada ili raste može se pratiti ekonomski napredak društva i životni standard stanovništva. Njegov poseban značaj se ogleda u međunarodnom poređenju visine nacinalnog proizvoda po glavi stanovnika između pojedinih zemalja. Danas se u svim, a posebno razvijenim zemljama sistematski prati kretanje nacionalnog dohotka i njegovih sastavnih delova i preduzimaju se potrebne mere da bi se obezbedio potreban nivo rasta nacionalnog dohotka iz godine u godinu. Tako nacinalni dohodak predstavlja najvažniji pokazatelj usmerenosti ekonomskog razvoja i obezbeđenje uslova za sve veće zadovoljenje pojedinačnih i zajedničkih potreba društva koje se stalno uvećava.

Iako smo istakli ovde njihovu veliku primenu, ne treba zaboraviti da je reč o najglobalnijim agregatima koji ipak ne mogu biti osnova za neku podrobniju ekonomsku analizu. Pošto često imamo potrebu za takvim analizama, takve zahteve možemo zadovoljiti zakvaljujući sistemu društvenog računovodstva ili makroekonomskih bilansa.

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NEW APPROACH FOR WATER QUALITY ANALYSIS AND MODELING

Abstract

Watercourses present a special case of water reservoirs. Regardless to the method of their investigation, there is still a search for the convenient method for processing of collected measurements of water quality parameters. Research direction was defined by the EU directive framework for aquatic bodies. Taking into consideration the existing methods for water quality analysis, this paper presents a proposal of a new method for analysis and modeling the aquatic body behavior. The measurements conducted at five stations on the river Ibar in the period from 2007 to 2012 are used as a basis. The basic method is based on multivariable analysis of unevenly time spaced measuring data. The basis was the correlation analysis that defined dependent parameters for determination the SWQI indices. Analyses have shown that the obtained results can be used for establishing an integral monitoring the water quality of aquatic system of the river Ibar. Also, they pointed out the possible directions for measurement and analysis upgrading.

Keywords: *modeling, water reservoirs, SWQI, measurement BOD-5*

INTRODUCTION

Humans have evolved from psychologically relatively insignificant consumers to the clever, intellectual beings and geochemical users of external energy resources and materials for building of their civilization and enhancement of domination. People waste 10 to 20 times (on the northern hemisphere 50 to 100 times) more energy than what is needed for their metabolism. Disruption of water surroundings indirectly caused by the energy consumption can exceed the one that causes ejection of excretions (Figure 1). Most of the energy that industrial society uses as its advantage (making heat, landscape management, urban structure, agriculture, forestry, geological studies, building of dams) in the end affects and disrupts the ecosystem. People - as terrestrial beings - directly affect the primarily terrestrial environment; but, since terrestrial and aquatic ecosystems are connected and due to the sensibility of the latter, the emphasized impact of civilization on the ecology primarily is reflected on the aquatic ecosystem. Many consequences of energy dissipation are also noticeable in the atmosphere, which behaves as the efficient assembly line for many pollutants. Human power to disturb environment tends to go above technological capabilities to respond to impact on the environment [1].

Ecosystem can be defined as the unit of environment where, as the result of solar energy input, biological community (primary producers, consumers and decomposers) is reflected; energy flow is used for organi

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zation of the system and is followed by the cycles of water, nutrients and other elements and by the life cycle through different food consumers at different levels. Members of the ecosystem are connected by different feedbacks (homeostasis) and as so are adapted to coexistence for the purpose of mutual progression. Network of control and balances includes many transfers of organic and inorganic substances - a network of food, nutrients, allelochemicals - and makes ecosystem a functional unit [2].

The Second Law of Thermodynamics states that each spontaneous process shall be followed by increase of entropy:

$$dS\ (\text{source, drain}) + dS(\text{ecosystem}) \geq 0.$$

Due to the condition d*S* (source, drain)>0, ecosystem entropy can decline, that is, to be:

$$-dS\ (\text{ecosystem}) \leq dS\ (\text{source, drain}).$$

Declination is seen in the arrangement of ecosystem and in the presence of incredibly high integration of energy as living beings. Their organization is maintained at the expense of increasing entropy in the environment.

Up to now, it was tried to approach different subjects in a quantitative and rigorous way. In this research, on the contrary, we have to rely on qualitative and often speculative arguments, because our understanding of elasticity of aquatic ecosystem is seriously hampered by the lack of theoretical and sufficient empirical information on the effects of physical and chemical disorders of aquatic ecosystems [3].

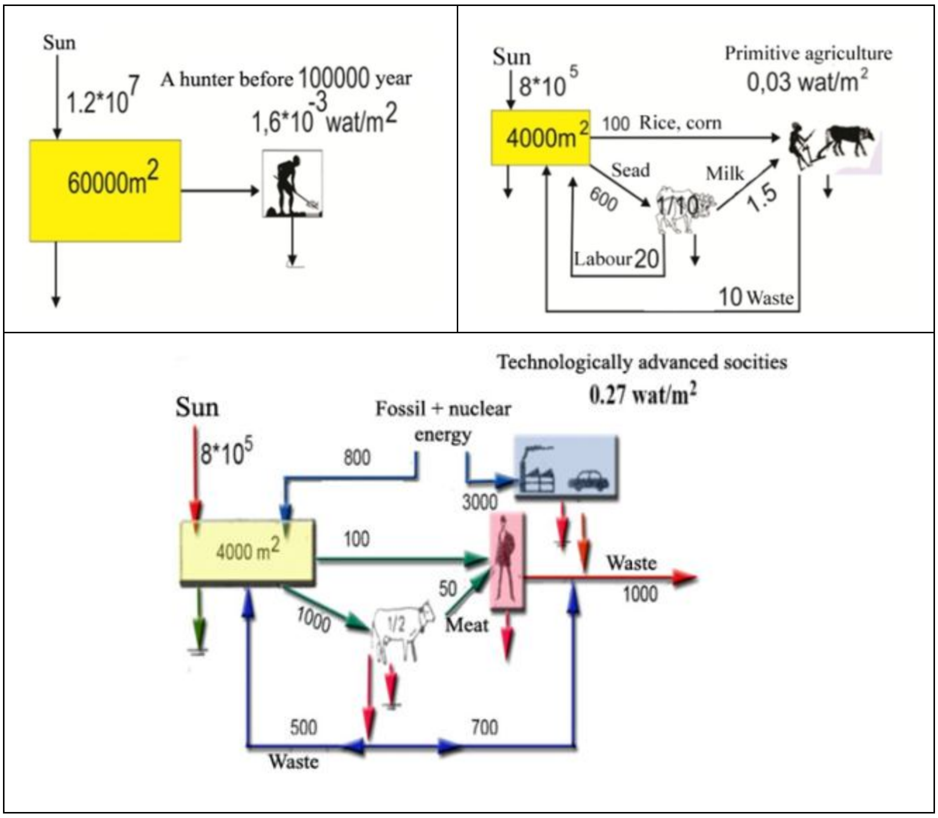

Figure 1 *Energy and land demands of the primitive and modern man*

For preservation of our culture and civilization and the improvement of life quality, and especially for food production for growing the world population, it is necessary to continue to depend on the utilization of technology and energy. Social criteria and growing pressure for social equality must simultaneously establish the scientific and technological development.

Watercourses represent a special case of water reservoirs. From the aspect of water quality analysis, watercourses present a set of interactions of biodiversities and human (anthropogenic) activities, which are variable in time and space. If changes occur in one part of the watercourse, after a certain period of time, it is either distributed throughout the water body or transferred to the other place. Monitoring of water quality in watercourse presents a problem. Status of watercourses, that is the water quality, currently is determined by methodology of conventional sampling followed by measurement of values of appropriate parameters.

Regardless the fact that our country falls into areas with relatively developed aquatic network, it is not certain that, if this trend of pollution continues, the water itself shall become deficient resource.

For the time being, the current system for measuring the water quality, index of water quality and its variations applied in our country is SWQI (SERBIAN WATER QUALITY INDEX) developed by the Serbian Environmental Protection Agency. The idea of setting or defining the such index is to use one number to clearly indicate the quality of aquatic body that would be understandable and would point out the potential existing problems to wider community. Selection of parameters used for determination the water quality index most closely reflects the water quality, whereby each of those parameters has different weigh in the analysis. System itself indicates the existence of certain "partiality" of the water quality index, which does not necessarily mean that the index is not good, but still indicates a lack of explicitness of the index itself [4].

Another problem is the lack of representative sampling methodology. Sampling presents a crucial part of each measurement methodology. If one looks at development of measurement techniques, measurement methodology, data processing as well as modeling, all these areas have experienced the significant improvements in methodology, quality and so on, except in the way of sampling the entity for analysis.

Problem of the water quality analysis in watercourses is enlarged by the fact that a sample is valid only for the location and time of sampling, therefore the time period between sampling and analysis of sample is very important.

METHODOLOGY (ACQUISITION AND DATA PROCESSING, MODELING)

For the purpose of analysis and possible upgrading the integral monitoring of watercourses quality, the analysis of existing data for the river Ibar and five sampling stations during the period 2007-2012 were realized. Also, an appropriate calculated SWQI was conducted. The paper presents the analysis of data for the river Ibar and five sampling stations for the period 2007-2012 on the basis of calculated values of SWQI. The aim of this research is to estimate a possibility for upgrading the integral monitoring of the river Ibar water quality for the time period from 2007 to 2012 on the basis of data analysis.

The results are based on the obtained measurements of the RHMS of Serbia and Serbian Environmental Protection Agency. The mean annual values of the parameters used for calculation of SWQI during the period from 2007 to 2012, and the mean annual values of SWQI for the same period are presented in Table 1 [5].

Table 1 *SWQI of the river Ibar water quality for the period 2007-2012.*

Parameters	2007	2008	2009	2010	2011	2012
Temperature (^oC)	12.78	12.47	11.00	11.31	11.46	11.79
pH	8.43	8.42	8.36	8.24	8.47	8.48
Conductivity (µS/cm)	416.20	448.62	428.73	433.33	447.08	432.50
Oxygen saturation (%)	99.14	93.49	94.22	99.63	95.5	95.43
BOD-5 (mg/l)	3.03	2.76	2.30	2.37	2.12	2.02
Suspended matter (mg/l)	21.05	25.78	24.24	21.45	26.95	27.41
Total N (mg/l)	1.73	2.10	1.42	0.93	1.21	0.86
Orthophosphate (mg/l)	0.11	0.14	0.11	0.10	0.11	0.09
Ammonium (mg/l)	0.02	0.01	0.03	0.25	0.14	0.24
Coliform bacteria (u 100 ml)	13483.33	15274.33	15150.00	14703.33	7714.60	174.65
SWQI	**78**	**77**	**81**	**78**	**81**	**82**

RESULTS AND DISCUSSION

Term „correlation" originates from the Latin word "correlatio" mutual relationship. Term "correlation analysis" implies the measurement of the levels of stochastic interdependences, that is, measurement the degree of congruence of variances of the observed quantities in relative terms.

Coefficients of **linear correlation** or correlation index for nonlinear regression models are used for measurement the degree of correlations (dependences) between two variables. There are close relations between regression and correlation analysis. In practice, we are most often affected with occurrences that mutually influence, and therefore the study of existence of interrelations is of great importance. Study can be performed on the basis of basic set or on the basis of samples regarding basic set, and all this carries a certain risk of error that can be controlled. Functional relation between occurrences can be deterministic (strictly determined-mathematical) or stochastic. Stochastic dependence between variables is expressed in many cases as the mean relation and has higher or lower variation of individual cases regarding the functional relation. Stochastic dependence is expressed conditionally by mathematical functions best approximated by the given empirical data with a certain selection error. The aim of regression analysis is to determine a functional analysis between the observed concepts, and correlation analysis to indicate the existence of relations between the analyzed entities.

Correlation analysis of parameters dependence and SWQI for the same time period is given in Figure 2 and Table 2 [6,7].

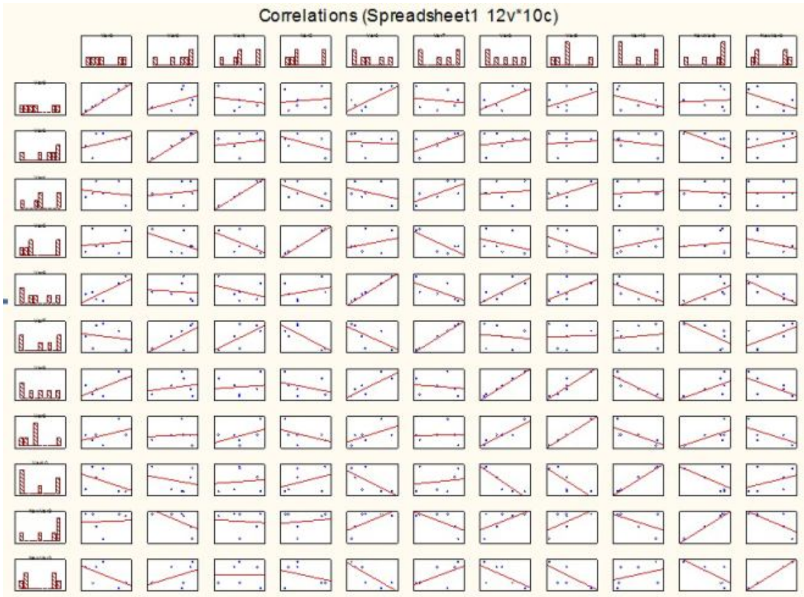

Figure 2 *Graphical representation of correlation matrix*

Table 2.*Correlation analysis of SWQI and parameters for calculation*

	T (°C)	**pH**	**Cond. (μS/cm)**	**Oxygen saturat. (%)**	**BOD$_5$ (mg/l)**	**Suspen. solids (mg/l)**	**Total N (mg/l)**	**Orto P (mg/l)**	**NH$_3$ (mg/l)**	**Coli-form bacteria**	**SWQI**
T (°C)	1.00	0.42	-0.18	0.14	0.78	-0.18	0.65	0.43	-0.44	0.07	-0.58
pH	0.42	1.00	0.16	-0.48	-0.09	0.68	0.20	0.08	-0.23	-0.63	0.42
Cond. (μS/cm)	-0.18	0.16	1.00	-0.59	-0.37	0.67	0.10	0.47	0.10	-0.09	-0.01
Oxygen saturat. (%)	0.14	-0.48	-0.59	1.00	0.29	-0.79	-0.33	-0.47	0.37	0.14	-0.33
BOD-5 (mg/l)	0.78	-0.09	-0.37	0.29	1.00	-0.64	0.79	0.58	-0.68	0.65	-0.82
Suspen. solids (mg/l)	-0.18	0.68	0.67	-0.79	-0.64	1.00	-0.13	0.05	0.15	-0.66	0.60
Total N (mg/l)	0.65	0.20	0.10	-0.33	0.79	-0.13	1.00	0.91	-0.91	0.60	-0.63
Orto P (mg/l)	0.43	0.08	0.47	-0.47	0.58	0.05	0.91	1.00	-0.75	0.61	-0.63
NH$_3$ (mg/l)	-0.44	-0.23	0.10	0.37	-0.68	0.15	-0.91	-0.75	1.00	-0.59	0.37
Coliform bacteria	0.07	-0.63	-0.09	0.14	0.65	-0.66	0.60	0.61	-0.59	1.00	-0.73
SWQI	-0.58	0.42	-0.01	-0.33	-0.82	0.60	-0.63	-0.63	0.37	-0.73	1.00

The results obtained by correlation analysis and presented in Table 2 show that there is no correlation between the measured parameters and calculated SWQI value. The only significant correlation exists between the parameter BOD-5 and SWQI. The analysis itself is interesting because SWQI is calculated on the basis of these parameters and between the measured parameters and SWQI should be linear dependence.

This means that between the measuring points in time there are uncontrolled changes caused by different influences or what is more likely by different pollutants placed along the river Ibar watercourse between the measuring stations. Although SWQI is calculated from the above parameters, correlation only exists between BOD-5 and SWQI, even though the index is calculated from all of the foregoing. This can be explained by the fact that each parameter is calculated with certain weight that disturbs correlation. The existence of correlation itself between BOD-5 and SWQI suggests that quick estimation of SWQI index can be performed based on monitoring the changes of BOD-5 values, as shown in Figure 3.

At this point, we would not enter into debate on value of weighted factors that are entered for each parameter for calculation of SWQI, as well as defining their values. Since the basis of this paper is the idea for improving the monitoring of integral quality of watercourses, that is, the river Ibar, BOD-5 parameter shall be analyzed as a possible indicator of SWQI index. For this analysis the normalized mean annual values of BOD-5 and SWQI were used for the period from 2007 to 2012, as shown in Figure 3 [7].

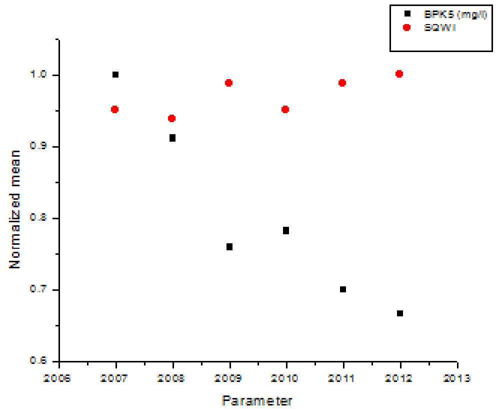

Figure 3 *Normalized mean annual values of BOD-5 and SWQI along the river Ibar*

As shown in Figure 3, the value change of SWQI follows the value change of BOD-5. This fact can be used to define the model for monitoring the pollution of aquatic body. Biological oxygen demand is quantity of oxygen necessary for biological decomposition of contaminated substances. From the aspect of self-purification of watercourses, the aeration and reaeration are the key processes. Organic pollution of aquatic environment activates a range of biological activities (bacteria, algae and fungi) that lead to conversion of organic matter to the final inorganic products. Reaeration and BOD-5 as two basic reactions during the process of self-purification of aquatic environment present the basis for determination the spatial and time distribution of dissolved oxygen, that is, oxygen balance. The result of these two processes presents the real content of dissolved oxygen along the whole watercourse. If calculation, methodology or model SWQI are analyzed, it cannot be clearly defined how the reaeration of aquatic environment is quantified. Therefore, it is necessary to define the potential pollutants (mainly organic matter) in the investigated water ourse. If we look at the distribution of measuring stations on aquatic body, we can define the general and potential pollutants at locations between the measuring stations. This defines a "tree of pollutants" and locations of potential pollutions of aquatic body. The tree of pollutants is shown in Figure 4 [7]. It can be seen that between each measuring station there is a pollutant with higher or lower intensity.

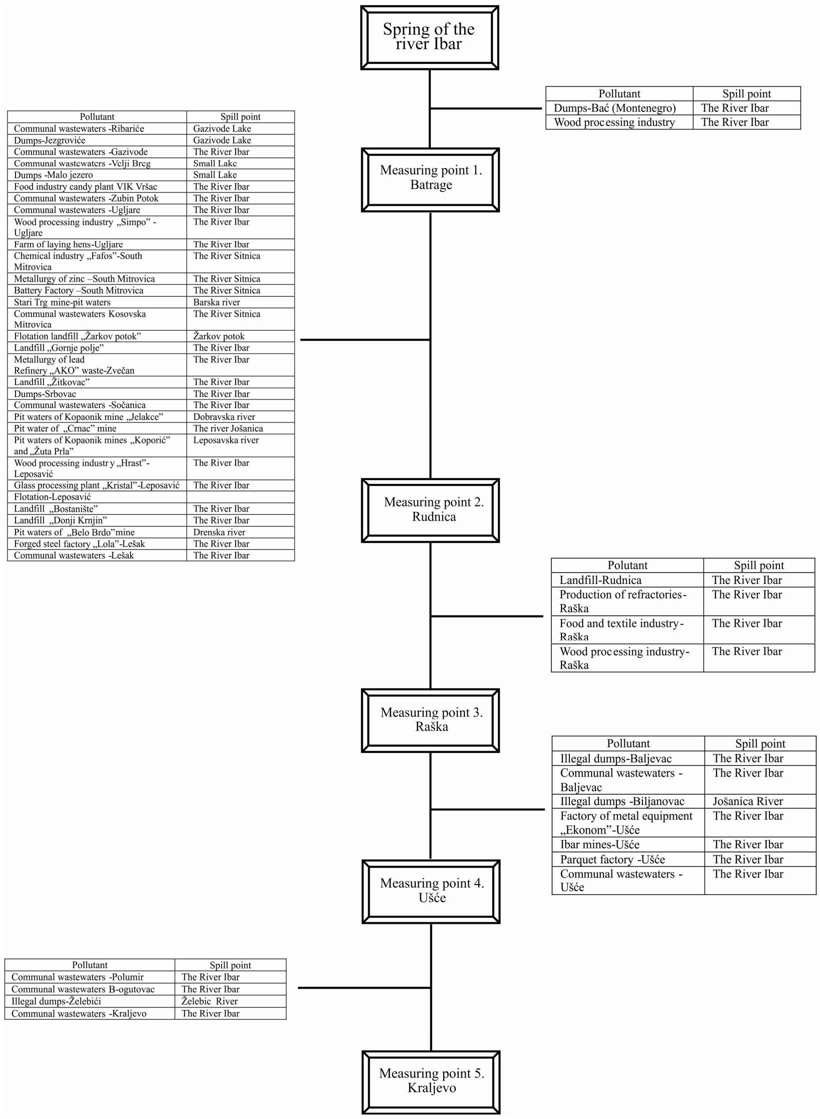

Figure 4 *Tree of pollutants [7]*

It is difficult to determine the level of pollution, because there are no accurate data on quantity of waste material. As it can be seen, there is a reasonable assumption that some of the parameters and their variations will vary during the time and that thereby it will not significantly affect the value of SWQI. One of the representative water quality parameters is biological oxygen demand (BOD-5). The degree of water pollution by organic compounds is defined by the quantity of oxygen needed for oxidation the present biologically degradable elements of water performed by aerobic microorganisms. This quantity of oxygen is called biological oxygen demand (BOD). The needed quantity is proportional to the present quantity of organic matter. The temperature and time of degradation affect the value of BOD, that is, with an increase of temperature increases the speed and oxygen demand (biochemical oxidation). It can be considered that it takes 5 days for decomposition of major part (70-80%) of present organic matters in darkness at the constant water temperature of 20^0C, and therefore is called BOD. BOD is not a typical pollutant, but a measure of oxygen quantity needed for bacteria and other microorganisms involved in stabilization of decomposition the organic matter during a certain period of time. BOD is the measure of oxygen consumption, or potential oxygen consumption. Liquid waste with high BOD can be harmful to the river if consumption of oxygen is large enough to cause anaerobic conditions.

The analysis of BOD change during the time along the watercourse given through the mean annual values for the period 2007-2012 per measurement point with standard deviations is presented in Figure 5 [7]. An increase in BOD towards the mouth of the river Ibar into West Morava indicates that the quantity of organic pollutant increases.

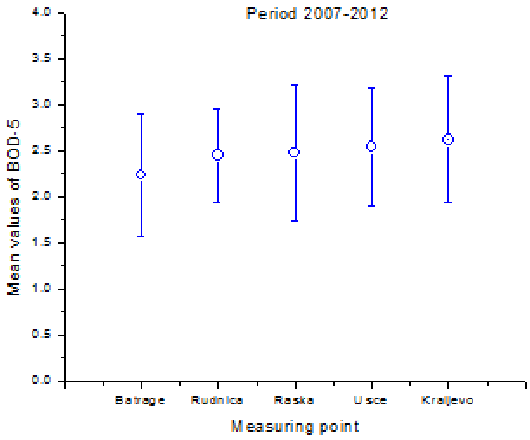

Figure 5 *Mean annual values of BOD-5 for the period 2007-2012.*

It is evident that there is an increasing trend of mean values per measuring stations toward mouth of the river Ibar into West Morava. Also, if measurement variation (standard deviation) is observed, it is possible to see that those deviations over the period of 6 years vary by measuring station or locations. Therefore, defining the tree of pollutants gains in importance because the time variations of measured parameters indicate the increased or reduced pollution (organic matters) at the measuring station and defined time period (2007-2012).

However, if the coefficient of variation is analyzed as well as the changes of BOD over time and at measuring points, it can be seen that such change is not linear, which means that includes a random un controlled pollution between the measuring stations.

Statistical analysis of BOD changes for the period 2007-2012 is presented in Table 3.

Table 3 *Statistical analysis of BOD-5 value for the period 2007-2012.*

Measuring point	Mean value.	STD	Stand. Error mean value	Variat.	Coeff. of variations	Mean value of absolu. deviation	Min.	Mean	Max.
Batrage	2.24	0.672	0.084	0.452	0.299	0.524	0.6	2.23	3.6
Rudnica	2.45	0.509	0.072	0.259	0.207	0.382	1.2	2.45	3.8
Raska	2.48	0.747	0.086	0.558	0.300	0.581	1	2.3	5.2
Usce	2.54	0.637	0.078	0.405	0.250	0.511	0.72	2.6	4
Kraljevo	2.62	0.686	0.070	0.471	0.261	0.508	0.6	2.5	4.5

Graph chart of minimum and maximum BOD value difference per measuring points is shown in Figure 6 [3]. It can be seen that maximum differences in the period from 2007 to 2012 were measured at the measuring station Raska.

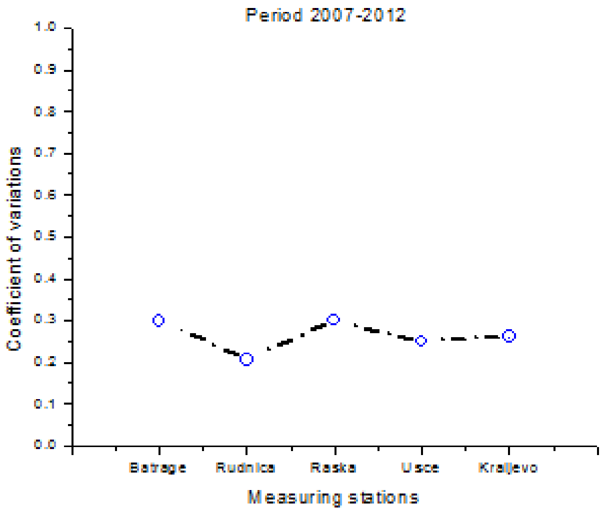

Figure 6 *Differences of minimum and maximum BOD-5 values per measuring stations*

Two assumptions can be set here. According to the assumed tree of pollutants (Figure 4), the greatest number of pollution sources is found between the measuring stations 1 Batrage and 2 Rudnica at distance of about 128 km. Since BOD difference is between minimum and maximum value, BOD consumption is smaller in Rudnica than in Batraga (Figure 7) and it can be assumed that the river Ibar in that course has capacity to overcome the possible entered organic matter in aquatic body. Between the measuring point 2 Rudnica and measuring point 3 Raska, the following pollutants, di rectly discharged into the river Ibar, were found:

- Landfill Rudnica;
- Production of refractory materials Raska;
- Communal waste water Rudnica;
- Communal waste water Raska;
- Food and textile industry Raska;
- Wood processing industry Raska.

Distance between the measuring stations 2 Rudnica and 3 Raska is shorter than distance of all measuring stations. If it is assumed that the level of organic pollutants input is similar along the whole investigated course of the river Ibar, and taking into consideration that the analysis presented in Figure 6 shows the greatest differences of minimum and maximum values of BOD consumption between these two stations, it can be concluded that the aquatic system itself is not able to react by self-purification at this distance.

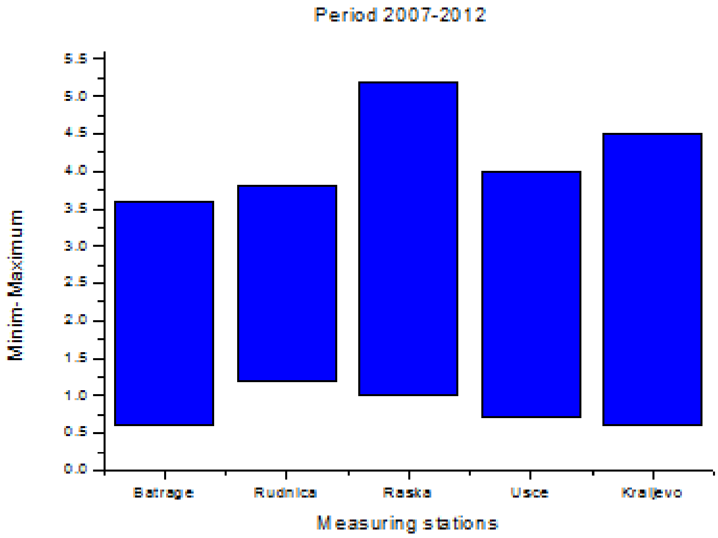

Figure 7 *Differences between minimum and maximum mean annual values of BOD -5 for the period from 2007 to 2012*

According to the given results it is evident that the studied ecosystem depends on the water quantity and time needed to move that quantity from one place to another or from different processes of self-purification, aeration, reaeration, sedimentation and others that cannot be quantified on the basis of the existing results. It would be interesting to ask whether the relation between cumulative SWQI at the measuring station and time distribution of oxygen consumption for the same measuring point can define an index of self-purification the aquatic environment or at least to define minimum required value of BOD that is necessary to maintain the water quality at the required level quantified by SWQI.

The river Ibar is not able to overcome the additional organic load, either by pollutant or some other, at short distance between the measuring stations Rudnica and Raska. It means that there is not enough potential for overcoming the additional organic load which occurs after Rudnica. Further variations, differences of minimum and maximum values, indicate that there are the new organic matter loads in the river Ibar and that the aquatic body itself by its potential and sufficient length has potential to mitigate the effect of organic load to a certain degree.

If we now go back to calculated quality indices of SWQI, presented in Table 1, we can see that they present more important annual fluctuations in values, it means, according to such calculated annual values, that the aquatic body had minimum variations of water quality along the whole length.

CONCLUSION

Based on the presented research, it can be concluded that SWQI is a clear indicator of water quality, but, like all integral parameters, does not indicate the processes along aquatic system or water basin. Analysis of the results showed that SWQI should be supplemented by index of self-purification or by index of pollution along the watercourse length that would originate from the tree of pollutants.

In the world as well as here, there are automatic measuring stations, but their maintenance is very expensive and requires trained and qualified technicians. Another problem is analysis of the measured data and in some way generalization the model of watercourses behavior. In recent decades, the situation with watercourses has become complicated, their use as landfills that are practically impossible to control as well as specification the pollutants that should be monitored. It is obvious that in this area, a part from great number of measurement data, work on the processing methodology, in order to improve the entire system of water resources management, that is, watercourses, should continue. Whether it is necessary to develop a system for early warning the existence of sudden uncontrolled pollution or developing models for water courses at appropriate locations is a matter of applied research and generally the way of viewing water as a resource and as a potential source of drinking water [8].

The solution in terms of methodology would be setting up 24 hourly measurement probes that would in real-time on a specific measuring station monitor the changes of parameters according to which SWQI is calculated. It is clear that such system would also define the system of early warning the existence of pollution the aquatic systems, which is in some way the "Holy Grail" of all participants in the management system of water resources and water basins [9].

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NOVI PRISTUP ANALIZI I MODELOVANJU KVALITETA VODE

Izvod

Vodotokovi predstavljaju poseban slučaj vodnih basena. Bez obzira na način njihovog ispitivanja još uvek se traži pogodan način obrade sakupljenih parametara kvaliteta vode. Pravac istraživanja je definisana okvirna EU direktiva za vodna tela. Uzimajući u vidu postojeće metode analize kvaliteta vode, u radu je prikazan predlog nove metode modelovanja ponašanja vodnog tela. Za osnovu su poslužila merenja na pet stanica na reci Ibar u vremenskom periodu od 2007 - 2012. godine. Osnova metode se bazira na multivarijabilnoj analizi nejednako vremenski raspoređenih mernih podataka. Osnova je bila korelaciona analiza koja je definisala zavisne parametre za određivanje SWQI indeksa. Analize su pokazale da se dobijeni rezultati mogu koristiti za uspostavljanje integralnog praćenja kvaliteta vode akvatičnog sistema Ibra. Takođe, ukazali su i na pravce unapređenja merenja i analize.

Ključne reči: *modelovanje, vodeni baseni, SWQI, merenja BPK-5*

UVOD

Ljudi su se razvili od psihološko relativno beznačajnih potrošača do domišljatih, intelektualnih bića i geohemijskih korisnika spoljnih izvora energije i materijala za građenje svoje civilizacije i povećanje dominacije. Ljudi troše 10 do 20 puta (na severnoj hemisferi 50 do 100 puta) više energije nego što je potrebno za njihov metabolizam. Poremećaj vodenog okruženja indirektno uzrokovano energetskom potrošnjom, može da nadmaši onu koja uzrokuje izbacivanje izlučevina (slika 1). Većina energije koju industrijsko društvo koristi kao svoju prednost (pravljenje toplote, upravljanje pejzažom, gradskom strukturom, poljoprivredom, šumarstvom, geološkim istraživanjima, građenjem brana) na kraju utiče i narušava ekosistem. Ljudi - kao kopnena bića - direktno utiču prvenstveno na kopnenu okolinu; ali, pošto su kopno i vodeni ekosistem povezani i zbog osetljivosti ovog drugog, naglašen uticaj civilizacije na ekologiju se prvo odražava na vodeni ekosistem. Mnoge posledice rasipanja energije su primetne i u atmosferi, koja se ponaša kao efikasana pokretna traka za mnoge zagađivače. Ljudska moć da remeti okolinu, teži da ide ispred tehnoloških mogućnosti za odgovor na uticaj na okolinu [1].

Ekosistem može da se definiše kao jedinica okoline u kojoj se, kao rezultat ulaza sunčeve energije, biološka zajednica (primarni proizvođači, potrošači i razlagači) održava; protok energije se koristi da se organizuje sistem i praćen je ciklusima vode, nutrienata i drugih elemenata i životnim

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ciklusom kroz različite korisnike hrane na različitim nivoima. Članovi ekosistema su povezani različitim povratnim spregama (homeostaza) i kao takvi prilagođeni koegzistenciji u svrhu zajedničkog napredovanja. Mreža kontrola i ravnoteža uključuje mnoštvo prenosa organskih i neorganskih supstanci - mrežu hrane, nutrienata, alelohemikalija - i stvara od ekosistema funkcionalnu jedinicu [2].

Drugi zakon termodinamike kaže da će svaki spontani proces biti praćen porastom entropije:

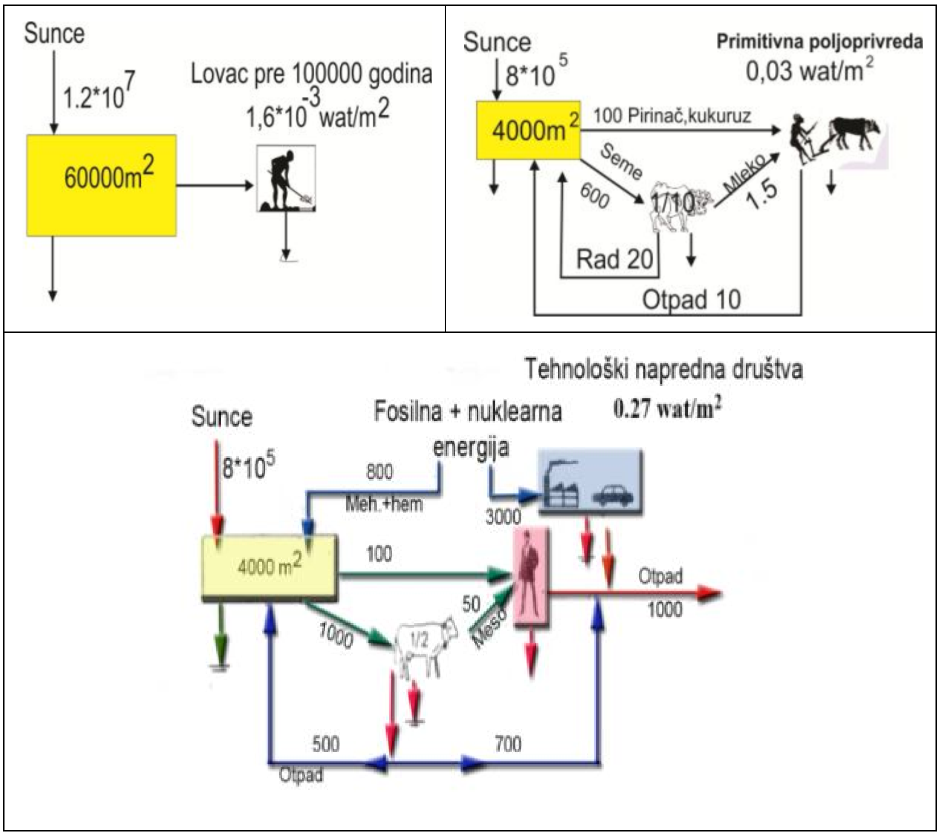
$$dS\ (\text{izvor, odvod}) + dS(\text{ekosistem}) \geq 0.$$

Zbog uslova d*S* (izvor, odvod) > 0, entropija ekosistema može da opada, tj. da bude:

$$-dS(\text{ekosistem}) \leq dS(\text{izvor, odvod}).$$

Opadanje se ogleda u sređivanju ekosistema i prisustvu neverovatno visokog sjedinjavanja energije kao živih bića. Njihova organizacija je uređena na račun povećanja entropije u okolini.

Do sada smo nastojali da različitim subjektima priđemo na kvantitativan i rigorozan način. U ovom poglavlju, naprotiv, često ćemo morati da se oslonimo na kvalitativne, a često i spekulativne argumente, jer je naše poimanje elastičnosti vodenog ekosistema ozbiljno ometeno nedostatkom teorijskih i dovoljnih empirijskih informacija o efektima fizičkih i hemijskih poremećaja vodenih ekosistema [3].



Sl. 1. *Potrebe za energijom i zemljom kod primitivnog i modernog čoveka*

Za održavanje naše kulture i civilizacije i poboljšanje kvaliteta života, a posebno za proizvodnju hrane za sve veću svetsku populaciju, potrebno je da nastavimo da zavisimo od upotrebe tehnologije i energije. Društveni kriterijumi i rastući pritisak za socijalnom jednakošću moraju uporedo utvrditi naučni i tehnološki razvoj, naučni i tehnološki razvoj.

Vodotokovi predstavljaju poseban slučaj vodnih basena, prvo sa aspekta analize vodotokova predstavljaju skup interakcija biodiverziteta i ljudskog delovanja koji je pokretan u prostoru. Znači, ukoliko dođe do neke promene na jednom delu vodotoka za određeno vreme usled mešanja ili distribuira u po celom vodnom telu ili se prenose na drugo mesto. Samim tim praćenje kvaliteta vode ili opšte rečeno dešavanja u odgovarajućem vodotoku predstavljaju problem. Vodotokovi i sam kvalitet vode trenutno se meri klasičnim uzorkovanjem i određivanjem vrednosti izabranog broja parametara.

Bez obzira što naša zemlja spada u oblasti sa relativno razvijenom vodnom mrežom nije sigurno da, ukoliko se nastavi ovakav trend zagađivanja, i sama voda za piće će postati nedostajajući resurs.

Za sada važeći sistem merenja kvaliteta vode, indeks kvaliteta vode i njegova varijacija primenjena u našoj zemlji je SWQI (SERBIAN WATER QUALITY INDEX) koja je razvila Agencija za zaštitu životne sredine. Ideja postavljanja ili definisanja ovakvog indeksa je da se jednim brojem jasno ukaže na kvalitet vodnog tela kako bi postao jasan i ukazivao na eventualno postojeće probleme široj zajednici. Izbor parametara koji se koriste za određivanje indeksa kvaliteta vode oslikava najbliže kvalitet vode, pri čemu svaki od tih parametara ima različitu težinu pri analizi. Sam taj sistem ukazuje na postojanje izvesne „pristrasnosti” indeksa kvaliteta vode, što ne mora da znači da sam indeks nije dobar, ali ukazuje na još uvek nedovoljnu eksplicitnost samog indeksa [4].

Drugi problem je nepostojanje metodologije reprezentativnog uzorkovanja. Uzorkovanje predstavlja ključni deo svake metodologije merenja. Ako se pogleda razvoj merne tehnike, merne metodologije, obrade rezultata kao i modelovanje, sve pomenute oblasti su doživele značajna unapređenja u samoj metodologiji, u kvalitetu itd., sem u načinu uzorkovanja samog entiteta za analizu.

Problem analize kvalieta vode kod vodotokova je uvećan činjenicom da uzorak važi samo za lokaciju i samo za vreme uzorkovanja (tačkasti), tako da je veoma značajan vremenski period između uzorkovanja i analize uzetog uzorka.

METODOLOGIJA (PRIKUPLJANJE I OBRADA PODATAKA, MODELOVANJE)

U cilju analize i mogućih unapređenja integralnog praćenja kvaliteta vodotokova urađena je analiza postojećih podataka za reku Ibar i pet mernih stanica za period 2007 - 2012. godine i odgovarajućih izračunatih SWQI. U radu je izvršena analiza podataka za reku reku Ibar i pet mernih stanica za period 2007 - 2012. godina na osnovu izračunatih vrednosti SWQI. Cilj rada je bio da se na bazi analza podataka u vremenskom period od 2007 - 2012. godine oceni mogućnost unapređenja integralnog praćenja kvaliteta toka reke Ibar.

Rezultati su bazirani na merenjima, RHMZ Srbije, odnosno Agencije za zaštitu životne sredine. U tabeli 1 prikazane su srednje godišnje vrednosti parametara koje se koriste za izračunavanje SWQI u periodu 2007 - 2012. godine, kao i srednje godišnje vrednosti SWQI za isti period [5].

Tabela 1. *SQWI kvalitet vode reke Ibar za period 2007 - 2012. godine*

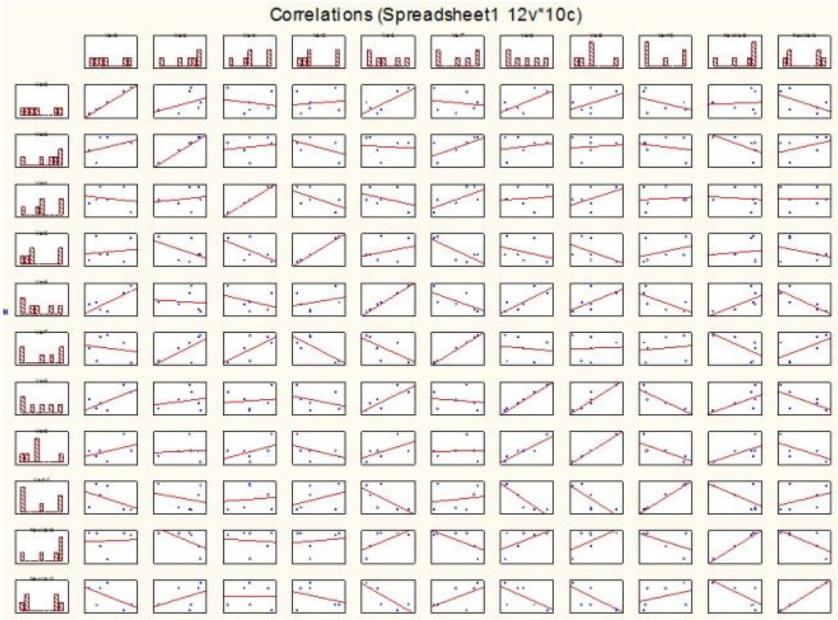
Parametri	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Temperatura (^oC)	12,78	12.47	11.00	11.31	11.46	11.79
pH vrednost	8,43	8.42	8.36	8.24	8.47	8.48
Elektroprovodljivost (µS/cm)	416,20	448.62	428.73	433.33	447.08	432.50
Zasićenost kiseonikom (%)	99,14	93.49	94.22	99.63	95.5	95.43
BPK_5 (mg/l)	3,03	2.76	2.30	2.37	2.12	2.02
Suspendovane materije (mg/l)	21,05	25.78	24.24	21.45	26.95	27.41
Ukupni oksidi azota (mg/l)	1,73	2.10	1.42	0.93	1.21	0.86
Ortofosfati (mg/l)	0,11	0.14	0.11	0.10	0.11	0.09
Amonijum (mg/l)	0,02	0.01	0.03	0.25	0.14	0.24
Koliformne bakterije (u 100ml)	13483,33	15274.33	15150.00	14703.33	7714.60	174.65
SQWI	**78**	**77**	**81**	**78**	**81**	**82**

REZULTATI I DISKUSIJA

Termin „korelacija" potiče od latinske riječi „correlatio" - međuodnos. Pod pojmom korelacione analiza podrazumeva se merenje nivoa stohastičkih međuzavisnosti tj. merenje stepena slaganja varijacija posmatranih veličina u relativnom smislu.

Za merenje stepena korelacije (zavisnosti) između dve promenljive koristi se koeficijent **linearne korelacije** ili indeks korelacija za nelinearne regresione modele. Između regresione i korelacione analize postoje uske veze. U praksi se najčešće srećemo sa pojavama koje, utiču jedna na drugu, i prema tome značajno je ispitivanje postojanja međusobnih veza. Ispitivanje može da se vrši na bazi osnovnog skupa ili na bazi uzoraka o osnovnom skupu a sve to nosi određen rizik greške koji se može kontrolisati. Funkcionalna veza između pojava može da bude deterministička (strogo određena - matematička) ili stohastička. Stohastička zavisnost između promjenjivih se ispoljava u masi slučajeva, kao srednji odnos i ima veću ili manju varijaciju individualnih slučajeva u odnosu u funkcionalnu vezu. Stohastička zavisnost izražava se uslovno matematičkim funkcijama koje najbolje aproksimiraju dati emparijski podaci uz određenu grešku izbora. Cilj regresione analize je da se odredi funkcionalna veza između posmatranih pojmova, a korelacione da ukase na postojanje veza izmedju analiziranih entiteta.

Korelaciona analiza zavisnosti parametara i SWQI za isti period prikazana je na slici 2 i u tabeli 2 [6,7].



Sl. 2. *Grafički prikaz korelacione matrice*

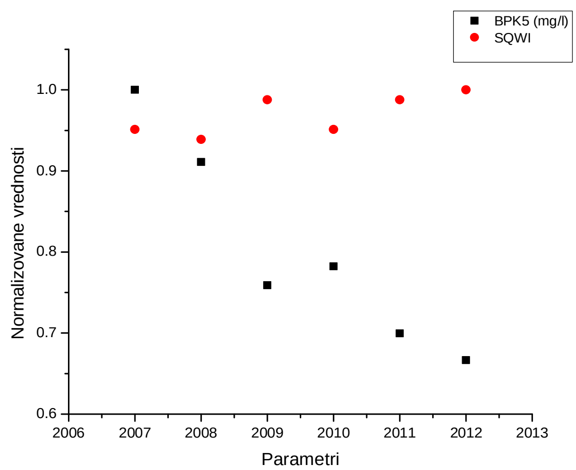
Tabela 2. *Korelaciona analiza SWQI i parametara za izračunavanje*

	T (°C)	**pH**	**Elektp. (μS/cm)**	**Zas. kise. (%)**	**BPK_5 (mg/l)**	**Susp. m. (mg/l)**	**Ukupni N (mg/l)**	**Orto P (mg/l)**	**NH_3 (mg/l)**	**Kolifor. bakter.**	**SWQI**
T (°C)	1,00	0,42	-0,18	0,14	0,78	-0,18	0,65	0,43	-0,44	0,07	-0,58
pH	0,42	1,00	0,16	-0,48	-0,09	0,68	0,20	0,08	-0,23	-0,63	0,42
Elektp. (μS/cm)	-0,18	0,16	1,00	-0,59	-0,37	0,67	0,10	0.47	0,10	-0,09	-0,01
Zas. kis. (%)	0,14	-0,48	-0,59	1,00	0,29	-0,79	-0,33	-0,47	0,37	0,14	-0,33
BPK_5 (mg/l)	0,78	-0,09	-0,37	0,29	1,00	-0,64	0,79	0,58	-0,68	0,65	-0,82
Suspm. m (mg/l)	-0,18	0,68	0,67	-0,79	-0,64	1,00	-0,13	0,05	0,15	-0,66	0,60
Ukupni N (mg/l)	0,65	0,20	0,10	-0,33	0,79	-0,13	1,00	0,91	-0,91	0,60	-0,63
Orto P (mg/l)	0,43	0,08	0,47	-0,47	0.58	0,05	0,91	1,00	-0,75	0,61	-0,63
NH_3 (mg/l)	-0,44	-0,23	0,10	0,37	-0,68	0,15	-0,91	-0,75	1,00	-0,59	0,37
Kolifor. bakterije	0,07	-0,63	-0,09	0,14	0,65	-0,66	0,60	0,61	-0,59	1,00	-0,73
SQWI	-0,58	0,42	-0,01	-0,33	-0,82	0,60	-0,63	-0,63	0,37	-0,73	1,00

Rezultati dobijeni korelacionom analizom i prikazanim u tabeli 2 pokazuju da ne postoji korelacija između merenih parametara i izračunate vrednosti SWQI. Jedina značajna korelacija postoji između BPK-5 parametra i SWQI. Sama ta analiza je interesantna, jer na osnovu tih parametara se računa SWQI i trebalo bi da postoji linearna analiza između merenih parametara i SWQI.

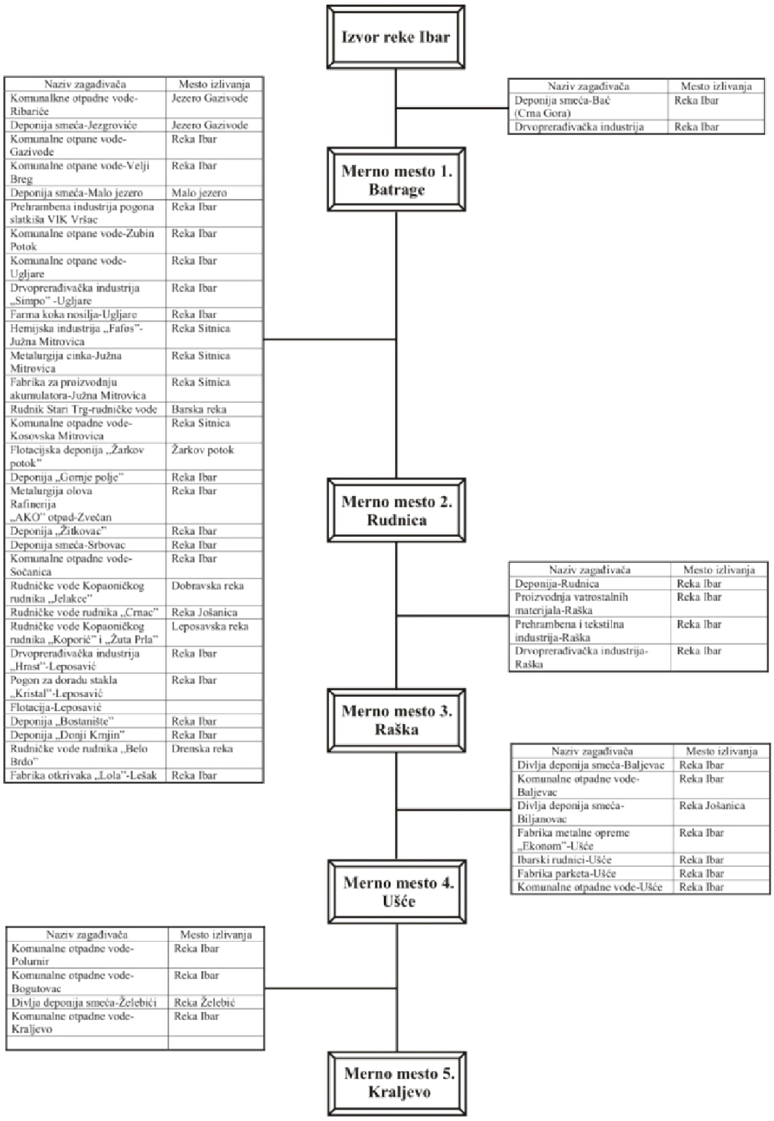
To znači da između mernih mesta u vremenu postoje promene koje su nekontrolisane odnosno izazvane rezličitim uticajima ili što je veća verovatnoća različitim zagađivačima koji se nalaze duž vodotoka Ibra između mernih stanica. Iako se SWQI izračunava iz navedenih parametara korelacija postoji samo između BPK-5 i SWQI iako se indeks izračunava iz svih pomenutih. To je objašnjivo činjenicom da se svaki od parametara računa sa odgovarajućom težinom koja remeti korelaciju. Samo postojanje korelacije između BPK-5 i SWQI ukazuje na činjenicu da brza procena SWQI indeksa može uraditi na osnovu praćenja promene vrednosti BPK-5, kao što je to prikazano na slici 3.

Na ovom mestu ne bi smo ulazili u diskusiju vrednosti težinskih faktora koji se unose za svaki parametar pri izračunavanju SWQI, kao i definisanju njihove vrednosti. S obzirom da je u osnovi ovog rada ideja o poboljšanju praćenja integralnog kvaliteta vodotokova odnosno reke Ibar. Analiziraćemo parametar BPK-5 kao mogući brzi pokazatelj SWQI indeksa. Za tu analizu koristili smo normalizovane srednje godišnje vrednosti BPK-5 i SWQI za period od 2007 - 2012. godine, prikazane na slici 3 [7].



Sl. 3. *Normalizovane srednje godišnje vrednosti BPK-5 i SWQI po celoj dužini Ibra*

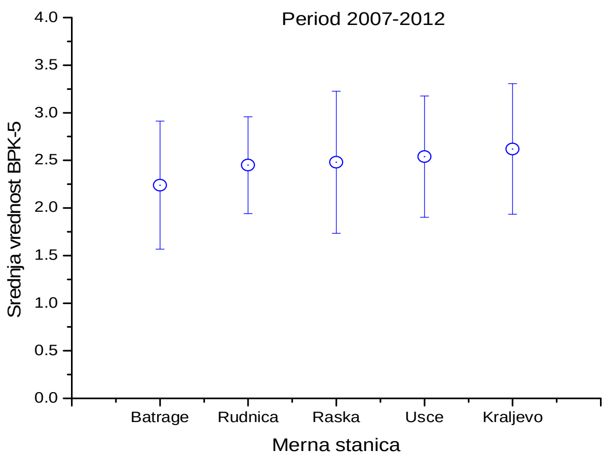
Kao što se sa slike vidi, promena vrednosti SWQI prati promenu vrednosti BPK-5. Ta činjenica se može iskoristiti za define-sanje modela praćenja zagađivanja vodnog tela. Biološka potrošnja kiseonika pred-stavlja količinu kiseonika neophodnu za biološko razlaganje kontaminirane materije. Sa aspekta samoprečišćavanja vodotokova aeracija reaeracija su ključni procesi. Organskim zagađenjem akvatične sredine aktivira se niz bioloških aktivnosti (bakterije, alge i gljivice) koje dovode do pretvaranja organske materije u konačne neorganske proizvode. Reaeracija i BPK-5 kao dve osnovne reakcije u toku procesa samoprečišćavanja akvatične sredine predstavljaju osnov za određivanje prostorne i vremenske raspodele rastvorenog kiseonika odnosno bilansa kiseonika. Rezultanta ova dva procesa predstavlja realni sadržaj rastvorenog kiseonika duž celog vodotoka. Ako se analizira izračunavanje, metodologija ili model SWQI, ne može da se jasno definiše kako se kvantifikuje reaeracija akvatične sredine. Zbog toga je neophodno definisati i potencijalne zagađivače (pre svega organskim materijama) na ispitivanom vodotoku. Ako posmatramo raspodelu mernih stanica na vodnom telu možemo definisati okvirno i potencijalne zagađivače na lokacijama između mernih stanica. Time se definiše „Stablo zagađivača” i lokacije potencijalnih mesta zagađivanja vodnog tela. Prikazano je stablo zagađivača na slici 4 [7], gde se vidi da između svake merne stanice postoji zagađivač većeg ili manjeg intenziteta.



Sl. 4. *Stablo zagađivača [7]*

Teško je odrediti nivo zagađenja jer ne postoje tačni podaci o količinama otpadnih materija koje dolaze. Kao što se može videti postoji opravdana pretpostavka da će se neki od parametara menjati kao i njihove varijacije tokom vremena a da pri tome to neće znatno uticati na vrednost SWQI. Jedan od reprezentativnih parametara za kvalitet vode je biološka potrošnja kiseonika (BPK-5). Stepen zagađenosti vode organskim jedinjenjima definisan je količinom kiseonika potrebnog za oksidaciju prisutnih biloški razgradivih sastojaka vode koju vrše aerobni mikroorganizmi. Ta količina kiseonika naziva se biohemijska potrošnja kiseonika (BPK). Potrebna količina proporcionalna je prisutnoj količini organskih materije. Temperatura i vreme razgradnje utiču na veličinu BPK, tj. sa povećanjem temperatura raste i brzina i potrošnje kiseonika (biohemijska oksidacija). Smatra se da je potrebno 5 dana kako bi se razgradio veći deo (70-80%) prisutnih organskih materija, i to u tami, na stalnoj temperaturi vode od 20^0C, zbog čega se i naziva BPK. BPK nije specifični zagađivač, već mera količine kiseonika neophodne za bakterije i ostale mikroorganizme uključene u stabilizaciji raspadanja organske materije tokom određenog vremenskog perioda. BPK je mera upotrebe kiseonika, ili potencijalne upotrebe kiseonika. Tekući otpad sa velikim BPK-om može biti štetan po reku ako je upotreba kiseonika dovoljno velika da uzrokuje anaerobična stanja.

Analiza promene tokom vremena po dužini vodotoka prikazana je na slici 5 [7], pokazuje povećanje BPK kako se ide prema ušću Ibra u Zapadnu Moravu tako da slobodno možemo reći da se količina organskog zagađenja povećava.



Sl. 5. *Srednje godišnje vrednosti BPK-5 za period 2007-2012. godinu*

Slika 5 pokazuje srednje godišnje vrednosti BPK za period 2007 - 2012. godine po mernom mestu sa standardnim odstupanjima tokom godine.

Ono što je vidljivo sa grafika je da postoji trend porasta srednje vrednosti po mernim stanicama prema ušću Ibra u Zapadnu Moravu. Takođe, ako se posmatra varijacija merenja (standardna devijacija) moguće je videti da i ta odstupanja tokom perioda od 6 godina variraju po mernim stanicama ili lokacijama čime definisanjem stable zagađivača dobija na svom značaju, jer vremenske varijacije izmerenih parametara ukazuju na povećano ili smanjeno zagađenje (organskih materija) na tom mernom mestu i definisanom vremenskom periodu (2007 - 2012. godine.).

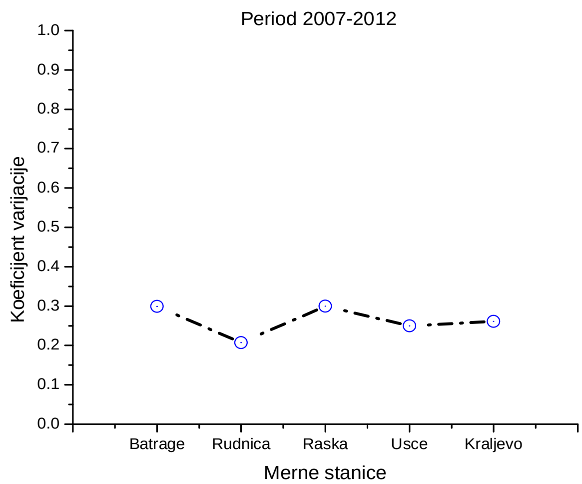
Međutim, ako analiziramo koeficijent varijacije, promene BPK tokom vremena i na mernim mestima vidimo da ta promena nije linearna, što znači da uključuje i slučajnog nekontrolisanog zagađenja između mernih stanica.

Statistička analiza promene BPK za period 2007-2012. prikazana je u tabeli 3.

Tabela 3. *Statističaka analiza vrednosti BPK5 za period 2007-2012. g.*

Merno mesto	Srednja vredn.	STD	Stand. greška srednja vredn.	Varijac.	Koef. varijac.	Sred. vredn. absol. odst.	Min.	Medij.	Max.
Batrage	2,24	0,672	0,084	0,452	0,299	0,524	0,6	2,23	3,6
Rudnica	2,45	0,509	0,072	0,259	0,207	0,382	1,2	2,45	3,8
Raska	2,48	0,747	0,086	0,558	0,300	0,581	1	2,3	5,2
Usce	2,54	0,637	0,078	0,405	0,250	0,511	0,72	2,6	4
Kraljevo	2,62	0,686	0,070	0,471	0,261	0,508	0,6	2,5	4,5

Grafički prikaz razlike minimalne i maksimalne vrednosti BPK po mernim mestima prikazana je na slici 6 [3]. Tu se vidi da su najviše razlike u periodu 2007 - 2012. godine izmerene na mernoj stanici Raška.

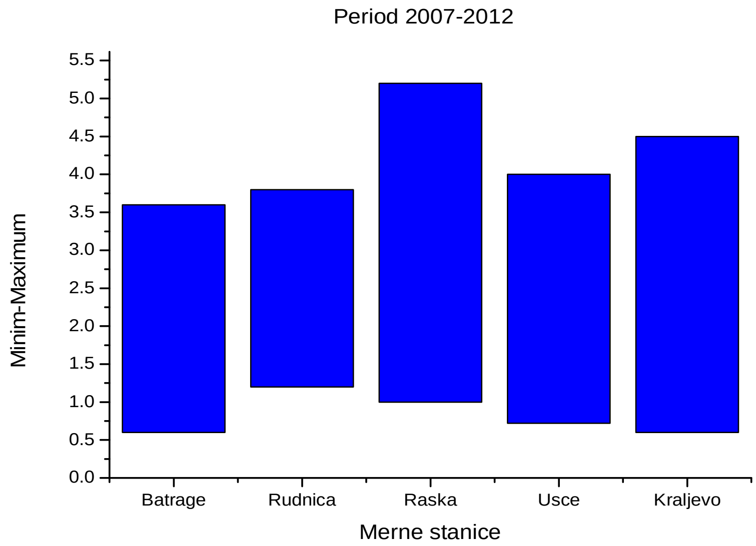


Sl. 6. *Razlika minimalne maksimalne vrednosti BPK-5 po mernim mestima*

Ovde možemo postaviti dve pretpostavke. Prema pretpostavljenom stablu zagađivača (slika 4) najveći broj izvora zagađenja se nalazi između mernih stanica 1 Batrage i 2 Rudnica čije je rastojanje oko 128 km. Pošto je BPK razlika između minimalne i maksimalne, potrošnja BPK manja u Rudnici nego u Batragama (slika 7) možemo pretpostaviti da Ibar u tom toku ima kapacitet da savlada eventualno unetu organsku materiju u vodnom telu. Između mernog mesta 2 Rudnice i mernog mesta 3 Raška nalaze se sledeći zagađivači koji se direktno izlivaju u Ibar:

- Deponija Rudnica
- Proizvodnja vatrostalnih materijala Raška
- Komunalne otpadne vode Rudnica
- Komunalne otpadne vode Raška
- Prehambena i tekstilna industrija Raška
- Drvoprerađivačka industrija Raška

Rastojanje između mernih stanica 2 Rudnica i 3 Raška je najkraće od rastojanja svih mernih stanica. Ako pretpostavimo da je nivo unosa organskog zagađivača sličan na celom ispitivanom toku reke Ibar, i imajući u vidu da analiza prikazana na slici 6 pokazuje da se najveće razlike minimalne i maksimalne vrednosti potrošnje BPK između ove dve stanice, možemo zaključiti da sam akvatični sistem nije u stanju da reaguje samoprečišćavanjem na ovom rastojanju.



Sl. 7. *Razlika između minimalne i maksimalne vrednosti srednjih godišnjih vrednosti BPK-5 za period 2007 - 2012. godine*

Iz prikazanih rezultata sasvim je jasno da ispitivani ekosistem zavisi od količine vode i vremena potrebnog da se ta količina premesti sa jednog mesta na drugo, odnosno i od različitih procesa samoprečišćavanja, aeracije, reaeracije, sedimentacije i ostalih koje je nemoguće kvantifikovati na osnovu postojećih rezultata. Ovde bi bilo interesantno postaviti pitanje da li je odnos između zbirnog SWQI na mernoj stanici i vremenske raspodele potrošnje kiseonika za isto merno mesto, mogu da definišu neku vrstu indeksa samoprečišćavanja akvatične sredine ili bar da je definišu minimalnu potrebnu vrednost BPK koja je neophodna da se održi kvalitet vode na zahtevanom nivou koji je kvantifikovan SWQI.

Dodatno opterećenje organsko, bilo zagađivača ili nekog drugog, na kratkom rastojanju između mernih stanica Rudnica i Raška, Ibar ne može da savlada, što će reći, nema dovoljno potencijala da sam savlada dodatno organsko opterećenje koje se očigledno javlja posle Rudnice. Dalje varijacije, razlike minimalnih i maksimalnih vrednosti, ukazuju da dolazi do novih opterećenja organskom materijom u Ibru, a da samo vodno telo svojim potencijalom i dovoljnom dužinom ima potencijal da donekle ublaži efekat organskog opterećenja.

Ako se sada vratimo na izračunate indekse kvaliteta SWQI, prikazanog u tabeli 1, vidimo da oni ne pokazuju značajnije fluktuacije godišnje u samim vrednostima, odnosno da po tako izračunatim godišnjim vrednostima, vodno telo praktično je imalo minimalne varijacije kvaliteta vode po celoj dužini.

ZAKLJUČAK

Iz prikazanog teksta pokazano je da je SWQI jasan pokazatelj kvaliteta vode ali da, kao i svi integralni parametri, ne ukazuje na procese duž akvatičnog sistema ili vodenog basena. Analiza rezultata je pokazala da je SWQI neophodno dopunuti ili sa indeksom „samoprečišćavanje" ili indeksom zagađenja po dužini vodotoka koji bi proizašao iz stabla zagađivača.

U svetu, kao i kod nas, postoje automatski merne stanice, ali njihovo održavanje je izuzetno skupo i zahteva obučene i kvalifikovane tehničare. Drugi problem je sama analiza izmerenih podataka i na neki način generalizovanje modela ponašanje vodotokova. U poslednjih nekoliko decenija situacija u vodotokovima se komplikuje, njihovim korišćenjem kao deponije koje praktično nemoguće je kontrolisati kao i specificirati zagađivače koje treba pratiti. Očigledno je da ovoj oblasti, pored veklikog broja mernih podataka, treba još uvek raditi i na samoj metodologiji obrade, kako bi se unapredio čitav sistem upravljanja vodnim resursima odnosno vodotokovima. Da li treba razvijati sistem za rano upozorenje postojanja iznenadnog nekontrolisanog zagađivanja ili razvijati modele za vodotokove na odgovarajućim lokacijama je pitanje primenjenih istraživanja i uopšte načina posmatranja vode kao resursa i kao potencijalnog izvora vode za piće [8].

Rešenje u metodološkom smislu bi bilo postavljanje 24 časovnih mernih sondi koje bi u realnom vremenu na određenoj mernoj stanici pratile promene parametara na osnovu koje se računa SWQI. Jasno je da bi takvim sistemom bio i definisan sistem ranog upozorenja na postojanje zagađenja akvatičnog sistema, što je na neki način i „SVETI GRAL" svih učesnika u sistemu upravljanja vodnim resursima i vodenim basenima [9].

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THE EFFECT OF IMPURITIES ON HIGH-TEMPERATURE RESISTANCE OF PLATINUM AND ITS ALLOYS**

Abstract

This paper presents the testing results of impact both the individual and total content of impurities in platinum and its alloys of different purity. Relative probability is presented of distribution of Al, Si, Fe, Mg, Ni, Pb, Cu, Ag, as well as their maximum content in the alloys of PtRh7, PtRh10, PtRh5Pd15 and PtRh5Pd15Ru1.5 composition. Also, the results of impact the purity degree of platinum to its high temperature resistance are given after applied thermo-mechanical processing regime. The conclusion is that, if content of impurities is higher in platinum metals and alloys, greater is the probability of their negative impact on technological and exploitation properties.

Keywords: *impurities, platinum, platinum alloys, high temperature resistance*

INTRODUCTION

The presence of chemical elements - impurities in platinum metals and alloys is related to the composition of starting mineral raw materials as well as the technological processes for their obtaining, processing and exploitation in the industrial conditions [1-3].

The presence of impurities in platinum metals and alloys has a major impact on their physical and mechanical properties. Due to this reason, the purity of platinum metals and alloys is one of their key characteristics [4-6]. The conditional definition of platinum metals of technical (99.50% wt.), chemical (99.90% wt.), physical (99.99% wt.) and spectral (99.999% wt.) purity is often used to evaluate the cumulative content of impurities. In accordance with the present standard, platinum metals are divided into three groups: type A-0, A-1 and A-2 with the corresponding following purities: 99.98, 99.95 and 99.90% [7-11].

Purity of platinum is determined by calculation from the difference 100% of metal mass and the sum of percent of 10-15 control impurities. In addition, the total number of control impurities, as a rule, also includes the platinum group of metals and gold. Impurities such as Rh, Ru Pd, Ir and Au lead to an improvement of mechanical characteristics of platinum, or to increase of its high temperature resistance [13].

For example, contaminated platinum with content of 0.055% of other platinum metals and gold, can be considerably better batch material in comparison to pure platinum type A-0 with 0.01% impurities such as Si, Al, Pb, and others, but at the same time represent a very unfavorable batch material for making the high-temperature alloys.

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However, an important classification of platinum metals do not take into account the possible existence of 50-70 usually not control impurities, whose cumulative content may amount to $10^{-2} – 10^{-3}$ % wt [14].

EXPERIMENTAL TECHNIQUE

Platinum, rhodium and palladium for making the alloys were obtained as a by-product within the production of electrolytic copper in RTB, Serbia. The required purity is achieved by the additional refining. Composition of analyzed alloys is listed in Table 1.

Table 1 *Content of alloying elements in the analyzed samples (mass %)*

Alloy	Rh (mass%)	Pd (mass%)	Ru (mass%)
PtRh7	7	-	-
PtRh10	10	-	-
PtRh5Pd15	5	15	-
PtRh5Pd15Ru1.5	5	15	1.5

Melting of samples was carried out in a medium-frequency induction oven. Annealing of samples was carried out in an electric resistance oven, type LP08.

A universal device for tension testing of materials at high temperature, manufacturer Karl Frank, type 81221, was used to test the mechanical characteristics of samples.

Chemical analysis of material for samples was carried out on atomic absorption spectrophotometer.

RESULTS AND DISCUSSION

Products based on platinum and its alloys are widely used in many branches of modern industry, primarily in chemical industry.

For durability and efficiency of listed products in the exploitation conditions, the purity of starting materials is very important.

For this purpose, the control of impurities in platinum and platinum alloys in all stages of technological and exploitation process, occupies a very important place.

Results of testing the content of certain impurities in the starting material (Pt Type A-1 (99.95% wt.) from which the alloy of composition PtRh20Pd10Ir0.1Au0.1 was synthesized, are given in Table 2.

Table 2 *Individual content of impurities in platinum 99.95%*

Element	Be	B	F	Na	He	Ge	As	Se	Pr
c $x10^{-5,}$,%	0.03-0.09	0.01-0.60	7.0-80	0.2-40	1.3-8.3	2.8-7.7	1.5-22	0.06-3.9	1.5-2.7

Element	Ti	V	Cr	Nd	Sm	Eu	Mg	Al	Si
c x 10^{-5},%	1.8-230	0.08-3.0	2.5-13	1.5-2.8	1.5-2.9	1.6-3.0	3.0-90	0.8-480	1.7-82

Element	P	S	Cl	K	Ca	Rb	Sr	Y	Zr
c x 10^{-5}, %	0.05-12	0.8-2.8	0.07-3100	0.1-2.2	0.5-31	0.1-5.1	0.1-0.3	0.2-0.5	0.4-3.3

Element	Nb	Mo	Ag	Dy	Ho	Er	Tm	Yb	Lu
c x 10^{-5}, %	0.1-0.6	0.3-9.3	2.0-62	1.7-3.2	1.7-3.2	1.7-3.2	1.7-3.3	1.8-3.4	1.8-3.4

Element	Sc	Mn	Fe	Co	Ni	Cu	Zn	Br	Cd
c x 10^{-5}, %	0.04-0.46	0.5-1.1	0.05-370	10.-23	3.9-520	3.6-85	1.7-310	0.9-4.1	1.6-3.1

Element	Tb	O_2	C	Cu	In	Sn	Sb	Te	I
c x 10^{-5}, %	1.6-3.1	310	15	0.9-6.5	0.3-3.4	2.3-11	1.0-4.2	6.2-36	0.3-2.4
Element	**Cs**	**Ba**	**La**	**Ce**	**Hf**	**Ta**	**W**	**Re**	**Hg**
c x 10^{-5}, %	4.1-18	0.4-4.0	1.4-2.7	1.4-2.7	1.2-3.5	3.4-22	2.8-8.9	1.9-11	1.6-9.0

Element	Tl	Pb	Bi	Th	U
c x 10^{-5}, %	0.3-34	5.9-110	0.7-61	0.8-1.6	0.9-1.8

It is obvious that the individual contents of nonvolatile impurities in platinum type A-1 (99.95%) and alloys based on them is in the range of c x 10^{-7} to c x 10^{-3}%. Total content of all 68 impurities of base metals and Ag does not exceed 0.02%.

In platinum alloys, intended for industrial conditions, total content of 10-12 control impurities, in many cases, can be very high, up to 0.1%, although it is often no more than 0.02–0.05 % (Table 3 and Figure 1).

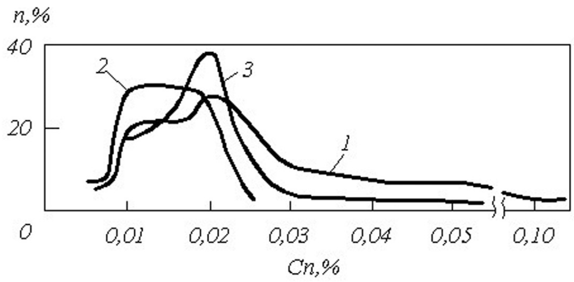

Figure 1 *Relative probability of distribution the control impurities (n), in the function of concentration, c_n, in the alloys PtRh10 (1), PtRh7 (2) and PtRh5Pd15 (3) [12]*

Table 3 *Maximum content of control impurities of base metals and Ag in platinum alloys in wt%*

Impurities	PtRh7	PtRh10	PtRh5Pd15	PtRh10Pd25Ru1.5
Ag	0.003	0.012	0.003	0.003
Fe	0.010	0.030	0.015	0.010
Mg	0.020	0.025	0.020	0.010
Cu	0.001	0.001	0.014	0.003
Ni	-	-	0.003	-
Pb	-	-	0.003	-
Al	0.005	0.006	0.002	0.003
Si	-	0.007	0.003	0.002
S	-	0.010	-	-
$\sum$	0.04	0.10	0.07	0.03

Concentration of some impurities is generally lower than 0.001 to 0.002%, and the cases may be when the content of some impurities increases to 0.004-0.006% and further to 0.01–0.03%, as shown in Figure 2.

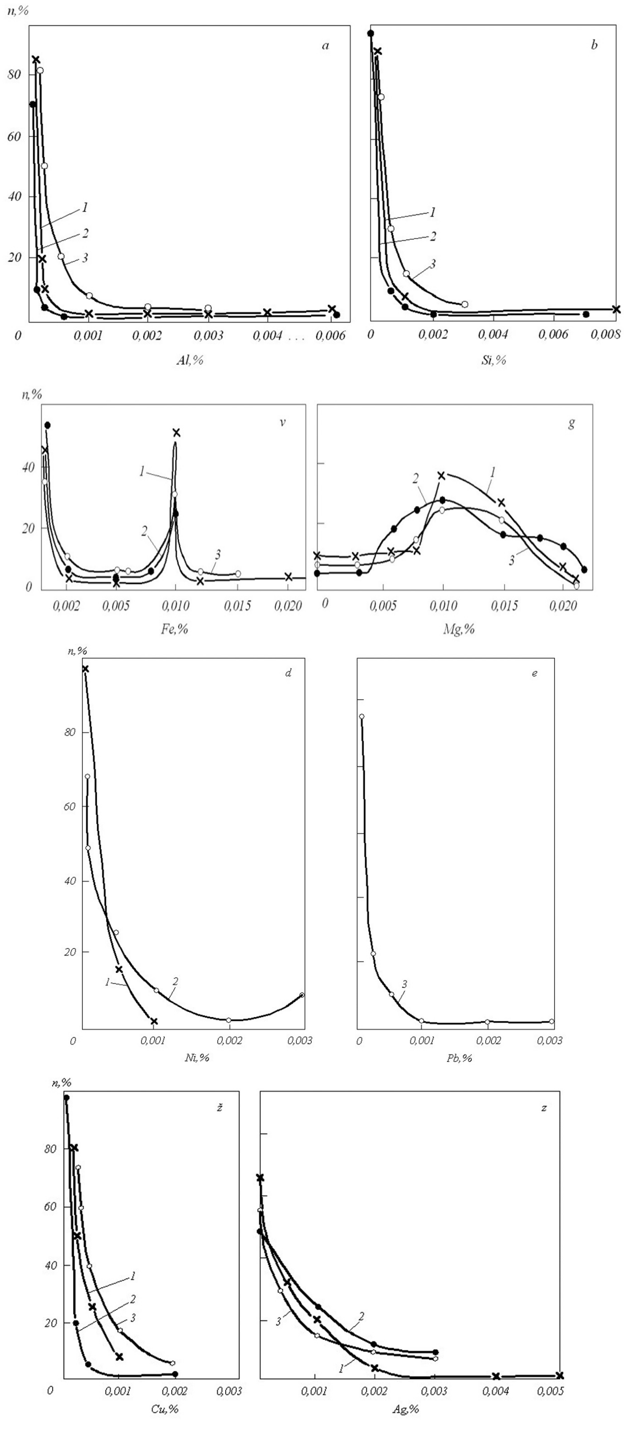

Figure 2 *Relative probability of distribution the aluminum (a), silica (b), iron (c), magnesium (d), nickel (e), lead (f), copper (g) and silver (h) in the alloys PtRh10 (1), PtRh7 (2) and PtRh5Pd15Ru1.5*

Particular attention is turned by distribution of Mg and Fe (at content higher than 0.005%), which is characterized by the whole Gaussian curves, while distribution of others analyzed impurities presents only the right side of distribution curve by Gauss. The assumption is that the top and left side of distribution curve by Gauss, are in such low concentrations of analyzed impurities, which are impossible to identify using the method of spectral analysis.

Maximum on distribution curves of total content, Figure 1, as well as distribution of Fe and Mg, Figure 2, correspond to the concentration of 0.01–0.02%. It is obvious that Fe and Mg are the main pollutants of platinum alloys. The curve of Fe of distribution is characterized by two peaks, at concentration of 0.001 and 0.01%. The left peak (concentration of 0.001%) corresponds to the content of iron in the initial batch, while the right peak (concentration 0.01%) most likely corresponds to the dirty scratched alloy in the processing and exploitation process.

Contamination of platinum alloys with magnesium in the amount of 0.005 - 0.015% is associated with the melting of platinum alloys in ceramic pots of MgO composition as magnesium content in the starting batch does not exceed the concentration of 0.001 to 0003.

According to the English standard, high purity platinum content has permitted following impurities in %: $1x10^{-5}$Cu; $1x10^{-5}$Ag; < $1x10^{-4}$Pb; $7x10^{-5}$Fe; <$1x10^{-4}$Ni; <$1x10^{-4}$ Mg; <$1x10^{-5}$Zr; $4x10^{-4}O_2$; $2x10^{-5}$Pd; $2x10^{-5}$ Rh; <$1x10^{-4}$Au [12].

Based on the allowable content of impurities, according to this standard, high purity platinum can be reached only in its obtaining by chemical methods, while the zonal refining in a stream of oxygen or removing of impurities at high temperatures in a stream of oxygen or vacuum, can significantly reduce the quantities of these impurities.

Table 4 presents the results obtained by AAS technique for platinum purity of 99.999%.

Table 4 *Content of impurities in platinum purity of 99.999%*

Element	**Pb**	**W**	**Ta**	**Ag**	**Cu**	**Ni**	**Fe**	**Cr**	**Ti**
c x 10^{-4}, %	$1x10^{-5}$	$4x10^{-6}$	$3x10^{-5}$	$6x10^{-6}$	$5x10^{-6}$	$1.5x10^{-4}$	$2x10^{-3}$	$1.2x10^{-4}$	$1.4x10^{-4}$

Element	**Ca**	**S**	**P**	**Si**	**Al**	**Mg**	**Na**	**O_2**	**N**
c x 10^{-5}, %	$3x10^{-4}$	$3x10^{-4}$	$1x10^{-4}$	$7x10^{-4}$	$1x10^{-3}$	$3x10^{-4}$	$1x10^{-4}$	$3x10^{-3}$	$1x10^{-3}$

Element	**B**	**Au**	**Pd**	**Rh**
c x 10^{-5}, %	$4x10^{-3}$	$3x10^{-5}$	$2.7x10^{-3}$	$3x10^{-5}$

Tendency for obtaining the platinum metals and alloys of high purity is directed towards the goal of achieving the certain exploitation characteristics, as well as the necessity of preventing crack for mations in hot forging and metal processing.

Table 5 presents the results of impact the degree of purity on platinum hardness after deformation and annealing at 600°C for 0.5 h.

Table 5 *Hardness of different purity platinum (sheet metal)*

Platinum purity	**ε, %**	**l, mm**	**HV, MPa after deformation**	**HV, MPa after annealing at 600 °C, 0.5 h**
99.50	81.3	1.87	980	420
99.90	81.3	1.87	980	370
99.99	82.5	1.75	880	350

The effect of platinum purity degree on the recrystallization temperature is shown in Figure I.3.

It is obvious that with increasing purity of platinum, the recrystallization temperature is reduced.

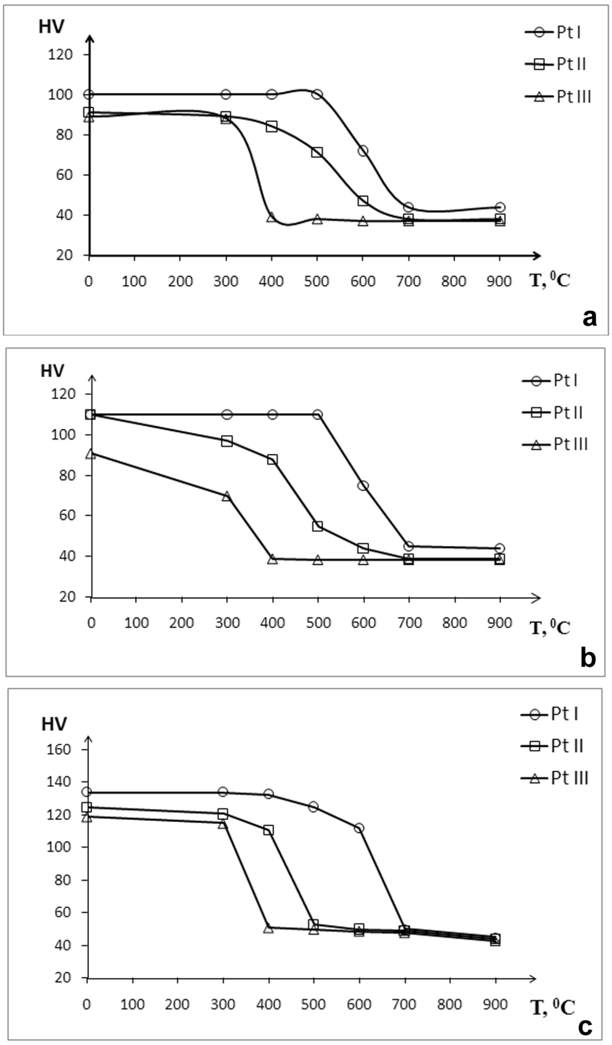

Figure 3 *Dependence of platinum hardness of technical (PtI), chemical (PtII) and physical purity (PtIII) on temperature after annealing of 30 minutes at deformation degrees 82 (a), 90 (b) and 95% (c)*

Recrystallization of remelted technically pure platinum in an induction oven ends at 700°C.

Testing the samples of platinum in the form of wire on break at 900°C has showed that with increasing purity, the time of re sistance and flow limit of platinum are reduced.

Testing results of samples after annealing at 900°C for a period of 1 hour were as follows:

Platinum purity	99.50	99.90	99.99
R_m, MPa	78	60	63
R_p0.2, MPa	46	31	30
A, %	28	33	28

Such lawfulness is only applied in the case of short-term tests in the specified temperature range. With increasing temperature and time of tests, the reciprocity of platinum and impurities are reinforced, and thus the effect on thermal resistance is changed.

CONCLUSION

Based on the previous research results, it can be said that some impurities are permissible in platinum, some must be strictly controlled in order to use the same for special purposes and in the end, the presence of certain impurities results in a disastrous outcome.

Therefore, platinum classification according to the purity and application in the exploitation conditions, based on extensive testing, can be conditionally as follows: for application at room temperature, maximum impurity content is 0.02%. For operation at high temperatures the preferred platinum is with total impurity content below 0.013%, while desirable platinum in the production of platinum thermocouples is with less than 0.002% of impurities. In the end, in making the equipment, in the glass industry, for a specific application in the production of optical glass fibers, platinum is recommended containing impurities of not more than 0.0010%.

Total content of iron and copper in such platinum, must not be higher than 0.0001%. In most cases, total content of these impurities does not exceed 0.0005%.

In general, the conclusion is that if there is higher content of impurities in the platinum metals and alloys, the higher is proba bility of their negative impact on technological and exploitation properties.

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UTICAJ SADRŽAJA NEČISTOĆA NA VISOKOTEMPERATURNU OTPORNOST PLATINE I NJENIH LEGURA[**]

Izvod

U radu su predstavljeni rezultati ispitivanja uticaja kako pojedinih, tako i ukupnog sadržaja primesa u platini i njenim legurama različite čistoće. Predstavljena je relativna verovatnoća raspodele Al, Si, Fe, Mg, Ni, Pb, Cu i Ag, kao i njihov maksimalni sadržaj u legurama sastava PtRh7, PtRh10, PtRh5Pd15 i PtRh5Pd15Ru1.5. Takođe, dati su rezultati uticaja stepena čistoće platine na njenu visokotemperaturnu otpornost, nakon primenjenog termomehaničkog režima prerade. Zaključak je da, ukoliko je viši sadržaj nečistoća u platinskim metalima i legurama, utoliko je veća verovatnoća njihovog negativnog uticaja na tehnološka i eksploataciona svojstva.

Ključne reči: *nečistoće, platina, platinske legure, visokotemperaturna otpornost*

UVOD

Prisustvo hemijskih elemenata - nečistoća u platinskim metalima i legurama povezano je sa sastavom polaznih rudnih sirovina kao i sa tehnološkim operacijama njihovog dobijanja, prerade i eksploatacije u industrijskim uslovima [1-3].

Prisustvo nečistoća u platinskim metalima i legurama ima veliki uticaj na njihova fizička i mehanička svojstva. Iz tog razloga, čistoća platinskih metala i legura jedna je od njihovih ključnih karakteristika [4-6]. Za ocenu zbirnog sadržaja nečistoća često se koristi uslovna definicija platinskih metala tehničke (99.50% tež.), hemijske (99.90% tež.), fizičke (99.99% tež.) i spektralne (99.999% tež.) čistoće. Saglasno sadašnjem standardu platinski metali podeljeni su u tri grupacije: tip A-0, A-1 i A-2 kojima odgovaraju sledeće čistoće: 99.98, 99.95 i 99.90% [7-11].

Čistoća platine određuje se računskim putem iz razlike 100% mase metala i sume procenta 10–15 kontrolnih nečistoća. Pri tom, u ukupnom broju kontrolnih nečistoća, po pravilu nalaze se i metali platinske grupe i zlato. Nečistoće poput Rh, Ru Pd, Ir i Au dovode do poboljšanja mehaničkih karakteristika platine, odnosno do porasta njene visoko temperaturne otpornosti [13].

Na primer, zaprljana platina sa sadržajem 0.055% drugih platinskih metala i zlata, može biti znatno bolji šaržni materijal u odnosu na čistu platinu tipa A-0 sa 0.01% nečistoća poput Si, Al, Pb i drugih, ali istovremeno predstavljati vrlo nepodoban šaržni materijal za izradu visokotemperaturnih legura. Međutim, bitna klasifikacija platinskih metala ne uzima u obzir mogućnost postojanja 50-70 obično ne kontrolnih nečistoća, čiji zbirni sadržaj može iznositi $10^{-2} – 10^{-3}$ % tež [14].

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EKSPERIMENTALNA TEHNIKA

Platina, rodijum i paladijum za izradu legura su dobijeni kao sporedan proizvod u okviru proizvodnje elektrolitičkog bakra RTB, Srbija. Dodatnom rafinacijom postignuta je neophodna čistoća. Sastav ispitivanih legura je naveden u tabeli 1.

Tabela 1. *Sadržaj legirnih elemenata u ispitivanim uzorcima (maseni %)*

Legura	**Rh (mas.%)**	**Pd (mas. %)**	**Ru (mas. %)**
PtRh7	7	-	-
PtRh10	10	-	-
PtRh5Pd15	5	15	-
PtRh5Pd15Ru1.5	5	15	1.5

Topljenje uzoraka vršeno je u srednjefrekventnoj indukcionoj peći. Žarenje uzoraka vršeno je u elektrootpornoj peći tipa LP08.

Za ispitivanje mehaničkih karakteristika uzoraka na visokim temperaturama korišćen je univerzalni aparat za ispitivanje materijala zatezanjem na viskoim temperaturama, proizvođača Karl Frank, tip 81221.

Hemijska analiza materijala za uzorke izvršena je na atomskom apsorpcionom spektrofotometru.

REZULTATI I DISKUSIJA

Proizvodi na bazi platine i njenih legura nalaze veliku primenu u mnogim granama savremene industrije, pre svega u hemijskoj industriji.

Za dugotrajnost i efikasnost navedenih proizvoda u eksploatacionim uslovima, veoma je bitna čistoća polaznih materijala.

U tom cilju, kontrola sadržaja nečistoća u platini i platinskim legurama, u svim fazama tehnološkog i eksploatacionog procesa, zauzima veoma bitno mesto.

Rezultati ispitivanja sadržaja pojedinih nečistoća u polaznom materijalu (Pt tipa A-1 (99.95% tež.)), od kojih je sintetizovana legura sastava PtRh20Pd10Ir0.1Au0.1 dati su u tabeli 2.

Tabela 2. *Pojedinačni sadržaj nečistoća u platini čistoće 99.95%*

Element	**Be**	**B**	**F**	**Na**	**He**	**Ge**	**As**	**Se**	**Pr**
c x$10^{-5,}$,%	0.03-0.09	0.01-0.60	7.0-80	0.2-40	1.3-8.3	2.8-7.7	1.5-22	0.06-3.9	1.5-2.7

Element	**Ti**	**V**	**Cr**	**Nd**	**Sm**	**Eu**	**Mg**	**Al**	**Si**
c x 10^{-5},%	1.8-230	0.08-3.0	2.5-13	1.5-2.8	1.5-2.9	1.6-3.0	3.0-90	0.8-480	1.7-82

Element	**P**	**S**	**Cl**	**K**	**Ca**	**Rb**	**Sr**	**Y**	**Zr**
c x 10^{-5}, %	0.05-12	0.8-2.8	0.07-3100	0.1-2.2	0.5-31	0.1-5.1	0.1-0.3	0.2-0.5	0.4-3.3

Element	**Nb**	**Mo**	**Ag**	**Dy**	**Ho**	**Er**	**Tm**	**Yb**	**Lu**
c x 10^{-5}, %	0.1-0.6	0.3-9.3	2.0-62	1.7-3.2	1.7-3.2	1.7-3.2	1.7-3.3	1.8-3.4	1.8-3.4

Element	**Sc**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**Br**	**Cd**
c x 10^{-5}, %	0.04-0.46	0.5-1.1	0.05-370	10.-23	3.9-520	3.6-85	1.7-310	0.9-4.1	1.6-3.1

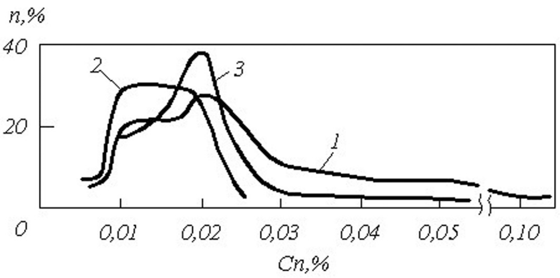
Element	Tb	O_2	C	Cu	In	Sn	Sb	Te	I
c x 10^{-5}, %	1.6-3.1	310	15	0.9-6.5	0.3-3.4	2.3-11	1.0-4.2	6.2-36	0.3-2.4

Element	Cs	Ba	La	Ce	Hf	Ta	W	Re	Hg
c x 10^{-5}, %	4.1-18	0.4-4.0	1.4-2.7	1.4-2.7	1.2-3.5	3.4-22	2.8-8.9	1.9-11	1.6-9.0

Element	Tl	Pb	Bi	Th	U
c x 10^{-5}, %	0.3-34	5.9-110	0.7-61	0.8-1.6	0.9-1.8

Očigledno je, da pojedinačni sadržaj neisparljivih nečistoća u platini tipa A-1 (99.95%) i legurama na bazi njih kreće se u granicama od c x 10^{-7} do c x 10^{-3}%. Ukupni sadržaj svih 68 nečistoća neplemenitih metala i Ag ne prelazi 0.02%.

U platinskim legurama namenjenim industrijskim uslovima ukupni sadržaj 10–12 kontrolnih nečistoća, u mnogim slučajevima može biti veoma visok, do 0.1%, premda često ne bude više od 0.02–0.05% (tabela 3 i slika 1).

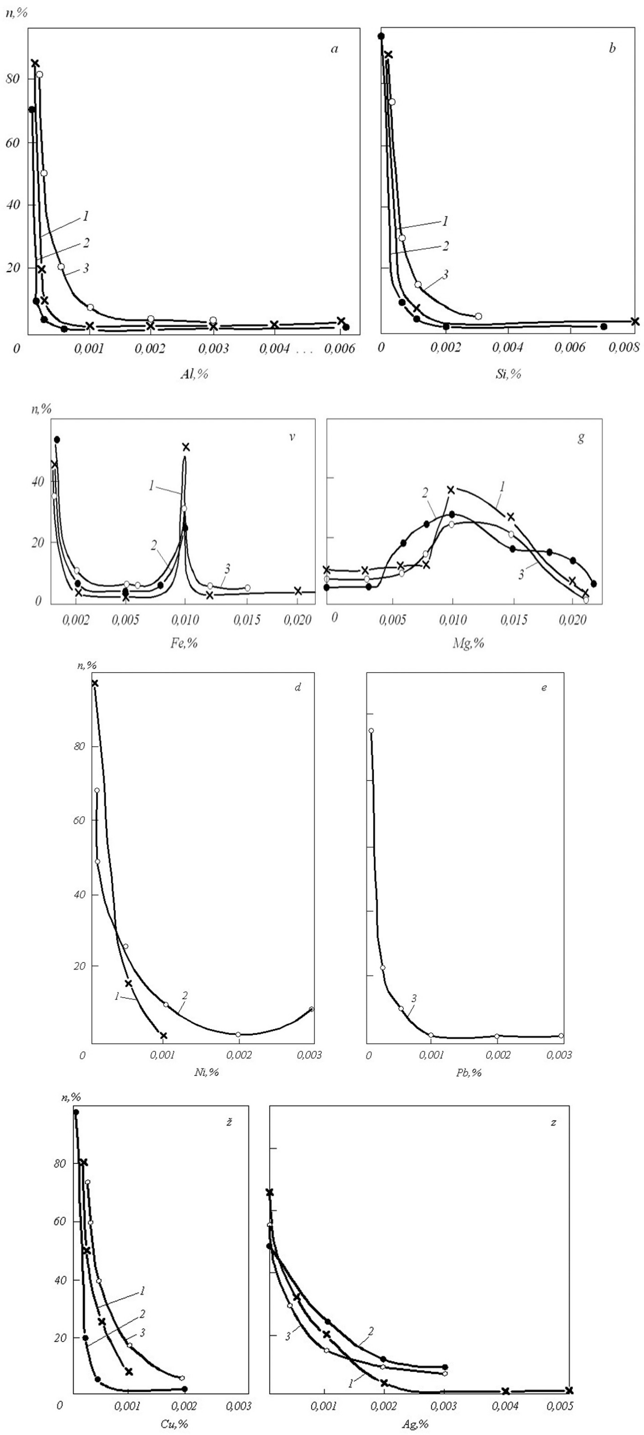


Sl. 1. *Relativna verovatnoća raspodele kontrolnih nečistoća (n), u funkciji koncentracije, c_n, u legurama PtRh10 (1), PtRh7 (2) i PtRh5Pd15 (3) [12]*

Tabela 3. *Maksimalni sadržaj kontrolnih nečistoća neplemenitih metala i Ag u platinskim legurama u tež %*

Nečistoće	PtRh7	PtRh10	PtRh5Pd15	PtRh10Pd25Ru1.5
Ag	0.003	0.012	0.003	0.003
Fe	0.010	0.030	0.015	0.010
Mg	0.020	0.025	0.020	0.010
Cu	0.001	0.001	0.014	0.003
Ni	-	-	0.003	-
Pb	-	-	0.003	-
Al	0.005	0.006	0.002	0.003
Si	-	0.007	0.003	0.002
S	-	0.010	-	-
∑	0.04	0.10	0.07	0.03

Koncentracija pojedinih nečistoća uglavnom je niža od 0.001 do 0.002%, a može biti slučajeva, kada sadržaj pojedinih nečistoća raste do 0.004 - 0.006% i dalje do 0.01 - 0.03%, kako je predstavljeno na slici 2.



Sl. 2. *Relativna verovatnoća raspodele aluminijuma (a), silicijuma (b), železa (v), magnezijuma (g), nikla (d), olova (e), bakra (ž) i srebra (z) u legurama PtRh10 (1), PtRh7 (2) i PtRh5Pd15Ru1.5*

Posebnu pažnju skreće raspodela Mg i Fe (pri sadržaju višem od 0.005%), koja se karakteriše celim Gausovim krivama, dok raspodela drugih analiziranih nečistoća predstavlja samo desnu stranu krive raspodele po Gausu. Pretpostavka je da se vrh i leva strana krive raspodele po Gausu, nalaze u oblasti tako niskih koncentracija za analizirane nečistoće, koje je nemoguće identifikovati korišćenjem metode spektralne analize.

Maksimum na krivima raspodele ukupnog sadržaja, slika 1, kao i raspodele Fe i Mg, slika 2, odgovaraju koncentraciji od 0.01–0.02%. Očigledno je, da su Fe i Mg osnovni zagađivači platinskih legura. Na krivoj raspodele Fe karakteristična su dva maksimuma, pri koncentraciji od 0.001 i 0.01%. Levi maksimum (koncentracija od 0.001%) odgovara sadržaju železa u polaznoj šarži, dok desni maksimum (koncentracije 0.01%) najverovatnije odgovara zaprljanju legure u pocesu prerade i eksploatacije.

Zaprljanje platinskih legura magnezijumom u količini od 0.005 – 0.015% povezano je sa topljenjem platinskih legura u keramičkim loncima sastava MgO, s obzirom da sadržaj magnezijuma u polaznoj šarži ne prelazi koncentraciju od 0.001 - 0.003.

Prema Engleskom standardu, za platinu visoke čistoće dozvoljen je sadržaj sledećih nečistoća u %:

$1x10^{-5}$Cu; $1x10^{-5}$Ag; $<1x10^{-4}$Pb; $7x10^{-5}$Fe; $<1x10^{-4}$Ni; $<1x10^{-4}$Mg; $<1x10^{-5}$Zr; $4x10^{-4}O_2$; $2x10^{-5}$Pd; $2x10^{-5}$Rh; $<1x10^{-4}$Au [12].

Na osnovu dozvoljenih sadržaja nečistoća, prema navedenom standardu, do platine visoke čistoće može se doći jedino pri njenom dobijanju hemijskim putem, dok se zonalnom rafinacijom u struji kiseonika ili uklanjanjem nečistoća na visokim temperaturama u struji kiseonika ili vakuuma, mogu znatno smanjiti količine navedenih nečistoća.

U tabeli 4 predstavljeni su rezultati dobijeni tehnikom AAS za platinu čistoće 99,999%.

Tabela 4. *Sadržaj nečistoća u platini čistoće 99.999 %*

Element	Pb	W	Ta	Ag	Cu	Ni	Fe	Cr	Ti
c x 10^{-4}, %	$1x10^{-5}$	$4x10^{-6}$	$3x10^{-5}$	$6x10^{-6}$	$5x10^{-6}$	$1.5x10^{-4}$	$2x10^{-3}$	$1.2x10^{-4}$	$1.4x10^{-4}$

Element	Ca	S	P	Si	Al	Mg	Na	O_2	N
c x 10^{-5}, %	$3x10^{-4}$	$3x10^{-4}$	$1x10^{-4}$	$7x10^{-4}$	$1x10^{-3}$	$3x10^{-4}$	$1x10^{-4}$	$3x10^{-3}$	$1x10^{-3}$

Element	B	Au	Pd	Rh
c x 10^{-5}, %	$4x10^{-3}$	$3x10^{-5}$	$2.7x10^{-3}$	$3x10^{-5}$

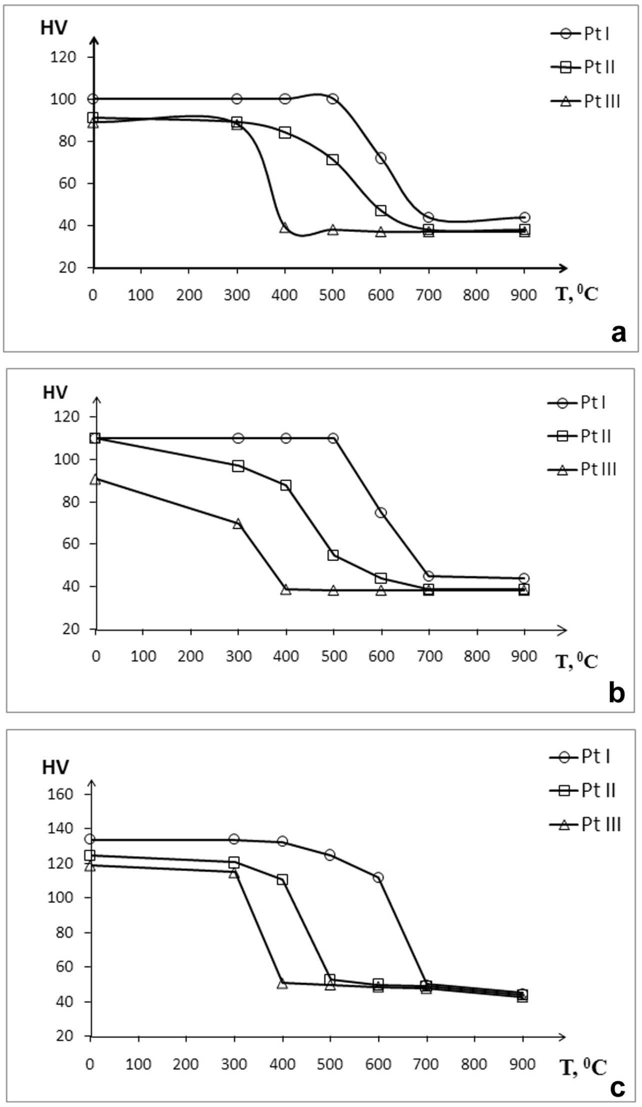
Težnja ka dobijanju platinskih metala i legura visoke čistoće usmerena su ka cilju postizanja određenih eksploatacionih karakteristika, kao i neophodnosti sprečavanja obrazovanja naprslina pri toplom kovanju i preradi metala.

U Tabeli 5 dati su rezultati uticaja stepena čistoće na tvrdoću platine nakon deformacije i žarenja na 600°C u trajanju od 0.5 h.

Tabela 5. *Tvrdoća platine različite čistoće (lim)*

Čistoća platine	ε, %	l, mm	HV, Mpa nakon deformacije	HV, Mpa nakon žarenja na 600 °C, 0.5 h
99.50	81.3	1.87	980	420
99.90	81.3	1.87	980	370
99.99	82.5	1.75	880	350

Uticaj stepena čistoće platine na temperaturu rekristalizacije prikazan je na slici 3. Očigledno je da se sa povećanjem čistoće platine smanjuje temperatura rekristalizacije.



Sl. 3. *Zavisnost tvrdoće platine tehničke (PtI), hemijske (PtII) I fizičke čistoće (PtIII), od temperature nakon 30 minutnog žarenja, pri stepenima deformacije 82 (a), 90 (b) i 95% (c)*

Rekristalizacija pretopljene tehnički čiste platine u indukcionoj peći završava se na 700°C.

Ispitivanjem uzoraka platine u obliku žice na prekid, na 900°C, pokazalo je, da se sa povećanjem čistoće, vreme otpora i granica tečenja platine se smanjuju.

Rezultati ispitivanja uzoraka nakon žarenja na 900°C, u trajanju od 1 h su sledeći:

Čistoća platine	99.50	99.90	99.99
R_m, MPa	78	60	63
R_p0.2, MPa	46	31	30
A, %	28	33	28

Ovakva zakonitost važi samo u slučaju kratkovremenih ispitivanja u navedenom temperaturnom intervalu. Sa povećanjem temperature i vremena ispitivanja pojačava se uzajamno dejstvo platine i nečistoća, pa samim tim uticaj na temperaturnu otpornost se menja.

ZAKLJUČAK

Na osnovu dosadašnjih rezultata istraživanja, može se reći da, u platini neke nečistoće su dopustive, neke se moraju strogo kontrolisati radi korišćenja iste u specijalne svrhe i na kraju, prisustvo određenih nečistoća ima za posledicu katastrofalan ishod.

Zato, klasifikacija platine prema čistoći i primeni u eksploatacionim uslovima, na osnovu obimnih ispitivanja, uslovno može biti sledeća: za primenu na sobnoj temperaturi maksimalni sadržaj nečistoća iznosi 0.02%. Za rad na visokim temperaturama najpoželjnija je platina sa ukupnim sadržajem nečistoća ispod 0.013%, dok je za izradu termoparova poželjna platina sa manje od 0.002% nečistoća. Na kraju, za izradu opreme, u industriji stakla, za konkretnu primenu kod proizvodnje optičkih staklenih vlakana, preporučuje se platina sa sadržajem nečistoća ne većim od 0.0010%.

Ukupan sadržaj železa i bakra u takvoj platini, ne sme biti veći od 0.0001%. U većini slučajeva, ukupan sadržaj ovih nečistoća ne prelazi 0.0005%.

Generalno, zaključak je, da ukoliko je viši sadržaj nečistoća u platinskim metalima i legurama, utoliko je veća verovatnoća njihovog negativnog uticaja na tehnološka i eksploataciona svojstva.

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