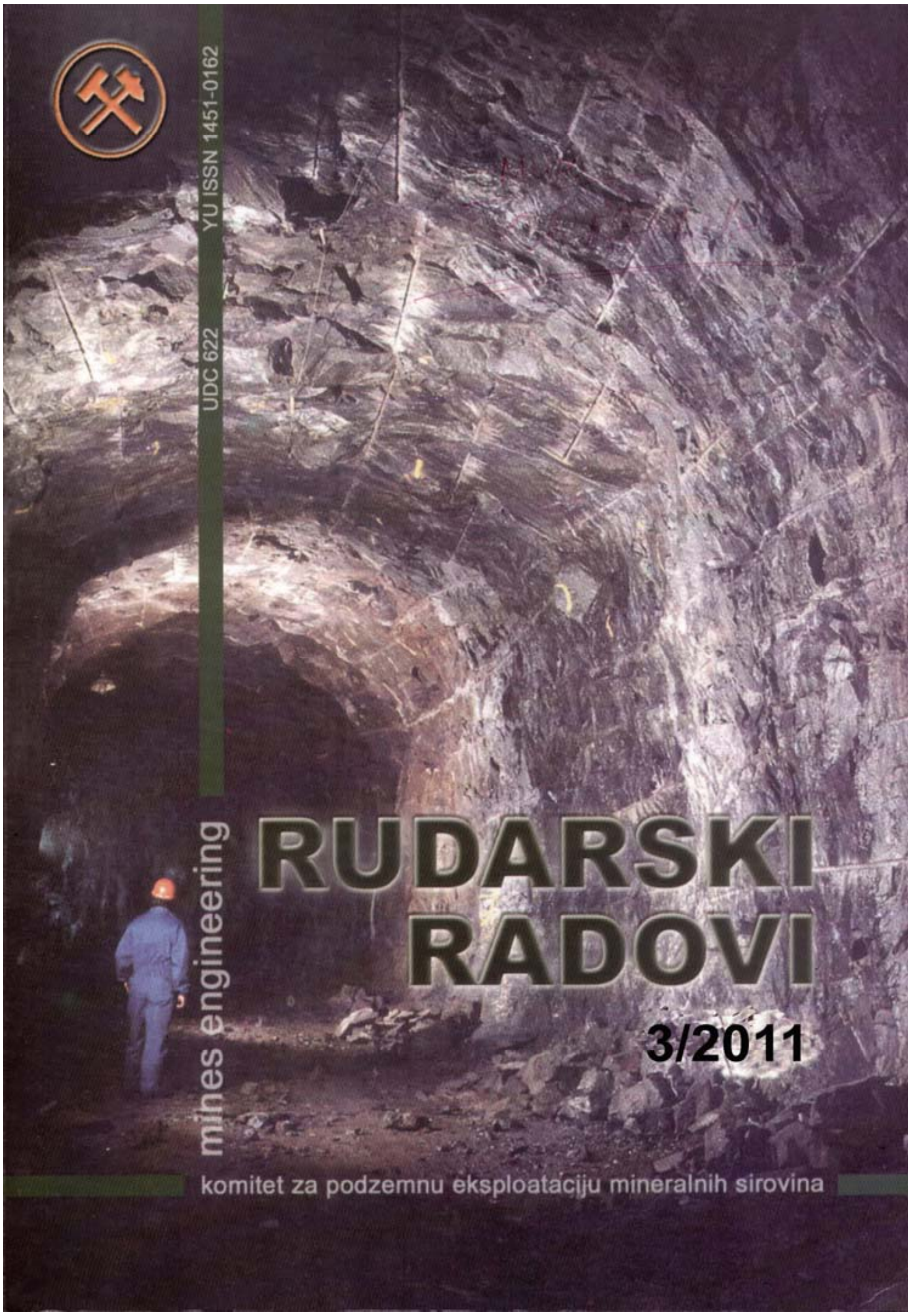
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Dragan Komljenovic, *Jacek Paraszczak***, *Vladislav Kecojevic****

POSSIBILITIES FOR OPTIMIZATION OF RELIABILITY AND MAINTENANCE IN MINING OPERATIONS BASED ON EXPERIENCE IN NUCLEAR INDUSTRY****

Abstract

This paper discusses possibilities of technology and knowledge transfer from the Nuclear industry to Mining Operations in the field of Reliability and Maintenance. Both industries face important challenges with regard to safety, productivity and environment. The Nuclear Industry has achieved significant levels of productivity while remaining safe through a systematic approach using accumulated knowledge and developing industry tailored Reliability and Maintenance Processes. Some examples of their potential application in mining have been given. The paper presents also some indications and suggestions concerning further research work in this field.

Key words: *Reliability, Maintenance, Optimization, Nuclear Industry, Risk*

1. INTRODUCTION

Production and cost figures for mining operations depend considerably on performance of the equipment employed. As modern production equipment is increasingly capital intensive and sophisticated keeping standby units becomes unafford

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able due to a prohibitive cost. This leads to the situation where most of mining systems have little or no redundancy. At the same time, operating conditions, particularly underground, are extremely harsh which results in numerous equipment failures, often difficult to predict and prevent. With limited redundancy many such failures may severely affect mine production, causing substantial losses. Following Faitakis et al. (2004), 5% of North American mining production is lost every year due to unscheduled downtime. About a third of the latter is attributable to equipment failures, some of which may also involve substantial hazards, both in terms of safety and environmental impact.

On the other hand, maintenance costs are relatively high. Following different sources (Campbell, 1995; Knights, 1999; Lewis, 2000; Knights and Oyaneder, 2005), in open-pit and underground mines in North America, Australia and Chile, direct maintenance costs often account for over 30% of the total production cost. This is partly due to the fact that in many mines, particularly in the underground ones, a substantial part of maintenance actions are still reactive; sometimes well over 50% (Paraszczak et al., 1997; Knights and Oyaneder, 2005).

This is very far from 15% and 20% benchmarks given by Mitchell (2002) and Caterpillar (2002) respectively. On the other hand, in many cases, maintenance schedules and tasks recommended by Original Equipment Manufacturers (OEM) cannot be considered optimal.

Manufacturers' generic maintenance programs do not take into account substantial differences between various mine sites in terms of requirements and operating and service conditions.

Due to that, recommended maintenance tasks are often too cumbersome, unnecessarily timeconsuming and costly, up to the point where their scope, content, frequency or even pertinence may be questioned. There is also a potential conflict of interest for equipment manufacturers between developing a maintenance program optimal for a customer and the one that is the best for them.

In this context, mine companies need proper tools, methodologies and processes to rationalize and optimize their maintenance policies and procedures in order to enhance equipment reliability and availability. This is one of the principal conditions to render key production equipment more effective and, consequently, to reduce production cost. As stated by Kumar (2003a, 2003b), reliability and maintenance function in the mining industry has a significant impact on mine profitability. Thus, many mining companies have identified maintenance and its management as a strategic area for research and development.

As the mining industry is not always reputed to be in the forefront of innovation, some people turn their eyes on other industries trying to identify methodologies or processes transferable to mining. Among the examples are the attempts of some high scale open-pit operations to implement Reliability Centered Maintenance (RCM). Accordingly to Ednie (2002), RCM has been used in Canada by Iron Ore of Canada, Quebec Cartier Mining, Syncrude's Aurora mine and BHP Ekati mine. Although in general terms the improvement of equipment reliability and a decrease of maintenance costs have been reported, little or no detailed information about the actual results has been provided. RCM practices were to be implemented also by Falconbridge's Raglan underground mine (Mercier et al., 2004).

As it does not seem (at least yet) that classical RCM is a universal remedy for the problems the mines live with reliability and maintenance of their equipment fleets, it is worthwhile investigating other potentially interesting "technology transfers". It appears that the nuclear industry may become a source of inspiration for mining people. In this context, this paper presents an overview of RIAM, AP-913 quipment Reliability and PMO processes developed for the nuclear industry. It discusses also an issue how the experience and lessons learned there may be useful and beneficial in terms of improvement of mining equipment effectiveness, environment protection and safety.

2. EXPERIENCE OF THE NUCLEAR INDUSTRY IN THE AREA OF RELIABILITY AND MAINTENANCE

There are some analogies between mining and the nuclear industry. Nuclear power stations in North America are also expected to produce more energy at a lesser cost, while respecting increasingly demanding safety and environmental standards and requirements. Although different in their nature, the questions of safety, profitability, and environment are definitely key concerns in loom over both industries. Equipment reliability and maintenance optimization are crucial with regard to these objectives (Coppock, 2004). Following the efforts of World Association of Nuclear Operators (WANO), its Institute of Nuclear Power Operations (INPO), regulatory bodies, and numerous research institutions (in particular Electrical Power Research Institute - EPRI), the nuclear industry has developed its own reliability and maintenance processes that enable meeting these requirements. The recent work has lead to a development of an integral Equipment Reliability Process (ERP) AP-913, and Preventive Maintenance Optimization (PMO), now widely used in the nuclear industry.

The PMO concept is based on a more streamlined Reliability Centred Maintenance (RCM) approach (Johnson, 1998, 2003; Turner, 2002; Harazim and Ferguson, 2003; Messaoudi et al., 2003; Coppock, 2004; Messaoudi, 2005). A classical RCM (Moubray, 1997) proved to be cumbersome process in the nuclear industry with little benefits at significant costs (Johnson, 1998; Harazim and Ferguson, 2003; Messaoudi, 2005). With PMO, many nuclear generating stations have achieved very high capacity factors (over 90%) at a lower cost, and ensuring a safe production (Johnson, 1998, 2003; Coppock, 2004; Messaoudi, 2005).

These two processes i.e.: ERP and PMO, are an integral part of a more global process developed in the nuclear industry named Risk-Informed Asset Management (RIAM). The latter will be discussed more in detail in the next section. It should be stressed that ERP and PMO may be implemented as standalone at a plant (or at another complex facility) without implementing the whole RIAM process.

2.1. Risk Informed Asset Management (RIAM) for Nuclear Generating Plants

The economically regulated nuclear generating industry has developed several physical and financial asset management tools. Life Cycle Management (LCM) and business planning are being done at almost all commercial nuclear power plants. Formerly, LCM was focused on reliability improvement and cost reduction. Nowadays, the evaluation of plant improvement projects is generally based on best-estimate, point-value technical (safety and reliability) and economic (net present value-NPV) methods (Liming, 2002).

In this context, nuclear power generating industry has been developing a process for riskinformed asset management (RIAM) of its facilities. The main objective of the RIAM concept is to develop a rigorous systematic risk-informed approach for assessment, analysis, prediction, and monitoring of power plant economic (i.e. financial) performance while maintaining high confidence levels that pre-established safety limits are not and will not be 635 breached (DOE-DP-STD-3023-98, 1998; NUREG-1513, 2001; Liming, 2002; NUREG-0800, 2002; Coppock, 2004; Messaoudi, 2005).

The RIAM process consists of modeling and probabilistic quantification of decision support performance indicators. It assists decision-makers in determining not only which facility improvement investment options should be implemented, but also how to prioritize resources for their implementation based on their predicted levels of profitability (Liming, 2002). Key decision support indicators include, among the others:

- Net Present Value (NPV);
- Projected Earnings;
- Projected Costs;
- Nuclear Safety (core damage frequency, large early release frequency, etc.);
- Power Production (availability, capacity factor, etc.);
- Efficiency (heat rate);
- Regulatory Compliance.

The RIAM approach complements and integrates in-plant existing activities such as probabilistic risk assessment (PRA), equipment and component reliability process (ERP), preventive maintenance optimization (PMO), and life cycle management (LCM) methodologies. RIAM involves the integrated assessment of many characteristics and performance measures related to nuclear power generating stations. This process is intended to maximize both net present value (NPV) of the facility, and long term profitability through a continuous support to a decision-making process.

RIAM introduces numerous models and supporting performance metrics that can ultimately be employed in order to support decisions that affect the allocation and management of plant resources (i.e., financial support, employment, scheduling, etc.). The experience has also shown that decision support metrics should be applicable to sets of multiple improvement options in order to support effective resource optimization.

While the initial RIAM applications have been developed for nuclear power stations, it can be adapted to provide a decision-making support to other types of power stations, complex facilities (usually capital-intensive), or even groups of such facilities across a wide variety of industries. Figure 1 presents a general block model of the RIAM process.

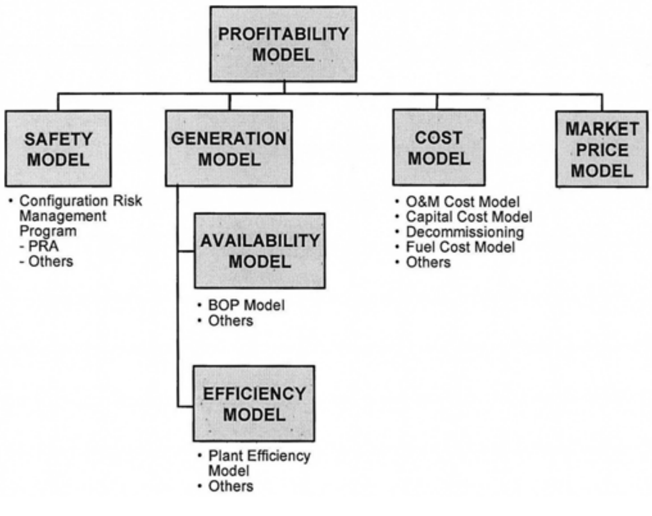

Figure 1. *RIAM Conceptual Model Outline (Liming, 2002)*

This paper focuses mostly on Equipment Reliability Process (ERP) AP-913, and Preventive Maintenance Optimization (PMO) as integral parts of RIAM process. These processes are incorporated more or less into following models: safety, generation, availability, cost, and efficiency.

2.2. Equipment Reliability Process AP-913

Institute of Nuclear Power Operations (INPO) has developed a fundamental equipment reliability process AP-913, aimed to assist member utilities to maintain high levels of safe and reliable plant operations in an efficient manner (INPO, 2001). INPO defines the equipment reliability process as an integration and coordination of a broad range of equipment reliability activities into one process. It is developed for the plant personnel to evaluate important station equipment, conceive, work-out and implement long-term equipment health plans, monitor equipment performance and condition, and make continuing adjustments to preventive maintenance tasks and frequencies based on equipment operating experience (INPO, 2001).

This process includes activities normally associated with such programs as classical reliability centred maintenance (RCM), or some of its streamlined versions, preventive maintenance (periodic, predictive, and planned), Maintenance Rule, surveillance and testing, life-cycle management (LCM) planning, and equipment performance and condition monitoring. INPO defines the following objectives for this ERP:

a) The process is efficient, incorporates human factor considerations, and ensures effective performance during all phases of plant operations,
b) In the case of a company operating several plants, a uniform process to be used by all of them,
c) The lessons learnt in-house and throughout the industry that are applicable are incorporated into the process to improve adequacy and efficiency,

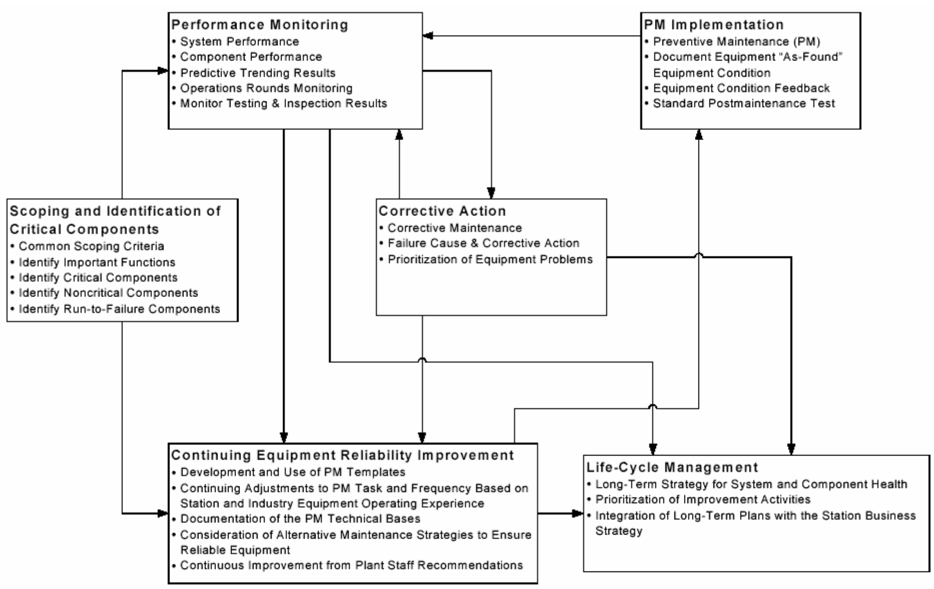

Figure 2. *Top Level Diagram of AP-913 Equipment Reliability Process (INPO, 2001)*

d) Changes to the process are timely, responsive to user's feedback, and implemented at all affected plants.

The ERP also lists various equipment performance objectives. The top level diagram of this process is shown in Figure 2 (INPO, 2001; Komljenovic et al., 2004). It includes major process elements and their relationship. The reference AP-913 (INPO, 2001) also gives a process flowchart including detailed activities indispensable to achieve the process objectives.

The intent of AP-913 is to identify, organize, and integrate equipment reliability activities into a single efficient and effective process. When available, RIAM, with its treatment of risk and plant-level life-cycle equipment reliability, will be a tool to assist utilities in implementing AP-913 process (directly incorporated into both safety and generation models, see Figure 1).

The potential benefits stemming from the application of the integral AP-913 ERP are as follows:

- Consistent, systematic and rigorous approach to major investment value-based decision making;
- Consistent treatment and integration of plant safety, reliability, efficiency, and cost factors in the decision-making process;
- Consistent framework for continuous monitoring, and projection of plant safety and production performance;
- Operating & Maintenance procedure improvement and procedure training prioritization;
- Trade-offs between on-line and off-line maintenance;
- Capital spares procurement analysis and prioritization;
- Unit efficiency improvement, etc.

2.3 Preventive Maintenance Optimization

As previously mentioned, a classical RCM was not found to be an optimal process with regard to the needs and expectations of the nuclear industry. It usually led to the creation of a new preventive maintenance program ather than to enhance and revise the existing one (Johnson, 1998; arazim and Ferguson, 2003; Messaoudi et al., 2003; Messaoudi, 2005). A considerable amount of time and effort required to perform an analysis and implement PM tasks recommendations has been considered as a major weakness for standard (classical) RCM applications (Johnson, 1998; Turner, 2002; Messaoudi et al., 2003; Messaoudi, 2005).

This situation is due to the level of details required and excessive documentation produced as a result of the rigid process steps. In mid-1990s the nuclear industry initiated research projects to develop ways to perform RCM more cost effectively, based on its own experience. Some concepts have been developed in order to demonstrate that the standard (classical) RCM methodology could be streamlined to reduce the cost of analysis while maintaining a high quality product. Messaoudi (2005) compiles, among others, the most significant results of these initiatives (works of EPRI, Fractal-solutions, INPO, etc.).

The experience has shown that approximately 60% of the time required to accomplish a classical system RCM analysis is spent on the following two major steps:

a) Failure Modes and Effects Analysis (FMEA) – identification of equipment critical for each system function;

b) Logic Tree Analysis (LTA) – identification of the most feasible and effective PM tasks to prevent critical component failure modes and causes of concern.

Thus, a considerable amount of effort has been put to enhance the classical RCM analysis methodology in these two areas. As a result of this enhancement three following main concepts have been developed:

- Streamlined Classical Process and,
- PMO Process and Criticality Checklist (see Table 1).

Table 1 shows also a comparison between the classical RCM analysis and streamlined
methods.

Table 1. *Comparison of various RCM concepts (after Messaoudi, 2005)*

Classical RCM analysis phases	Streamlined analyses		
	Streamlined Classical Process	PMO Process	Criticality Checklist
Determine System Boundaries	X	X	X
Determine Subsystems	6)		
Data Collection and Plant History Review	X	X	X
Identify system Functions and Functional Failures	1)	1)	
FMEA	2)	3)	4)
Instrument Matrix [7)]	X		
Non-critical Evaluation	X	X	X
LTA PM Task Recommendations (Critical/Non-critical)	5)	5)	5)
Task Comparison	X	X	X

1) Identify all system functions, and classify into two major groups: (1) Important functions, and (2) Non-Important functions.
2) Perform only FMEA on Perform only FMEA on components and equipment, which support important functions.
3) Perform a streamlined FMEA, which combines dominant failure modes and plant effects into one component record on components (equipment) that support important functions.
4) Component (Equipment) is critical if its failure will result in one of several pre-selected plant effects, which one wants to prevent through a PM program.
5) Maintenance Templates added to formal LTA. LTA only formally documented in modified classical analysis.
6) Only for very large (complex) systems.
7) Replaces FMEA for Instrumentation & Control (I&C) equipment

Efficiency and savings related to performing LTA in the nuclear industry have been achieved through a concept of *"Maintenance Template"* for a given component or equipment type. At the stage of a template development, several component characteristics such as equipment frequency of usage, operational and service environment as well as functional importance are taken into account. Each maintenance template recommends appropriate tasks for a given component or equipment type in terms of condition monitoring tasks, time directed tasks, and surveillance tasks. They provide major additional savings. In the nuclear industry there currently exist maintenance templates for nearly 80 major components and/or equipment considered crucial with regard to both safety and power generation. They have been developed through a teamwork involving manufacturers, nuclear industry people, and EPRI experts who benefited from over 20 years of operating experience, including data collection and analysis.

The PMO concept has also proven to be highly efficient in the nuclear industry in terms of achieved savings and overall results (Johnson, 1998 and 2003; Harazim and Ferguson, 2003; Messaoudi, 2005), and it will be described in more details. This process may be very easily integrated into AP-913 ERP (see Figure 2). The PMO analysis method shows that it is an efficient tool to achieve previously mentioned ERP goals.

As shown in Table 1, the PMO employs many of the same analysis techniques as the classical RCM analysis, but it represents a more streamlined approach. The classical RCM analysis begins at the top with a system, breaks it down into subsystems, identifies critical components, and recommends PM tasks. The latter are subsequently compared to those already in place (existing PM tasks) which leads to final task recommendations. PMO begins at the opposite end. The PM procedure is split into tasks that are reviewed to identify the failure they are intended to prevent. Subsequently, related data are collected, critically reviewed and analyzed in order to make final task recommendation (Johnson, 1998; Messaoudi, 2005). Another major difference in the PMO process vs. the classical RMC analysis is that the standard FMEA and LTA have been streamlined and combined into one record (see Table 1). The PMO process documents the most important failure modes for a component/equipment (usually three dominant ones), and allows documenting the most dominant plant effects (typically three) in one component/equipment record. Such record is used to determine criticality of a component/equipment. If the latter is considered critical, PM tasks are recommended using maintenance templates.

The most significant elements contributing to the successful completion of the system analysis using this concept are as follows:

- Combination of failure modes and plant effects into one record;
- Combination of FMEA and LTA into one component record with less formal documentation.

The experience has shown that experienced analysts using PMO process have been able to achieve results similar to the modified classical RCM process (Johnson, 1998 and 2003; Messaoudi, 2005). As an example of the PMO process advantages, some results concerning improving equipment reliability and plant efficiency and obtained at Kewaunee Nuclear Power Plant (KNPP) will be presented (Johnson, 1998, 2003). The PM Optimization was initiated following the need to shift the plant's PM program from a 12- to 18-month cycle.

The technical basis (justification) of maintenance tasks and frequencies needed to be reestablished because the original records were not retrievable. Initial efforts to compile similar information consisted of a more classical RCM program. In five years, RCM evaluations were completed on only 8 of the plant's 65 systems. Critical review of the RCM results and of its progress revealed that although the process was rendering useful information, it was advancing too slowly given KNPP's needs and expectations. In mid-1990s, the KNPP management decided to turn to PMO.

A plan was defined with a following main objective: *"Maximize plant generating capability and equipment reliability"*. The other objective was to establish a general plant maintenance program that would minimize power reductions and forced outages resulting from equipment failures, procedural errors, technical inadequacies, and human error. The program considered long-term plant operation. In order to meet general objectives, several specific ones were also defined. PMO streamlined approach was used to achieve them. One year after the PMO program had been initiated, the analysis of all plant systems was accomplished. As a result, PM task change recommendations were drawn and, subsequently implemented into existing KNPP programs (Johnson, 1998). An overall evaluation performed four years later (Johnson, 2003) revealed that since the beginning of KNPP's Living Program the following significant results have been achieved (list is not exhaustive):

- 1.5 $M US saved from PM interval extension and task elimination over a four year period;
- Many PM tasks dropped and some new added;
- 12% reduction in maintenance staffing;
- Number of PM work orders dropped drastically due to grouping related tasks between plant organisations;
- Reliability Program recognized as a strength by US Nuclear Regulatory Commission (USNRC) and INPO;
- Spin-off of other maintenance processes;
- Acceptance of a new program was made through staff involvement; etc.

As shown above, the PMO process has proven its efficiency, and is now widely used in the nuclear industry. In brief, its potential benefits are the following:

- Elimination of unnecessary PM tasks;
- Decrease of corrective maintenance in terms of time, man-labour and cost;
- Reduction of forced outages;
- Improvement of plant availability;
- Focus of maintenance resources on critical equipment and components.

PMO balances corrective, preventive and predictive maintenance tasks along with equipment availability and maintenance cost considerations. The ultimate goal consists in maximizing plant value while remaining safe (Liming, 2002). RIAM provides a framework for employing those tools and methods. It extends the scope from plant maintenance policies and practices to all aspects of asset management. Rather than optimizing on the basis of reliability, availability and cost, as is the case of a conventional approach, RIAM does an optimization on the net present value (NPV) as a principal profitability parameter (Liming, 2002).

Following encouraging results obtained through PMO applications in the nuclear industry, there are the reasons to believe that its implementation could be rewarding in other industries, too. In this context, the next section discusses some possible applications of the PMO process in mining.

3. POTENTIAL FOR IMPLEMENTA TION OF NUCLEAR INDUSTRY PRACTICES IN MINING EQUIPMENT

In the preceding sections it has been shown that in some cases classical RCM is a timeconsuming process. At the same time, applications of the ERP and PMO processes in the nuclear industry delivered encouraging results in terms of saving time, effort and money while remaining safe. One may expect that these processes may be transferable to the mining industry. It seems that there are two basic fields where the practices and positive experience of the nuclear industry have a potential to become equally beneficial:

- High-scale open-pit mines where capital and operational cost of the equipment as well as its performance are significant contributors to the production cost;
- Existing and future underground mines where production depends (or will depend) to a large extent on highly automated production equipment.

In both cases, in the context of fierce international competition, the mines need the highly effective equipment. There are however some significant differences between them. Open-pit mines employ huge fleets of capital-intensive equipment and their production systems have got a limited redundancy. Many of them operate around the clock for 365 days a year often in extreme atmospheric conditions. In these circumstances, ensuring high equipment reliability and availability is a very challenging task and a success depends to a large extent on adequate maintenance policies and strategies. Even if in some cases classical RCM seems to deliver anticipated results, it is worth trying less time- and resource-intensive processes, such as those reviewed in preceding sections.

In the second case, operational and service environment for highly automated machines is very specific and substantially different from that of man-operated equipment. Due to safety concerns and regulations, zones where automated equipment operates should be inaccessible to human workers. In the case of a failure that requires human intervention, it is an imperative that all man-less traffic and operations in the area concerned be suspended and/or shut down or. Due to that, some machine-related problems may bring a whole section of the mine to a virtual halt and, thus, induce considerable production losses. Also some minor (from a technical point of view) problems that would otherwise be rapidly solved by a human operator may lead to production interruptions. At the same time, automated machines are expensive items to acquire and operate. Since in underground mines there is usually even less redundancy (if any) in production systems than at open-pits, automated drill jumbos and/or rigs, LHDs and trucks are really critical for a whole production process.

In each of these cases, the improvement of reliability and optimization of maintenance (preventive, predictive, condition based) are key factors related to production efficiency and cost. In this context there is apparently some potential for the application of ERP and PMO processes in the mining industry.

At the beginning these processes need to be conceived and developed in the way to adapt them to a specific character and context of mining. At the early stages, the work should focus on some selected categories of equipment considered criticalwith regard to its role in the production system (including a degree of redundancy), its working conditions and environment, intensity of their use, maintainability and maintenance support. Cable (electric) shovels, hydraulic shovels and crushers in open-pit mines, and underground automated jumbos, production drill rigs and LHD are good examples here. Databases and maintenance templates for those may be developed with an input from OEM, mine operators and maintenance management people, consultants and research institutions. They are founded reasons to believe that a successful development of specific ERP and PMO and their implementation at mine sites will bring substantial benefits such as:

- Less time and effort deployed, but with similar results compared to classical RCM;
- Substantial reduction of reactive maintenance, whose share at many mine sites is by far too high;
- Rationalization and optimization of proactive maintenance tasks will definitely contribute to an increase of availability and reduction of a maintenance cost;
- Better utilization of maintenance resources due to focusing on the truly critical equipment and/or its components;
- ERP may be considered almost a closed-loop system that once properly implemented will lay ground for continuous reliability and PM improvement (see Fig. 2);
- Increase of equipment effectiveness and better life-cycle management.

It should not be forgotten however, that the development and implementation of these two processes are not instantaneous and their success requires some time, effort, proper understanding, support and commitment as well as patience from all involved parties (especially from the Management).

4. CONCLUSIONS

Facing tough international competition, mining companies in North America are constantly forced to produce more at the lesser cost. One of the key concerns to achieve it is related to an increase of overall equipment effectiveness. Adequate preventive and proactive maintenance policies and tasks (particularly in what concerns their scope, content and frequency) are among the most crucial factors. However, the mining industry has not yet developed its own original processes for this purpose and it relies predominantly on achievements and experience gained in other industries. This paper intends to indicate that there is a potential for transferring some important know-how from the nuclear power generation industry. This includes two processes, namely: Equipment Reliability Process (ERP) and Preventive Maintenance Optimization (PMO). The ultimate success of such endeavour requires careful and adequate adaptation of these with regard to operational and business context of the mining industry. Another fundamental success factor is related to a close collaboration and exchange between OEM, mine operators and their maintenance management personnel as well as other involved personal. This approach may be undoubtedly beneficial for mining companies facing a tough competition at the international level.

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ODREĐIVANJE BILANSNIH REZERVI LEŽIŠTA KALCITA "KAONA" I OPTIMALNE KONTURE POVRŠINSKOG KOPA PROGRAMOM MINEX 5.2.3

Izvod

U radu su prikazani rezultati optimizacije ležišta kalcita "Kaona" računarskim programom Minex 5.2.3, odnosno njegovim alatom Pit optimiser. Prikazan je rad ovog programa, definisane su bilansne rezerve i određene optimalne konture za površinsku eksploataciju.
Ključne reči: *Minex 5.2.3, Optimizacija, Bilansne rezerve, optimalna kontura kopa*

1. UVOD

Razvojem računarske tehnike, i usled informatičke revolucije sredinom osamdesetih godina dvadesetog veka pojavili su se prvi programski paketi specijalizovani za oblasti geologije i rudarstva. Danas su ti programi evoluirali u izuzetno moćan i koristan alat čiji je cilj skraćivanje vremena potrebnog za izradu geomodela istraživanog ležišta i površinskih kopova, ušteda novca i što detaljniji 3D prikaz rudnih tela i kopova. Jedan od tih programa je i Minex 5.2.3 koji predstavlja specijalizovani program za 3D modeliranje isključivo slojevitih ležišta, a pre svega ležišta ugljeva.

Ovim softverom moguće je da se izradi geološki model slojevitih ležišta [3, 5, 6], modeliraju rasedi [4], odredi optimalna kontura površinskog kopa [7], konstruiše detaljan izgled površinskog kopa i odlagališta jalovine [10], determiniše dinamika otkopavanja i odlaganja jalovine [8, 9].

2. OPIS PROGRAMA MINEX 5.2.3

Polazna osnova za rad u ovom programu su situaciona karta (topografija za nove kopove ili početno stanje radova za otvorene kopove) u digitalnom obliku (najčešće u *Auto CAD* formatu) i podaci iz istražnih bušotina o njihovom prostornom položaju, litologiji i kvalitativnim parametrima u *Excel* formatu [1]. Na osnovu podataka o bušotinama kreira se geo – model ležišta [11]. Svaki sloj u geo – modelu ima svoj grid (površina predstavljena mrežom određenih dimenzija) krovine, podine i moćnosti, kao i grid kvaliteta za svaku posmatranu komponentu. Geo – model se izrađuje sledećim alatima:

- *Borehole DB* – Formiranje baze bušotina za geološko modeliranje
- *Statistical analisys* – Analiza zakonomernosti raspodele komponenti u ležištu

* *Institut za rudarstvo i metalurgiju Bor*

- *Seam model* – Modelovanje slojeva i obračun geoloških rezervi

Kada je kreiran geo – model i unešeno početno stanje terena, vrši se optimizacija, odnosno određivanje optimalne konture površinskog kopa prema tehno – ekonomskim parametrima eksploatacije [6, 7, 8, 9]. Dobijena optimalna kontura je vodilja za detaljnu konstrukciju površinskog kopa. Ova faza projektovanja vrši se alatom *Pit optimiser*.

U programu *Minex 5.2.3* moguće je detaljno konstruisanje završnog izgleda površinskog kopa i odlagališta jalovine sa transportnim putevima i gornjom i donjom ivicom svake etaže, kao i kreiranje dinamike otkopavanja alatom *Pit design*.

Takođe ovim programom se vrši izrada kompletne rudarko – geološke grafičke dokumentacije.

3. OPTIMIZACIJA MODULOM PIT OPTIMISER

Optimizacija površinskog kopa u programu *Minex 5.2.3*, odnosno njegovom alatu *Pit Design* vrši se opcijom *Pit Optimiser* koja se bazira na *Lerches and Grossman* algoritmu [1]. *Lerches and Grossman* algoritam je postupak za određivanje optimalnog kopa kao onog sa najvećom vrednošću za odgovarajući set troškova i faktora povraćaja.

Ulazni parametri za optimizaciju ležišta „Kaona“ su:

1. topografija,
2. geomodel ležišta,
3. zapreminska masa mineralne sirovine,
4. iskorišćenje na separaciji,
5. jedinična cena tone peska svedena na sadržaj SiO_2,
6. srednji i minimalni sadržaj SiO_2,
7. ugao završne kosine kopa,
8. mimimalna završna širina etažne ravni,
9. troškovi otkopavanja jalovine, peščara i separacijske prerade.

Topografija i geomodel ležišta dobijeni su digitalnom obradom situacione karte terena odnosno digitalnom interpretacijom podataka dobijenih istražnim bušenjem.

Zapreminska masa peščara uzeta za optimizaciju kopa je srednja vrednost zapreminskih masa u prirodnom stanju iz istražnih bušotina i iznosi $\gamma = 1{,}716\, t/m^3$ [2].

Iskorišćenje na flotaciji na osnovu učešća pojedinačnih klasa peščara iznosi 85% [2].

Prema istraživanju tržišta, jedinična cena tone peska za srednji kvalitet ležišta iznosi 14 $/t, odnosno 0,15 $ svedeno na 1% SiO_2 [2].

Srednji sadžaj SiO_2 u ležištu prema podacima iz geomodela iznosi 94%. Donji granični sadržaj SiO_2 se usvaja na 85% [2].

Pretrpostavljeni ugao etažne kosine i završni ugao kosine kopa se usvajaju na osnovu sledećih fizičko – mehaničkih karakteristika radne sredine [2]:

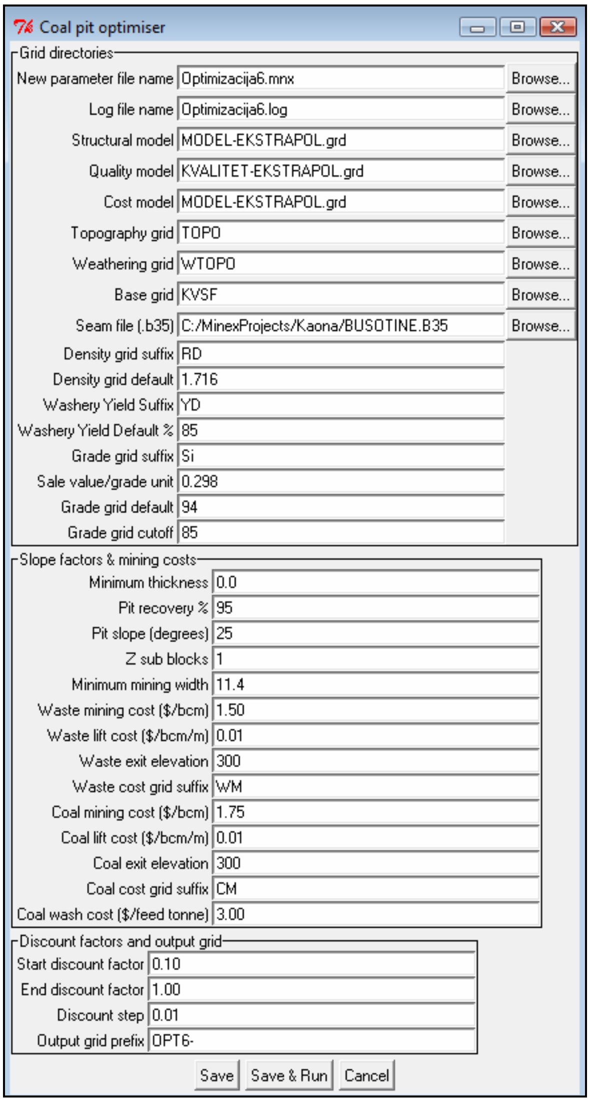
- zapreminska težina peščara, $\gamma = 16{,}83\ kN/m^3$;
- kohezija peščara, C = 0 kPa;
- ugao prirodnog držanja peščara, $\varphi = 27{,}6°$.

Ugao etažne kosine za minimalni koeficijent sigurnosti F_s = 1,10, uz visinu etaže od 10 m i završnu širinu etažne ravni od 11,4 m iznosi 45°. Ugao završne kosine kopa za minimalni koeficijent sigurnosti F_s = 1,30 i maksimalnu dubinu kopa od 80 m iznosi 25° [2].

Troškovi otkopavanja jalovine, peščara i separacijske prerade procenjeni su na osnovu očekivane potrošnje normativnog materijala, radne snage, amortizacije i održavanja opreme za zahtevane kapacitete i radne uslove – prvenstveno očekivane transportne relacije za kamione od 500 m za jalovinu i 600 m za peščar. Procenjeni troškovi po fazama [2] iznose:

- otkopavanje jalovine: 0,47 $/$m^3$
- otkopavanje peščara: 0,48 $/ m^3
- separacijska prerada: 0,38 $/t

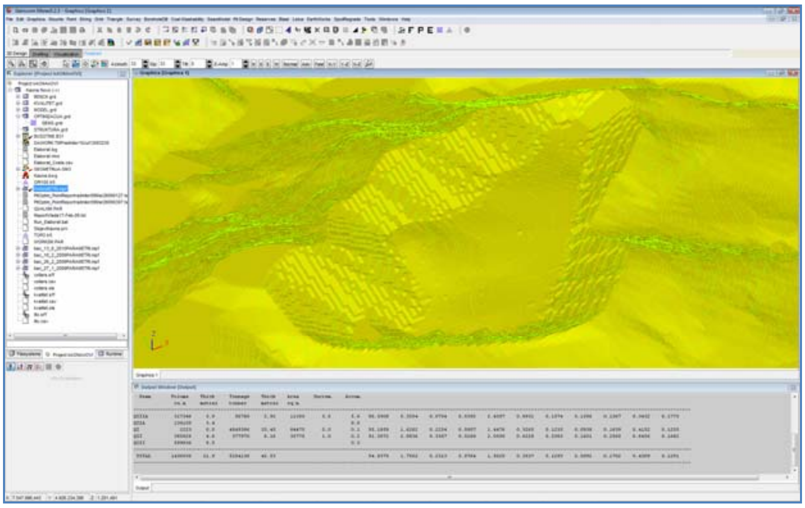
Definisanje parametara optimizacije u programu Minex 5.2.3 prikazano je na slici 1.



Sl. 1. *Unos parametara optimizacije u programu MINEX 5.2.3*

4. REZULTAT OPTIMIZACIJE

Kao rezultat optimizacije dobijeni su kopovi sa različitom količinom iskopina i različitom diskontovanom vrednošću. Bilansne rezerve su za kop koji ima vrednost faktora povraćaja $R_v = 1$ (Revenu factor – 0,5 do 1,5 od bazne cene sa definisanim korakom). Kop sa bilansnim rezervama je prikazan na slici 2. Količine bilansnih rezervi po klasama kvaliteta prikazane su tabelom 1.



Sl. 2. *Prikaz kopa sa faktorom povraćaja R_v = 1*

Tabela 1. *Bilansne rezerve ležišta kalcita „Kaona“*

Sloj	Jalovina		Mineralna sirovina			Koeficijent raskrivke		Komponenta										
	Zapremina	Moćnost	Količina	Moćnost	Površina	Parcijalni	Kumulativni	SiO_2	Al_2O_3	CaO	Cr_2O_3	Fe_2O_3	K_2O	MgO	Na_2O	S	SO_3	TiO_2
	m^3	m	t	m	m^2			%	%	%	%	%	%	%	%	%	%	%
QIIIA	317 346	5,9	56 780	2,9	11 350	5,6	5,6	88,59	5,36	0,07	0,04	2,44	0,89	0,16	0,16	0,14	0,34	0,18
QIIA	134 105	3,4	0	0,0	0	0,0	8,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
QI	2 223	0,0	4 849 386	33,5	84 475	0,0	0,1	95,19	1,63	0,23	0,08	1,45	0,33	0,12	0,09	0,16	0,42	0,13
QII	385 026	4,6	377 970	6,2	35 775	1,0	0,2	91,31	2,88	0,33	0,03	2,06	0,62	0,20	0,16	0,26	0,65	0,17
QIII	599 836	8,0	0	0,0	0	0,0	0,3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Total	1 438 536	21,9	5 284 136	42,5				94,84	1,76	0,23	0,08	1,50	35,00	0,13	0,10	0,17	0,43	0,13

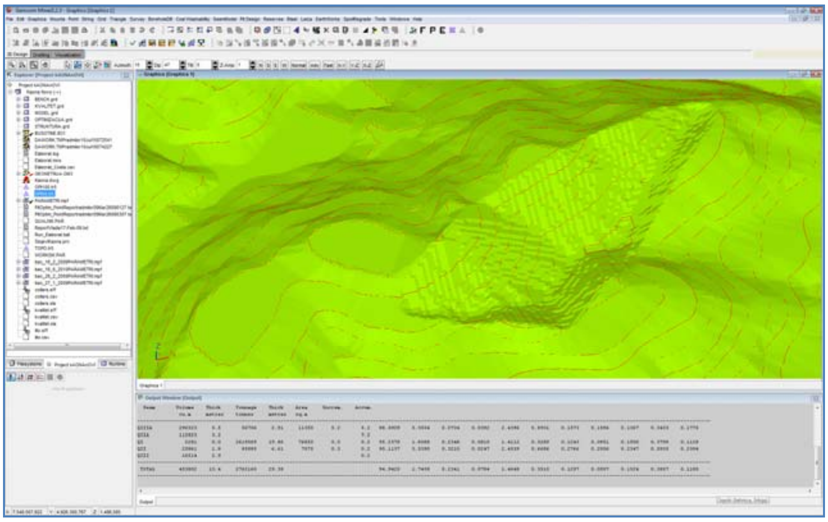
Eksploatacione rezerve su redukovane u odnosu na bilansne za gubitke prilikom otkopavanja. Ovi gubici nastaju usled pojave negabarita i proslojaka jalovine unutar ležišta. Eksploatacione rezerve prikazane su tabelom 2.

Tabela 2. *Eksploatacione rezerve ležišta kalcita „Kaona“*

Sloj	Jalovina		Mineralna sirovina			Koeficijent raskrivke		Komponenta										
	Zapremina	Moćnost	Količina	Moćnost	Površina	Parcijalni	Kumulativni	SiO_2	Al_2O_3	CaO	Cr_2O_3	Fe_2O_3	K_2O	MgO	Na_2O	S	SO_3	TiO_2
	m^3	m	t	m	m^2			%	%	%	%	%	%	%	%	%	%	%
QIIIA	317 346	5,9	56 780	2,9	11 350	5,6	5,6	88,59	5,36	0,07	0,04	2,44	0,89	0,16	0,16	0,14	0,34	0,17
QIIA	134 105	3,4	0	0,0	0	0,0	8,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
QI	11 016	0,0	4 834 297	33,5	84 475	0,0	0,1	95,19	1,63	0,23	0,08	1,45	0,33	0,12	0,09	0,16	0,42	0,12
QII	386 826	4,6	374 882	6,2	35 775	1,0	0,2	91,33	2,88	0,33	0,03	2,06	0,62	0,20	0,16	0,25	0,64	0,16
QIII	599 836	8,0	0	0,0	0	0,0	0,3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Total	1 449 129	21,9	5 265 959	42,5				94,84	1,76	0,23	0,08	1,50	35,00	0,13	0,10	0,17	0,43	0,12

Optimalna kontura površinskog kopa mora da zahvati najmanje 50% ukupnih bilansnih rezervi. Na osnovu geo – modela ležišta izvršena je optimizacija za varijacije vrednosti diskontnog faktora od R_{vmin} = 0,3 do R_{vmax} = 1,3 sa korakom 0,5. Kao rezultat optimizacije dobijeno je 17 prostorno definisanih kontura kopova sa količinama kalcita, jalovine, koeficijentom raskrivke i sadržajem značajnih parametara.

Kop sa diskontnim faktorom R_v = 0,5 ima najmanju količinu iskopina koja obuhvata više od 50% bilansnih rezervi. Zavisno od potrebnih kapaciteta otkopavanja i posmatranog perioda eksploatacije, biće izabrane konture kopova koje će biti vodilje za projektovanje konačnog izgleda kopa sa etažama i transportnim putevima. Izgled kopa sa diskontnim faktorom R_v = 0,5 prikazan je na slici 3, a količine iskopine i sadržaji u dobijenim kopovima prikazani su u tabeli 3.



Sl. 3. *Prikaz kopa sa faktorom povraćaja R_v = 0,5*

Tabela 3. *Kopovi dobijeni optimizacijom*

Sloj	Jalovina		Mineralna sirovina		Koeficijent raskrivke	Komponenta										
	Zapremina	Moćnost	Količina	Moćnost		SiO_2	Al_2O_3	CaO	Cr_2O_3	Fe_2O_3	K_2O	MgO	Na_2O	S	SO_3	TiO_2
	m^3	m	t	m		%	%	%	%	%	%	%	%	%	%	%
Pit050	45 382	13,4	2 762 160	29,4	0,02	94,94	1,75	0,23	0,08	1,46	0,35	0,13	0,10	0,15	0,39	0,12
Pit055	506 180	14,6	3 181 270	31,0	0,16	94,95	1,74	0,23	0,08	1,47	0,35	0,13	0,10	0,15	0,39	0,12
Pit060	568 543	14,9	3 711 174	33,5	0,15	94,93	1,74	0,23	0,08	1,47	0,35	0,13	0,10	0,16	0,40	0,12
Pit065	663 217	17,2	4 097 044	35,5	0,16	94,93	1,74	0,23	0,08	1,47	0,35	0,13	0,10	0,16	0,40	0,12
Pit070	775 155	18,6	4 470 577	37,5	0,17	94,91	1,74	0,23	0,08	1,48	0,35	0,13	0,10	0,16	0,42	0,12
Pit075	881 192	19,1	4 767 366	39,3	0,18	94,90	1,74	0,23	0,08	1,48	0,35	0,13	0,10	0,17	0,42	0,13
Pit080	1 000 698	20,0	4 971 956	40,4	0,20	94,90	1,74	0,23	0,08	1,49	0,35	0,13	0,10	0,17	0,43	0,13
Pit085	1 136 021	20,5	5 129 166	41,4	0,22	94,90	1,75	0,23	0,08	1,50	0,35	0,13	0,10	0,17	0,43	0,13
Pit090	1 249 657	20,9	5 218 771	42,0	0,24	94,90	1,75	0,23	0,08	1,50	0,35	0,13	0,10	0,17	0,43	0,13
Pit095	1 347 568	21,4	5 265 960	42,4	0,26	94,80	1,76	0,23	0,08	1,50	0,35	0,13	0,10	0,17	0,43	0,13
Pit100	1 438 536	21,9	5 284 136	42,5	0,27	94,80	1,76	0,23	0,08	1,50	0,35	0,13	0,10	0,17	0,43	0,13

5. ZAKLJUČAK

U svetu se optimizacija ležišta obavlja uz pomoć računarskih programa a što je postao ustaljeni standard za brzo i kvalitetno rešavanje ove problematike. Jedan od računarskih programa kojim se određuje optimalna kontura površinskih kopova je i program *Minex 5.2.3*, proizveden u Australiji u firmi Surpac Minex Group Pty Ltd, koji se primenjuje u Institutu za rudarstvo i metalurgiju Bor. Optimizacija se vrši prema istraženim i ispitanim tehničkim i ekonomskim parametrima.

Važan činilac upotrebe programa *Minex 5.2.3* je mogućnost promene i upoređivanja više varijanti ulaznih parametara optimizacije. Takođe je značajno mnogo kraće vreme određivanja optimalne konture u odnosu na klasično projektovanje. Upotrebom ovog programa projektovanje je znatno poboljšano sa aspekta vremena i kvaliteta usled mogućnosti brze analize u cilju odabira najboljih rešenja. Primena ovog i sličnih programa postala je neminovnost i standard u projektovanju površinskih kopova.

Određivanje optimalne konture površinskog kopa je neophodan korak pri projektovanju u površinskoj eksploataciji. Osnovna karakteristika ove faze projektovanja jeste složenost i veliki broj mogućih rešenja koja odgovaraju tehničko – tehnološkim zadatim uslovima ali se međusobno razlikuju prema ekonomskom efektu. Zato je potrebno da se različita rešenja podvrgnu tehno – ekonomskoj analizi pojedinih varijanti i usvoji rešenje koje će biti optimalno za date uslove.

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DETERMINATION OF BALANCE RESERVES IN THE CALCITE DEPOSIT "KAONA" AND DETERMINATION OF OPTIMUM OPEN PIT MINE CONTOUR USING MINEX 5.2.3 PROGRAM

Abstract

This paper presents the results of optimization the calcite deposit "Kaona" using the Minex 5.2.3 computer program, or its tool the Pit Optimizer. The work of this program was present, the balance reserves were defined and optimum contours for open pit mining are determined.

Key words: *Minex 5.2.3, Optimization, balance reserves, optimum open pit contour*

1. INTRODUCTION

Development of computer technology and informatics revolution in the mid eighties of the twentieth century have resulted with the appearance of the first software packages, specialized for the fields of geology and mining. Today, these programs have evolved into extremely powerful and useful tool aimed to the time reduction required for development the geomodel of explored deposit and open pits, money saving and as more as possible detailed 3D model of ore bodies and open pits. One of these programs is Minex 5.2.3 which is a specialized program for 3D modeling exclusively of layered deposits, especially coal deposits.

Using this software, it is possible to develop a geological model of layered deposits [3, 5, 6], to model the faults [4], determine the optimum contour of open pit [7], to construct a detailed view of open pit and tailing dumps [10], to determine the dynamics of mining and tailings disposal [8, 9].

2. DESCRIPTION OF MINEX 5.2.3 PROGRAM

The starting point for work in this program are situational maps (topography for the new open pits or initial state of the open pits) in a digital format (usually in AutoCAD format) and data from prospecting boreholes on their spatial position, lithology and quality parameters in *Excel* format [1]. Based on data on drill holes, a geo-model of deposit is created bearing model [11]. Each layer in geo model has its grid (an area represented by a network of certain dimensions) of roof, floor and thickness as well as the grid quality for each observed component. Geo-model is developed using the following tools:

- *Borehole DB* – Formation the data base of boreholes for geological modeling
- *Statistical analysis* – Analysis the regularities of distribution the components in deposit

* *Mining and Metallurgy Institute Bor*

- *Seam model* – Modeling of layers and calculation of geological reserves

When the geo-model is created and initial condition of the field entered, the optimization is performed, i.e. determination of optimum contour of the open pit according to the techno - economic exploitation parameters [6, 7, 8, 9]. The resulted optimum contour is a guideline for detailed construction of open pit. This phase of design is done using the *Pit Optimizer* tool.

Using *Minex 5.2.3*, a detailed design is possible for final view of open pit and tailing dump with the transport roads and top and bottom edges of each bench as well as creating the mining dynamic using *Pit design*.

Also, development of complete mining – geological documentation is carried out using this program.

3. OPTIMIZATION USING PIT OPTIMIZER MODULE

Optimization of the open pit mine using *Minex 5.2.3* program or its tool *Pit Design Optimizer* is done by the *Pit Optimizer* option, based on the *Lerches and Grossman* algorithm [1]. The *Lerches and Grossman* algorithm is a procedure for determining the optimum open pit as one with the highest value for the corresponding set of costs and recovery factors.

Input parameters for optimization the deposit "Kaona"are:

1. Topography
2. Geo-model of deposit
3. Mass volume of mineral raw material
4. Recovery on separation
5. Unit price of ton of sand reduced to the content of SiO_2
6. Medium and minimum content of SiO_2
7. Final slope angle of open pit
8. Minimum final width of bench plane
9. Mining costs of tailings, sandstone and separation processing

Topography and geo-model of deposit were obtained by digital processing the location map of the field, which is digital interpretation of data obtained by prospecting drilling.

Mass volume of sandstone, taken to optimize the open pit, is the mean value of mass volumes in the natural state from prospecting boreholes and it is $\gamma = 1{,}716\ t/m^3$ [2].

Flotation recovery, based on participation of some sandstone classes, is 85% [2].

According to the market investigation, the unit price of one ton of sand for medium quality of deposit is 14 \$/t, or 0.15 \$ reduced to 1% S_iO_2 [2].

Medium content of SiO_2 in a deposit, according to the data from geo-model, is 94%. Lower limit of SiO_2 is adopted at 85% [2].

The assumed angle of bench slope and final angle of open pit slope are adopted based on the following physical - mechanical characteristics of working environment [2]:

- bulk density of sandstone $\gamma = 16.83$ kN/m^3,
- sandstone cohesion C = 0 kPa,
- angle of natural sandstone condition, $\varphi = 27.6°$.

The angle of bench slope for minimum safety coefficient $F_s = 1.10$, with the bench height of 10 m and final width of a bench plane of 11.4 m is 45°. The angle of final open pit slope for minimum safety coefficient $F_s = 1.30$ and maximum open pit depth of 80 m is 25° [2].

Costs of excavation the tailings, sandstone and separation processing are estimated, based on expected consumption of normative material, labor, equipment depreciation and maintenance for the required capacities and working conditions - primarily the expected transport relations for trucks from 500 m for tailings 600 m for sandstone. The estimated costs for each phase [2] are:

- ➢ Excavation of tailings: 0.47 $/m[3]
- ➢ Excavation of sandstone: 0.48 $/ m[3]
- ➢ Separation processing: 0.38 $/t

Defining the optimization parameters by MINEX 5.2.3 program is shown in Figure 1.

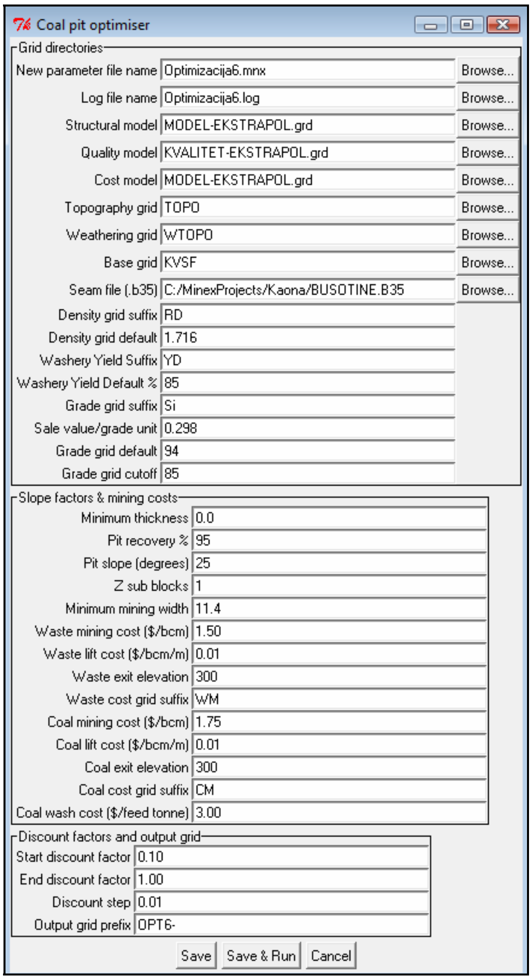

Fig. 1. *Input the optimization parameters in MINEX 5.2.3 program*

4. RESULT OF OPTIMIZATION

As the optimization result, the open pits were obtained with different amounts of excavations and different discounted value. Balance reserves are for the open with the revenue factor value R_v = 1 (revenue factor - 0.5 to 1.5 of the base price with a defined step). Open pit with balance reserves is shown in Figure 2. The quantities of balance reserves per quality classes are shown in Table 1.

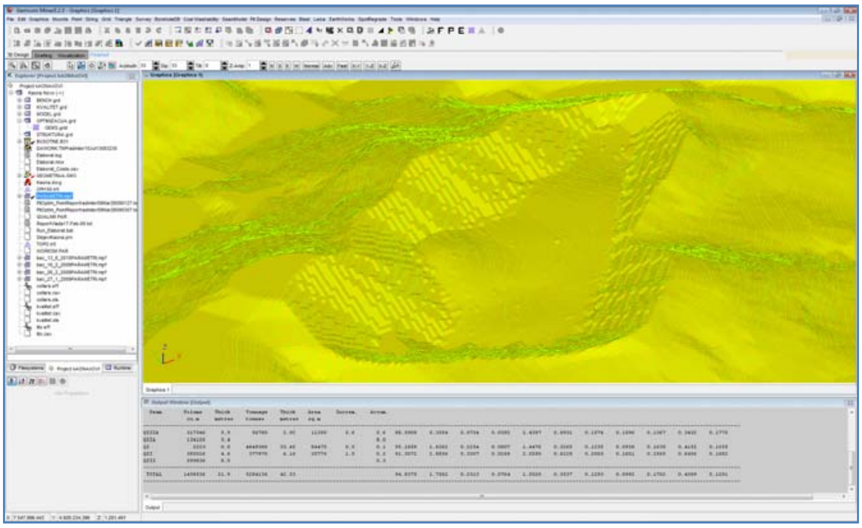

Fig. 2. *Review of open pit with the revenue factor $R_v = 1$*

Table 1. *Balance reserves of the "Kaona"calcite deposit*

Seam	Waste		Mineral raw material			Strip ratio		Component										
	Volume	Thickness	Quantity	Thickness	Area	Partial	Total	SiO_2	Al_2O_3	CaO	Cr_2O_3	Fe_2O_3	K_2O	MgO	Na_2O	S	SO_3	TiO_2
	m^3	m	t	m	m^2			%	%	%	%	%	%	%	%	%	%	%
QIIIA	317 346	5.9	56 780	2.9	11 350	5.6	5.6	88.59	5.36	0.07	0.04	2.44	0.89	0.16	0.16	0.14	0.34	0.18
QIIA	134 105	3.4	0	0.0	0	0.0	8.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
QI	2 223	0.0	4 849 386	33.5	84 475	0.0	0.1	95.19	1.63	0.23	0.08	1.45	0.33	0.12	0.09	0.16	0.42	0.13
QII	385 026	4.6	377 970	6.2	35 775	1.0	0.2	91.31	2.88	0.33	0.03	2.06	0.62	0.20	0.16	0.26	0.65	0.17
QIII	599 836	8.0	0	0.0	0	0.0	0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	1 438 536	21.9	5 284 136	42.5				94.84	1.76	0.23	0.08	1.50	35.00	0.13	0.10	0.17	0.43	0.13

Mining reserves are reduced compared to the balance of losses during excavation. These losses arise due to the appearance of overall dimensions and partings of waste within the deposit. Mining reserves are shown in Table 2.

Table 2. *Mining reserves of the "Kaona"calcite deposit*

Seam	Waste		Mineral raw material			Strip ratio		Component										
	Volume	Thickness	Quantity	Thickness	Area	Partial	Total	SiO_2	Al_2O_3	CaO	Cr_2O_3	Fe_2O_3	K_2O	MgO	Na_2O	S	SO_3	TiO_2
	m^3	m	t	m	m^2			%	%	%	%	%	%	%	%	%	%	%
QIIIA	317 346	5.9	56 780	2.9	11 350	5.6	5.6	88.59	5.36	0.07	0.04	2.44	0.89	0.16	0.16	0.14	0.34	0.17
QIIA	134 105	3.4	0	0.0	0	0.0	8.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
QI	11 016	0.0	4 834 297	33.5	84 475	0.0	0.1	95.19	1.63	0.23	0.08	1.45	0.33	0.12	0.09	0.16	0.42	0.12
QII	386 826	4.6	374 882	6.2	35 775	1.0	0.2	91.33	2.88	0.33	0.03	2.06	0.62	0.20	0.16	0.25	0.64	0.16
QIII	599 836	8.0	0	0.0	0	0.0	0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	1 449 129	21.9	5 265 959	42.5				94.84	1.76	0.23	0.08	1.50	35.00	0.13	0.10	0.17	0.43	0.12

Optimum contour of the open pit has to draw at least 50% of balance reserves. Based on the geo-model of deposit, the optimization was done for the value varia tions of discount factor of $R_{vmin} = 0.3$ do $R_{vmax} = 1.3$with a step 0.5. As the optimization result, 17 spatially defined contours of open pits were obtained with the amounts of calcite, waste, overburden coefficient and content of important parameters.

Open pit with a discount factor R_v = 0.5 has the lowest amount of excavations with more than 50% of balance reserves. Depending on the required capacity of mining and the observed exploitation period, the pit contours will be selected that will be guiding for design the final view of open pit with benches and transport roads. The view of open pit with discount factor R_v = 0.5 is shown in Figure 3, and the amounts of excavations and contents in the obtained open pits are shown in Table 3.

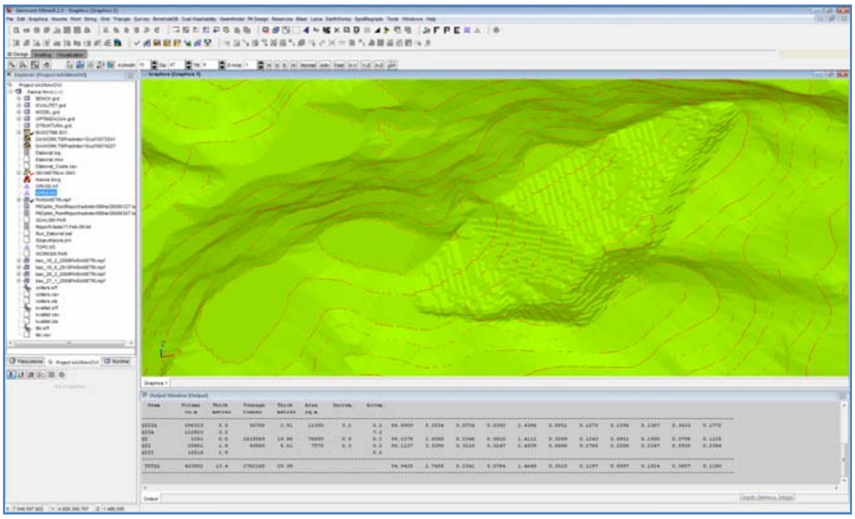

Fig. 3. *Review of the open pit with the revenue factor Rv = 0.5*

Table 3. *Open pits obtained by optimization*

Seam	Waste		Mineral raw material		Strip ratio	Component										
	Volume	Thickness	Quantity	Thickness		SiO_2	Al_2O_3	CaO	Cr_2O_3	Fe_2O_3	K_2O	MgO	Na_2O	S	SO_3	TiO_2
	m^3	m	t	m		%	%	%	%	%	%	%	%	%	%	%
Pit050	45 382	13.4	2 762 160	29.4	0.02	94.94	1.75	0.23	0.08	1.46	0.35	0.13	0.10	0.15	0.39	0.12
Pit055	506 180	14.6	3 181 270	31.0	0.16	94.95	1.74	0.23	0.08	1.47	0.35	0.13	0.10	0.15	0.39	0.12
Pit060	568 543	14.9	3 711 174	33.5	0.15	94.93	1.74	0.23	0.08	1.47	0.35	0.13	0.10	0.16	0.40	0.12
Pit065	663 217	17.2	4 097 044	35.5	0.16	94.93	1.74	0.23	0.08	1.47	0.35	0.13	0.10	0.16	0.40	0.12
Pit070	775 155	18.6	4 470 577	37.5	0.17	94.91	1.74	0.23	0.08	1.48	0.35	0.13	0.10	0.16	0.42	0.12
Pit075	881 192	19.1	4 767 366	39.3	0.18	94.90	1.74	0.23	0.08	1.48	0.35	0.13	0.10	0.17	0.42	0.13
Pit080	1 000 698	20.0	4 971 956	40.4	0.20	94.90	1.74	0.23	0.08	1.49	0.35	0.13	0.10	0.17	0.43	0.13
Pit085	1 136 021	20.5	5 129 166	41.4	0.22	94.90	1.75	0.23	0.08	1.50	0.35	0.13	0.10	0.17	0.43	0.13
Pit090	1 249 657	20.9	5 218 771	42.0	0.24	94.90	1.75	0.23	0.08	1.50	0.35	0.13	0.10	0.17	0.43	0.13
Pit095	1 347 568	21.4	5 265 960	42.4	0.26	94.80	1.76	0.23	0.08	1.50	0.35	0.13	0.10	0.17	0.43	0.13
Pit100	1 438 536	21.9	5 284 136	42.5	0.27	94.80	1.76	0.23	0.08	1.50	0.35	0.13	0.10	0.17	0.43	0.13

5. CONCLUSION

In the world, the reservoir optimization is done using the computer programs that has become the established standard for quickly and efficiently solution of this problem. One of the computer programs to determine the optimum contour of open pits is *Minex 5.2.3* program, produced in Australia in the company Surpac Minex Group Pty Ltd, which is applied in the Mining and Metallurgy Institute Bor. Optimization is done according to researched and tested technical and economic parameters.

An important factor in the use of *Minex 5.2.3* is the ability to change and compare several versions of input parameters of optimization. Also, much more less time is also important to determine the optimum contours regarding to the classic design. Using this program, the design is much improved in terms of time and quality due to the possibility of rapid analysis in order to select the best solution. The application of this and similar programs has become a necessity and standard in design of open pits.

Determining the optimum contour of the open pit is a necessary step in design and open pit mining. The main characteristic of this phase of design is the complexity and large number of possible solutions that meet the given technical – technological conditions, but they are differ mutually according to the economic effect. Therefore it is necessary to undergo various solutions to the techno - economic analysis of individual variants and adopt a solution that will be optimum for the given conditions.

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DIGITALNI 3D MODEL TERENA**

Izvod

3D model danas predstavlja standardan način za interpretaciju površina terena u digitalnom obliku. Površina terena se predstavlja matematičkim modelom koji se bazira na korišćenju pravilne mreže visina (grid) ili na korišćenju mreže nepravilnih trouglova (tin). Ovi modeli se formiraju na osnovu poznatih pozicija i visina tačaka i karakterističnih linija (strukturne i prelomne linije) površi terena.

U tom smislu, za kvalitetno formiranje digitalnog 3D modela terena, od primarnog značaja je odabir optimalnog reprezentativnog uzorka podataka koji će u pogledu količine, rasporeda i kvaliteta obezbediti modeliranje površine terena u skladu sa zahtevanom tačnošću.

Ključne reči: *3D model – vrste i izrada, grid, tin*

1. UVOD

Za savremeno planiranje i projektovanje, nije potrebna samo klasična podloga, nego je potrebno da se teren vidi trodimenzionalno. Za 3D modeliranje, bilo koje vrste terena, od primarne je važnosti imati pouzdane i ažurne ulazne podatke, odnosno adekvatno prikupljene podatke na terenu i njihovu obradu u jedan funkcionalan 3D model.

3D modeli predstavljaju matematički prikaz trodimenzionalnog prostora. U suštini radi se o skupu podataka o tačkama u 3D prostoru i drugih informacija koje računar interpretira u virtualni objekt koji se vizuelno prikazuje na monitoru ili nekom drugom izlaznom uređaju računara.

2. VRSTE 3D MODELA

Kada se govori o 3D modelima prostora najčešće se podrazumevaju digitalni model reljefa (DMR) i digitalni model terena (DMT) [1, 2].

* *Institut za rudarstvo i metalurgiju Bor*

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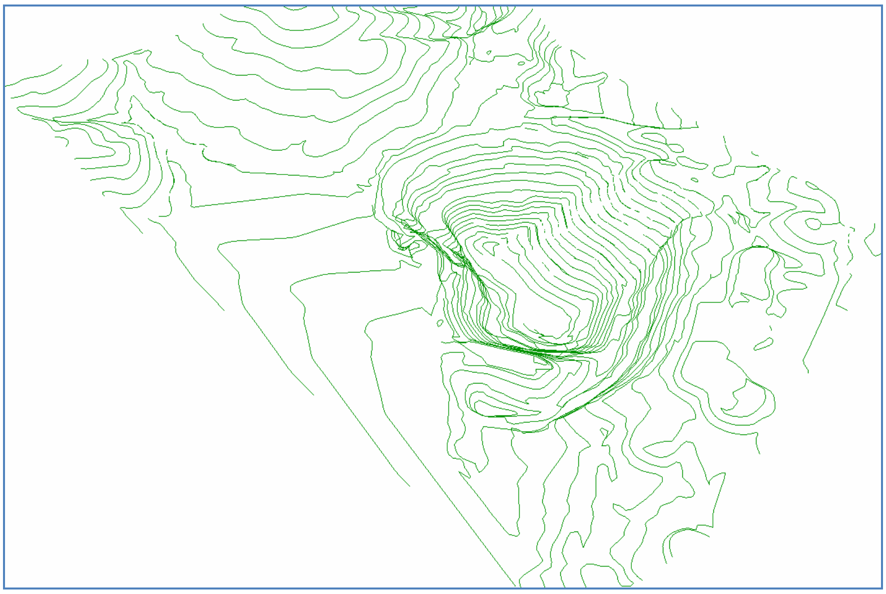
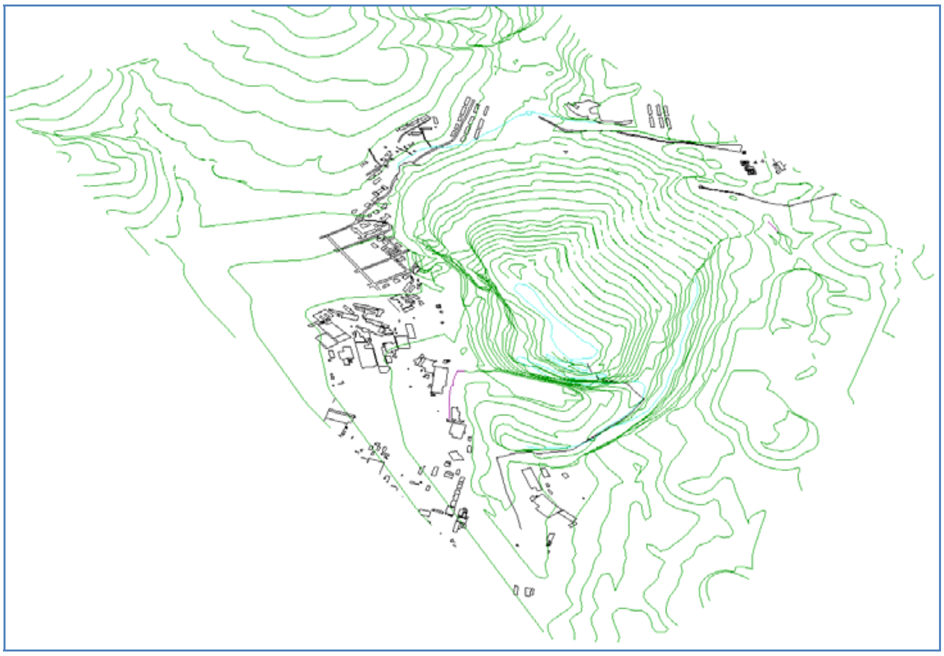
Digitalni model reljefa – DMR predstavlja skup tačaka na površini Zemlje čije su prostorne koordinate pogodne za računarsku obradu [3]. On sadrži numerički zapis položajno i visinski određenih tačaka i geometrijskih elemenata koji prikazuju reljef zemljišta. To je "čisti" model terena Zemlje bez vegetacije, građevina i drugih objekata. Digitalni model reljefa se koristi u različite svrhe. U aerofotogrametriji čini osnovu za izradu digitalnog ortofota [4]. Takođe se koristi za određivanje vidljivosti [5], za vizualizaciju [6], hidrološke analize [7], u proceni nekretnina [8] i dr. Digitalni model reljefa je definisan kao kontinualna površina u kojoj svaka tačka u položajnom smislu ima samo jednu pripadajuću visinu [9] (slika 1).



Sl. 1. *3D model reljefa*

To znači da nije moguće ispravno modelirati teren kod zahtevnih karakteristika reljefa kao što je vertikalna stena ili kod veštačkih objekata kao što su brane, mostovi, vijadukti i dr. Za tu svrhu se koristi digitalni model terena – DMT. U literaturi se upotrebljava i pojam digitalni model površine – DMP. Digitalni model terena je topografski model Zemljine površine koji uključuje objekte, vegetaciju, puteve i prirodnu površinu terena. Sadrži i druge geografske elemente (npr. vodotokve i sl.) Takođe može da uključi i ostale izvedene elemente na terenu poput nagiba, zakrivljenosti, vidljivosti i dr. On nastaje spajanjem dva modela: digitalnog modela reljefa i digitalnog modela objekata. Digitalni model objekata nastaje prikupljanjem podataka o izgrađenim objektima i najbolje se može opisati kao skup malih pojedinačnih 3D objekata koji nisu međusobno povezani.

Digitalni model terena je takođe kontinualni model, ali u kojem svaka tačka u položajnom smislu može imati jednu ili više pripadajućih visina. To se postiže spajanjem modela reljefa i objekata tako da model objekata isključuje model reljefa na mestima na kojima se nalazi i obrnuto (slika 2). Digitalni model terena koristi se u geologiji [10, 11, 12, 13], rudarstvu [14, 15, 16, 17], građevinarstvu, prostornom planiranju, i dr.

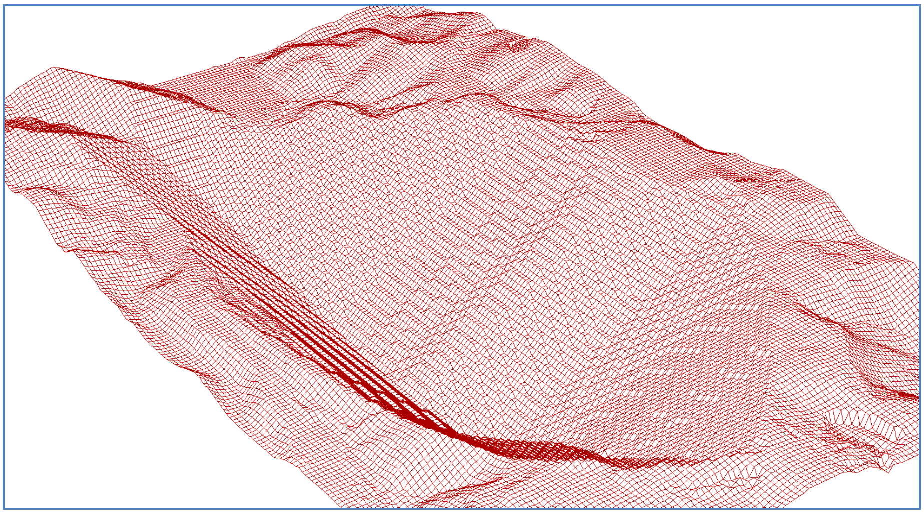


Sl. 2. *3D model terena*

3. STRUKTURA 3D MODELA

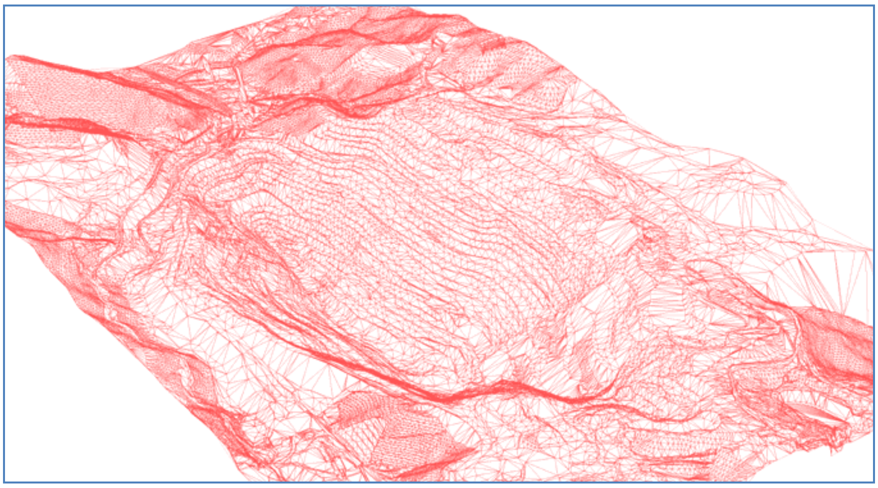
Raspored tačaka u 3D modelu može biti pravilan (*regular square grid* - RSG) i nepravilan (*triangulated irregular network* - TIN). Kod pravilnog rasporeda koristi se kvadratna mreža, a kod nepravilnog najčešće trougaona mreža [1].

Kod RSG modela kvadratna ili pravougaona mreža se postavlja preko prostora koji je predmet obrade. Vrednosti nadmorske visine (elevacije) dodeljuju se centru svake ćelije mreže, tako da mreža predstavlja uzorak smešten u prostor ograničen X i Y koordinatama, dok se vrednost Z koordinate čuva unutar ovog prostora [18] (slika 3).

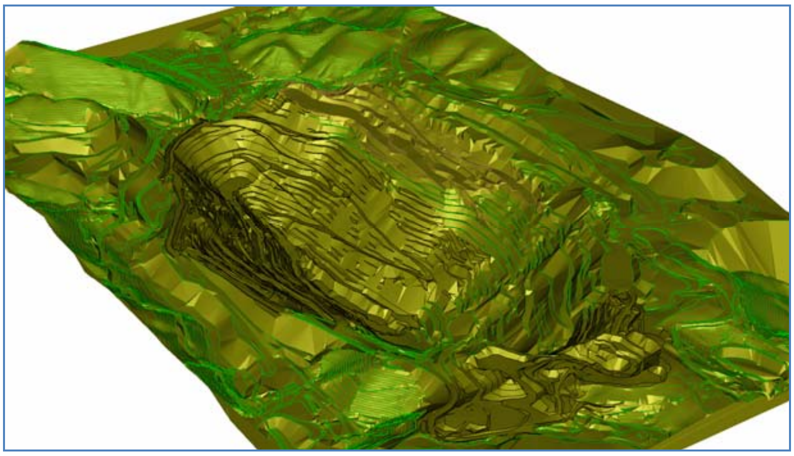


Sl. 3. *RSG model*

Kod TIN modela prostor se modelira trougaonom mrežom. Vrednosti nadmorske visine (elevacije) dodeljuju se svakom temenu trougla, tako da svaka tačka mreže ima jedinstvenu X, Y, i Z koordinatu (slika 4).



Sl. 4. *TIN model*



Sl. 5. *TIN model – SURFACE*

4. IZRADA 3D MODELA

3D modeli prostora izrađuju se iz prostornih podataka dobijenih različitim metodama: terestričkim merenjem, aerofotogrametrijom, laserskim skeniranjem, satelitima, dubinomerima i iz postojećih kartografskih podataka. Tačnost 3D modela direktno zavisi od tačnosti podataka od kojih se izrađuje.

5. TERESTRIČKA MERENJA

U terestričke metode merenja i prikupljanja 3D koordinata tačaka u prostoru ubrajaju se:

- tahimetrija
- GPS
- terestrički laserski skeneri.

Tahimetrijska metoda podrazumijeva merenje ugla i dužine između stajne i ciljne tačke totalnom stanicom, a visina ciljne tačke određuje se merenjem vertikalnog ugla ili zenitne udaljenosti [19]. Ova je metoda pogodna za izradu 3D modela prostora manjeg područja.

Kod GPS-a najčešće se primjenjuju dve metode: RTK (*Real time Kinematic*) i DGPS (*Differential* GPS). Kao i kod tahimetrijske, ove su metode pogodne za manja područja.

U novije vreme za izradu 3D modela objekata i površina na manjem području koriste se terestrički laserski skeneri. Njihov princip rada temelji se na tahimetriji, odnosno merenju horizontalnog i vertikalnog ugla i udaljenosti do pojedine tačke prostora. Rezultat je skup trodimenzionih XYZ koordinata tačaka. Ovom metodom otvorena je mogućnost prikupljanja velike količine 3D podataka o prostoru i pojedinačnih objekata i terena [20].

6. AEROFOTOGRAMETRIJA

Ovom metodom podaci o prostoru se dobijaju procesom beleženja, merenja i interpretacije vazdušnih snimaka [5]. 3D model se dobija stereofotogrametrijskom restitucijom snimaka. Metoda je pogodna za izradu digitalnog modela reljefa većih područja.

7. LASERSKO SKENIRANJE IZ VAZDUHA

Ova metoda je afirmisana u poslјednjih desetak godina kao potpuno automatizovana i izuzetno efikasna u prikupljanju prostornih podataka [21]. U literaturi se uobičajeno koristi pojam laserska altimetrija ili LiDAR (*Light Detection and Ranging*). S obzirom na veliku učestnlost merenja i do 200 kHz, u kratkom vremenu je moguće detaljno izmeriti oblik površine terena i objekata na njoj. Radi dobijanja položajnih koordinata uz laser se upotrebljava i inercijalni sistem (*Inertial Navigation System*) i GPS senzor koji istovremeno određuje položaj. Prednost ove metode je direktno dobijanje digitalnog modela terena. Takođe treba istaknuti da je metoda mnogo brža od aerofotogrametrijske i pogodna je za izradu digitaslnog modela terena većih područja.

8. SATELITI

Snimanje Zemljine površine moguće je primenom senzora smeštenih na satelitima. S obzirom na izvore energije ti uređaji mogu biti pasivni i aktivni. Pasivni uređaji registruju emitovana ili reflektovanja zračenja objekata na površini Zemlje, dok se aktivni uređaji koriste sopstvenim izvorom energije koja se odašilje prema površini Zemlje, odakle se njen reflektovan deo prima i registruje. Najčešće primenjivani podaci u praksi za izradu digitalnog modela reljefa jesu podaci SRTM-a (*Shuttle Radar Topography Mission*). Satelitskim metodama mogu se izrađivati 3D modeli velikih područja, ali sa smanjenom tačnošću.

9. DUBINOMERI

Dubinomeri se koriste za merenje dubina i izradu 3D modela morskog dna. Osim na moru ova metoda se primenjuje i na kopnu kod reka, jezera i dr.

10. POSTOJEĆI KARTOGRAFSKI PODACI

Iz postojećih analognih kartografskih podataka moguće je izrađivati digitalni model reljefa i digitalni model terena. U tu svrhu je s analognih izvora potrebno digitalizovati izohipse i kote prikazanih karakterističnih tačaka. Izohipse su na analognoj karti prikazane kao linije sa određenom elevacijom.

Svaka izohipsa sadrži beskonačan broj tačaka na istoj visini. Kod digitalizacije izohipsa se vektorizuje određenim brojem tačaka. Najčešće se radi o tačkama infleksije uzduž izohipse [22], a pravilo je da digitalna izohipsa ne sme odstupati od njene odgovarajuće analogne izohipse.

ZAKLJUČAK

3D interpretacija terena predstavlja izuzetnu pomoć za proces projektovanja u geologiji, rudarstvu, građevinarstvu i dr. Tu se pre svega misli na početnu fazu projektovanja, koja podrazumeva potrebu projektanta da stekne utisak o geografskim osobinama terena i bez neposrednog izlaska na lokaciju, kao i osnovu za analize i proračune u namenskim softverima.

Primarni uslov za pravilno formiranje digitalnog 3D modela terena je kvalitetna baza i pravilan izbor totpografskih podataka i podataka o objektima, koji će u pogledu količine, rasporeda i kvaliteta obezbediti modeliranje površine terena u skladu sa zahtevanom tačnošću.

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DIGITAL 3D TERRAIN MODEL**

Abstract

Nowadays, 3D model today is the standard way for interpretation the terrain surfaces in a digital form. Terrain surface is present by a mathematical model, based on the use of proper height grid or the use of irregular triangles grid (TIN). These models are formed on the basis of known position and point height and characteristic lines (structural and break lines) of the terrain surface.

In this sense, the optimum selection of a representative sample of data has a primary importance for quality formation of digital 3D terrain model, which will provide the quantity, distribution and quality modeling of the terrain surface in accordance with the required accuracy.

Key words: *3D model - types and development, grid, tin*

1. INTRODUCTION

For modern planning and design, the classic background is not only required, but a three-dimensional view of a terrain is needed.

For 3D modeling of any type of terrain, having the reliable and accurate data entry is of the primary importance that is the adequate collected data in the field and their processing in a functional 3D model.

3D models present a mathematical view of three-dimensional space. In essence, it is a set of data on points in 3D space, and other information that the computer interprets into virtual object to be visually displayed on a monitor or other computer output device.

2. TYPES OF 3D MODEL

When 3D models of space are discussed, a digital relief model (DMR) is usually included as well as a digital terrain model (DTM) [1, 2].

Digital terrain model - DMR is the set of points on the earth surface with suitable spatial coordinates for computer processing [3]. It contains a numeric entry in degree

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and height of certain points and geometric elements that show the relief of land. This is a "pure" model of the Earth without ground vegetation, buildings and other structures. Digital terrain model is used for different purposes. It forms, in the aerialphotogrametry, the basis for production the digital orthophoto [4]. It is also used to determine the visibility [5], for visualization [6], hydrological analysis [7], in the assessment of property [8] and others. Digital relief model is defined as a continuous surface where each point in the terms of degree has only one corresponding height [9] (Figure 1).

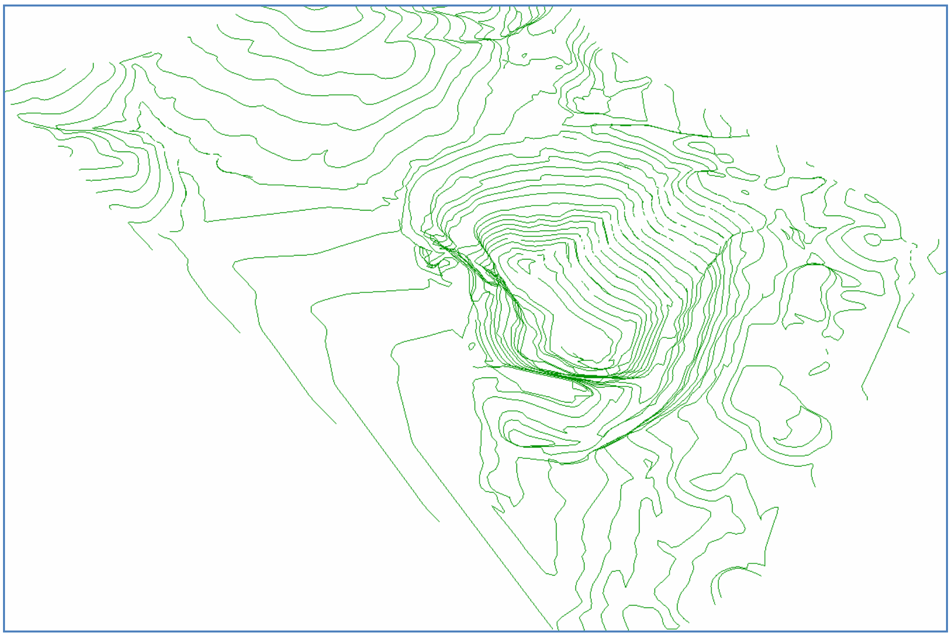

Fig. 1. *3D model of relief*

This means that it is not possible to model properly the terrain for the required terrain features such as vertical rock or in vertical artificial structures such as dams, bridges, viaducts, etc. For this purpose, the digital terrain model – DMT is used. The literature uses the term digital surface model - DMS. Digital terrain model is a topographic model of the Earth surface, which includes buildings, vegetation, roads and natural terrain surface. It also includes other geographic elements (e.g. watercourses etc.). It may also include other derived elements in the field such as slope, curvature, visibility, etc. It is created by merging two models: a digital terrain model and digital model of structures. Digital model of structures is created by data collecting on the built facilities and it can best be described as a collection of small individual 3D objects that are not interconnected.

Digital terrain model is also a continuous model, but in which every point in the sense in degree may have one or more corresponding heights. This is achieved by connecting relief model and objects such as the object model excludes the relief model in places where there is, and vice versa (Figure 2). Digital terrain model is used in geology [10, 11, 12, 13], mining [14, 15, 16, 17], civil engineering, spatial planning, and others.

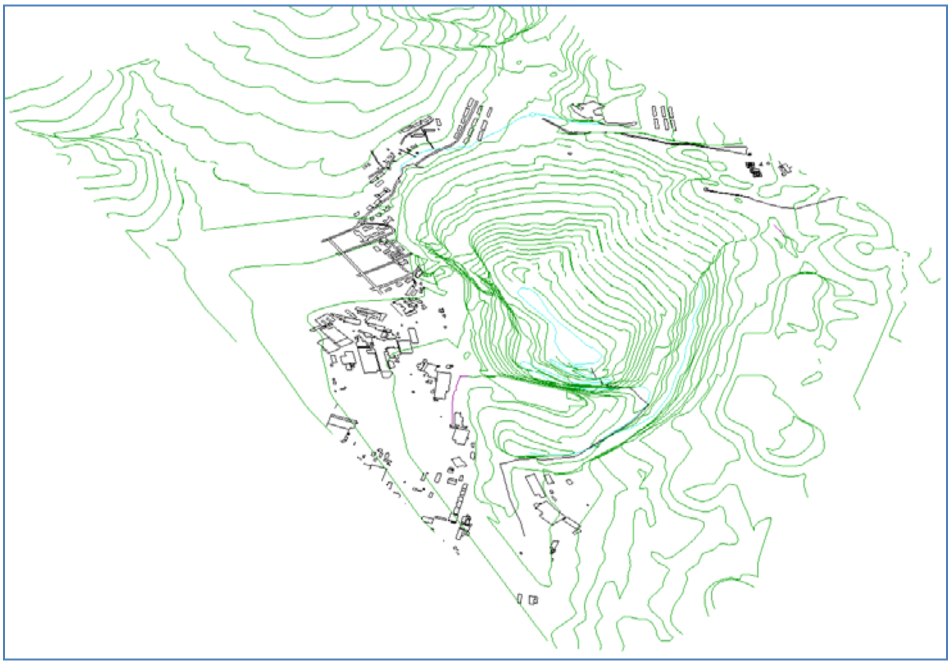

Fig. 2. *3D model of terrain*

3. STRUCTURE OF 3D MODEL

Distribution of points in 3D model may be regular (*regular square grid* - RSG) and irregular *(triangulated irregular network* - TIN). Regular distribution used the square grid, and irregular often uses the triangular grid [1].

In RSG model, the square or rectangular grid is placed over the area which is the subject of processing. The values of altitude (elevation) are assigned to the center of each cell of grid, so the grid presents a sample, placed in the space limited by X and Y coordinates, while the value of Z coordinate is kept within this space [18] (Figure 3).

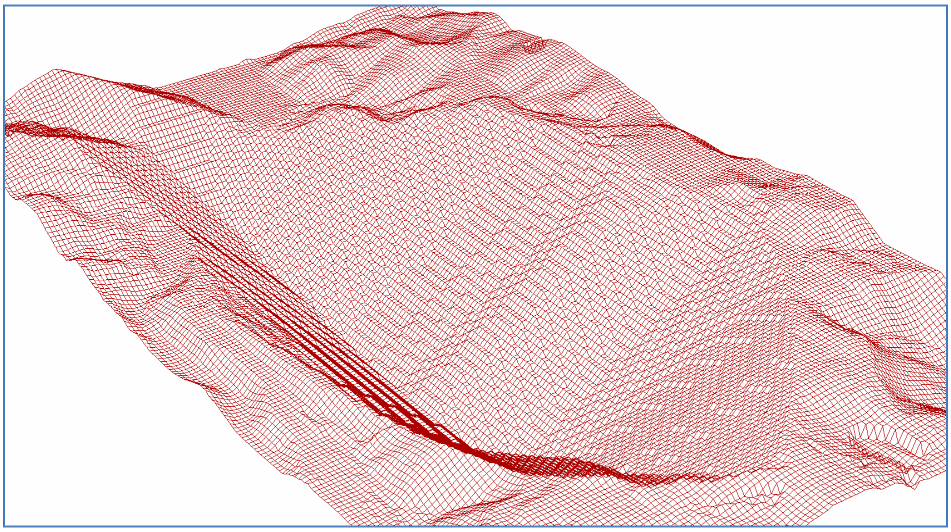

Fig. 3. *RSG model*

In TIN model, the space is modeled by triangular grid. The values of altitude (elevation) are assigned to each triangle top, so that each point of grid has the unique X, Y, and Z coordinates (Figure 4).

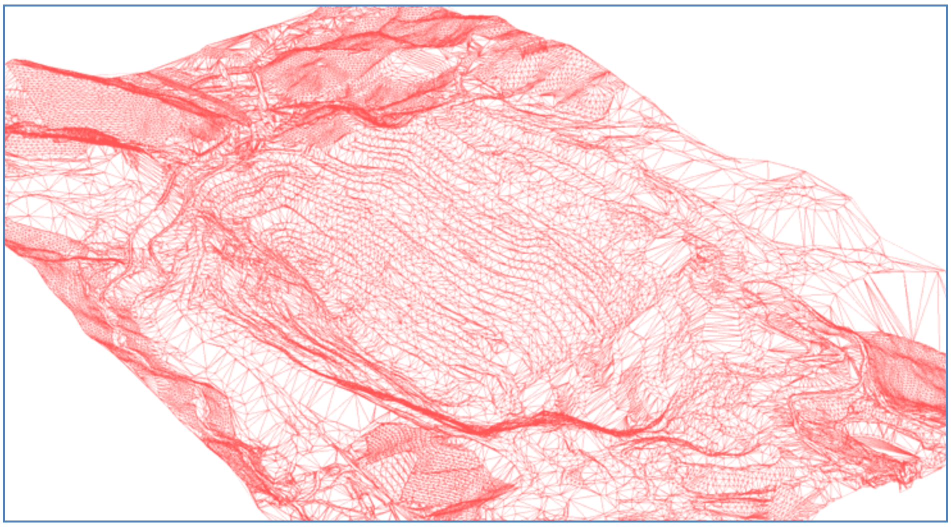

Fig. 4. *TIN model*

Figure 5 shows 3D model of terrain in software Gemcom 6, where TIN model is interpreted as SURFACE (Figure 5).

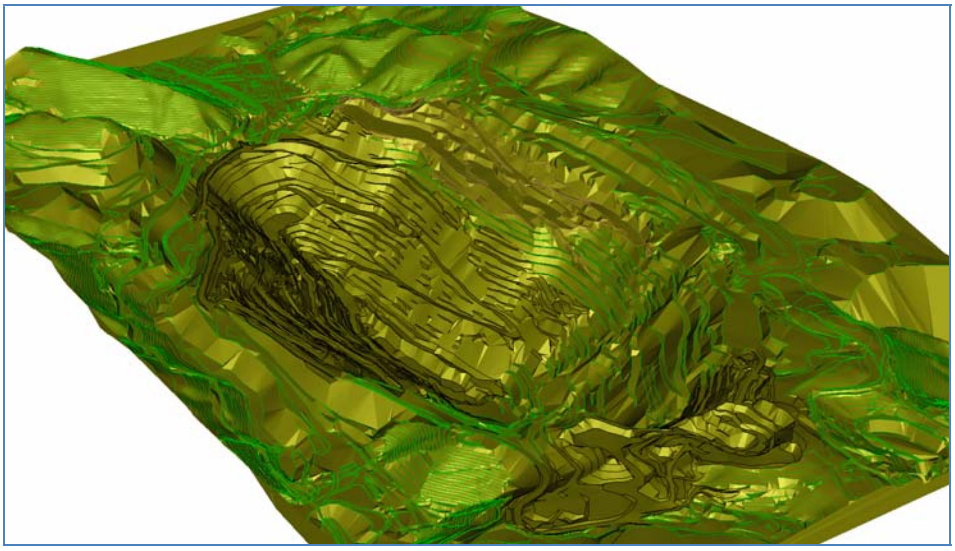

Fig. 5. *TIN model – SURFACE*

4. DEVELOPMENT OF 3D MODEL

3D models of space are made from spatial data obtained by different methods: terrestrial measurements, aerialphoto-grammetry, laser scanning, satellites, sounders and from the existing mapping data. The accuracy of 3D model directly depends on data accuracy of development.

5. TERRESTRIAL MEASUREMENTS

Terrestrial methods of measurements and collections the 3D coordinates of points in space include:

- tachometry
- GPS
- terrestrial laser scanners

Tachometrial method involves measuring the angle and distance between the landing and target point using the total station, and height of target point is determined by measuring the vertical angle or zenithal distance [19]. This method is suitable for development the 3D models of small areas of space.

In GPS, two methods are usually applied: RTK *(Real Time Kinematic)* and DGPS *(Differential GPS).* As with tachometrial method, these methods are suitable for smaller areas.

In recent times, terrestrial laser scanners are used in development 3D models of objects and surfaces in a small region.

Their operating principle is based on tachometry or measuring horizontal and vertical angle and distances to each point of space. The result is a set of three-dimensional XYZ coordinates of points. This method opened the possibility of collecting large amounts of 3D spatial data and individual buildings and grounds [20].

6. AERIALPHOTOGRAMETRY

Using this method, the data of space are obtained by the process of recording, measuring and interpreting the aerial images [5]. 3D model is obtained by steophotogrammetrial restitution of images. The method is suitable for development the digital terrain model of larger areas.

7. LASER SCANNING FROM THE AIR

This method has been affirmed in the last ten years as fully automated and highly efficient in collecting spatial data [21]. In the literature, the term laser altimetry or LiDAR *(Light Detection and Ranging)* is commonly used. Regarded to high frequency of measuring up to 200 kHz, in a short time, it is possible to measure in detail the form of terrain surface and objects on it. To obtain the positional coordinates, with laser, also the inertial system *(Inertial Navigation System)* and GPS sensor are used that determines the position at the same time. The advantage of this method is directly obtaining a digital terrain model. It should be also noted that the method is much faster than the aerialphotogrammetry method and suitable for development the digital terrain model of larger areas.

8. SATELLITES

Recording the Earth surface is possible using the sensors placed on satellites. Regarding to the energy sources, these devices can be passive and active. Passive devices register the emitted or reflecting radiations of objects on the Earth surface, while the active devices are used by their own source of energy that is emitted to the Earth surface, where it receives and registers its reflected part. The most common applied data in practice for development a digital terrain model are SRTM *(Shuttle Radar Topography Mission)* data. Satellite methods can generate 3D models of large areas, but with reduced accuracy.

9. SOUNDERS

Sounders are used to measure the depth and formation of 3D model of the seabed. Besides the sea, this method is also applied on the land of rivers, lakes, etc.

10. THE EXISTING MAP DATA

It is possible to develop a digital relief model and digital terrain model from the existing analogue map data. For this purpose, it is necessary to digitalize the contour lines and elevations of shown characteristic points from the analogue sources. Contour lines are shown on the analogue map as lines with a certain elevation.

Each contour line includes an infinite number of points at the same height. In digitizing, the contour line is vectorized by a certain number of points. Most often these are inflection points along the contour line [22], the rule is that digital contour must not deviate from its corresponding analogue contour lines.

CONCLUSION

3D interpretation of terrain is excellent support for the design process in geology, mining, construction and others. This is primarily connected to the initial phase of design, which implies the need for designers to gain an impression on geographic features of terrain and without directly entering the site, as well as the basis for analysis and calculations in the utility software.

Primary condition for regular formation the digital 3D terrain model is quality base and regular selection of topographic data and data on structures, which will provide the quantity, distribution and quality modeling of the terrain surface in accordance with the required accuracy.

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TRODIMENZIONALNI ASPEKTI ANALIZE STABILNOSTI KOSINA****

Izvod

Analiza stabilnosti kosina je u suštini trodimenzionalni problem. To je neposredna posledica nepravilnog oblika kliznog tela i posebno se odnosi na brojna klizišta u Srbiji. Međutim, sve do danas, nije razvijen opšti postupak trodimenzionalne analize stabilnosti koji bi važio za klizna tela proizvoljnog oblika. Umesto toga, najčešće se vrši dvodimenzionalna analiza kritičnog poprečnog preseka trodimenzionalnog kliznog tela. Međutim, ako su bočni tj. trodimenzionalni efekti kosine značajni, onda i njih treba uključiti u analizu stabilnosti. U ovom radu je prikazan aproksimativni postupak koji uvodi trodimenzionalne efekte u proračun stabilnosti, i polazeći od toga, urađena je trodimenzionalna analiza stabilnosti klizišta „Sebečevac“. U slučaju kada su trodimenzionalni efekti značajni, njihovo uključivanje u analizu omogućava da se dobiju realniji podaci o stabilnosti kosina. To je od posebnog značaja prilikom određivanja sanacionih mera kod klizišta.

***Ključne reči**: analiza stabilnosti kosina, trodimenzionalni aspekti, aproksimativni postupak.*

UVOD

Prilikom analize stabilnosti kosina bitno je da se problem pravilno postavi, a zatim i da se reši na adekvatan način. Ovo zahteva, pre svega, poznavanje geološko-geotehničkih karakteristika terena a posebno oblika kliznog tela, čvrstoće smicanja duž klizne površine i stanja podzemnih voda. U vezi sa tim treba istači da, u najvećem broju slučajeva, klizišta u Srbiji jako zavise od geoloških uslova u terenu. Tako na primer, kao posledicu regionalnih geoloških procesa, koji su se odigravali u toku stvaranja sadašnje

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**** *Ovaj rad je proizašao iz projekta TR 36014 "Geotehnički aspekti istraživanja i razvoja savremenih tehnologija građenja i sanacija deponija komunalnog otpada" koji finansira Ministarstvo za prosvetu i nauku Republike Srbije*

konstrukcije terena, suočavamo se sa činjenicom da se aktivnost brojnih klizišta, u dugom periodu njihovog razvoja, periodično ponavlja i to manje ili više duž postojećih kliznih površina. Polazeći od toga, treba da se vrši detaljno proučavanje svakog pojedinačnog klizišta, analizira njihova stabilnost i definišu optimalne sanacione mere, (Lokin, P., Ćorić, S.) [1].

OSNOVNE POSTAVKE ANALIZE STABILNOSTI

Analize stabilnosti kosina i određivanje realne vrednosti faktora sigurnosti su, u suštini, trodimenzionalni problemi. Ovo je posledica nepravilnog oblika kliznog tela i to je posebno karakteristično za mnoga klizišta u Srbiji (Ćorić, S., Čaki, L., Rakić, D.) [2]. Međutim, sve do danas, nije razvijen opšti postupak trodimenzionalne analize stabilnosti (3D) koji bi analizirao kliznu površinu nepravilnog oblika i bio dovoljno jednostavan za primenu u geotehničkoj praksi (Cheng and Yip) [3]. Umesto toga, obično se vrše dvodimenzionalne analize stabilnosti (2D) i to na kritičnom poprečnom preseku trodimenzionalnog kliznog tela tj. onom preseku koji ima minimalni faktor sigurnosti.

Analize stabilnosti mogu da se vrše u dreniranim ili nedreniranim uslovima. Izbor merodavnih uslova zavisi od stepena konsolidacije, odnosno od veličine vremenskog faktora

$$T = \frac{C_v \cdot t}{P^2} \qquad (1)$$

gde je:

T - vremenski faktor

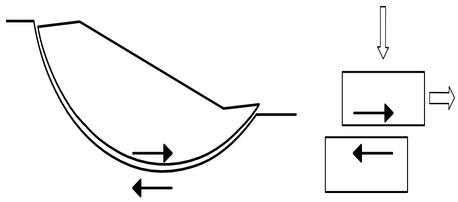
c_v - koeficijent konsolidacije

t - vreme građenja (opterećivanja)

P - dužina putanje dreniranja

Kada je T > 3.0 treba vršiti dreniranu, a kada je T ≤ 0.1 nedreniranu analizu stabilnosti. Za T između ovih dveju vrednosti trebalo bi vršiti obe analize. U vezi sa tim naglašavamo da su kod prirodnih kosina, u našim geološko-geotehničkim uslovima, klizanja najčešće posledica povećanja nivoa podzemne vode u kišnom periodu i takvi slučajevi se analiziraju u dreniranim uslovima.

Čvrstoća smicanja, duž kliznih površina, najčešće se određuje laboratorijski: iz opita direktnog smicanja i/ili rotacionog smicanja. Međutim, ukoliko je već došlo do smicanja, onda se čvrstoća smicanja može da odredi i povratnom analizom. U tom slučaju, klizište se tretira kao opit smicanja u stvarnoj razmeri (slika 1)



Sl. 1. *Princip određivanja čvrstoće smicanja iz povratne analize [4]*

Naglašavamo da je u relativno homogenim sredinama, na mnogobrojnim primerima, pokazano da se čvrstoće dobijene iz laboratorijskih opita i povratne analize poklapaju u opsegu tačnosti ±10% (Rakić, D., Čaki, L., Ćorić, S., Ljubojev, M.) [5]. Tako da se, sa pouzdanjem, može vršiti poređenje između čvrstoća dobijenih na ova dva načina. Saglasno tome, u slučajevima kada nije moguće dobijanje neporemećenih uzoraka iz klizne površine, povratna analiza predstavlja jedino efikasno sredstvo za određivanje čvrstoće smicanja tla. Kao uslov loma, duž klizne površine, po pravilu se usvaja Kulon-Morov kriterijum loma koji se linearizuje u opsegu merodavnih napona.

Analize stabilnosti treba da se vrše metodama granične ravnoteže koje zadovoljavaju sve uslove ravnoteže kliznog tela. Takve metode su: Janbuova opšta metoda, Morgenstern-Prajsova, Maksimovićeva i Fridland–Krenova metoda (Ćorić, S.) [6]. U kontekstu osnovnih postavki metoda granične ravnoteže one daju vrednosti faktora sigurnosti koje se ne razlikuju za više od ±6% od tkz. “tačne” vrednosti (Duncan) [7]. One su sasvim prihvatljive za geotehničku praksu, jer i geometrija kliznog tela, porni pritisci i čvrstoća smicanja retko mogu da se odrede sa tačnošću do ±6%. Tako da ako inženjer – geotehničar vrši analizu stabilnosti kosina, korišćenjem metoda koje zadovoljavaju sve uslove ravnoteže, on može da bude siguran da:

- izračunata vrednost faktora sigurnosti jeste “tačna” s obzirom na mehanizam klizanja i
- može da usmeri svoju pažnju na što bolju procenu svojstva tla i određivanje mera sanacije.

Međutim, opravdano se može da postavi pitanje tačnosti 2D analize u rešavanju 3D problema. Nedavna istraživanja (Duncan, and Wright) [8] jasno pokazuju da su faktori sigurnosti, sračunati korišćenjem 3D analize, veći od onih koji se dobijaju korišćenjem 2D analize. U ovom zaključku se podrazumeva da je 2D analiza vršena na kritičnom preseku 3D potencijalnog/stvarnog kliznog tela. Pri tome, greška koja je posledica primene 2D analize na 3D klizno telo nije velika i, u najvećem broju slučajeva, manja je od 10%.

Na osnovu toga, jasno je da 2D analize daju unekoliko konzervativne vrednosti faktora sigurnosti i stoga predstavljajuju realan i dovoljno tačan pristup u rešavanju najvećeg broja praktičnih problema analize stabilnosti kosina. Međutim, treba znati da čvrstoće smicanja, sračunate iz povratne 2D analize, daju vrednosti koje nisu konzervativne tj. nisu na strani sigurnosti. A poznavanje što tačnijih vrednosti čvrstoće smicanja ima veliki značaj, jer se one koriste kod proračuna sanacionih mera na klizištima. Stoga, kada su trodimenzionalni efekti padine značajni, onda i njih treba uključiti u analizu stabilnosti.

TRODIMENZIONALNI ASPEKTI ANALIZE STABILNOSTI

Kada su bočni efekti kosine značajni tada 2D analiza stabilnosti nije adekvatna i 3D efekti treba da se uzmu u obzir. Naravno da to zavisi, pre svega, od oblika kliznog tela i o tome u svakom konkretnom slučaju odluku donosi inženjer–geotehničar. U vezi sa tim treba reći da iako ne postoje tačne metode za 3D analizu složenog kliznog tela, ipak postoje postupci kojima se 3D efekti mogu da uvedu u proračun stabilnosti. Ovo ćemo ukratko prikazati u nastavku teksta.

Ponderisanje faktora sigurnosti

Lambe and Whitman [9] su predložili da se analizira nekoliko karakterističnih paralenih preseka kroz klizno telo (slika 2), da se zatim odredi faktor sigurnosti za svaki presek i da se onda izračuna ponderisana vrednost faktora sigurnosti F_s. Tako da bi se, u slučaju tri poprečna preseka, dobilo da je faktor sigurnosti kliznog tela jednak:

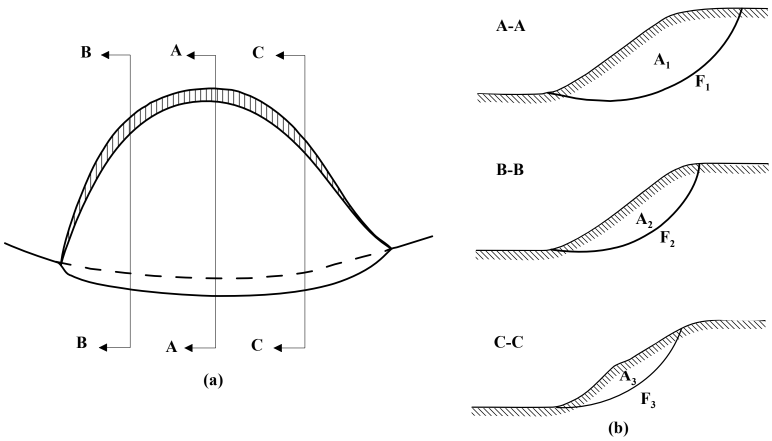
$$F_s = \frac{F_{s1} \cdot A_1 + F_{s2} \cdot A_2 + F_{s3} \cdot A_3}{A_1 + A_3 + A_3} \qquad (2)$$

gde je:

F_s – ponderisani faktor sigurnosti kliznog tela

F_{s1}, F_{s2}, F_{s3} – faktori sigurnosti poprečnih preseka A-A, B-B, C-C

A_1, A_2, A_3 – površine poprečnih preseka A-A, B-B, C-C



Sl. 2. *Aproksimacija trodimenzionalnih efekata ponderisanjem faktora sigurnosti*

Redukcija smičućeg napona

Skempton [10] predlaže da se, pošto se izvrši 2D analiza na kritičnom poprečnom preseku, izvrši redukcija smičućeg napona u kliznoj površini količnikom

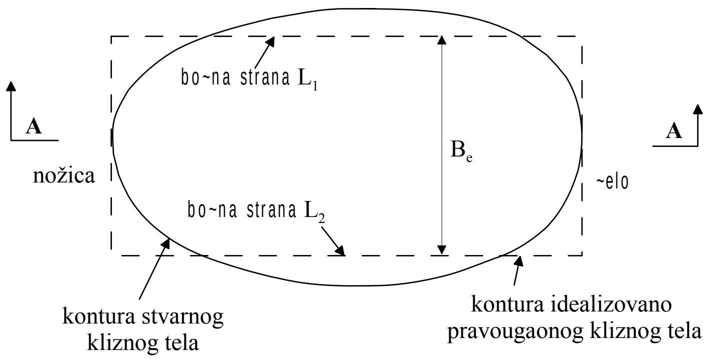
$$\frac{1}{1+K\cdot\frac{H}{B}} \tag{3}$$

gde je:

H – prosečna visina kliznog tela
B – prosečna širina kliznog tela
K – koeficijent bočnog pritiska tla

Aproksimacija geometrije kliznog tela

Trodimenzionalna analiza stabilnosti može da se vrši i tako što će se stvarno klizno telo aproksimirati ekvivalentnim – geometrijski idealizovanim kliznim telom (slika 3.) za koje će se izračunati trodimenzionalni faktor sigurnosti (Ćorić, S., Čaki, L., Rakić, D.) [11]. Polazeći od toga, predlažemo da se na sledeći način odrede dvodimenzionalni F_s^{2D} i trodimenzionalni faktor sigurnosti F_s^{3D}.



Sl. 3. *Aproksimacija stvarnog kliznog tela ekvivalentnim geometrijski idealizovanim kliznim telom*

Dvodimenzionalni faktor sigurnosti F_s^{2D} karakterističnog poprečnog preseka A-A je

$$F_s^{2D} = \frac{R}{D} \qquad (4)$$

gde je:

F_s^{2D} – faktor sigurnosti poprečnog preseka A-A

R – otporne sile ili momenti

D – gurajuće sile ili momenti

Trodimenzionalni faktor sigurnosti ekvivalentnog kliznog tela F_s^{3D} određuje se iz jednačine

$$F_s^{3D} = \frac{B_e \cdot \vec{R} + R_{L1} + R_{L2}}{B_e \cdot D} = F_s^{2D} + \frac{R_{L1} + R_{L2}}{B_e \cdot D} \qquad (5)$$

gde je:

F_s^{3D} - faktor sigurnosti ekvivalentnog kliznog tela

B_e - širina ekvivalentnog kliznog tela

R_{L1} - otporne sile ili momenti duž bočne strane L_1

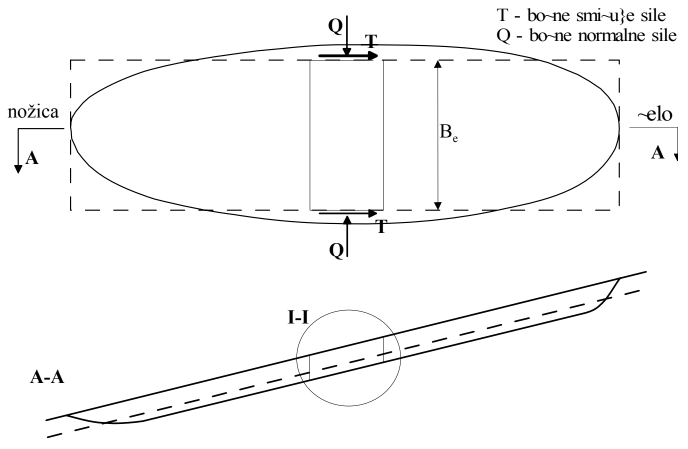
R_{L2} - otporne sile ili momenti duž bočne strane L_2

Ova metoda može da se primeni i na dreniranu i na nedreniranu analizu stabilnosti i to kako za kružne tako i za složene klizne površine (Ćorić, S., Čaki, L., Rakić, D.) [12]. Naravno da primena ove metode zahteva dobru inženjersku procenu prilikom aproksimacije stvarnog/potencijalnog klizišta ekvivalentnim kliznim telom.

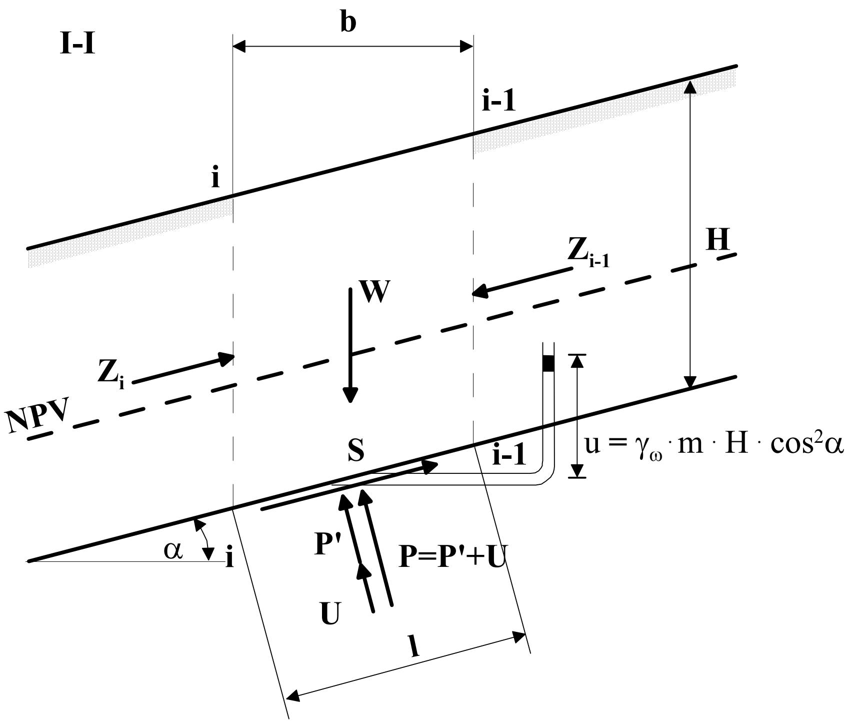
U nastavku teksta prikazaćemo aproksimaciju beskonačne kosine pravilnim kliznim telom i proračun faktora sigurnosti F_s^{3D}.

TRODIMENZIONALNA ANALIZA STABILNOSTI BESKONAČNE KOSINE

U mnogim slučajevima, npr. u terenima sa razvijenom zonom raspadanja, klizna površina leži plitko i paralelna je površini terena. To je, na primer, karakteristično za klizišta u naseljima Medaković i Mirijevo u Beogradu. U takvim slučajevima klizna površina je, po pravilu, dugačka u odnosu na debljinu kliznog tela i stoga se analiza stabilnosti može da vrši kao za beskonačnu kosinu. Takva analiza zanemaruje međulamelarne sile (Z_i, Z_{i-1}) kao i otporne i gurajuće sile na donjem i gornjem kraju kliznog tela (Slika 4 i Slika 5).



Sl. 4. *Aproksimacija beskonačne kosine ekvivalentnim geometrijski idealizovanim kliznim telom*



Sl. 5. S*ile koje deluju na lamelu beskonačne kosine slučaj dvodimenzionalne analize stabilnosti [5]*

Dvodimenzionalni faktor sigurnosti F_s^{2D} u preseku A-A je:

$$F_s^{2D} = \frac{c + H \cdot \cos^2 \alpha \cdot (\gamma_z - \gamma_w \cdot m) \cdot tg\varphi}{\gamma_z \cdot H \cdot \sin \beta \cdot \cos \alpha} \quad (6)$$

gde je:

- c, φ - parametri čvrstoće smicanja duž klizne površine
- α - nagib kosine
- γ_z - zapreminska težina zasićenog tla
- γ_w - zapreminska težina vode
- H - visina kosine
- $m{\cdot}H$ - visina od klizne površine do nivoa podzemne vode ($0 \leq m \leq 1$)

Trodimenzionalni faktor sigurnosti F_s^{3D}, u koji su uključeni uticaji bočnih nomalnih Q i smičućih T sila, je:

$$F_s^{3D} = \frac{1}{\sin\alpha} \cdot \left\{ \left(\frac{1}{H \cdot \cos\alpha} + \frac{2}{B_e} \right) \cdot \frac{c}{\gamma_z} + \left[\cos\alpha \cdot \left(1 - m \cdot \frac{\gamma_w}{\gamma_z} \right) + \frac{K \cdot H}{B_e} \cdot \left(1 - m^2 \cdot \frac{\gamma_w}{\gamma_z \cdot \cos^2 \alpha} \right) \right] \cdot tg\varphi \right\} \quad (7)$$

gde je:

K – koeficijent bočnog pritiska tla

Za dreniranu analizu stabilnosti u jednačinama (6) i (7) koriste se efektivni parametri čvrstoće smicanja tj.

$$c = c'; \quad \varphi = \varphi' \tag{8}$$

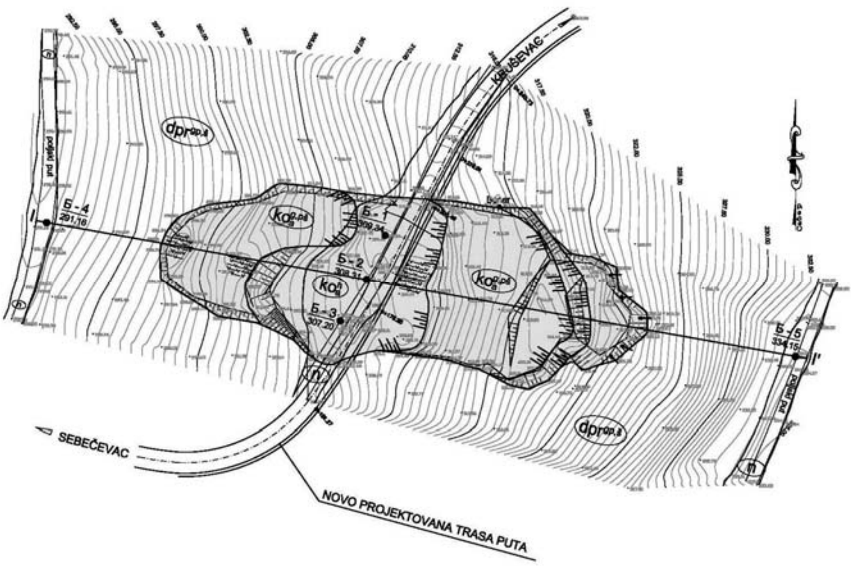
Za nedreniranu analizu stabilnosti u jednačinama (6) i (7) koriste se ukupni parametri čvrstoće smicanja tj.

$$c = c_u; \quad \varphi = \varphi_u = 0 \tag{9}$$

U nastavku teksta prikazaćemo aproksimaciju klizišta "Sebečevac" ekvivalentnim kliznim telom i proračune faktora sigurnosti F_s^{2D} i F_s^{3D}.

TRODIMENZIONALNA ANALIZA STABILNOSTI NA PRIMERU KLIZIŠTA "SEBEČEVAC"

Klizište „Sebečevac" se nalazi na lokalnom putu Sebečevac - Kupci. Formirano je na desnoj dolinskoj padini potoka koji pripada slivu reke Pepeljuše. Nagib prirodne padine je između 8^0 i 14^0. Klizište je zahvatilo planum puta i padinu iznad i ispod puta u dužini od oko 90-115 m sa jasno vidljivim granicama. Deformacije su u vidu ulegnuća, istrbušenja i otvorenih pukotina zeva do 20 cm i na površini su brojna zabarenja. Čeoni ožiljak je na padini iznad puta i udaljen je oko 50 m od osovine puta. Nožica klizišta se nalazi na padini ispod puta, i od njega je udaljena oko 40 m (slika 6). Do klizanja je došlo početkom 2006 god., posle velikih padavina i naglog topljenja snega, kada je čitavo klizno telo bilo vodom zasićeno sa brojnim zabarenjima na površini terena [13].

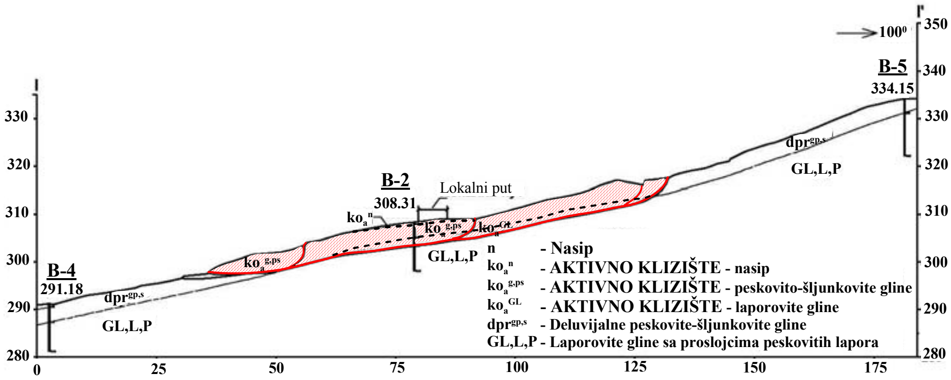


Sl. 6. *Situacioni plan klizišta "Sebečevac"*

Litološke sredine, zahvaćene kliženjem, su heterogene po sastavu i fizičko-mehaničkim svojstvima. Veći deo klizišta čine gline peskovito-šljunkovite, deluvijano-proluvijanog porekla (d-pr^{gp,š}). U čeonim i centralnim delovima klizišta, kliženjem je zahvaćena i fizičko -hemijski izmenjena zona jezerskih sedimenata - laporovitih glina sa proslojcima peskovitih lapora, poluvezanih peščara i šljunkovitih peskova (GL, L, P).

Maksimalna debljina klizišta je oko 5.0 m. Materijal je pretežno jače provlažen do vodozasićen (izmerene prirodne vlažnosti i do 37%), sa granicom tečenja w_l = 44-90%, indeksom plastičnosti I_p = 25-61%, indeksom konsistencije I_c = 0.72-1.0. Parametri čvrstoće smicanja su: vršne vrednosti φ' = 21^0-29^0 i c' = 22-28 kPa, a rezidualne φ_r = 19^0 i c_r = 0 kPa. Po USCS klasifikaciji spada u grupe CL i CH.

Na karakterističnom geotehničkom preseku terena I-I` (Slika 7) urađena je dvodimenzinalna povratna analiza stabilnosti (za F_s^{2D} = 1.0) sa sledećim ulaznim podacima H = 5.0 m, α = 11^0, m = 1, γ_z = 21 kN/m^3, c'_r = 0. Na ovaj način dobijena je vrednost mobilisanog ugla unutrašnjeg trenja $\varphi'_{usl}{}^{2D}$ = 20.4^o.



Sl. 7. *Karaktreristični geotehnički presek terena I-I*

Za trodimenzionalnu analizu stabilnosti klizišta "Sebečevac" potrebno je odrediti širinu ekvivalentnog kliznog tela i ona iznosi B_e = 35.0 m (slika 6.). Zatim je sa uglom unutrašnjeg trenja φ = 20.4^o urađena trodimenzionalna analiza stabilnosti i dobijen je faktor sigurnosti F_s^{3D} = 1.10, odnosno mobilisani ugao unutrašnjeg trenja za trodimenzinalne uslove $\varphi'_{usl}{}^{3D}$ = 18.6^o. Ovu vrednost ugla unutrašnjeg trenja trebali bi koristiti prilikom projektovanja sanacionih mera za klizište "Sebečevac". Treba istaći da ona odgovara rezidualnom uglu unutrašnjeg trenja dobijenom laboratorijskim ispitivanjima u Institutu za puteve.

U vezi sa ovim rezultatima geostatičkih proračuna želimo da istaknemo da razlike u faktoru sigurnosti dobijene iz 2D i 3D analize stabilnosti nisu velike. Međutim, kada se uzme u obzir da se kod sanacije klizišta, u geotehničkoj praksi, često usvaja da je zadovoljavajući faktor sigurnosti F_s = 1.15-1.20, onda ovo povećanje F_s sa 1.0 na 1.10 može da bude vrlo značajno u dobijanju racionalnog inženjerskog rešenja.

ZAKLJUČAK

Zaključci koji proizilaze iz ovog rada su sledeći:

- ne postoje tačne metode 3D analize stabilnosti složenog kliznog tela koje su prihvatljive u geotehničkoj praksi, ali za najveći broj praktičnih problema 2D analize stabilnosti daju realne i dovoljno tačne vrednosti faktora sigurnosti.
- kada su 3D efekti kosine značajni, tada ih treba uključiti u analizu stabilnosti i, stoga je, razvijen opšti aproksimativni postupak 3D analize stabilnosti koji je u radu konkretizovan za beskonačnu kosinu.
- faktor sigurnosti dobijen iz 3D analize uvek je veći od faktora sigurnosti koji je izračunat primenom 2D analize na kritičnom preseku kliznog tela.
- ako se u povratnoj analizi stabilnosti zanemaruju 3D efekti, tada se dobijaju povećane vrednosti čvrstoće smicanja duž klizne površine - u odnosu na realne vrednosti, što kod projektovanja sanacionih mera dovodi do rešenja koja nisu na strani sigurnosti.

Ovi zaključci su potvrđeni i na primeru klizišta “Sebečevac”.

Na osnovu napred iznetog može se zaključiti da su 3D analize stabilnosti posebno važne prilikom određivanja sanacionih mera kod klizišta koja se pomeraju duž postojećih kliznih površina tj. u svim onim slučajevima kada se čvrstoća smicanja određuje iz povratne analize stabilnosti.

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THREE-DIMENSIONAL ASPECTS OF THE SLOPE STABILITY ANALYSIS****

Abstract

Slope stability analysis is essentially a three-dimensional problem. This is a direct consequence of irregular shaped sliding body and specifically refers to a number of landslides in Serbia. However, until now, a general three-dimensional stability analysis procedure has not been developed that would be applied for the sliding bodies of arbitrary shape. Instead of this, the two-dimensional cross-sectional analysis of the critical three-dimensional sliding body is the most frequently done. However, if the side or three-dimensional effects of a slope are significant, then they should be included in the stability analysis. This paper presents an approximate procedure that introduces the three-dimensional effects in the calculation of stability, and starting from this, the three-dimensional stability analysis of the landslide "Sebečevac"was carried out. In the case when the three-dimensional effects are significant, their inclusion in the analysis makes it possible to obtain the realistic data on slope stability. This is particularly important in determining the remedial actions of landslides.

Key words: *slope stability analysis, three-dimensional aspects, approximate procedure.*

INTRODUCTION

In the analysis of slope stability, it is essential that the problem is properly set, and then to be solved adequately. This requires, above all, the knowledge of geological and geotechnical characteristics of the terrain and, in particular, the form of sliding body, shear strength along the sliding surface and groundwater conditions. In this connection, it should be emphasized that, in most cases, the landslides in Serbia strongly depend on the geological conditions in the terrain. For example, as the result of regional geological processes that occurred during the formation of the current terrain structure, we are faced with the fact that the activity of numerous landslides,

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over a long period of their development, is periodically repeated more or less along the existing sliding surfaces. Starting from this, a detailed study of each individual landslide should be done, to analyze its stability and define the optimum remedial measures, (Lokin, P., Ćorić, S.) [1].

BASIC ASSUMPTIONS FOR STABILITY ANALYSIS

Analyses of the slope stabilities and determination the correct value of safety factors are essentiually the three-dimensional problems. This is a consequence of the irregular shape of sliding body and that is particularly characteristic for many landslides in Serbia (Ćorić, S., Čaki, L., Rakić, D.) [2]. However, until now, a general three-dimensional stability analysis procedure (3D) has not been developed that would be applied for the sliding bodies of irregular shape and simple enough for use in geotechnical practice (Cheng and Yip) [3]. Instead of this, the two-dimensional cross-sectional analyses (2D) at the critical cross section of three-dimensional sliding body, i.e. intersection with minimum safety factor, are the most frequently done.

Stability analyses can be done in drained or undrained conditions. The choice of applicable requirements depends on the consolidation degree, i.e. the size of time factor

$$T = \frac{C_v \cdot t}{P^2} \qquad (1)$$

where:

T – time factor

c_v - consolidation coefficient

t - construction time (loading)

P - drainage path length

When T > 3.0, the drained stability analysis has to be done, and when T ≤ 0.1, the undrained stability analysis has to be done. For T between these two values, both analyses have to be done. In this regard, we emphasize that in the natural slope in our geological and geotechnical conditions, the sliding is the most commonly result of increase the groundwater levels in the rainy period, and such cases they are analyzed in drained conditions.

Shear strength along the sliding surfaces, is usually determined by laboratory: from direct shear and/or rotational shear tests. However, if the shear has occurred, then the shear strength can be determined by the back analysis. In this case, the landslide is treated as the shear tests in the real scale (Figure 1).

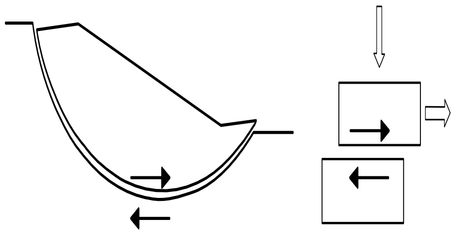

Fig. 1 *Principle of determining the shear strength of feedback analysis* [4]

We emphasize that in relatively homogeneous environments, in many examples, it was shown that the strengths obtained from laboratory experiments and dback analysis are matched in the accuracy range ± 10% (Rakić, D., Čaki, L., Ćorić, S., Ljubojev, M.) [5]. So, with confidence, the comparison between the strength obtained in these two ways can be done. Accordingly, in cases where it is not possible to obtain the undisturbed samples from the sliding surface, the dback analysis is the only effective means for determining the shear strength of soil. As the failure condition along the sliding surface, the Coulon-Mohr failure criterion is adopted and as a rule, it is linearized in the range of applicable voltage.

Stability analyses should be carried out by the limit equilibrium methods that satisfy all equilibrium conditions of sliding body. Such methods are: the general Janbu method, the Morgenstern-Price method, the Maksimović method and the Fridland-Kren method (Ćorić, S.) [6]. In the context of basic settings the limit equilibrium methods, they give the values of safety factors which do not differ by more than ± 6% of the so-called "correct" value (Duncan) [7]. They are quite acceptable for geotechnical practice, because the geometry of sliding body, pore pressures and shear strength can rarely be determined with accuracy up to ± 6%. So if an engineer – geo technician carries out the slope stability analysis, using methods that satisfz all equilibrium conditions, he can be sure that:

- calculated value of safety factor is "correct" regarding to the sliding mechanism, and
- it can focus its attention on the best assessment of soil properties and determining the remediation measures.

However, it can be justified to ask the question on accuracy of 2D analysis in solving 3D problems. Recent researches (Duncan and Wright) [8] clearly show that the safety factors, calculated using 3D analysis, are higher than those obtained using 2D analysis. This conclusion implies that 2D analysis was carried out the critical intersection of 3D potential/actual sliding body. In doing so, the error resulting from application of 2D analysis to 3D sliding body is not large and, in most cases, is less than 10%.

Based on this, it is clear that 2D analyses give somewhat conservative values of the safety factor and therefore they present the realistic and sufficiently accurate approach to the solution of the most practical problems of the slope stability analysis. However, it should be known that the shear strengths, calculated from 2D back analysis, give values that are not conservative, i.e. they are not on the safety side. Knowing as much as possible accurate values of the shear strength is of great importance, because they are used in calculations of landslide remedial meannes. Therefore, when the three-dimensional effects of a slope are significant, then they should be included in the stability analysis

THREE-DIMENSIONAL ASPECTS OF STABILITY ANALYSIS

When the side effects of slope stability are significant, then 2D analysis is not adequate and 3D effects should be taken into account. Certainly, it depends primarily on a shape of sliding body and, in every case, an engineer-geotechnician decides about this. Regarding to this, it should be noted that although there are no accurate methods for 3D analysis of complex sliding body, there are procedures that can introduce 3D effects in the stability calculation. This will be summarized below.

Weighting of the safety factors

Lambe and Whitman [9] have proposed to analyze some characteristic parallel sections through the sliding body (Figure 2), then to determine the safety factor for each section and then to calculate the weighted value of the safety factor F_s. So that, in the case of three cross-sections, the sliding safety factor of sliding body would be obtained as equal to:

$$F_s = \frac{F_{s1} \cdot A_1 + F_{s2} \cdot A_2 + F_{s3} \cdot A_3}{A_1 + A_3 + A_3} \qquad (2)$$

where:

F_s –weighted safety factor of the sliding body

F_{s1}, F_{s2}, F_{s3} –safety factors of cross-sections A-A, B-B, C-C

A_1, A_2, A_3 –surfaces of cross-sections A-A, B-B, C-C

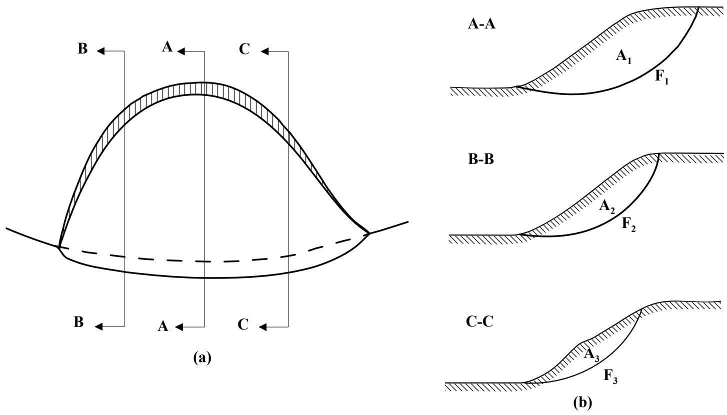

Fig. 2 *Approximation of three-dimensional effects by weighting the safety factors*

Reduction of the shear stress

Skempton [10] have suggested that after carrying out 2D analysis for the critical cross-section, it hasto make the reduction of shear tress in the sliding surface by the quotient

$$\frac{1}{1 + K \cdot \frac{H}{B}} \qquad (3)$$

where:

H – average height of the sliding body
B – average width of the sliding body
K – coefficient of the side pressure of soil

Approximation the geometry of sliding body

Three-dimensional stability analysis can be done such as the actual sliding body will be approximated by the equivalent - geometrically idealized sliding body (Figure 3), and for it will be calculated three-dimensional safety factor (Ćorić, S., Čaki, L., Rakić, D.) [11]. Proceeding from this, we propose to determine the following two-dimensional F_s^{2D} and three-dimensional safety factors F_s^{3D}.

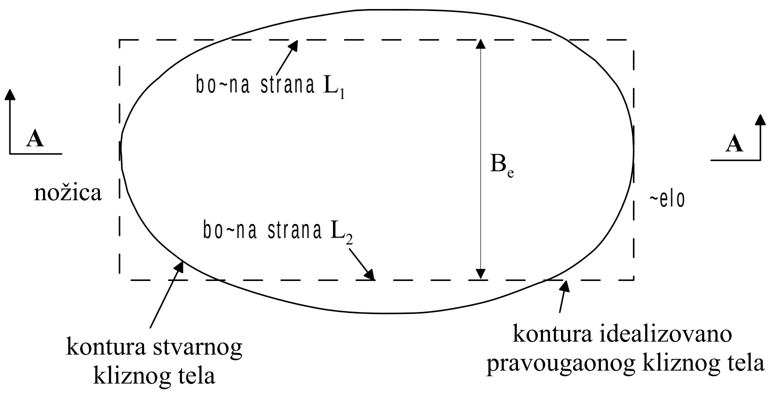

Fig. 3. *Approximation the real sliding body by the equivalent - geometrically idealized sliding body*

Two-dimensional safety factor F_s^{2D} of the characteristic cross-section A-A is

$$F_s^{2D} = \frac{R}{D} \tag{4}$$

where:

- F_s^{2D} – safety factor of the cross-section A-A
- R – resistance forces or moments
- D – disturbing forces or moments

Three-dimensional safety factor of the equivalent sliding body F_s^{3D} is determined from equation

$$F_s^{3D} = \frac{B_e \cdot R + R_{L1} + R_{L2}}{B_e \cdot D} = F_s^{2D} + \frac{R_{L1} + R_{L2}}{B_e \cdot D} \tag{5}$$

where:

- F_s^{3D} - safety factor of the equivalent sliding body
- B_e - width of the equivalent sliding body
- R_{L1} - resistance forces or moments along lateral side L_1
- R_{L2} - resistance forces or moments along lateral side L_2

This method can be applied to the drained and undrained stability analysis both for circular and complex sliding surfaces (Ćorić, S., Čaki, L., Rakić, D.) [12]. Certainly, the use of this method requires good engineering approximation to estimate the actual / potential landslide by the equivalent sliding body.

In the following, we will show an approximation of infinite slope by the proper sliding body and calculation of safety factor F_s^{3D}.

THREE-DIMENSIONAL STABILITY ANALYSIS OF THE INFINITE SLOPE

In many cases, for example in terrains with developed decomposition zone, the sliding surface is shallow and parallel to the terrain surface. That is, for example, characteristic for the landslides in the urban settlements Medaković and Mirijevo in Belgrade. In such cases, the sliding surface, as a rule, is long compared to the thickness of sliding body and therefore the stability analysis can be carried out for an infinite slope. Such analysis ignores interslice forces (Z_i, Z_{i-1}) as well as the resistant and disturbing forces on the lower and upper end of the sliding body (Figure 4 and Figure 5).

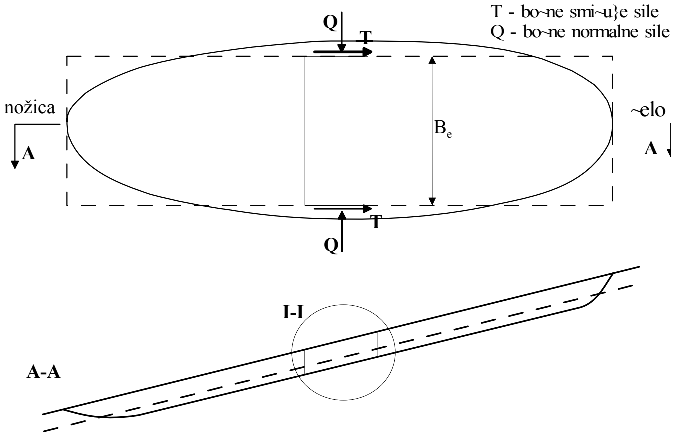

Fig. 4. *Approximation of the infinite slope by the equivalent – geometrically idealized sliding body*

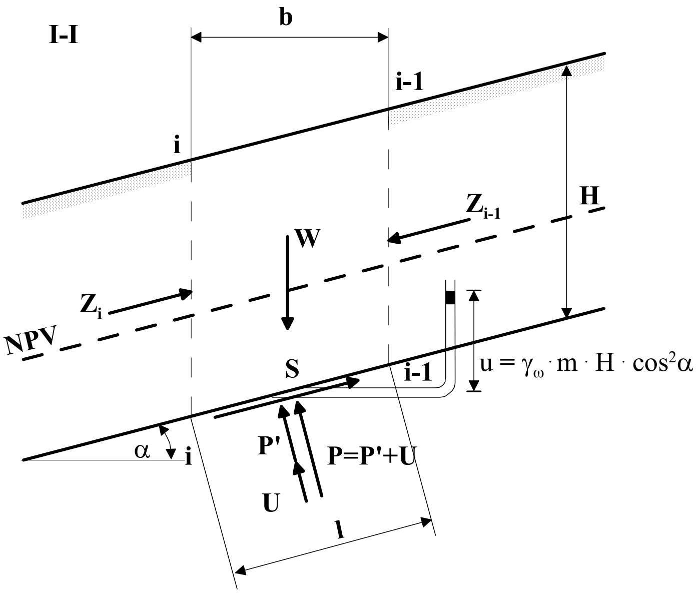

Fig. 5. *The forces acting on the slice of infinite slope - the case of two-dimensional stability analysis* [5]

Two-dimensional safety factor F_s^{2D} in the cross-section F_s^{2D} is:

$$F_s^{2D} = \frac{c + H \cdot \cos^2\alpha \cdot (\gamma_z - \gamma_w \cdot m) \cdot tg\varphi}{\gamma_z \cdot H \cdot \sin\beta \cdot \cos\alpha} \quad (6)$$

where:

- c, φ - *shear strength* parameters along the sliding surface
- α - slope inclination
- γ_z - bulk density of saturated soil
- γ_w - bulk density of water
- H - slope height
- $m \cdot H$ - height from sliding surface to the groundwater level ($0 \le m \le 1$)

Three-dimensional safety factor F_s^{3D}, with the included effects of the lateral normal Q and shear T strengths, is:

$$F_s^{3D} = \frac{1}{\sin\alpha} \cdot \left\{ \left(\frac{1}{H \cdot \cos\alpha} + \frac{2}{B_e} \right) \cdot \frac{c}{\gamma_z} + \left[\cos\alpha \cdot \left(1 - m \cdot \frac{\gamma_w}{\gamma_z} \right) + \frac{K \cdot H}{B_e} \cdot \left(1 - m^2 \cdot \frac{\gamma_w}{\gamma_z \cdot \cos^2\alpha} \right) \right] \cdot tg\varphi \right\} \quad (7)$$

where:

K – coefficient of lateral soil pressure

For drained stability analysis, in equations (6) and (7), the effective shear strength parameters are used, that is

$$c = c'; \quad \varphi = \varphi' \quad (8)$$

For undrained stability analysis in equations (6) and (7), the total shear strength parameters are used, that is

$$c = c_u ; \quad \varphi = \varphi_u = 0 \qquad (9)$$

In the following, we will show an approximation of the "Sebečevac" landslide by the equivalent sliding body and calculations of safety factors F_s^{2D} i F_s^{3D}.

THREE-DIMENSIONAL STABILITY ANALYSIS ON THE EXAMPLE OF THE "SEBEČEVAC" LANDSLIDE

The "Sebečevac" landslide is located on the local road Sebečevac - Kupci. It was formed on the right valley slope of the stream that belongs to the basin of the Pepeljuša River. Natural inclination of the slope is between 8^0 and 14^0. Landslide has affected the road subgrade and slope above and below the road at distance of about 90-115m with clearly visible borders. Deformations are in the form of dents, cracks and open holes to 20 cm and there are numerous cracks. Frontal scar is on the slope above the road and about 50 m from the road axis. Toe of the landslide is located on the slope below the road, and it is about 40 m (Figure 6). Sliding occurred in the early 2006, after heavy rainfall and rapid snow melt, when the whole sliding body was saturated with water and numerous water puddles on terrain surface [13].

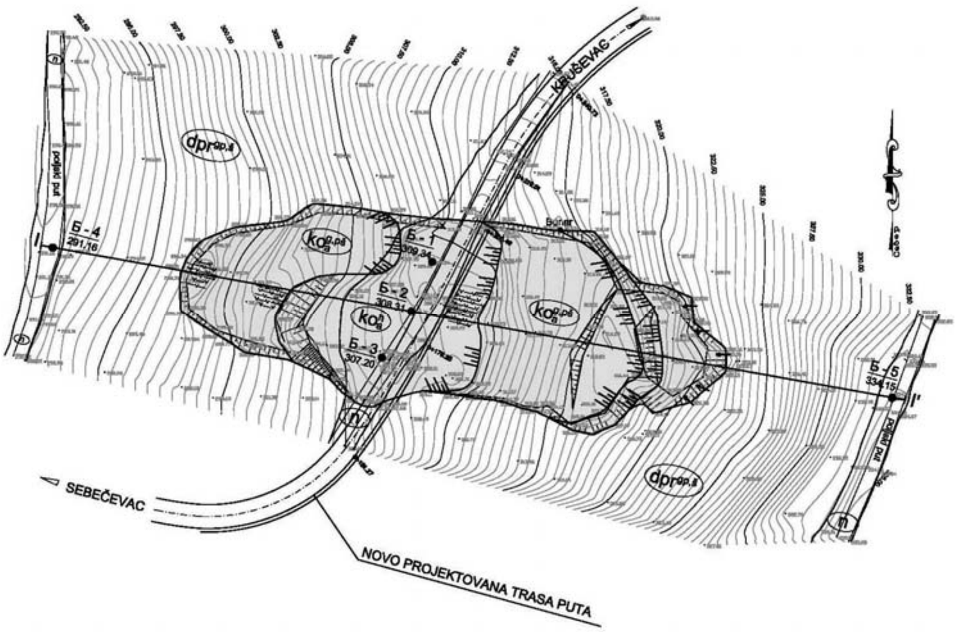

Fig. 6. *Location plan of the landslide "Sebečevac"*

Lithological environments, affected by sliding, are heterogeneous in composition and physical-mechanical properties. Most of the landslide includes sandy-clay gravel of deluvial-proluvial origin (d-pr^{gp,š}). In the frontal and central parts of the landslide, the sliding has also affected the altered physical-chemical zone of lake sediments -

- marly clays with the inter-beds of sandy marls, semi-bonded sandstones and gravel sands (GL, L, P).

Maximum thickness of the landslide is about 5.0 m. The material is mainly to highly wetted the water saturated (measured natural moisture up to 37%) with the liquid limit w_l = 44-90%, index plasticity I_p = 25-61%, index consistency I_c = 0.72-1.0. Shear strength parameters are: peak values $\varphi' = 21^0$-29^0 and c' = 22-28 kPa and residual values $\varphi_r = 19^0$ and c_r = 0 kPa. According to the USCS classification, it belongs to the groups of CL and CH.

For the characteristic geotechnical cross-section of terrain I-I\` (Figure 7), the two-dimensional back stability analysis (for F_s^{2D} = 1.0) was done with the following input data H = 5.0 m, $\alpha = 11^0$, m = 1, γ_z = 21 kN/m^3, c'_r = 0. In this way, the value of mobilized angle of internal friction $\varphi'_{usl}{}^{2D} = 20.4^o$ was obtained.

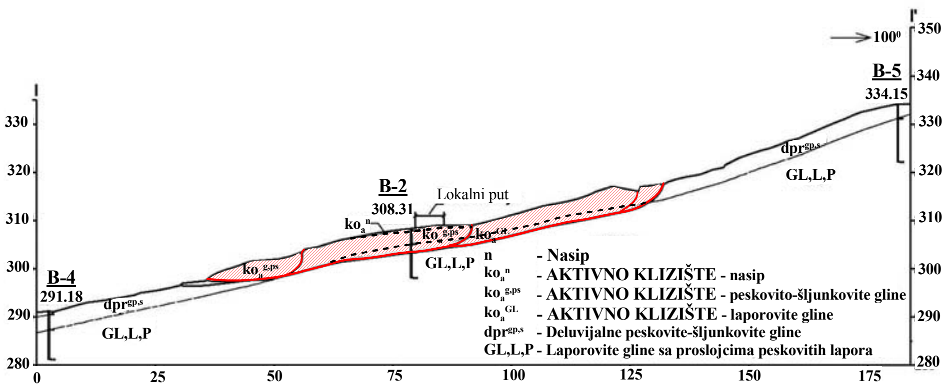

Fig. 7. *Characteristic geotechnical cross-section of field I-I*

For the three-dimensional stability analysis of the landslide “Sebečevac”, it is necessary to determine the width of equivalent sliding body and it is B_e = 35.0 m (Figure 6). Then, the three-dimensional stability analysis was done with the angle of internal friction $\varphi = 20.4^o$ and the safety factor F_s^{3D} = 1.10 was obtained. So the mobilized angle of internal friction for three-dimensional conditions is $\varphi'_{usl}{}^{3D}$ = 18.6^o. This value of the internal friction angle should be used in designing the remedial measures for the landslide “Sebečevac”. It should be noted that it corresponds to the residual angle of internal friction, obtained by the laboratory tests in the Highway Institute.

In connection with these results of geostatic calculations, we want to point out that differences in the safety factor, obtained from 2D and 3D stability analysis are not high. However, when it is considered that for remedial measures of landslides in geotechnical practice, often is adopted that the satisfactory safety factor F_s = 1.15-1.20, then this increase of F_s from 1.0 to 1.10 may be very important in obtaining the rational engineering solution.

CONCLUSION

The conclusions of this paper are the following:

- there are no accurate methods of 3D analysis the stability of complex sliding body that are acceptable in geotechnical practice, but for most practical problems, the 2D stability analyses provide the realistic and reasonably accurate values of safety factors.
- when 3D effects of the slope are significant, then they should be included in the stability analysis and, therefore, the general approximate procedure for 3D stability analysis was developed and it is concretized in the paper for infinite slope.
- safety factor obtained from 3D analyses is always higher than the safety factor calculated using the 2D analysis for critical cross-section of sliding body.
- if the back stability analysis ignores 3D effects, then increased values of shear strength along the sliding surface are obtained regarding to the real values as it leads, in design of remedial measures, to the solutions that are not on the side of safety.

These conclusions were confirmed in the example of the landslide "Sebečevac".

Based on the above given, it can be concluded that 3D stability analyses are particularly important in determining the remedial measures for landslides that slip along the existing sliding surfaces, i.e. in all cases where the shear strength is determined from the dback stability analysis.

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INOVIRANI BLOK MODEL LEŽIŠTA RUDE BAKRA JUŽNI REVIR-MAJDANPEK KAO OSNOVA ZA ANALIZU OPTIMALNOG RAZVOJA POVRŠINSKOG KOPA PRIMENOM SOFTVERSKIH PAKETA WHITTLE I GEMCOM***

Izvod

Svetske rudarske kompanije kod procene finansijske održivosti i definisanja optimalne strategije za razvoj rudnika koriste neke od softvera za optimizaciju i projektovanje, a među vodećim su Whittle i Gemcom, koje poseduje i Institut za rudarstvo i metalurgiju u Boru.

Na bazi litoloških, hemijskih i drugih laboratorijskih analiza na uzorcima iz istražnih bušotina i podzemnih istražnih hodnika na lokalitetu Južni revir kod Majdanpeka, formirana je baza podataka na osnovu koje je u softveru Gemcom, izrađen inovirani blok model ležišta.

Dobijeni blok model ležišta predstavlja polaznu osnovu u procesu strateškog planiranja i projektovanja površinskog kopa, za šta se takođe koriste odgovarajući softverski paketi, Gemcom i Whittle.

Ključne reči: *blok model, strateško planiranje i optimizacija profita, projektovanje, softveri Gemcom i Whittle.*

1. UVOD

Ležište bakra Južni revir - Majdanpek nalazi se južno od grada Majdanpeka, u njegovoj neposrednoj blizini. Postojanje ležišta potvrđeno je detaljnim geološkim istraživanjima, u periodu od 1949. do 1957. godine, koja su omogućila otvaranje rudnika površinskim kopom 1959. godine. Dosadašnjom eksploatacijom ovog ležišta, od 1959. godine, otkopano je oko 330.000 000 t rude i 777.000.000 tona jalovih masa (otkrivke i pratećih stena).

Rudnik bakra Majdanpek u proizvodnom, tehničkom i tehnološkom smislu predstavlja kompleksan rudarski

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*** *Rad je proizašao iz projekta broj 33038 „Usavršavanje tehnologija eksploatacije i prerade rude bakra sa monitoringom životne i radne sredine u RTB Bor Grupa“, koji je finansiran sredstvima Ministarstva za prosvetu i nauku Republike Srbije*

sistem koji ima aktivnosti od geoloških istraživanja mineralnih resursa, eksploatacije i pripreme rude do niza pratećih aktivnosti kao neophodne podrške osnovnim delatnostima. Proizvodnja i prerada rude u RBM – u, koja se na dva površinska kopa Severni revir i Južni revir odvija već više od 50 godina, od izuzetnog je značaja za proizvodnju bakra u sistemu RTB Bor-Grupa.

Prema Planu razvoja proizvodnje rude bakra u RTB-u, koji je usvojen od strane menadžmenta Kompanije, površinski kop Južni revir označen je kao nosioc proizvodnje rude bakra u RBM-u, pri čemu je planirani godišnji kapacitet na otkopavanju i preradi od 8,5 miliona tona.

Nastavak eksploatacije rude bakra na površinskom kopu Južni revir podrazumeva da se na osnovu postojećih uslova eksploatacije definiše njegov dalji razvoj, uz ostvarivanje maksimalne dobiti (profita) pri eksploataciji. To svakako podrazumeva i smanjenje troškova materijala i radne snage u procesu otkopavanja i prerade rude na nivo svetskih troškova u rudnicima sa sličnim uslovima rada, uz maksimalno iskorišćenje geoloških rezervi.

Prateći svetske trendove u oblasti projektovanja rudnika, strategija razvoja površinskog kopa Južni revir oslanja se na primenu vodećih softvera za za strateško planiranje i optimizaciju profita u rudarstvu i projektovaje rudnika *Whittle* i *Gemcom*.

2. KOMPJUTERSKO MODELIRANJE LEŽIŠTA BAKRA JUŽNI REVIR MAJDANPEK

Kao što je poznato blok model predstavlja trodimenzionalnu matricu koja sadrži sve neophodne (određene) podatke o ležištu potrebne da se projektuje njegovo otkopavanje.

Obrada ležišta bakra Južni revir Majdanpek započeta je unosom podataka iz nekoliko datoteka istražnih bušotina i podzemnih istražnih radova sa nivoa na kotama +347, +300 i +200 m. Za svaku bušotinu datoteke sadrže sledeće podatke:

- ime,
- koordinate,
- karakteristične kote,
- litološke članove u geološkim presecima bušotina (koji su relevantni za procenu sadržaja u izdvojenim geološkim sredinama),
- hemijske analize pojedinačnih i kompozitnih proba za glavnu komponentu (Cu) i prateće elemente (Au, Ag, Mo i S),
- litološke članove u geološkom profilu bušotina, koji su relevantni za procenu sadržaja u izdvojenim geološkim sredinama.

Za svaku bušotinu dat je opis izdvojenih tipova stena, odnosno geološki stub bušotine, a zatim su uneti podaci o karakteristikama svakog izdvojenog tipa stene, neophodni za dalju obradu (tabela 1), jer je sadržaj korisnih komponenti zavisan i od litološkog sastava. Podaci iz podzemnih istražnih radova uneti su kao tačke sa kotama, koordinatama i sadržajima analiziranih elemenata.

Tabela 1. *Podaci o izdvojenim tipovima stena u ležištu bakra Južni revir Majdanpek*

Stena	Opis stene	Kod stene	γ (t/m^3)	Primedba
N	Površinski pokrivač	1	2,60	Jalovina
J3	Krečnjak	2	2,64	Jalovina
A	Andezit	20	2,65	Ruda
GG	Gnajs-granit	21	2,65	Ruda
G	Gnajs-amfibolski	22	2,65	Ruda
S	Škriljac zelene facije	23	2,80	Jalovina
KDP	Kvarc-diorit-porfirit	24	2,65	Ruda
KMS	Kvarc-muskovitski škriljac	25	2,65	Moguća ruda
Px	Masivni pirit	30	3,20	Ruda
R	Rasedna glina	31	2,30	Ruda
TB	Tektonska breča	32	2,90	Ruda
SK	Skarnoid	33	2,65	Ruda
LM	Limonit	40	2,00	Moguća ruda

Takođe su uneti i podaci o topografiji terena, koji su dobijeni su od Geodetske službe RBM-a, gde je i izvršena digitalizacija (programskim paketom *AutoCAD*).

Geološka interpretacija ležišta sa aspekta definisanja litoloških članova unutar i oko samog ležišta izvršena je u softveru *Gemcom*, u modulu *Geo-model*.

Interpretacija ležišta i okolnog prostora u obliku blok modela podrazumeva podelu prostora, koji zahvata ležište na blokove pravilnih dimenzija, pri čemu je njihova veličina uslovljena brojnim faktorima. Blokovi ne smeju biti suviše mali, jer se na taj način povećava greška proračuna („procene“). Takođe, veličina bloka zavisi i od metode eksploatacije. Imajući u vidu sve ovo, usvojena veličina blokova za ležište bakra Južni revir Majdanpek je 15×15×15 m.

Blok modelom ležišta zahvaćen je prostor sa geodetskim koordinatama prikazanim u tabeli 2.

Tabela 2. *Konture prostora u kome je vršena interpretacija ležišta bakra Južni revir Majdanpek*

Koordinate	
Y	X
7 573 905	4 917 205
7 573 905	4 920 375
7 575 770	4 920 375
7 575 770	4 917 205

Po opisanoj proceduri formiran je blok model ležišta sa: 212 redova, 125 kolona i 44 etaža (E +545 do E –100).

Izradom blok modela, za svaki blok, definisane su sledeće vrednosti:

(1) Vrsta stene;

(2) Zapreminska masa;

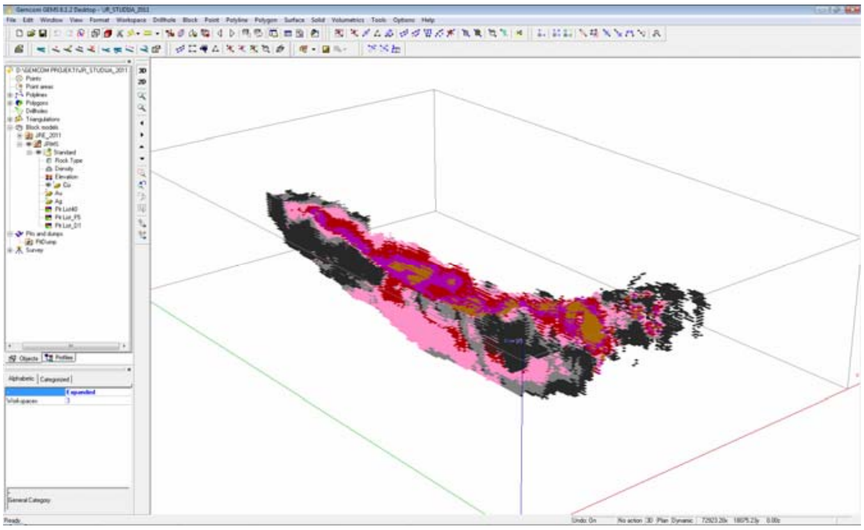
(3) Sadržaj korisne komponente Cu (%) i pratećih komponenti S (%); Au (g/t); Ag (g/t); Mo (g/t);
(4) Ekonomska vrednost bloka, odnosno količina bakra u bloku ili profit, koji se ostvaruje otkopavanjem tog bloka.

Vrsta stene i njena zapreminska masa u bloku dobijeni su na osnovu geološke interpretacije na etažama. Za interpretaciju su korišćeni podaci iz istražnih bušotina i podzemnih istražnih rudarskih radova.

Određivanje sadržaja bakra u blokovima započeto je izradom variograma, koji predstavljaju osnovu za proračun („procenu“) sadržaja. Za ležište Južni revir Majdanpek, urađena su tri variograma za bakar, što je odlučeno pošto se prostori u ležištu razlikuju po načinu distribucije bakra. Sa ovim variogramima, pri proceni (krigovanju) blok modela, dobijeni su najveći koeficijenti korelacije i najveća slaganja srednjih vrednosti i procenjenih vrednosti.

Za potrebe procene (krigovanja) zlata u blok modelu korišćena su tri variograma iz istog raloga kao i za bakar. Za krigovanje srebra i sumpora korišćen je po jedan variogram za celo ležište. Variogram za molibden nije rađen iz razloga što je sadržaj navedene komponente nizak i nije ekonomski interesantan.

Na slici 1 prikazan je trodimenzionalni izgled blok modela Cu u ležištu Južni revir.



Sl. 1. *Trodimenzionalni izgled blok modela Cu u ležištu Južni revir*

Proračun količina rude i srednjeg sadržaja u okviru geoloških rezervi, po kategorijama rezervi, izvršen je tako što su prvo urađeni zatvoreni modeli („SOLID“ modeli), a potom je izvršen proračun u okviru formiranih trodimenzionalnih prostora.

U tabeli 3 dat je pregled ukupnih geoloških rezervi ležišta bakra Južni revir Majdanpek sa srednjim sadržajem i količinama korisnih komponenti u konturi graničnog sadržaja 0,15% Cu.

Proračun količina rude i srednjeg sadržaja u okviru geoloških rezervi, po kategorijama rezervi, izvršen je tako što su prvo urađeni zatvoreni modeli („SOLID“ modeli), a potom je izvršen proračun u okviru formiranih trodimenzionalnih prostora.

U tabeli 3 dat je pregled ukupnih geoloških rezervi ležišta bakra Južni revir Majdanpek sa srednjim sadržajem i količinama korisnih komponenti u konturi graničnog sadržaja 0,15% Cu.

Tabela 3. *Geološke rezerve u ležištu bakra Južni revir Majdanpek u konturi graničnog sadržaja 0,15% Cu*

Kate-gorija	Količina rude (t)	Srednji sadržaj Cu (%)	Količina Cu (t)	Srednji sadržaj Au (g/t)	Količ. Au (kg)	Srednji sadržaj Ag (g/t)	Količ. Ag (kg)	Srednji sadržaj S (%)	Količina S (t)
A	78 432 380	0,433	339 792	0,274	21 456	1,731	135 750	1,178	923 944
B	153 258 013	0,312	477 837	0,170	26 082	1,273	195 125	0,891	1 364 845
C_1	231 437 451	0,280	647 927	0,150	34 618	1,302	301 398	1,357	3 140 747
A+B+C	463 127 844	0,316	1 465 556	0,178	82 156	1,365	632 274	1,172	5 429 536

Tabela 4. *Geološke rezerve u ležištu bakra Južni revir Majdanpek u konturi graničnog sadržaja 0,20% Cu*

Kate-gorija	Količina rude (t)	Srednji sadržaj Cu (%)	Količina Cu (t)	Srednji sadržaj Au (g/t)	Količ. Au (kg)	Srednji sadržaj Ag (g/t)	Količ. Ag (kg)	Srednji sadržaj S (%)	Količina S (t)
A	82 576 199	0,422	348 426	0,262	21 619	1,653	136 519	1,171	966 828
B	150 739 803	0,309	466 518	0,171	25 756	1,257	189 447	0,929	1 400 803
C_1	175 855 328	0,301	528 736	0,141	24 848	1,257	221 071	1,297	2 281 191
A+B+C_1	409 171 330	0,328	1 343 679	0,177	72 222	1,337	547 037	1,136	4 648 822

Proračun geoloških rezervi u Elaboratu o rezervama ležišta bakra Južni revir – Majdanpek iz 2006. godine izvršen je sa blok modelom u kome je granični sadržaj metala bakra u rudi iznosio GS = 0,20 % (tabela 4). Blokovi čiji je sadržaj bakra ispod GS tretirani su kao jalovina.

Na osnovu toga se može konstatovati da su u inoviranom blok modelu proračunom dobijene veće količine rude, sa pripadajućim količinama metala bakra, zlata i srebra i to:

- rude 53 956 514 t
- metala bakra 121 877 t
- metala zlata 9 934 kg
- metala srebra 8 5237 kg

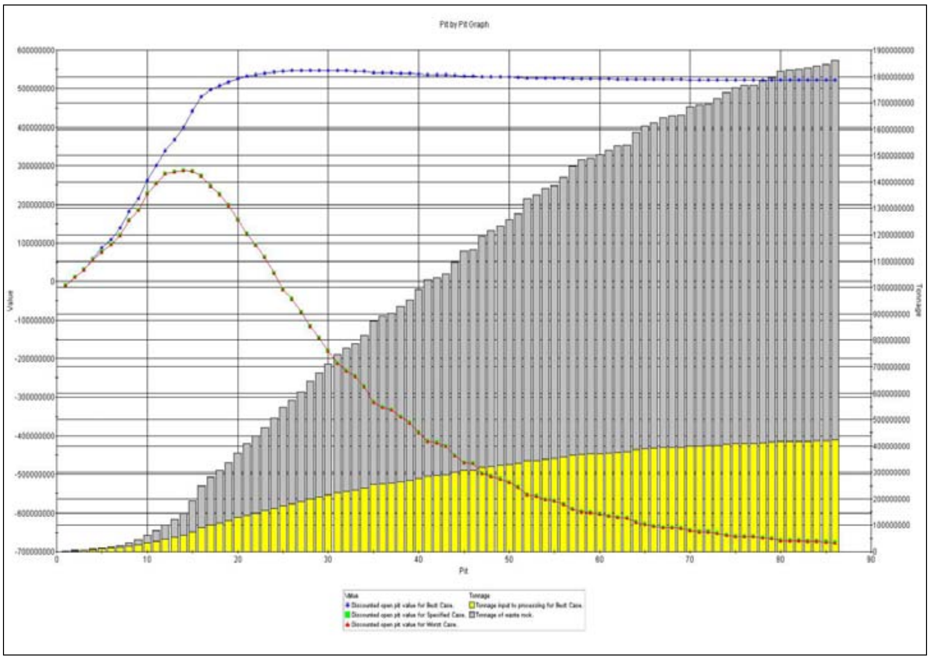
3. STRATEŠKO PLANIRANJE I PROJEKTOVANJE POVRŠINSKOG KOPA JUŽNI REVIR PRIMENOM SOFTVERA WHITTLE I GEMCOM

Svetske rudarske kompanije kod procene finansijske održivosti i definisanja optimalne strategije za razvoj rudnika koriste neke od softvera za optimizaciju i projektovanje, a među vodećim su *Whittle* i *Gemcom*, koje poseduje i Institut za rudarstvo i metalurgiju u Boru.

opremljenosti i stepena modernizacije rudnika sa jedne strane, a sa druge strane od stanja cene metala na berzama u Svetu. Na osnovu toga se može zaključiti da i optimalna kontura kopa nije stalna, već promenljiva kategorija.

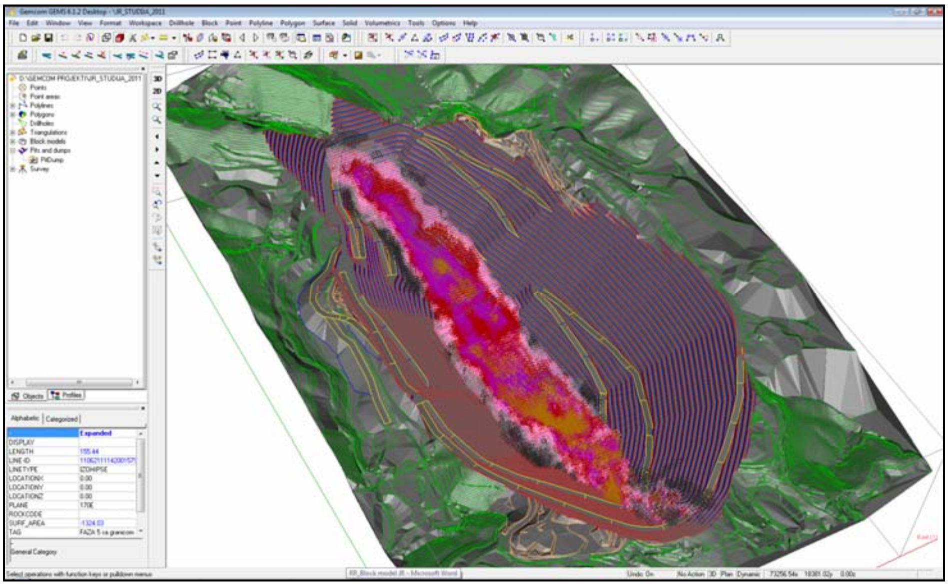
Da bi se ostvario puni ekonomski potencijal poslovanja nekog rudnika i ostvario maksimalni profit, softver omogućava da se unutar konačne optimalne konture definišu faze razvoja kopa, tzv. *pushback*-ovi.

Na slici 2. grafički su prikazani rezultati optimizacije za baznu cenu bakra od 6.000 USD/t, na osnovu čega se vrši izbor optimalne konture kopa i *pushback*-ova.



Sl. 2. *Rezultati optimizacije u Whittle-u*

Detaljna obrada rezultata koji su dobijeni u *Whittle*-u vrši se u softveru za projektovanje (dizajn) površinskih kopova *Gemcom*. Na slici 3. dat je izgled završne konture površinskog kopa Južni revir nakon obrade u *Gemcom*-u sa prikazom blok modela ležišta u 3D formatu.



Sl. 3. *Izgled završne konture površinskog kopa Južni revir nakon obrade u Gemcom-u sa prikazom blok modela ležišta u 3D formatu*

4. ZAKLJUČAK

Prema Planu razvoja proizvodnje rude bakra u RTB Bor-Grupi, koji je usvojen od strane menadžmenta Kompanije, površinski kop Južni revir u Majdanpeku označen je kao nosioc proizvodnje rude bakra u RBM-u, pri čemu je planirani godišnji kapacitet na otkopavanju i preradi od 8,5 miliona tona.

Prateći svetske trendove u oblasti projektovanja rudnika, strategija razvoja površinskog kopa Južni revir u narednom periodu oslanja se na primenu vodećih softvera za strateško planiranje i optimizaciju profita u rudarstvu i projektovaje rudnika *Whittle* i *Gemcom*.

Na osnovu ulaznih podataka dobijenih iz istražnih bušotina i podzemnih istražnih rudarskih radova u softveru *Gemcom* izvršeno je modeliranje ležišta Južni revir Majdanpek.

Dobijeni blok model poslužio je kako za obračun rezervi u ležištu (geoloških, bilansnih i vanbilansnih), tako i za buduću procenu finansijske održivosti i definisanja optimalne strategije za razvoj rudnika od strane menadžmenta kompanije.

S obzirom da je u inoviranom blok modelu za proračun geoloških rezervi usvojeno da granični sadržaj bakra u rudi iznosi 0,15%, dok je u postojećem granični sadržaj bio 0,20%, dobijene veće količine rude sa pripadajućim količinama metala bakra, zlata i srebra i to:

- rude 53.956.514 t
- metala bakra 121.877 t
- metala zlata 9.934kg
- metala srebra 8.5237kg

Za definisane ulazne tehnoekonomske parametre, koji predstavljaju promenljivu kategoriju, u softveru Whittle dobijena je optimalna kontura kopa, koja je kasnije detaljno obrađena u softveru *Gemcom*.

Kriterijum optimalnosti bio je ostvarivanje maksimalnog profita.

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UDK: 622.271:681.33(045)=20

Daniel Kržanović, Miodrag Žikić**, Zoran Vaduvesković**

INNOVATED BLOCK MODEL OF THE COPPER ORE DEPOSIT SOUTH MINING DISTRICT – MAJDANPEK AS A BASIS FOR ANALYSIS THE OPTIMUM DEVELOPMENT OF OPEN PIT USING THE SOFTWARE PACKAGES WHITTLE AND GEMCOM***

Abstract

The world mining companies in the assessment of financial sustainability and defining the optimum strategy for mine development use some of the software packages for optimization and design and, among them, the leading ones are Whittle and Gemcom, which Mining and Metallurgy Institute in Bor also owns.

Based on lithological, chemical and other laboratory analyses on samples from exploratory drill holes and underground drifts at the location of South Mining District near Majdanpek, a database was formed, based on which, an innovated model of deposit was developed in the software Gemcom.

The obtained block model of deposit presents the starting base in the process of strategic planning and design of open pit, for which the appropriate software packages, Gemco and Whittle, are also used.

Key words: *block model, strategic planning, profit optimization, designing, Gemcom and Whittle software packages*

1. INTRODUCTION

The copper deposit South Mining District – Majdanpek is located south of the town Majdanpek, in its immediate vicinity. The existence of deposit was confirmed by detailed geological surveys in the period since 1949 to 1957, which enabled the opening of mine by the open pit in 1959. Up to date exploitation of this deposit, since 1959, about 330 million tons of ore and 777 million tons of waste mass (overburden and associated rocks) were mined.

Copper Mine Majdanpek in production,

* *Mining and Metallurgy Institute Bor*
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technical and technological terms is the complex mining system with the activities from geological surveys of mineral resources, exploitation and processing of ore to a series of related activities as necessary support to the basic activities. Production and processing of ore in RBM - with two open pits, South Mining District and North Mining District, is carried out for more than 50 years and it is of great importance for copper production in the system of RTB Bor Group.

According to the Plan of development the copper ore production in RTB, which was adopted by the Management of Company, the open pit South Mining District is referred as the carrier of copper ore production in RBM, with the planned annual capacity of excavation and processing of 8.5 million tons.

Continuation of copper ore mining at the open pit South Mining District means that, based on the existing conditions of exploitation, it defines further development with achieving maximum profit in exploitation. This certainly includes the cost reduction of materials and labor in the process of ore mining and processing at the level of world costs in the mines with similar conditions, with maximum recovery the geological reserves.

Following the world trends in the field of mine design, a development strategy of the South Mining District relies on application the leading software for strategic planning and optimization of profits in mining and mine design - *Whittle* and *Gemcom*.

2. COMPUTER MODELING THE COPPER DEPOSIT SOUTH MINING DISTRICT MAJDANPEK

As it is known, a three-dimensional block model present a matrix containing all necessary (determined) data on deposit required to design its excavation.

Processing of the copper deposit South Mining District - Majdanpek began entering data from several files exploratory drill holes and underground exploratory works from levels to the elevations +347, +300 and +200 m. For each drill hole, the files contain the following data:

- name,
- coordinates,
- characteristic elevations,
- lithological members in geological cross-sections of drill holes,which are relevant for assessment the contents in separated geological areas.
- chemical analyses of individual and composite samples for the major component (Cu) and associated elements (Au, Ag, Mo and S).

Description of separated rock types or geological pillar of drill hole was provided for each drill hole, and then data were entered on characteristics of each separate type of rocks, which are necessary for further processing (Table 1), because the content of useful components is also dependent on lithological composition. Data from the underground exploratory works were entered as points with elevations, coordinates and contents of analyzed elements.

Table 1. *Data on individual types of rocks in the copper deposit South Mining District Majdanpek*

Rock	Rock description	Rock code	γ (t/m^3)	Remark
N	Surface cover	1	2.60	Waste
J3	Limestone	2	2.64	Waste
A	Andesite	20	2.65	Ore
GG	Gneiss-granite	21	2.65	Ore
G	Gneiss-amphibolitic	22	2.65	Ore
S	Green facies shale	23	2.80	Waste
KDP	Quartz-diorite-porphyrite	24	2.65	Ore
KMS	Quartz –muscovite shale	25	2.65	Possible ore
Px	Massive pyrite	30	3.20	Ore
R	Fault clay	31	2.30	Ore
TB	Tectonic breccia	32	2.90	Ore
SK	Skarnoid	33	2.65	Ore
LM	Limonite	40	2.00	Possible ore

Data on terrain topography were also entered, which were obtained from the Geodetic Department of RBM, where the program digitizing was done (*AutoCAD* software package).

Geological interpretation of deposit in terms of defining the lithological members inside and around the deposit was made in the software *Gemcom* in module of *Geo-model.*

Interpretation of deposit and surrounding area in the form of block model implies the division of area, which covers the deposit on blocks of regular size, while their size is determined by many factors. Blocks should not be too small, because in this way the error of calculation (assessment) increases. Also, the block size depends on mining method. Taking into account all of this, the adopted size of the blocks for the copper deposit South Mining District – Majdanpek is 15×15×15 m.

The area with geodetic coordinates shown in Table 2 is affected by the block model of deposit.

Table 2. *Contours of area where the interpretation was done on the copper deposit South Mining District Majdanpek*

Coordinates	
Y	X
7 573 905	4 917 205
7 573 905	4 920 375
7 575 770	4 920 375
7 575 770	4 917 205

According to the above described procedure, the block model of deposit was formed with: 212 rows, 125 columns and 44 benches (E +545 do E –100).

The following values are defined by development a block model for each block:

(1) rock type;
(2) density;
(3) content of useful components Cu (%) and associated components S (%); Au (g/t); Ag (g/t); Mo (g/t);
(4) economic value of a block or copper amount in a block or profit, realized by excavation of this block.

Rock type and its density in a block were obtained on the basis of geological interpretation at the benches. Data from exploratory drill holes and underground exploratory mining works were used for interpretation.

Determination of copper content in blocks started making the variograms, which are the basis for content calculation ("assessment").

Three variograms for copper were made for the deposit South Mining District - Majdanpek, what was decided as the spaces in deposit are differ in the manner of copper distribution . With this variograms, the highest correlation coefficients and the largest agreement of mean values and estimated values were obtained in the assessment (kriging) of a block mode.

Three variograms were used for the needs of assessment (kriging) of gold due to the same reason as for copper. One variogram was used for silver and sulphur kriging of the whole deposit. Variogram for molybdenum was not done due to very low content of the given component and it is not economically interesting.

Figure 1 shows a three-dimensional block model of Cu in the deposit South Mining District.

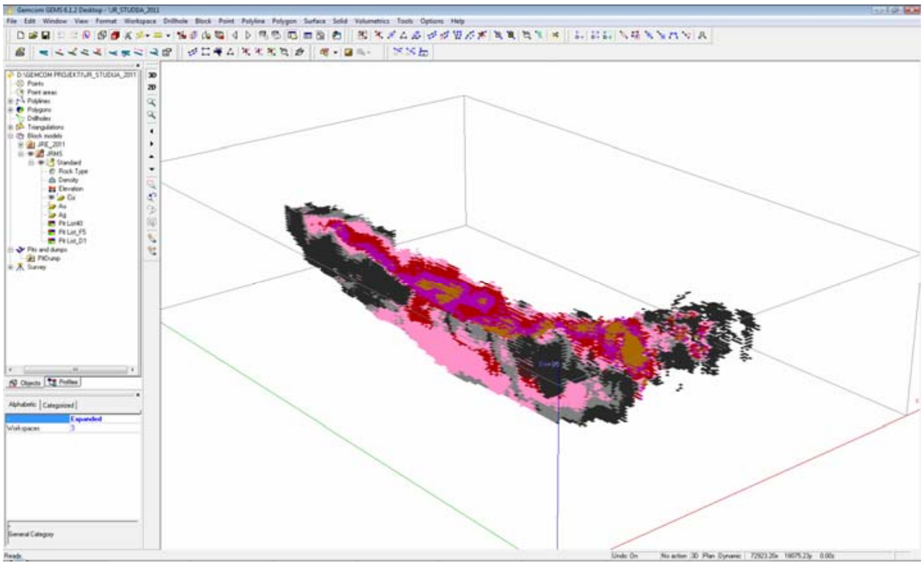

Fig. 1. *Three-dimensional block model of Cu in the deposit South Mining District*

Calculation of the ore amount and mean content within the geological reserves, by categories of reserves, was made such as the closed the models ("SOLID"models) were firstly made, and then the calculation was done within the formed three-dimensional areas.

Table 3 gives a review of total geological reserves of the copper deposit South Mining District – Majdanpek with the mean content and amounts of useful components in a contour of limit content 0.15% Cu.

Table 3. *Geological reserves in the copper deposit South Mining District Majdanpek in a contour of limit content 0.15% Cu*

Category	Ore quantity (t)	Mean Cu content (%)	Cu quantity (t)	Mean Au content (g/t)	Au quantity (kg)	Mean Ag cotent (g/t)	Ag quantity (kg)	Mean S content (%)	S quantity (t)
A	78 432 380	0.433	339 792	0.274	21 456	1.731	135 750	1.178	923 944
B	153 258 013	0.312	477 837	0.170	26 082	1.273	195 125	0.891	1 364 845
C_1	231 437 451	0.280	647 927	0.150	34 618	1.302	301 398	1.357	3 140 747
A+B+C_1	463 127 844	0.316	1 465 556	0.178	82 156	1.365	632 274	1.172	5 429 536

Calculation of geological reserves in the Study Report on reserves of the copper deposit South Minign District - Majdanpek in 2006 was doneusign the block model in which the limit content of copper metal in the ore was GS = 0.20% (Table 4). Blocks with copper content below GS were treated as waste rock.

Table 4. *Geological reserves in the copper deposit South Mining District Majdanpek in a contour of limit content 0.20% Cu*

Category	Ore quantity (t)	Mean Cu content (%)	Cu quantity (t)	Mean Au content (g/t)	Au quantity (kg)	Mean Ag content (g/t)	Ag quantity (kg)	Mean S content (%)	S quantity (t)
A	82 576 199	0.422	348 426	0.262	21 619	1.653	136 519	1.171	966 828
B	150 739 803	0.309	466 518	0.171	25 756	1.257	189 447	0.929	1 400 803
C_1	175 855 328	0.301	528 736	0.141	24 848	1.257	221 071	1.297	2 281 191
A+B+C_1	409 171 330	0.328	1 343 679	0.177	72 222	1.337	547 037	1.136	4 648 822

Based on this, it can be concluded that large quantities of ore, with corresponding quantities of copper, gold and silver metals, are obtained in the innovated block model by calculation, as follows:

- ore 53 956 514 t
- copper metal 121 877 t
- gold metal 9 934 kg
- silver metal 85 237 kg

3. STRATEGIC PLANNING AND DESIGN THE OPEN PIT SOUTH MINING DISTRICT USING THE SOFTWARE PACKAGES WHITTLE AND GEMCOM

The world mining companies in the assessment of financial sustainability and defining the optimum strategy for mine development use some of the software packages for optimization and design and, among them, the leading ones are Whittle and Gemcom, which Mining and Metallurgy Institute in Bor also owns.

Software for strategic planning and optimization of profits in mining - *Whittle* operates per the Lerch Grosmman algorithm by which the optimum pit contour is obtained on the basis of the economic value of individual mini-blocks in deposit. The essence of algorithm is that starting from the bottom of deposit, it takes blocks of economic interest including their value, and necessary expenses for their mining, that is the waste blocks that have to be mined to get to the ore block. In all of this, the attention is paid on a given corner of general slope of the open pit contour, which is obtained for the given techno-economic parameters, which are variable and depend on technical equipment and degree of modernization the mine on one side, and on the other side of the metal prices on the stock exchanges in the world. Based on this, it can be concluded that the optimum pit contour is not constant, but variable category.

In order to achieve full economic potential of mining operations and achieve maximum profit, the software allows defining the phases of open pit development, so called *pushbacks* inside the final optimum contour.

Figure 2 shows a graphical presentation of the optimization results for the basic copper price of 6 000 USD/t, based on which a selection of optimum open pit contour and *pushbacks* is done.

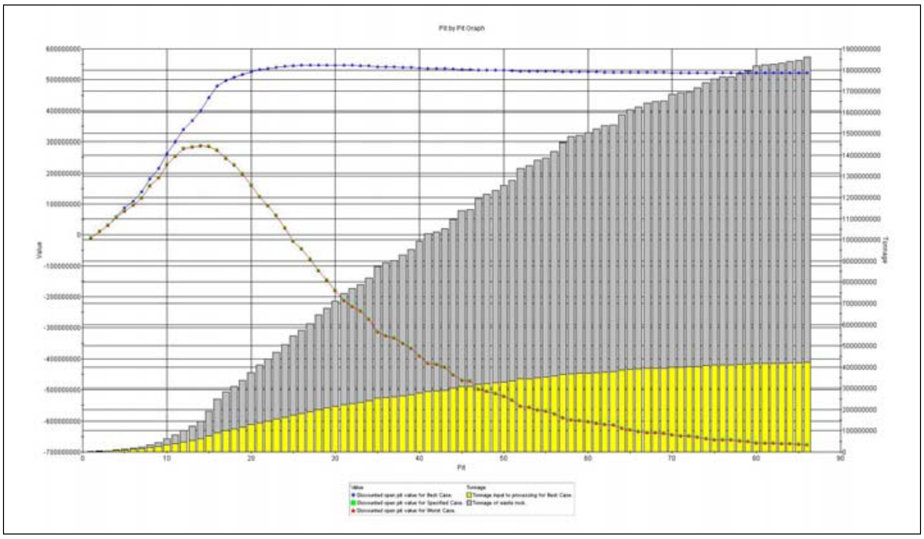

Fig. 2. *The results of optimization in Whittle*

Detailed processing of the results, obtained in *Whittle*, is done in the software for design (the the open pit *Gemcom*. Figure 3 gives a view of the final contour of the open pit South Mining District after processing in *Gemcom* with a review of the block model of deposit in 3D format.

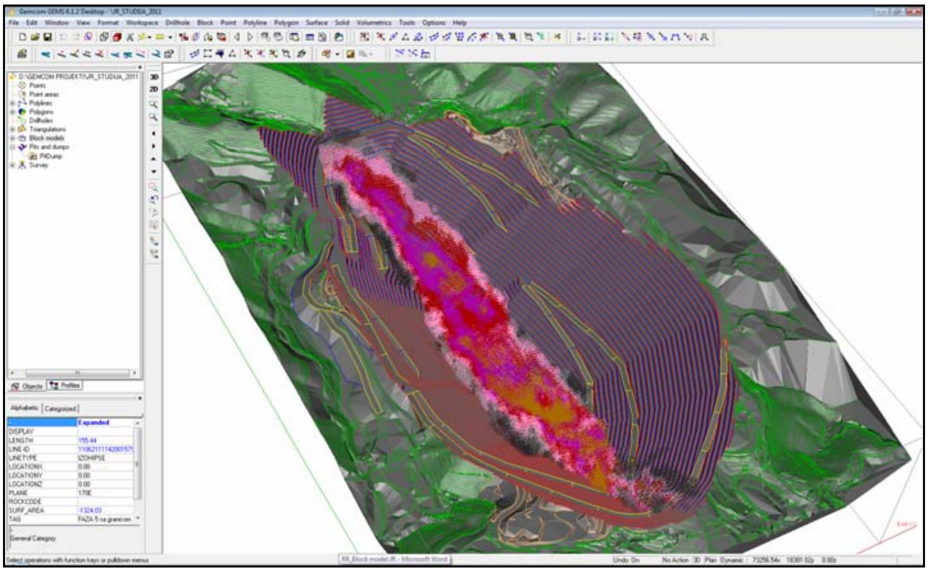

Fig. 3. *View of the final contour of the open pit South Mining District after processing in Gemcom with a review of the block model of deposit in 3D format.*

4. CONCLUSION

According to the Plan of development the production of copper ore in RTB Bor Group, which was adopted by the Management of Company, the open pit South Mining District in Majdanpek referred to as the carrier of copper ore production in RBM, with the planned annual capacity of mining and processing of 8.5 million tons.

Following the world trends in the field of mine design, development strategy of the open pit South Mining District in Majdanpek, in future period, relies on the application the leading software packages for strategic planning and optimization of profits in mining and mine design *Whittle* and *Gemcom*.

Based on the input data, obtained from exploratory drill holes and underground exploratory mining operations, modeling of the South Mining District – Majdanpek was developed in the software *Gemcom.*

The obtained block model was used both for calculation of reserves in deposit (geological, balance and off-balance) and future assessment the financial sustainability and defining the optimum strategy for mine development by the Company Management.

Since, in the innovated block model for calculation the geological reserves, it was adopted that the limit copper content in the ore is 0.15%, while, in the current, the limit content was 0.20%, large quantities of ore were obtained with corresponding quantities of copper, gold and silver metals, as follows:

- ore 53 956 514 t
- copper metal 121 877 t

– gold metal 9 934 kg
– silver metal 85 237 kg

The optimum open pit contour was obtained in the software *Whittle* for defined the input techno-economic parameters, which present the variable category, and later it was processed in detail in the software *Gemcom*.

Optimality criterion was achievement of maximum profit.

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UDK:681.33:622.79(045)=861

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3D MODEL ODLAGALIŠTA OŠTRELJ U PROGRAMU GEMCOM 6**

Izvod

3D model – Solid odlagališta „Oštrelj“ u programu Gemcom 6, konstruisan je na osnovu 3D površina – Surface paleoreljefa i konačne konture odlagališta. Ovaj model predstavlja osnovu za interpretaciju lokaliteta u digitalnom obliku. Za formiranje 3D modela, korišćeni su postojeći kartografski podaci. Korišćenjem ovog modela izračunata je količina odloženog materijala na lokalitetu.

Ključne reči: *Gemcom 6, odlagalište, 3D model, volumetrija*

1. UVOD

U periodu od 1975 do 1980 godine, jalovina sa površinskog kopa Bor odlagana je na više lokacija u blizini površinskog kopa, pri čemu su formirana spolja odlagališta. Jedno od njih je i odlagalište "Oštrelj" koje se još naziva i Istočno odlagalište, ili Cijanizacija. Nalazi se na krajnjem istoku od površinskog kopa Bor pored bivšeg pogona Cijanizacije koji nije više u funkciji, jer je deo kosine odlagališta za luženje kliznuo osamdesetih godina prošlog veka i onesposobio ovo postrojenje. To je ujedno i najviše odlagalište površinskog kopa Bor, čija je završna ravan na K+475 m, a nožica na koti K+375 m. Visina formiranog odlagališta iznosi 100 m sa nagibom kosine 38^0. U podnožju ovog odlagališta na jugoistočnoj strani nalazi se jezero Robule.

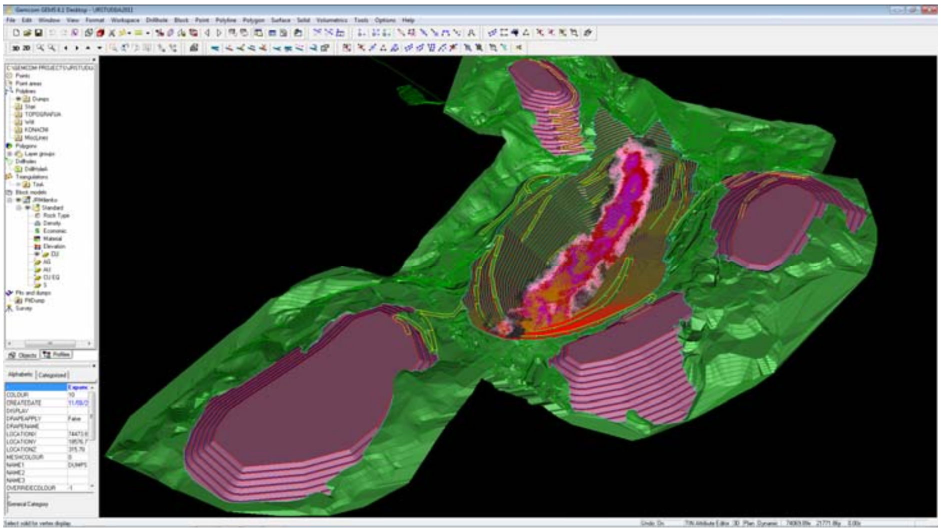
Razvojem računarske tehnike, i usled informatičke revolucije sredinom osamdesetih godina dvadesetog veka pojavili su se prvi programski paketi specijalizovani za oblasti geologije i rudarstva. Danas su ti programi evoluirali u izuzetno moćan i koristan alat čiji je cilj skraćivanje vremena potrebnog za izradu geomodela istraživanog ležišta, ušteda novca i što detaljniji 3D prikaz rudnih tela. Jedan od tih programa je i Gemcom 6 koji predstavlja specijalizovani softver za 3D modeliranje površinskih kopova.

* *Institut za rudarstvo i metalurgiju Bor*
** *Rad je proizašao iz projekta broj 37001 "Uticaj rudarskog otpada iz RTB-a Bor na zagađenje vodotokova sa predlogom mera i postupaka za smanjenje štetnog dejstva na životnu sredinu", koji je finansiran sredstvima Ministarstva za prosvetu i nauku Republike Srbije*

2. GEMCOM 6

Program Gemcom 6 koristi se za geološko modeliranje ležišta i obračun geoloških i eksploatacionih rezervi [1, 2, 3, 4], i za projektovanje površinskih kopova i određivanje dinamike otkopavanja [5, 6, 7, 8].

Prvi korak pri projektovanju površinskog kopa je geološko modeliranje ležišta na osnovu podataka dobijenih istražnim radovima. Pored geološke baze, drugi ulazni parametar za definisanje kopa je situaciona karta terena – topografija i/ili prethodno stanje radova. Podaci iz stubova bušotina o litologiji i sadržaju komponenti mogu da se importuju iz Excel tabela a situaciona karta iz AutoCAD-a [3, 4]. Po definisanju blok modela ležišta, konstruiše se konačna kontura kopa ili međuzahvat na osnovu geometrijskih parametara i potrebnih količina [5]. Kada su definisani početno i završno stanje konture kopa, određuje se dinamika otkopavanja za zahtevani period [6, 7]. Na slici 1 prikazan je konačan izgled površinskog kopa sa odlagalištima jalovine i goeloškim blok-modelom.



Sl. 1. *Površisnki kop sa odlagalištima jalovine i blok-modelom u program Gemcom 6*

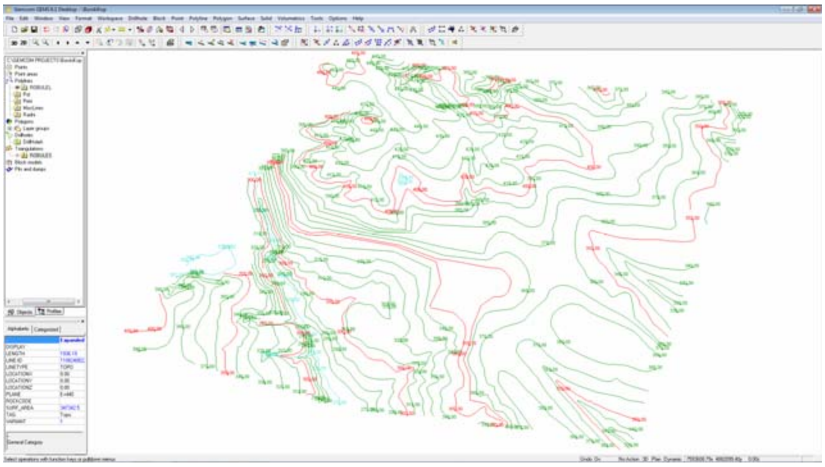
3. IZRADA 3D MODELA ODLAGALIŠTA

Jedan od načina za izradu 3D modela je na osnovu postojećih kartografskih podataka. U tu svrhu je s analognih izvora potrebno digitalizovati izohipse i kote prikazanih karakterističnih tačaka. Izohipse su na analognoj karti prikazane kao linije sa određenom elevacijom. Svaka izohipsa sadrži beskonačan broj tačaka na istoj visini. Kod digitalizacije izohipsa se vektorizuje određenim brojem tačaka. Najčešće se radi o tačkama infleksije uzduž izohipse, a pravilo je da digitalna izohipsa ne sme odstupati od njene odgovarajuće analogne izohipse.

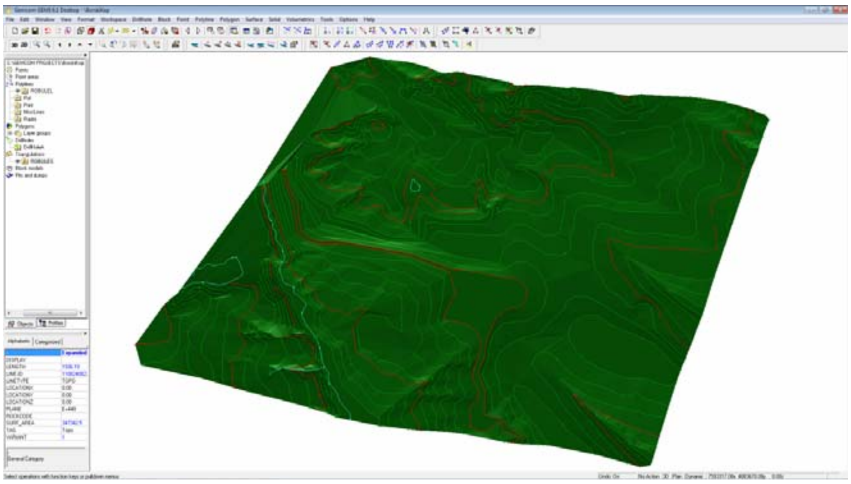
Za izradu 3D površina – Surface [9] paleoreljefa i konačne konture odlagališta korišćeni su kartografski podaci sa:

- Topografske karte šire okoline Bora (R = 1 : 50 000) na kojoj je prikazan konačan izgled odlagališta "Oštrelj", i
- Situacione karte terena pre izvođenja rudarskih radova na lokalitetu (R = 1 : 1 000) na kojoj je prikazan paleoreljef.

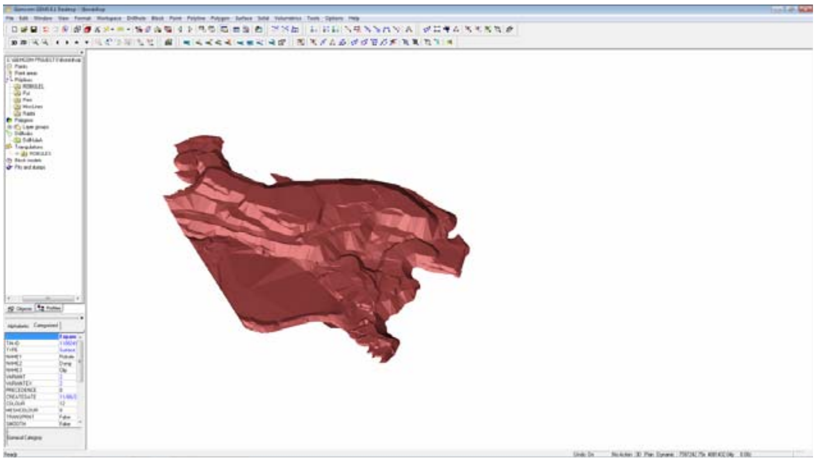
Izvršena je digitalizacija karata u AutoCAD-u i import dwg fajlova u Gemcom 6 odnosno formiranje asc fajlova. Od asc fajlova (slika 2) nakon njihove obrade i uklanjanja grešaka koje se uvek javljaju pri digitalizaciji (kolinearne tačke, ukrštanje linija, duplirane tačke, pikovi), formirane su 3D površine – Surface (slike 3 i 4) koje su osnova za konstrukciju 3D modela – Solid (slika 5).



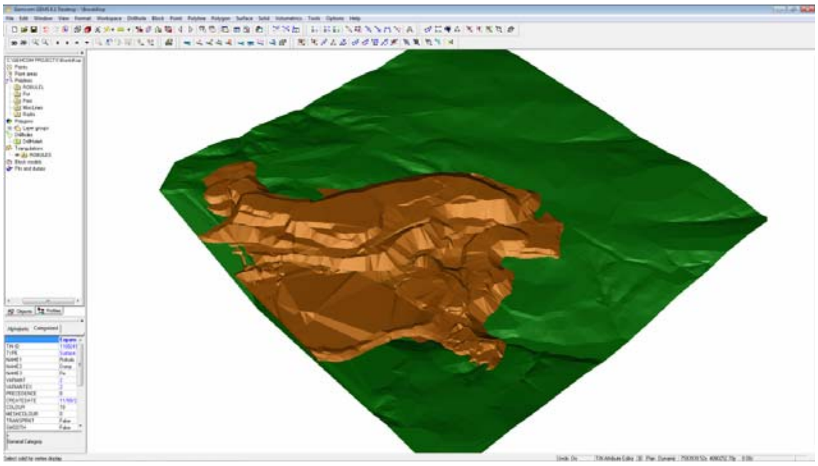
Sl. 2. *ASC fajl paleoreljefa u programu Gemcom 6*



Sl. 3. *3D površina – surface paleoreljefa u programu Gemcom 6*



Sl. 4. *3D površina – surface odlagališta u programu Gemcom 6*



Sl. 5. *3D model – solid odlagališta u programu Gemcom 6*

4. UPOTREBA 3D MODELA ODLAGALIŠTA

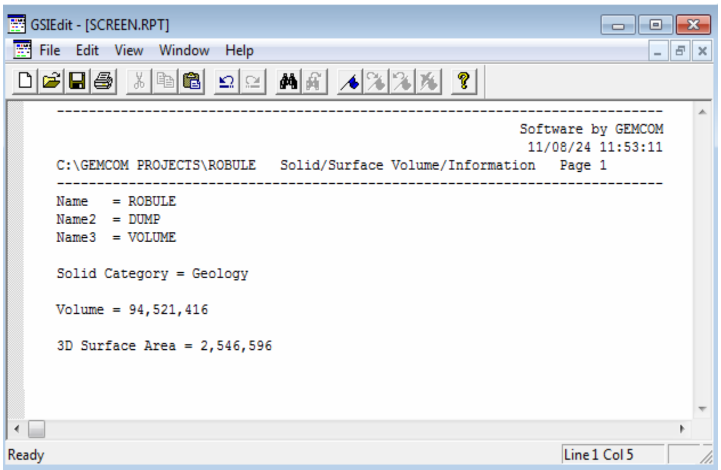
Tokom perioda odlaganja na odlagalištu "Oštrelj", granični sadržaj bakra u rudi bio je znatno veći nego danas, tako da postoji mogućnost eksploatacije ovog odlagališta luženjem ili klasičnim otkopavanjem.

3D model odlagališta predstavlja veliku pomoć projektantu u cilju sticanja utiska o geografskim osobinama terena i bez neposrednog izlaska na lokaciju.

Kreiranjem 3D modela odlagališta, definisana je granica za izradu blok –

modela odlagališta, unutar koje će blokovi imati vrednosti za analizirane parametre na osnovu geoloških podataka (sadržaj bakra, zlata i srebra, zapreminsku težinu, vrstu materijala, i sl.).

Alatom Volumetrics može da se odredi ukupna količina materijala i posmatranih elemenata unutar solida, a alatom Cut Evaluation može da se definiše dinamika otkopavanja po periodima eksploatacije za šta je takođe potreban solid. Na slici 6 prikazan je obračun količine materijala unutar odlagališta "Oštrelj".



Sl. 6. *Volumetrija solida u program Gemcom 6*

5. ZAKLJUČAK

Važan činilac upotrebe programa Gemcom 6 je mnogo kraće vreme i bolji kvalitet izrade projekata u odnosu na klasično projektovanje, što je u današnjim tržišnim uslovima od izuzetnog značaja pri dobijanju poslova i sklapanju povoljnih finansijskih ugovora.

3D model generalno predstavlja izuzetnu pomoć za proces projektovanja u geologiji i rudarstvu. Tu se pre svega misli na početnu fazu projektovanja, koja podrazumeva potrebu projektanta da stekne utisak o geografskim osobinama terena i bez neposrednog izlaska na lokaciju, kao i projektovanje geo – modela ležišta, konstrukcije kopova i odlagališta jalovine, i dinamike izvođenja rudarskih radova u programu Gemcom 6.

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UDK: 681.33:551.4 (045)=20

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3D MODEL OF THE WASTE DUMP OŠTRELJ IN THE SOFTWARE GEMCOM 6**

Abstract

3D model – Solid waste dump "Oštrelj" in the software Gemcom 6 was constructed based on 3D surface - Surface paleorelief and final contour of the waste dump. This model is the basis for interpretation the site in a digital form. The existing map data were used to form 3D model. The amount of disposed material on the site was calculated using this model.

Key words: *Gemcom 6, waste dump, 3D model, volumetry*

INTRODUCTION

In the period from 1975 to 1980, the waste material from the open pit Bor was disposed at several locations near the Open Pit, where the outside waste dumps were formed. One of them is the waste dump "Oštrelj" which is also called the Eastern waste dump or Cianization. It is located on the east of the Open Pit Bor near the former plant of Cianization which is no longer in use, because a part of the waste dump slope for leaching slided in the eighties and crippled this plant. It is also the highest waste dump of the Open Pit Bor with the final plane at level K+475 m, and pin at level K+375 m. Height of the formed waste dump is 100 m with a slope gradient 38°. The lake Robule is located on the bottom of this waste dump on the southeast side.

Development of computer technology and information revolution in the middle of eighties of the twentieth century have resulted into appearance of the first software packages, specialized in the areas of geology and mining. Today, these programs have evolved into extremely powerful and useful tool aimed at reducing the time needed for development a geomodel of investigated deposit, money saving and as much as possible detailed 3D model of ore body. One of these programs is Gemcom 6, which is the specialized software for 3D modeling of open pits.

GEMCOM 6

Gemcom 6 program is used for geological modeling of deposits and calculation the mining reserves [1, 2, 3, 4] and

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[**] *This paper work is the result of the Project TR 37001 "The impact of mining waste from RTB Bor on the pollution of surrounding water systems with the proposal of measures and procedures for reduction the harmful effects on the environment" funded by the Ministry of Education and Science of the Republic of Serbia.*

designing the open pits and determination the mining dynamics [5, 6, 7, 8].

The first step in design of open pit is the geological modeling of deposit based on data obtained from prospecting works. In addition to the geological base, the second input parameter to define the situational map of field - topography and/or previous condition of works. Data from the columns on lithology and content of components can be imported from the Excel spreadsheets and situational map from AutoCAD [3, 4].

By defining the block model of deposit, the final contour of open pit is constructed or intermediate web, based on geometric parameters and required amounts [5]. When the initial and final state of the open pit contour are defined, the mining dynamics is determined for the requested period [6, 7]. Figure 1 shows the final view of the open pit with waste dumps and geological block model.

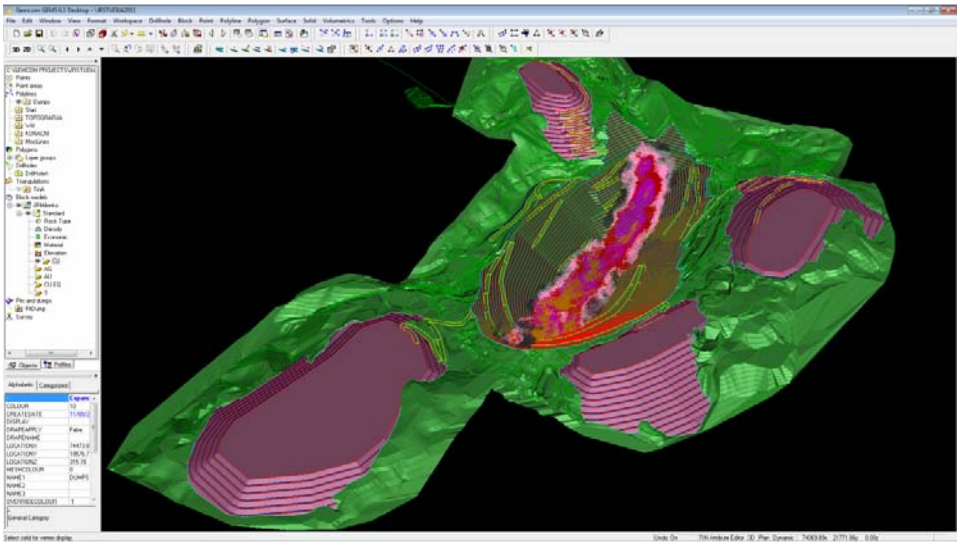

Fig. 1. *Open pit with waste dumps and block model in Gemcom 6 program*

DEVELOPMENT THE 3D MODEL OF WASTE DUMP

One of the ways to develop 3D model is based on the existing map data. For this purpose, it is needed to digitize the contour lines and elevation of present characteristic points from analogue sources. Contour lines are shown on analogue map as the lines with certain elevation. Each contour contains an infinite number of points at the same height. In digitizing, the contour is vectorized by the certain number of points. Most often, these are the inflection points along the contour line, and the rule is that digital contour must not deviate from its corresponding analogue contour line.

To develop 3D Surface [9] of paleorelief and the final contours of the waste dump. The map data were used with the following:

- Topographic maps of the surroundings of Bor (Scale = 1: 50 000) showing the final view of the waste dump "Oštrelj", and
- Location maps of the terrain before implementation of mining operations at the site (Scale = 1: 1 000) showing the paleorelief.

Digitizing of maps was done in Auto--CAD and import of dwg files in Gemcom 6, i.e. formation of asc files. From asc files (Figure 2) after their processing and removing of errors that always occur in digitizing (collinear points, crossing lines, duplicate points, peaks), 3D Surfaces were formed (Figures 3 and 4) which are the basis for the construction of 3D model - Solid (Figure 5).

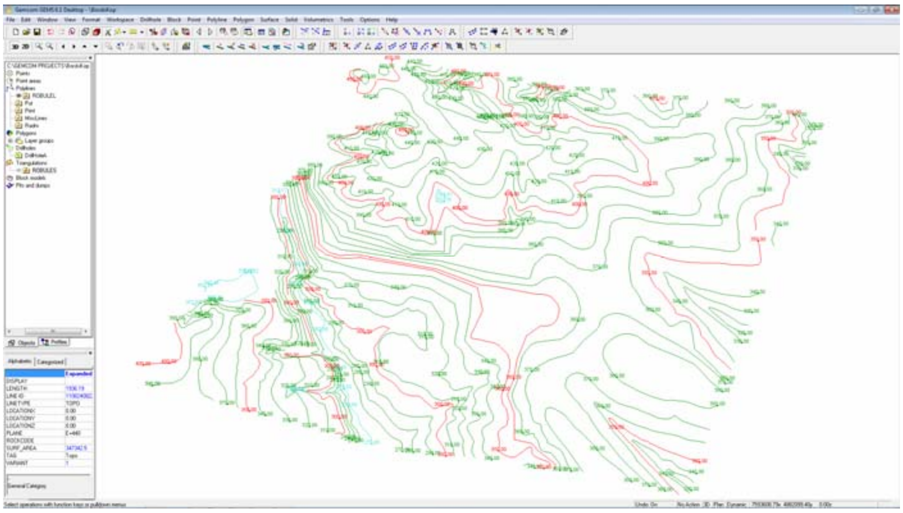

Fig. 2. *The asc file of paleorelief in Gemcom 6 program*

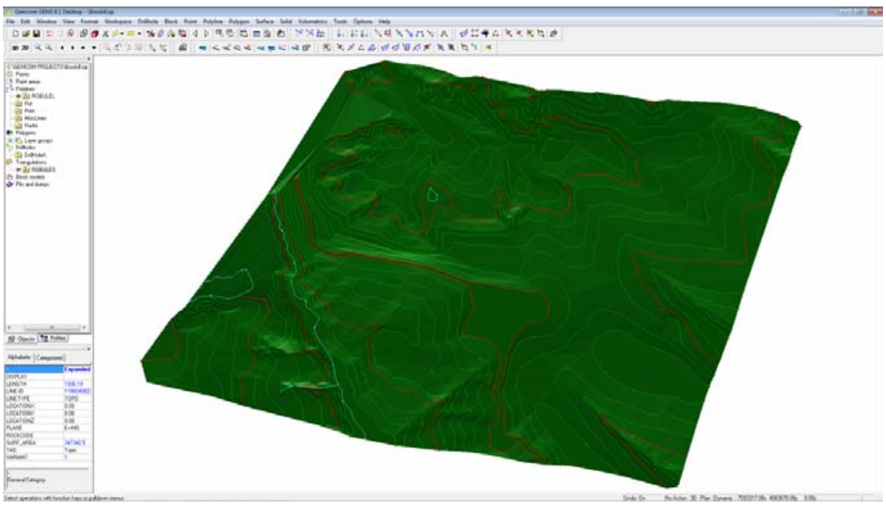

Fig. 3. *3D Surface of paleorelief in Gemcom 6 program*

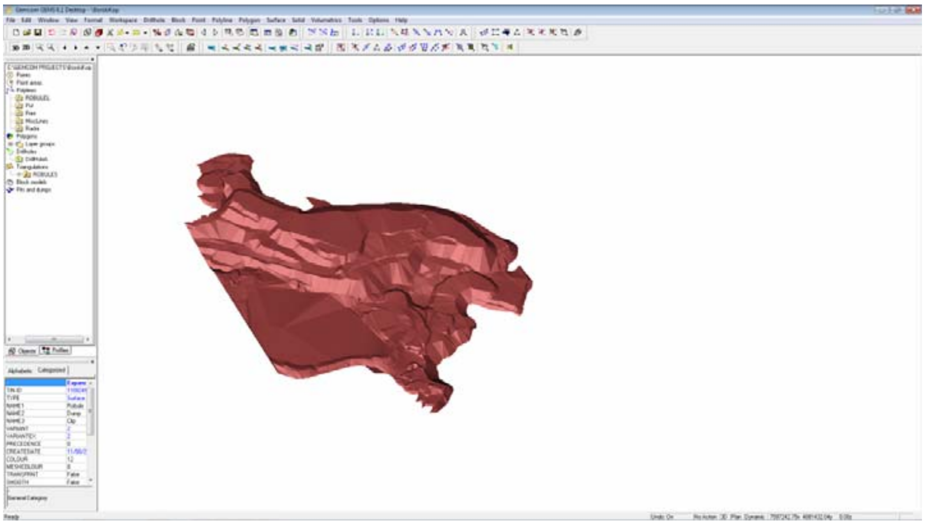

Fig. 4. *3D Surface of waste dump in Gemcom 6 program*

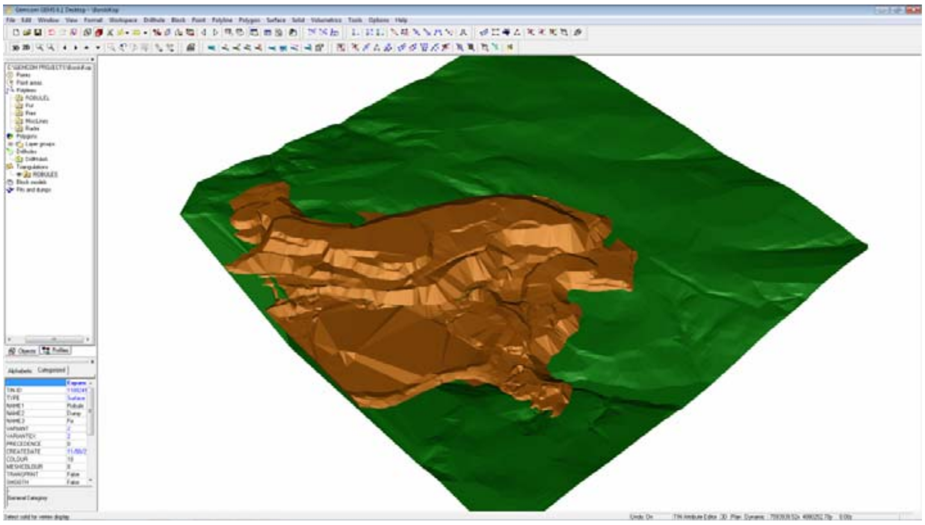

Fig. 5. *3D model – Solid of waste dump in Gemcom 6 program*

THE APPLICATION OF 3D MODEL OF WASTE DUMP

During the period of disposal at the waste dump "Oštrelj", limit copper content in the ore was significantly higher than today, so there is a possibility for exploitation of this waste dump by leaching or conventional mining.

3D model of the waste dump presents a great help to the designer in order to gain an impression on geographic features of terrain and without directly entering the site.

Creation of 3D model of waste dump defined the limit for development the block model of waste dump, inside which the blocks will have values for analyzed parameters on the basis of geological data (content of copper, gold and silver, bulk density, material type, etc.).

The tool Volumetrics 1 can determine the total quantity of materials and observed elements inside the solids, and the tool Cut Evaluation can define the mining dynamics per operation period for what the solid is also needed. Figure 6 shows the calculation of material amount inside the waste dump "Oštrelj".

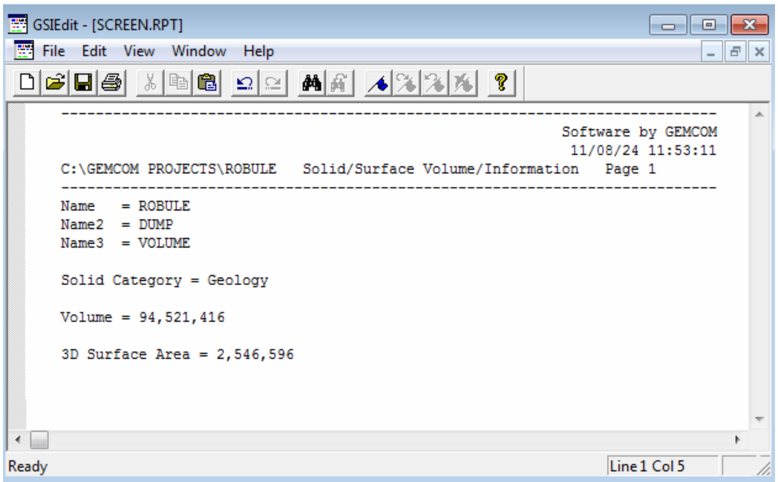

Fig. 6. *Volumetrics of solid in Gemcom 6 program*

CONCLUSION

An important factor in the use of Gemcom 6 program is much shorter time and better quality of development the projects than classic design which, in the present market conditions, is of great importance in obtaining the works and conclusion favorable financial agreements.

3D model generally presents a great help for design process in geology and mining. This is primarily the initial phase of design, which implies the need for designers to gain an impression of geographic features of terrain and without directly entering the field as well as design the geomodel of deposit, construction of open pits and waste dumps, and the dynamics of realization the mining works in Gemcom 6 program.

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ANALIZA PROSTORNOG POLOŽAJA RUDNIČKIH OBJEKATA RUDNIKA VELIKI KRIVELJ U ODNOSU NA PREDLOŽENU TRASU TUNELA ZA IZMEŠTANJE KRIVELJSKE REKE**

Izvod

Prostor doline Kriveljske reke predstavlja za sada jedinu realni lokaciju za deponovanje flotacijske jalovine nastale preradom rude bakra u flotaciji Veliki Krivelj. Da bi ovaj prostor bio u funkciji neophodno je postojeći kolektor za devijaciju Kriveljske reke staviti van upotrebe izgradnjom novog tunela, čija bi trasa išla delom kroz flotacijsko jalovište, a delom kroz stenski masiv.

Analizom prostornog položaja može se zaključiti da projektovani rudnički objekti neće ugroziti predloženu trasu tunela za devijaciju Kriveljske reke.

Ključne reči: *rudnik Veliki Krivelj, kolektor, tunel za izmeštanje Kriveljske reke.*

1. UVOD

Od početka rada rudnik bakra Veliki Krivelj bio je nosilac proizvodnje u preduzeću Rudnici bakra Bor (RBB), koji posluje u okviru RTB Grupe u Boru.

U okviru rudnika izdvajaju se dve tehnološke celine: površinski kop Veliki Krivelj i flotacija Veliki Krivelj. Osnovna delatnost površinskog kopa je eksploatacija rude bakra, a flotacije proizvodnja koncentrata bakra. Eksploatacijom ležišta, od 1982. do 2011. godine, otkopano je 213.530.000 t rude, odnosno 754.000 t bakra u rudi. Takođe je otkopano i 178.690.000 tona jalovih masa (otkrivke i pratećih stena).

U flotaciji Veliki Krivelj prerađeno je 198.295.000 t rude, pri čemu je dobijeno 689.333 t bakra.

Za deponovanje flotacijske jalovine, koja nastaje u procesu prerade rude, koristi se prostor dobijen pregrađivanjem doline

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

Kriveljske reke. Do 1990. godine za odlaganje se koristilo Polje 1, da bi se nakon toga jalovište proširilo zauzimanjem dodatnog prostora doline Kriveljske reke nizvodno od Polja 1. Pri tome formirano je novo jalovište Polje 2.

U Polju 2 za izvođenje Kriveljske reke van granica jalovišta izgrađen je betonski kolektor ukupne dužine 2.075 m. Usled nepoštovanja projektnih rešenja u pogledu kapaciteta jalovišta, došlo je do ozbiljnog oštećenja pomenutog kolektora.

Kako se rešenje postavljanja kolektora kroz Polje 2 pokazalo kao neadekvatno za primenu na predmetnom jalovištu pristupilo se traženju novog rešenja koje bi zamenilo kolektor. Kao optimalno rešenje predložena je izrada novog tunela, čija bi trasa išla delom kroz flotacijsko jalovište, a delom kroz stenski masiv.

2. STANJE POSTOJEĆIH RUDNIČKIH OBJEKATA I OBJEKATA ZA DEVIJACIJU KRIVELJSKE REKE 2011. GOD.

Radovi na površinskom kopu Veliki Krivelj obavljaju se u okviru definisane završne granice otkopavanja prema Dopunskom rudarskom projektu otkopavanja i prerade rude u ležištu Veliki Krivelj za kapacitet 8,5 x 10^6 tona vlažne rude godišnje iz 2006. godine. U 2011. godini razvoj površinskog kopa bio je uglavnom po planu, sa proširenjem od severnog do jugozapadnog boka kopa (slike 1a i 2).

Značajan porast cena bakra na svetskoj berzi i opredeljenje Vlade Republike Srbije da dugoročno investira u RTB Bor, stvorilo je nove okolnosti za razvoj i površinskog kopa Veliki Krivelj. U tom smislu definisana je nova završna granica otkopavanja za naredni period od 40 godina.

U sadašnjem trenutku flotacijska jalovina se odlaže u Polju 2 flotacijskog jalovišta Veliki Krivelj. Polje 2 nastalo je nizvodnim proširenjem postojećeg jalovišta izgradnjom peščane brane - brane 3. Projektovano je sa završnom kotom krune brane 3 na 350 m (kota uspora 345 m) i ukupnom zapreminom od 89,4 x 10^6 m^3 . Brana 3 je najvećom svojom dužinom već dostigla projektovanu visinu od 350 m. Kako je kota uspora u Polju 2 dostigla visinu od 345,95 m, to znači da je praktično sav slobodni akumulacioni prostor ovog polja iskorišćen do kraja i da u Polju 2 nema vise slobodnog prostora za deponovanje jalovine (slika 2).

Radi prevazilaženja problema usled nedostatka slobodnog akumulacionog prostora za dalje deponovanje jalovine iz flotacije Veliki Krivelj započete su aktivnosti na preseljenju tehnologije i objekata sa Polja 2 na Polje 1 flotacijskog jalovišta Veliki Krivelj.

Za devijaciju Kriveljske reke izgrađen je tunel kroz stenski masiv po levoj obali reke (slika 2) ukupne dužine 1.414 m, unutrašnjeg prečnika prečnika 3.000 mm, sa betonskom dvostrano armiranom oblogom debljine 2 000 mm. Prosečni nagib tunela je 1,1%. Uzvodno od tunela i brane 1A dozvoljeno je stvaranje retenzionog basena radi akumulacija katastrofalnih voda Kriveljske reke. Pri katasrofalnim padavinama verovatnoće 0,1% kota maksimalnog uspora retenzione akumulacije je 302,0 mnv.

Usled prolaska kiselih voda kroz tunel, pH vrednosti 2-4, došlo je do erozije dna tunela, te je potrebno izvršiti sanaciju dna tunela u celoj njegovoj dužini.

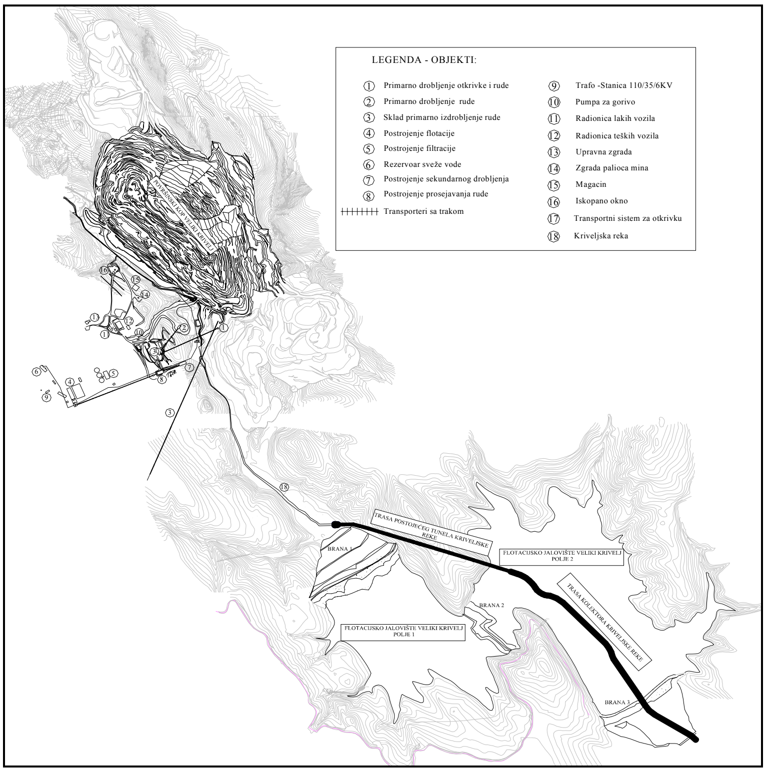
Kolektor kroz Polje 2 (slika 2) izrađen je za izvođenje voda Kriveljske reke van granica jalovišta. Projektovan je kao cev, prečnika 3.000 m, debljine 500 mm i ukupne dužine 2.075 m. Usled odstupanja od projektne dokumentacije u procesu formiranja flotacijskog jalovišta, došlo je do njegovog oštećenja u zoni brane 3, u dužini od oko 600 m. U cilju održanja kolektora u funkciji urađena je sanacija na napred navedenoj dužini tako da je slobodni profil kolektora smanjen na 2.200 mm, a u beton je ugrađena znatno veća armatura tako da se omogući zapunjavanje jalovišta do planiranog nivoa od k +345 m.

a)

b)

c)


Sl. 1. *a) Površinski kop*
b) Flotacija
c) Flotacijsko jalovište



Sl. 2. *Prikaz postojećih rudničkih objekata i postojećih objekata za devijaciju Kriveljske reke*

3. PROJEKTNA REŠENJA RUDNIČKIH OBJEKATA I PREDLOŽENA TRASA TUNELA ZA DEVIJACIJU KRIVELJSKE REKE

Na osnovu tehnoekonomskih parametara procesa otkopavanja i prerade rude bakra u rudniku Veliki Krivelj i prognozirane bazne cene bakra na svetskom tržištu od 6.000 $, primenom softvera za ekonomsku optimizaciju ležišta i strateško planiranje Whittle i softvera za dizajn površinskih kopova Gemcom, utvrđena je konačna (optimalna) granica površinskog kopa Veliki Krivelj, slika 4. U okviru utvrđene konačne granice otkopaće se 409.658.209 t rude, sa 1.327.292 t bakra i 503. 115 419 t otkrivke. Vek eksploatacije površinskog kopa iznosi 40 godina.

Imajući u vidu dugoročno gledano potrebe za odlaganjem flotacijske jalovine (za narednih 40 godina) iz prerađivačkih kapaciteta rudnika Veliki Krivelj, prostorne mogućnosti već definisane lokacije flotacijskog jalovišta u dolini Kriveljske reke, kao i postojeće stanje pojedinih instalacija, objekata i jalovišnog sistema u celini, a uvažavajući neophodnost maksimalnog korišćenja raspoloživog prostora u granicama morfoloških karakteristika terena projektovani koncept odlaganja flotacijske jalovine podrazumeva sledeće:

1) završetak eksploatacije Polja 2,
2) nadvišenje Polja 1 od sadašnjeg stanja k+352/344 do k+385/380,
3) proširenje flotacijskog jalovišta Veliki Krivelj na Polje 3 do k+375/370 uzvodno od Polja 1 izgradnjom brane 4 (Slika 4).

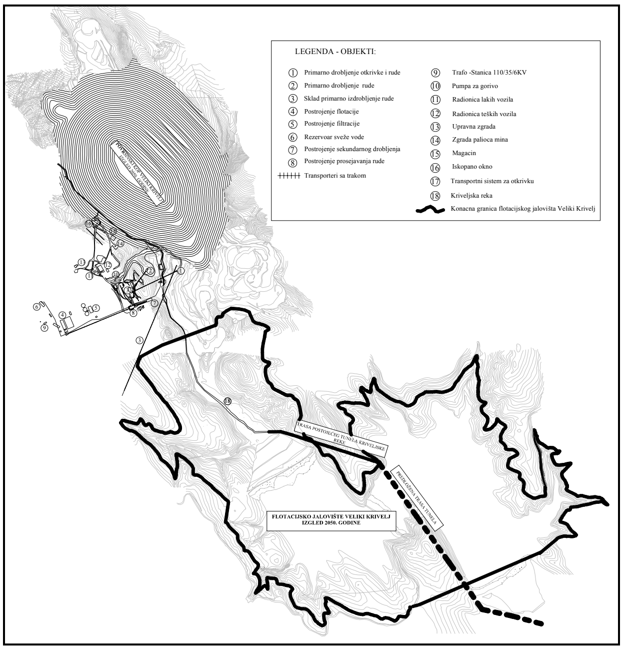
Projektovana trasa novog tunela polazi sa padine Tilva Satuli, zatim u dužini od oko 200 m prolazi ispod samog flotacijskog jalovišta Polja 2 (slika 3).

Na koti k +350 m trasa nastavlja preko padine Satuli. Na dužini od 1.820 m trasa menja azimut pružanja i od kote k +335 m skreće više ka istoku do izlaznog portala koji je nizvodno od brane 3A.

Ukupna dužina predložene nove trase tunela oznosi 2.400 m, a njen prostorni položaj u odnosu na postojeće rudničke objekte rudnika Veliki Krivelj prikazan je na slici 4.

Zbog velikog broja sigurnosnih stubova i sličnih geološko – tehničkih uslova eksploatacije, u radu je izabran jedan karakterističan stub (57/4), koji će služiti kao osnova za eksploataciju ostalih sigurnosnih stubova. Za ovaj stub proračun rudnih rezervi dat je u tabeli br. 1.

Sl. 3. *Deo Polja 2 ispod kojeg će proći nova trasa tunela*



Sl. 4. *Prikaz projektnog rešenje rudničkih objekata i predložene trase tunela za devijaciju Kriveljske reke*

ZAKLJUČAK

Buduća eksploatacija rude bakra u rudniku Veliki Krivelj, pored niza drugih faktora, uslovljena je i obezbeđenjem potrebenog prostora za odlaganje flotacijske jalovine. Iz tog razloga kao optimalno rešenje smatra se obezbeđenje uslova da se maksimalno iskoriste prosotrone mogućnosti koje pruža dolina Kriveljske reke. Međutim, ograničavajući faktor jeste opasnost od rušenja postojećeg kolektora Kriveljske reke.

Zbog lošeg stanja postojećeg kolektora Kriveljske reke i realne opasnosti od njegovog rušenja, jedino optimalno rešenje jeste izgradnja novog tunela, kojim bi se regulisao tok Kriveljske reke. Predložena trasa novog tunela išla bi delom kroz flotacijsko jalovište, a delom kroz stenski masiv.

Analizom prostornog položaja rudničkih objekata rudnika Veliki Krivelj i predložene trase novog tunela za devijaciju Kriveljske reke u narednom periodu, koji obuhvata razdoblje od 2011. godine do 2050. godine, može se zaključiti da ne postoji potencijalna ugroženost predložene trase novog tunela za devijaciju Kriveljske reke od rudničkih objekata i obratno, čime je omogućen nesmetan budući razvoj površinskog kopa i flotacijskog jalovišta Veliki Krivelj u napred navedenom periodu.

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ANALYSIS THE SPATIAL POSITION OF MINING FACILITIES OF THE VELIKIU KRIVELJ MINE TO THE PROPOSED TUNNEL ROUTE FOR RELOCATION THE KRIVELJ RIVER[**]

Abstract

The area of the Krivelj River valley currently presents the only realistic location for disposal of flotation tailings resulting from the copper ore processing in the Flotation Plant Veliki Krivelj. In order to put this area in operation, it is necessary to put out of use the existing collector for deviation the Krivelj River by construction the new tunnel, whose route will partly pass through the flotation tailing dump, and went through the flotation tailings in part, and partly through the rock massif.

By analyzing the spatial position, it can be concluded that the designed mining facilities will not affect the proposed tunnel route for deviation the Krivelj River.

Key words: *Veliki Krivelj mine, collector, tunnel for relocation the Krivelj River*

1. INTRODUCTION

Since the beginning of operation the Copper Mine Veliki Krivelj was the holder of production in the company Copper Mines Bor (RBB), which operates within RTB Bor Group in Bor.

Within the mine, two technological units are allocated: the Open Pit Veliki Krivelj and Flotation Plant Veliki Krivelj. The main activity of the Open Pit is copper ore mining, and the main activity of the Flotation Plant is the copper concentrate production.

By exploitation of deposit, since 1982 to 2011, 213 530 000 t of ore was mined, that is 754 000 t of copper in the ore. Also, 178 690 000 tons of barren mass was mined (overburden and associated rocks).

In the Flotation Plant Veliki Krivelj, 198 295 000 t of ore was processed, with the obtained 689 333 t of copper.

For disposal of flotation tailings,

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resulting in the ore processing, the space obtained by damming the Krivelj River valley is used. Until 1990, the Field 1 was used for disposal of tailings, and after that the tailing dump was expanded by taking the additional area of the Krivelj River valley downstream of the Field 1. During this, the new tailing dump – Field 2 was formed.

In the Field 2, the concrete collector, in the total length of 2075 m, was built for running the Krivelj River outside the boundaries of tailing dump. Due to the failure of design solutions in terms of the tailing dump capacity, there was a serious damage of the mentioned collector.

As the solution of setting the collector through Field 2 proved to be inadequate for the use on the subject tailing dump, finding a new solution approached that would replace the collector. Construction of a new tunnel was proposed as the optimum solution, with the route which will partly pass through the flotation tailing dump, and partly through the rock massif.

2. CONDITION OF THE EXISTING MINE FACILITIES AND FACILITIES FOR DEVIATION THE KRIVELJ RIVER

Works at the Open Pit Veliki Krivelj are realized within the defined final limit of mining according to the Supplementary Mining Design of ore mining and processing in the deposit Veliki Krivelj for capacity 8.5 x 10^6 t of wet ore annually from 2006. In 2011, a development of Open Pit was largely as planned with expansion from the north to the southwest side Open Pit (Figures 1a and 2).

A significant increase in copper prices on the world stock exchanges, and commitment of the Government of the Republic Serbia to make the long-term investment in RTB Bor, has created the new conditions for development the Open Pit Veliki Krivelj. In this sense, the new final border of mining was defined for the next period of 40 years.

At present, the flotation tailings are disposed in Field 2 Large of the Veliki Krivelj flotation tailing dump. Field 2 was formed downstream by extension the existing tailing dump with construction the sand dam – Dam 3. It was designed with the final crest elevation of Dam 3 at 350 m (345 m elevation backwater) and total volume of 89.4 x 10^6 m^3. Dam 3 has already reached the designed height of 350 m by its longest length. As the elevation of backwater in Field 2 has reached the height of 345.95 m, this means that practically all free accumulation area of this field was used to the end and that in Field 2 there is no more free space for disposal of tailings (Figure 2).

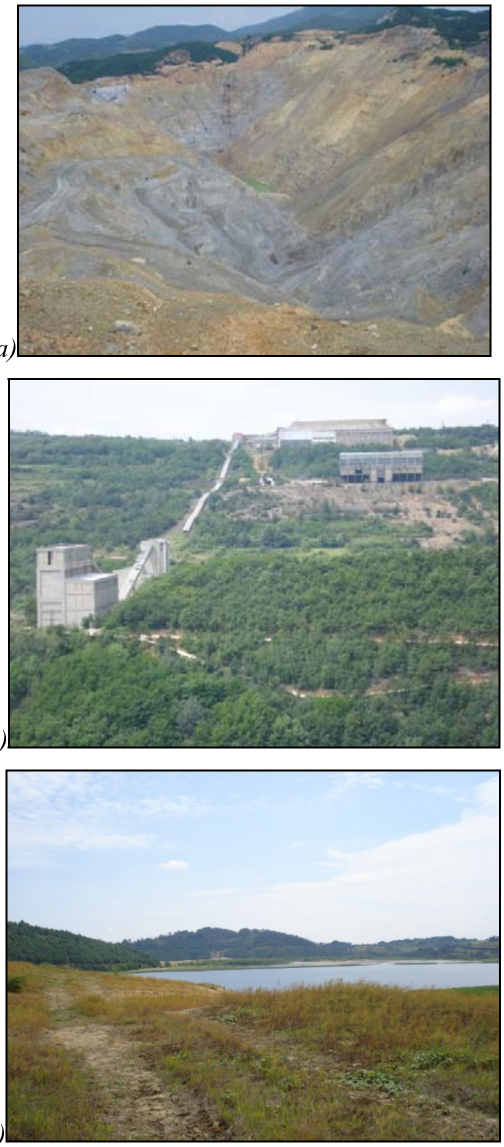
To overcome the problems due to a lack of free accumulation area for further disposal of tailings from the Veliki Krivelj Flotation Plant, the activities have started on relocation the technology and facilities from Field 2 on Field 1 of the Veliki Krivelj flotation tailing dump.

For deviation of the Krivelj River, a tunnel was built through the rock massif on the left bank of the river (Figure 2), the total length 1 414 m, inner diameter 3 000 mm, with double-reinforced concrete lining thickness of 2 000 mm. Average slope of the tunnel is 1.1%. Upstream of the tunnel and Dam 1A, the formation of retention basin is allowed for accumulation the disaster water of the Krivelj River. During disaster rainfall, the probability 0.1% of maximum backwater elevation of retention accumulation is 302.0 meters.

Due to the acidic water passing through the tunnel, pH value 2-4, there was an erosion of the tunnel bottom, and it is necessary to repair the tunnel bottom throughout its whole length.

Collector through Field 2 (Figure 2) was constructed for running the water of the Krivelj River outside the boundaries of the tailing dump. It was designed as a tube with diameter of 3 000 m, thickness of 500 mm and overall length of 2075 m.

Due to the deviations of design documentation in the process of formation the flotation tailing dump, damage appeared in the zone of Dam 3 in length of about 600 m. In order to maintain the collector function, a repair was done to the above mentioned length so that the collector clearance was reduced to 2 200 mm, and much higher reinforcement was embedded into concrete as to permit the filling of tailing dump to the planned level of k+345 m.



a) b) c)

Fig. 1. *a) Open Pit*
b) Flotation Plant
c) Flotation Tailing dump

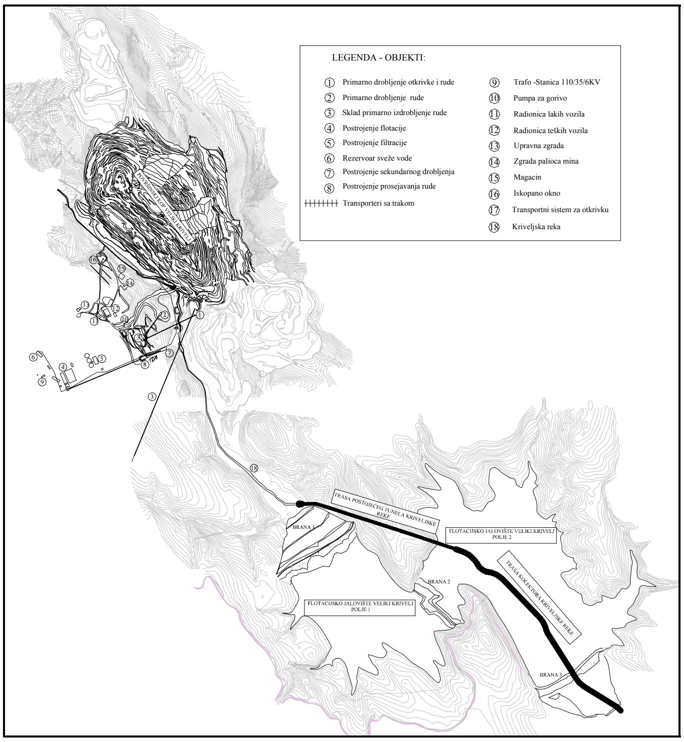


Fig. 2. *Review of the existing mining facilities and existing facilities for deviation the Krivelj River*

3. DESIGN SOLUTIONS OF MINIONG FACILITIES AND PROPOSED TUNNEL ROUTE FOR THE KRIVELJ RIVER DEVIATION

Based on techno-economic parameters of the copper ore mining and processing process in the Veliki Krivelj mine and forecast base price of copper on the world market of 6000 $, using the software for economic optimization of deposit and strategic planning Whittle and software for design the open pits Gemcom, the final (optimum) boundary of the Open Pit Veliki Krivelj was established, Figure. Within the established final boundary, 409 658 209 t of ore will be mined, with 1 327 292 t of copper and 503 115 419 t of overburden. Open Pit mining life is 40 years.

Regarding to the need for long term disposal of flotation tailings (for the next 40 years) from the processing capacities of the Veliki Krivelj mine, the spatial features of already predefined location of flotation tailing dump in the Krivelj River valley, as well as the current state of individual installations, facilities and tailing dump system as a whole, and recognizing the necessity of using maximum available space within the limits of morphological terrain characteristics, the designed concept of disposal the flotation tailings involves the following:

1) Completion the exploitation of Field 2
2) Overpasing Field 1 from current state k+352/344 to k+385/380
3) Expansion of the flotation tailing dump Veliki Krivelj to Field 3 to k+375/370 downstream of Field 1 by construction Dam 4 (Figure 4).

Designed route of the new tunnel starts from the slope Tilva Satuli in length of about 200 m and passes below the flotation tailing dump of Field 2 (Figure 3).

At elevation k + 350 m, the route continues over the slope Satuli. At length of 1 820 m, the route changes azimuth and at elevation of k + 335 m turns towards the east to the exit portal, which is downstream from Dam 3A.

Total length of the proposed new tunnel route is 2 400 m, and its spatial position to the existing mining facilities of the Veliki Krivelj mine is shown in Figure 4.

Fig. 3. *A part of Field 2 below which the new tunnel route will pass*

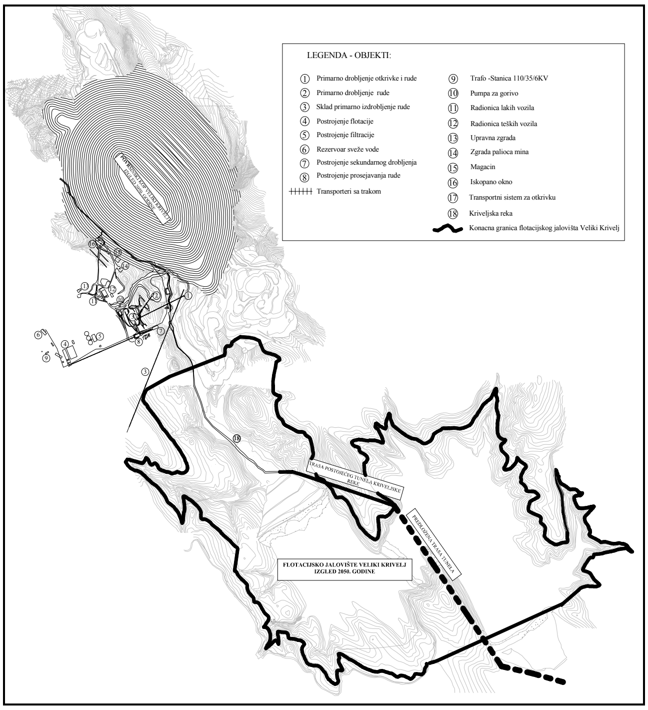


Fig. 4. *Review of design solution the mining facilities and proposed tunnel route for deviation the Krivelj River*

4. CONCLUSION

Future copper ore mining in the Veliki Krivelj mine, in addition to a number of other factors, is caused by providing the required space for disposal the flotation tailings. Due to this reason, providing the conditions for maximum use the spatial possibilities, provided by the Krivelj River valley, is considered as the optimum solution. However, the limiting factor is a danger of demolition the existing collector of the Krivelj River.

Due to poor condition of the existing collector of the Krivelj River and real danger of its demolition, the only optimum solution is a new tunnel construction, which would regulate the Krivelj River flow. The proposed route of new tunnel would partly pass through the flotation tailing dump and partly through the rock massif.

Analyzing the spatial position of mining facilities of the Veliki Krivelj mine and proposed the new tunnel route for deviation the Krivelj River in the future, covering the period from 2011 to 2050, it can be concluded that there is no a potential endanger to the new tunnel route for deviation the Krivelj River by the mining facilities and vice versa, what enables a normal future development of the open pit and Veliki Krivelj flotation tailing dump within the aforesaid period.

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Srđana Magdalinović, Dragan Milanović*, Branislav Čađenović*, Vesna Marjanović**

TEHNOLOŠKI POSTUPAK GRANULIRANJA ŠLJAKE RADI SNIŽENJA KRUPNOĆE NA ULAZU U FLOTACIJU**

Izvod

U ovom radu je prikazano jednostavno rešenje pri kojem je moguće da se snizi ulazna krupnoća šljake u proces flotacije a da se pri tome izbegne faza drobljenja. Proces granuliranja šljake je jeftin, a tehnološki potpuno opravdan što se može videti iz priloženog granulometrijskog sastava proizvoda drobljenja i granuliranja šljake.

Ključne reči: *šljaka, usitnjavanje, granuliranje*

UVOD

Projektom TR 33023 pod naslovom *Razvoj tehnologija flotacijske prerade ruda bakra i plemenitih metala radi postizanja boljih tehnoloških rezultata* koji finansira Ministarstvo prosvete i nauke u okviru Programa tehnološkog razvoja sprovedena su određena istraživanja u oblasti granuliranja šljake.

Višedecenijska prerada koncentrata u Boru dovela je do stvaranja deponije šljake koja predstavlja otpad iz metalurškog procesa. U ovom proizvodu su sadržane značajne količine korisnih metala. Ukupne rezerve šljake u tehnogenom ležištu bakra „Depo šljake – 1” su 9.190.940 t. Srednji sadržaj bakra iznosi 0,715%, zlata 0,282 g/t, srebra 4,50 g/t, molibdena 0,0413%. Desetak godina unazad flotacijskom koncentracijom u pogonu u Boru se dobijaju pomenuti korisni metali ali sa nizom poteškoća i manje uspešno nego u svetu na sličnim sirovinama. Pogon „Flotacija” u Boru je prvobitno projektovan za drugačiju vrstu sirovine a sada je samo prilagođen za preradu šljake. Šljaka je manje pogodna za usitnjavanje sa stanovišta potrošnje energije, obloga i meljućih tela od rude.

* *Institut za rudarstvo i metalurgiju Bor*

** *Ovaj rad je proistekao kao rezultat projekta TR 33023 „Razvoj tehnologija flotacijske prerade ruda bakra i plemenitih metala radi postizanja boljih tehnoloških rezultata“ finansiranog od strane Ministarstva prosvete i nauke Republike Srbije*

USITNJAVANJE ŠLJAKE U POGONU FLOTACIJE U BORU

Proces usitnjavanja šljake u pogonima Flotacije u Boru sastoji se iz drobljenja i mlevenja.

DROBLJENJE ŠLJAKE

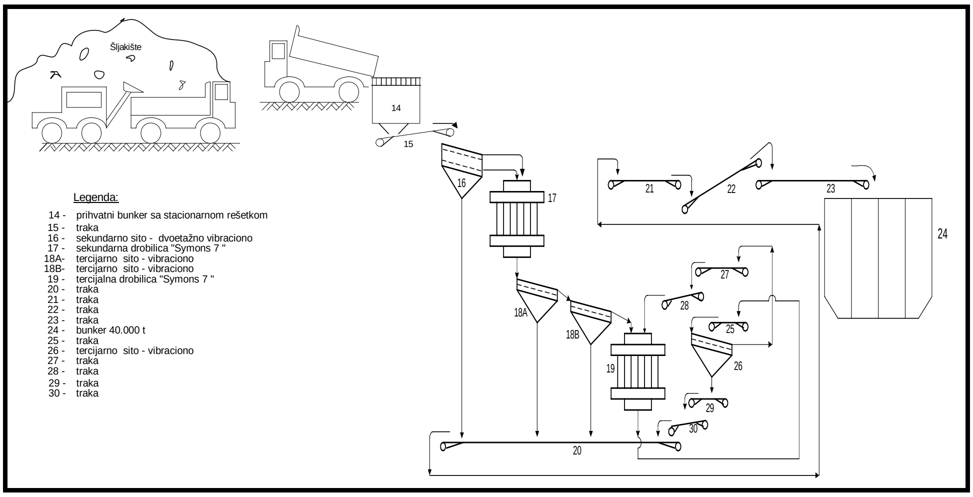
Primarno izdrobljena šljaka miniranjem na šljakištu, krupnoće 100 % - 200 +0 mm, doprema se kamionima do prihvatnog bunkera (poz.14) sa rešetkom otvora 200 mm ispred kose trake. Prihvatni bunker se nalazi na platou pored objekta drobljenja i iz istog se kosom trakom (poz.15) primarno usitnjena šljaka transportuje na jedno kružno-oscilatorno (turbo) sito (poz.16), na primarno prosejavanje. Prosev donje mreže sita, krupnoće 100% -12,5+0 mm, kao gotov proizvod drobljenja pada na tračni transporter (poz.20). Odsevi gornje i donje mreže sita idu na sekundarno drobljenje.

Sekundarno drobljenje rude se vrši u Standardnoj Symons drobilici (poz.17) od 2133,6 mm (7 Ft HD), čija je geometrija ulazne komore tipa Coarse, a otvor za pražnjenje drobilice ima veličinu od CSS = 31 mm. Izlaz iz drobilice, ide na dva linijski postavljena rezonantno-oscilatorna (FKR) sita, (poz.18A i B), na sekundarno prosejavanje. Sita su međusobno identična, otvori su dimezija a x b = 12,5 x 12,5 mm. Odsev ovih sita, krupnoće 100% - 64+12,5 mm, ide u jednu kratko konusnu drobilicu za tercijarno drobljenje šljake (poz. 19). Prosev sita, krupnoće 100 % - 12,5+0 mm, kao drugi deo gotovog proizvoda drobljenja, pada na sabirnu transportnu traku (poz.20).

Tercijarno drobljenje šljake se vrši u kratko konusnoj Symons drobilici (poz.19) od 2.133,6 mm (7 Ft HD), čija je ulazna komora tipa Coarse, a otvor za pražnjenje drobilice ima veličinu od CSS = 13 mm ili ½" Izlaz iz drobilice, krupnoće 100 % -25 mm pada na jedan trakasti transporter (poz.25), koji ga transportuje do jednog vibro (TSP) sita (poz.26), na tercijarno prosejavanje. Sito ima prosevnu površinu sa otvorma dimezija axb = 12,5x12,5 mm. Odsev ovog sita, krupnoće 100 % -25 mm, vraća se pomoću trakastih transportera (poz. 27 i 28) na tercijarno drobljenje, čime se zatvara ciklus tercijarnog drobljenja sa prosejavanjem. Prosev sita, krupnoće 100 % -12,5+0 mm, kao treći i završni deo gotovog proizvoda drobljenja, transportuje se transportnim trakama (poz. 29 i 30) na sabirnu transportnu traku (poz.20).

Definitivno izdrobljena šljaka, kontrolisane krupnoće (100 % -12,5+0 mm), transportuje se iz procesa drobljenja u bunker gotovog proizvoda drobljenja (poz.24), kapaciteta od oko 40.000 tona, posredstvom trakastih transportera (poz. 21, 22 i 23), a iz njega dalje do bunkera ispred flotacije posredstvom zvezdastih dodavača i sistema trakastih transportera.

Tehnološka šema drobljenja šljake prikazana je na slici 1.



Sl. 1. *Tehnološka šema drobljenja šljake*

MLEVENJE I KLASIRANJE ŠLJAKE

Definitivno izdrobljena ruda se iz bunkera 40.000 t, transportnim trakama doprema do bunkera ispred mlinskih sekcija B i C, zapremine oko 1 500 t. Mlevenje šljake obavlja se u dva stepena i to u mlinovima sa šipkama i mlinovima sa kuglama. Klasiranje izmlevene šljake na sekcijama B i C je jednostepeno.

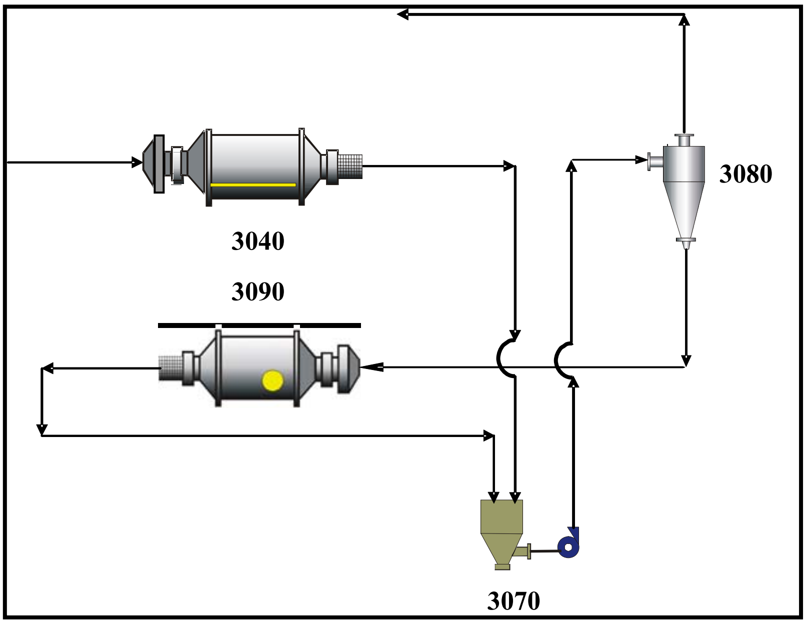
Mlinovi sa kuglama rade u zatvornom krugu sa hidrociklonima. Klasiranje samlevene šljake obavlja se u hidrociklonima (poz. 2080 i 3080) na obe mlinske sekcije. Prelivi hidrociklona se gravitacijski transportuju na čelo flotacijskih mašina za osnovno flotiranje.

Iz bunkera, koji odgovaraju B i C sekciji mlevenja u flotaciji, definitivno izdrobljena ruda se izvlači dodavačima, i dodaje na trakaste transportere - na kojima su instalirane tračne vage, a sa njih šalje na dvostadijalno mlevenje sa klasiranjem. Mlevenje definitivno izdrobljene rude sa klasiranjem vrši se kroz dve identične mlinske sekcije B i C flotacije u Boru, u dva stadijuma, od polazne krupnoće 100% -12,5+0 mm, do završne krupnoće 65% -0,074 mm, pri pojedinačnom sekcijskom časovnom kapacitetu prerade od 80 tona suve šljake, ili ukupno 160 t/h.

Primarno mlevenje šljake obavlja se u dva identična mlina sa šipkama, (poz. 2040 i 3040). Sekundarno mlevenje šljake se obavlja u dva identična mlina sa kuglama, (poz. 2090 i 3090).

Proizvodi mlinova sa šipkama i kuglama, sa obe sekcije, spajaju se u ciklonskim pumpama (poz. 2070 i 3070) i uz dodatak vode klasiraju u hidrociklonima (poz. 2080 i 3080) - sekcije B i C. Preliv hidrociklona je gotov proizvod i sadrži 65% klase -0,074 mm i isti se gravitacijski transportuje na osnovno flotiranje. Pesak hidrociklona se vraća u mlin sa kuglama i predstavlja kružnu šaržu.

Tehnološka šema mlevenja šljake na C sekciji prikazana je na slici 2. Tehnološka šema mlevenja na B sekciji je identična.



Sl. 2. *Tehnološka šema mlevenja šljake*

GRANULIRANJE ŠLJAKE

Uzorak topioničke šljake izuzet je iz procesa drobljenja u pogonu „Flotacije" u Boru. Ta ista šljaka je u laboratoriji Instituta za rudarstvo i metalurgiju u laboratorijskoj peći topljena na 1250°C. Ovim postupkom je simuliran proces dobijanja šljake u Topionici bakra u RTB Bor. Prilikom izlivanja šljake, u mlaz uzavrele šljake usmerena je mlaznica vode usled čega su se u prihvatnom sudu sa vodom formirale granule šljake. Izgled uzorka šljake izuzete iz procesa drobljenja prikazan je na slici 3, a izgled granulirane šljake prikazan je na slici 4.

Sl. 3. *Izgled uzorka šljake izuzete iz procesa drobljenja*

Sl. 4. *Izgled granulirane šljake*

GRANULOMETRIJSKI SASTAV PROIZVODA DROBLJENJA I PROIZVODA GRANULIRANJA

Granulometrijski sastav proizvoda iz procesa drobljenja šljake preuzet iz **„Glavnog rudarskog projekta otkopavanja šljake iz tehnogenog ležišta „*Depo šljake 1"* za godišnju proizvodnju od 1 200 000 t šljake"** [1] prikazan je u tablicama od 1 do 4. Granulometrijski sastav gotovog proizvoda drobljenja (ulaza u mlevenje) dobijen snimanjem procesa prikazan je u tablici 5. Granulometrijski sastav proizvoda granuliranja dobijenog u toku laboratorijskog eksperimenta granuliranja prikazan je u tablici 6.

Tabela 1. *Granulometrijski sastav primarno usitnjene šljake*

Klasa krupnoće	m%	D%	R%
-145+100	9,50	100,00	9,50
-100+75	2,62	90,50	12,12
-75+40	8,38	87,88	20,50
-40+30	3,00	79,50	23,50
-30+20	22,50	76,50	46,00
-20+15	16,20	54,00	66,20
-15+10	18,55	37,80	80,75
-10+8	2,75	19,25	83,50
-8+5	3,88	16,50	87,38
-5+2,362	6,12	12,62	93,50
-2,362+0	6,5	6,5	100,00

Tabela 2. *Granulometrijski sastav proizvoda sekundarne drobilice*

Klasa krupnoće	m%	D%	R%
-20+15	12,70	100,00	12,70
-15+10	36,16	87,30	48,86
-10+8	16,61	51,14	65,47
-8+5	11,40	34,53	76,87
-5+2,362	11,93	23,13	88,80
-2,362+0	11,20	11,20	100,00

Tabela 3. *Granulometrijski sastav proizvoda tercijarne drobilice*

Klasa krupnoće	m%	D%	R%
-15+10	14,13	100,00	14,13
-10+8	38,67	85,87	52,80
-8+5	23,20	47,20	76,00
-5+2,362	12,56	24,00	88,56
-2,362+0	11,44	11,44	100,00

Tabela 4. *Granulometrijski sastav ulaza u mlevenje (projektovani)*

Klasa krupnoće	m%	D%	R%
-15+10	0,57	100,00	0,57
-10+8	9,53	99,43	10,10
-8+5	41,17	89,90	51,27
-5+2,362	34,28	48,73	85,55
-2,362+0	14,45	14,45	100,00

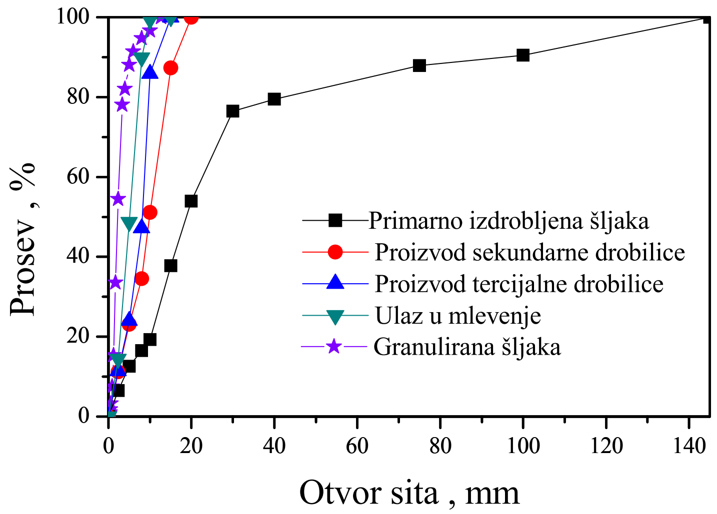
Tabela 5. *Granulometrijski sastav ulaza u mlevenje (snimljen)*

Klasa krupnoće	m%	D%	R%
-15+12	15,4	100,0	
-12+10	27,2	84,6	
-10+6,680	23,0	57,4	
-6,680+4,156	14,0	34,4	
-4,156+2,362	7,2	20,4	
-2,362+1,981	2,5	13,2	
-1,981+1,397	3,3	10,7	
-1,397+0,589	3,7	7,4	
-0,589+0,417	0,6	3,7	
-0,417+0,295	0,6	3,1	
-0,295+0,212	0,4	2,5	
-0,212+0,147	0,4	2,1	
-0,147+0,106	0,3	1,7	
-0,106+0,074	0,3	1,4	
-0,074+0	1,1	1,1	

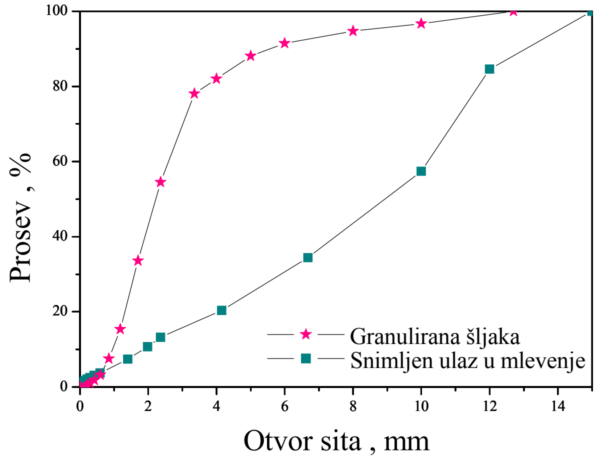
Tabela 6. *Granulometrijski sastav granulirane šljake*

Klasa krupnoće	m%	D%	R%
-145+100	3,30	100	3,30
-100+75	1,97	96,70	5,27
-75+40	3,29	94,73	8,56
-40+30	3,38	91,44	11,94
-30+20	6,02	88,06	17,96
-20+15	3,98	82,04	21,94
-15+10	23,60	78,06	45,54
-10+8	20,90	54,46	66,44
-8+5	18,20	33,56	84,64
-5+2,362	7,86	15,36	92,50
-2,362+0	7,50	7,50	100,00

Kolika je prednost granuliranja šljake bolje se vidi sa grafika. Na slici 5 prikazan je granulometrijski sastav proizvoda drobljenja šljake iz projekta uporedo sa granulometrijskim sastavom granulirane šljake. Na slici 6 prikazan je uporedo granulometrijski sastav gotovog proizvoda drobljenja (ulaza u mlevenje) dobijen snimanjem procesa i granulometrijski sastav granulirane šljake.

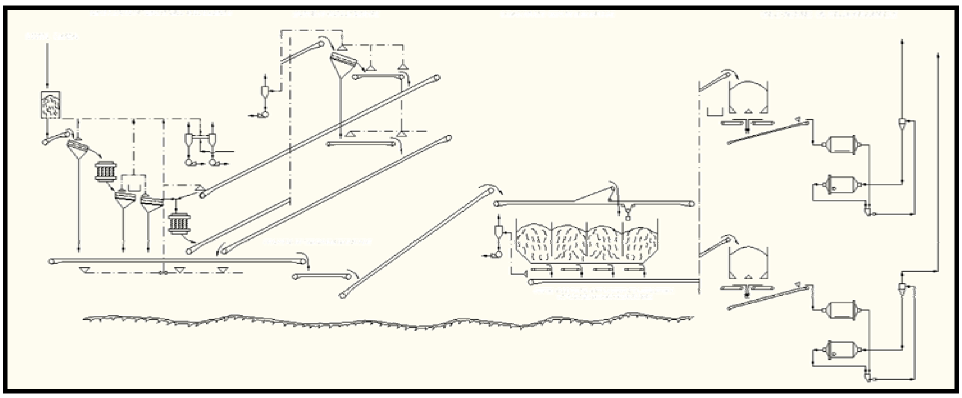


Sl. 5. *Uporedni granulometrijski sastav proizvoda drobljenja i granuliranja*

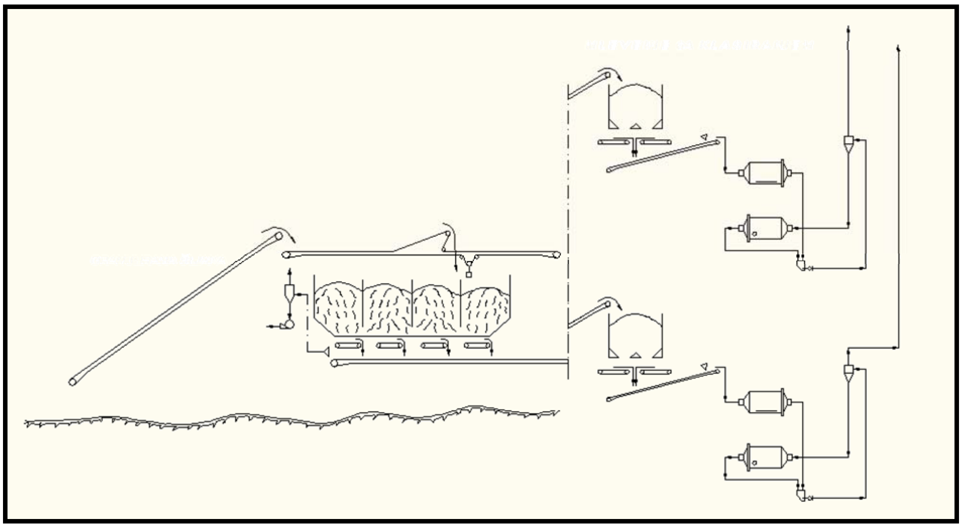


Sl. 6. *Uporedni granulometrijski sastav proizvoda drobljenja i granuliranja*

Sa prikazanih grafika očigledno je da je granulirana šljaka daleko sitnija od svih proizvoda drobljenja jer su svi prikazani granulometrijski sastavi proizvoda drobljenja ostali desno u odnosu na granulometrijski sastav granulirane šljake. Proces drobljenja je sa stanovišta krupnoće nepotreban, a granulirana šljaka je sitnija i od ulaza u mlin sa šipkama. Granuliranjem šljake izostavio bi se skup proces drobljenja šljake, a mogao bi da se očekuje i finiji proizvod mlevenja. U tehnološkom postupku, usitnjavanje šljake prikazano na slici 7 moglo bi da izgleda kao na slici 8.



Sl. 7. *Proces usitnjavanja šljake u pogonu flotacije Bor*



Sl. 8. *Proces usitnjavanja šljake posle granuliranja*

Očekuje se da se u nastavku rada na pomenutom projektu kroz eksperimente u industrijskim uslovima ostvari granulometrijski sastav granulirane šljake na nivou granulometrijskog sastava ulaza u mlin sa kuglama čime bi se stekli uslovi da se kao konačni rezultat dobije daleko finiji proizvod mlevenja. Sniženjem krupnoće samlevene šljake povećava se iskorišćenje bakra u koncentratu [2,3].

ZAKLJUČAK

Predlog ovog rešenja je da se procesom granuliranja šljake izuzme proces drobljenja iz procesa usitnjavanja šljake u industrijskim uslovima. Kada bi se prilikom izlivanja šljake u industrijskim uslovima, šljaka granulirala usmerenim mlazom vode u mlaz usijane šljake i kao takva hladila imala bi daleko nižu krupnoću. **Prednost ovog rešenja je u tome što bi se jednostavnim jeftinim postupkom izbegla skupa faza drobljenja, a ulaz u mlevenje bi bio sitniji pa time treba očekivati i da proizvod mlevenja bude sitniji što dokazano pospešuje iskorišćenje bakra u flotacijskom koncentratu.** U tom slučaju tehnološka šema procesa usitnjavanja šljake sastojala bi se samo iz mlevenja.

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Srđana Magdalinović, Dragan Milanović*, Branislav Čađenović*, Vesna Marjanović**

TECHNOLOGICAL METHOD OF SLAG GRANULATION TO REDUCE THE SIZE CLASS AT INLET INTO FLOTATION**

Abstract

This paper presents a simple solution in which it is possible to lower the input size class of slag in the flotation process and to avoid the crushing phase. Slag granulation process is inexpensive and technologically fully justified as it can be seen from the attached grain-size distribution of the crushing product and slag granulation.
Key words: *slag, comminution, granulation*

INTRODUCTION

By the Project TR 33023, entitled *Development of technologies for flotation processing the copper ore and precious metals in order to achieve better technological results,* financed by the Ministry of Education and Science within the Program of technological development, the certain investigations were carried out in the field of slag granulation.

Decades of processing the concentrate in Bor has led to the formation of waste slag dump which is the waste from metallurgical processes. This product contained significant amounts of valuable metals. Total reserves of slag in the technogenic copper deposit „Slag depot – 1“ t are 9,190,940 tons. Medium copper content is 0.715%, gold 0.282 g/t, silver 4.50 g/t, molybdenum 0.0413%. About ten years ago, the mentioned valueble metals are obtained using the flotation concentration in the plant in Bor, but with a series of difficulties and less successful than in the world on similar raw materials. Flotation Plant in Bor was originally designed for a different type of raw material and now is only adjusted for slag processing. Slag is less suitable for comminution from the point of energy consumption, linings and crushing media than the ore.

* *Mining and Metallurgy Institute Bor*
** *This work has resulted from the Project TR 33023, entitled "Technology Developments of Flotation Processing the Copper Ore and Precious Metals in Order to Achieve Better Technological Results", for which funding, on this occasion, we would like to thank the Ministry of Education and Science of the Republic of Serbia.*

SLAG COMMINUTION IN THE FLOTATION PLANT IN BOR

Comminution process of slag in the Flotation Plant in Bor consists of crushing and grinding.

SLAG CRUSHING

Primary crushed slag using blasting on the slag dump, grain size 100 % - 200+0 mm, is delivered by trucks to the receiving bin (pos. 14) with grid mesh 200 mm in front of the cone belt. The receiving bunker is located on a plateau next to the crushing facility and from the same the primary crashed slag is transported by cone belt (pos.15) to a circular-oscillating (turbo) sieve (pos.16), to the primary screening. Screen undersize of lower mesh sieve, grain size 100% -12.5 +0 mm, as a final crushing product fall off on a belt conveyor (pos.20). Sieve oversizes of upper and lower mesh sieve go to the secondary crushing.

Secondary slag crushing is carried out in the Standard Symons crusher (pos.17) of 2133.6 mm (7 ft HD), whose geometry of inlet chamber is the Coarse type and crusher discharge, and the opening has size of CSS = 31 mm. Output from the crusher goes to two-line set resonant oscillatory (FKR) sieves (pos.18A and B), for the secondary screening. Screens are identical to each other, and the openings have sizes a x b = 12.5 x 12.5 mm. Oversize of these screens, grain size 100% - 64 +12.5 mm, goes into a short cone crusher for tertiary slag crushing (pos. 19). Undersize of screen, grain size 100% - 12.5 mm +0, as the second part of the final crushing product, falls onto a collection conveyor belt (pos.20). Tertiary slag crushing is carried out in the short cone Symons crusher (pos.19) of 2133.6 mm (7 ft HD), whose entrance chamber is Coarse tyupe, and crusher discharge opening has size of CSS = 13 mm or ½". Output from crusher, grain size 100% -25 mm falls on a belt conveyor (pos.25), which transported it to a vibrating (TSP) sieve (pos.26) to the tertiary screening. Sieve has a screening surface with size of meshes a x b = 12.5x12.5 mm.

Sieve oversize of this screen, grain size 100% -25 mm, returns by belt conveyor (pos. 27 and 28) on the tertiary crushing, thus closing the cycle of tertiary crushing with screening. Sieve undersize, grain size 100% -12.5+0 mm, as the third and final part of the final crushing product, is transported by belt conveyors (pos. 29 and 30) to a collection conveyor belt (pos.20).

Definitely crushed slag, controlled grain size (100% -12.5+0 mm), is transported from the crushing process into the bin of final crushing product (pos.24) with a capacity of 40,000 tons, via belt conveyors (pos. 21, 22 and 23), and from it further to the bin in front of the flotation plant by star-feeders and belt conveyor systems.

Technological scheme of slag crushing is shown in Figure 1.

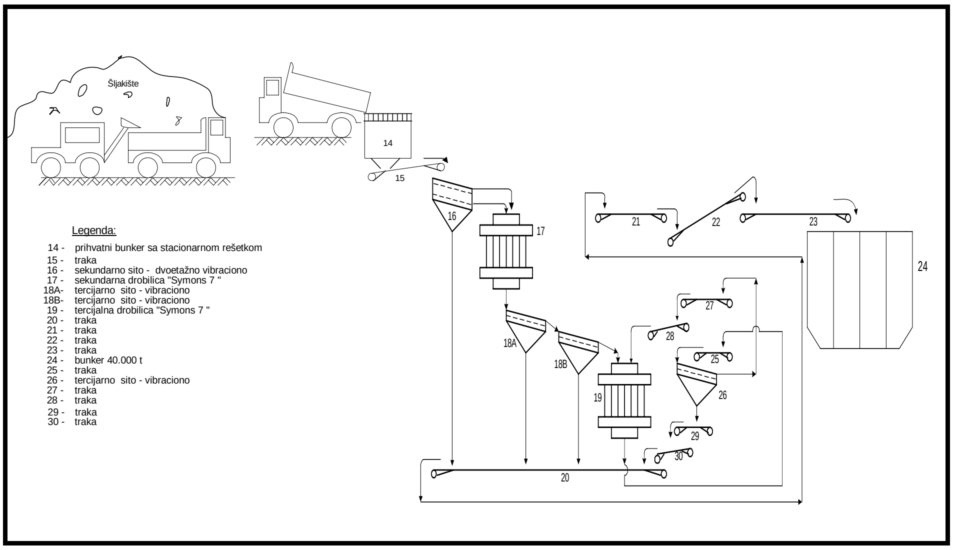

Fig. 1. *Technological scheme of slag crushing*

GRINDING AND CLASSIFICATION OF SLAG

Definitely crushed ore from bin 40 000 t, is delivered by belt conveyors to the bin in front of the mill sections B and C, volume of about 1 500 t. Slag grinding is carried out in two stages in the bar and ball mills. Classification of ground slag in sections B and C is a single.

Ball mills work in a closed circle with hydrocyclones. Classification of ground slag is carried out in hydrocyclones (pos. 2080 and 3080) on both milling sections. Overflows of hydroicyclones are transported by gravity at the head of flotation machines for basic flotation.

From bins, which correspond to B and C sections of grinding in the flotation, definitely crushed ore is extracted by feeders, and added onto belt conveyors – where the belt scales are installed, and from them sent it to two-stage grinding with classification. Grinding of definitely crushed ore with classification is carried out through two identical milling sections B and C flotation in Bor, in two stages, from initial grain size 100% -12.5+0 mm to the final grain size 65% -0.074 mm, with individual sectional hour processing capacity of 80 tons of dry slag or total of 160 t/h.

Primary grinding of slag is carried out in with two identical bar mills (pos. 2040 and 3040). Secondary grinding of slag is carried out in two identical ball mills (pos. 2090 and 3090). Products of rod and ball mills, from both sections, are connected in the cyclone pumps (pos. 2070 and 3070) and classed with addition of water in hydrocyclones (pos. 2080 and 3080) -

sections B and C. Overflow of hydrocyclone is the finished product and contains 65% size class -0.074 mm and the same is transported by gravity to the primary flotation. Hydrocyclone sand is returned to the ball mill and it presents a circular charge.

Technological scheme of slag grinding on section C is shown in Figure 2. Technological scheme of grinding on section B is identical.

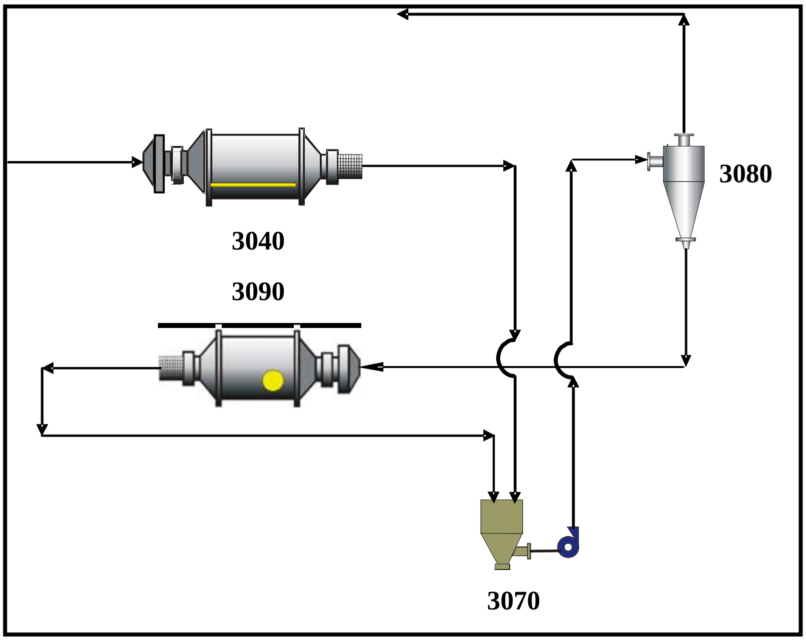

Fig. 2. *Technological scheme of slag grinding*

SLAG GRANULATION

A sample of smelting slag was taken from the crushing process in the Flotation Plant in Bor. This same slag was, at the Laboratory Mining and Metallurgy Institute, melted at 1250°C in laboratory furnace. This process simulated the process of slag obtaining in the Copper Smelter in RTB Bor. During discharge of slag, a water nozzle was directed into a jet of heated slag due to a formation of slag granules in the receiving vessel. The appearance of slag, takem from the crushing process, is shown in Figure 3 and the appearance of granulated slag is shown in Figure 4.

Fig. 3. *The appearance of a slag sample, taken from the crushing process*

Fig. 4. *The appearance of granulated slag*

GRAIN-SIZE DISTRIBUTION OF CRUSHING AND GRANULATION PRODUCTS

Grain-size distribution of products from the slag crushing process, taken from the **"Main Mining Design of Slag Mining from the Technogenic Deposit *"Slag Depot 1"*, for Annual Production of 1 200 000 t of Slag** [1] in shown in Tables from 1 to 4. Grain-size distribution of the final crushing product (input into grinding), obtained by the process recording, is shown in Table 5. Grain-size distribution of the granulation product, obtained during laboratory experiment of granulation, is shown in Table 6.

Table 1. *Grain-size distribution of the primary crushed slag*

Size class	m%	D%	R%
-145+100	9.50	100.00	9.50
-100+75	2.62	90.50	12.12
-75+40	8.38	87.88	20.50
-40+30	3.00	79.50	23.50
-30+20	22.50	76.50	46.00
-20+15	16.20	54.00	66.20
-15+10	18.55	37.80	80.75
-10+8	2.75	19.25	83.50
-8+5	3.88	16.50	87.38
-5+2.362	6.12	12.62	93.50
-2.362+0	6.5	6.5	100.00

Table 2. *Grain-size distribution of the secondary crushed products*

Size class	m%	D%	R%
-20+15	12.70	100.00	12.70
-15+10	36.16	87.30	48.86
-10+8	16.61	51.14	65.47
-8+5	11.40	34.53	76.87
-5+2.362	11.93	23.13	88.80
-2.362+0	11.20	11.20	100.00

Table 3 *Grain-size distribution of the tertiary crushed products*

Size class	m%	D%	R%
-15+10	14.13	100.00	14.13
-10+8	38.67	85.87	52.80
-8+5	23.20	47.20	76.00
-5+2.362	12.56	24.00	88.56
-2.362+0	11.44	11.44	100.00

Table 4 *Grain-size distribution of input into grinding (designed)*

Size class	m%	D%	R%
-15+10	0.57	100.00	0.57
-10+8	9.53	99.43	10.10
-8+5	41.17	89.90	51.27
-5+2.362	34.28	48.73	85.55
-2.362+0	14.45	14.45	100.00

Table 5 *Grain-size distribution of input into grinding (recorded)*

Size class	m%	D%	R%
-15+12	15.4	100.0	
-12+10	27.2	84.6	
-10+6.680	23.0	57.4	
-6.680+4.156	14.0	34.4	
-4.156+2.362	7.2	20.4	
-2.362+1.981	2.5	13.2	
-1.981+1.397	3.3	10.7	
-1.397+0.589	3.7	7.4	
-0.589+0.417	0.6	3.7	
-0.417+0.295	0.6	3.1	
-0.295+0.212	0.4	2.5	
-0.212+0.147	0.4	2.1	
-0.147+0.106	0.3	1.7	
-0.106+0.074	0.3	1.4	
-0.074+0	1.1	1.1	

Table 6 *Grain-size distribution of granulated slag*

Size class	m%	D%	R%
-145+100	3.30	100	3.30
-100+75	1.97	96.70	5.27
-75+40	3.29	94.73	8.56
-40+30	3.38	91.44	11.94
-30+20	6.02	88.06	17.96
-20+15	3.98	82.04	21.94
-15+10	23.60	78.06	45.54
-10+8	20.90	54.46	66.44
-8+5	18.20	33.56	84.64
-5+2.362	7.86	15.36	92.50
-2.362+0	7.50	7.50	100.00

The advantage of slag grannulation could be better seen from graphics. Figure 5 shows the grain size distribution of the final product of slag grinding from the project compared with the grain size distribution of granulated slag. Figure 6 shows comparative grain size distribution of final grinding product (input into grinding) obtained by recording the process and grain size distribution of granulated slag.

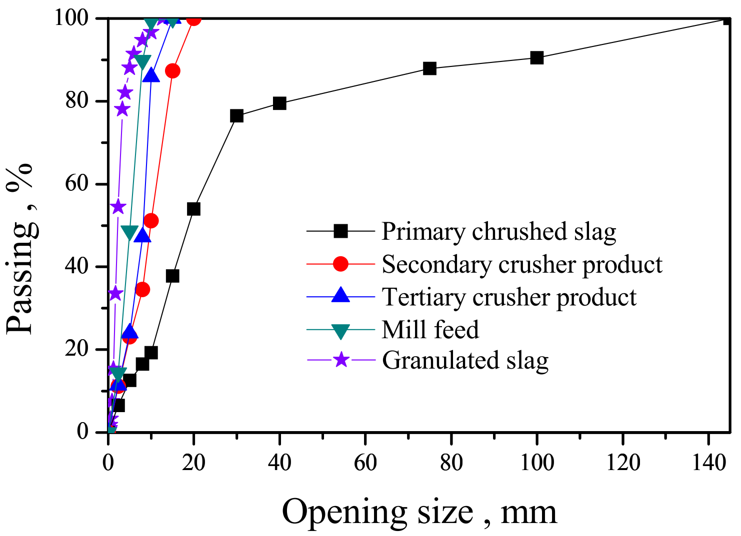

Fig. 5. *Comparative grain size distribution of grinding and granulation products*

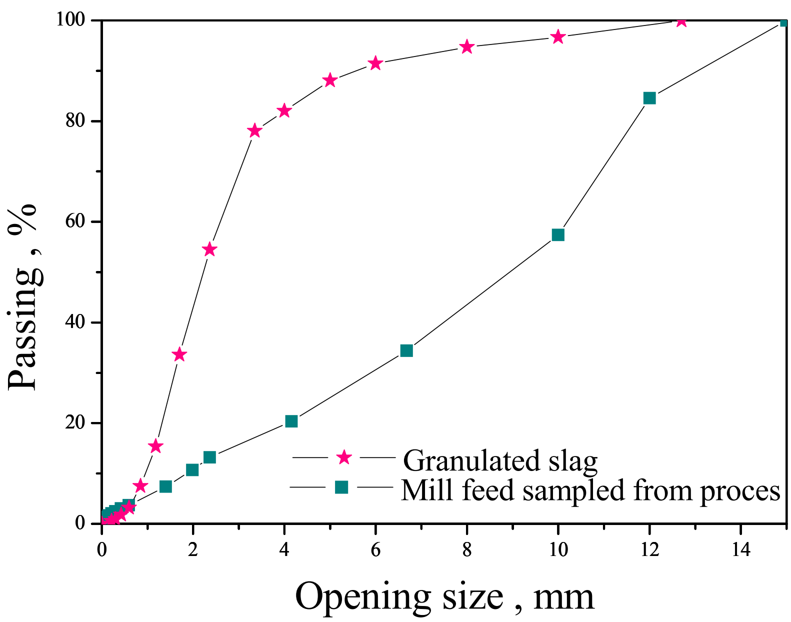

Fig. 6. *Comparative grain size distribution of grinding and granulation products*

It is obvious from present graphics that the granulated slag is far finer than any product of crushing because all shown grain-size distributions of crushing products are left right of the grain-size distribution of granulated slag.The crushing process from the point of size range is unnecessary and granulated slag is smaller than the inlet into the rod mill. By slag granulation, the expensive process of slag crushing would avoid, and finer grinding product would be expected. In technological process, slag comminution, shown in Figure 7, could look like in Figure 8.

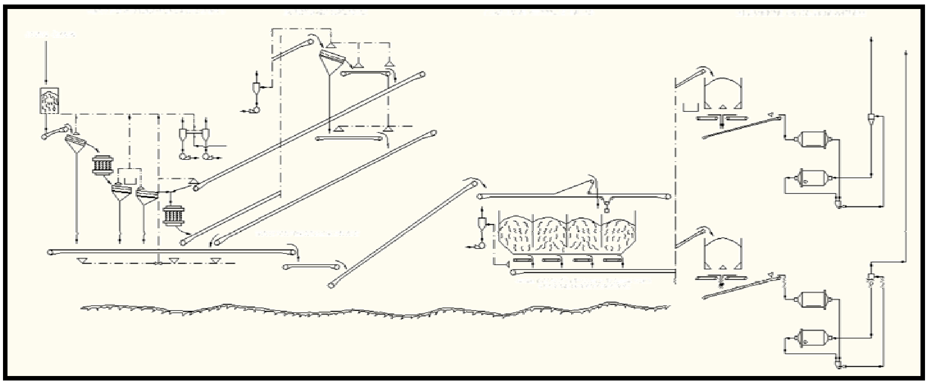

Fig. 7. *Slag comminution process in the Flotation Plant Bor*

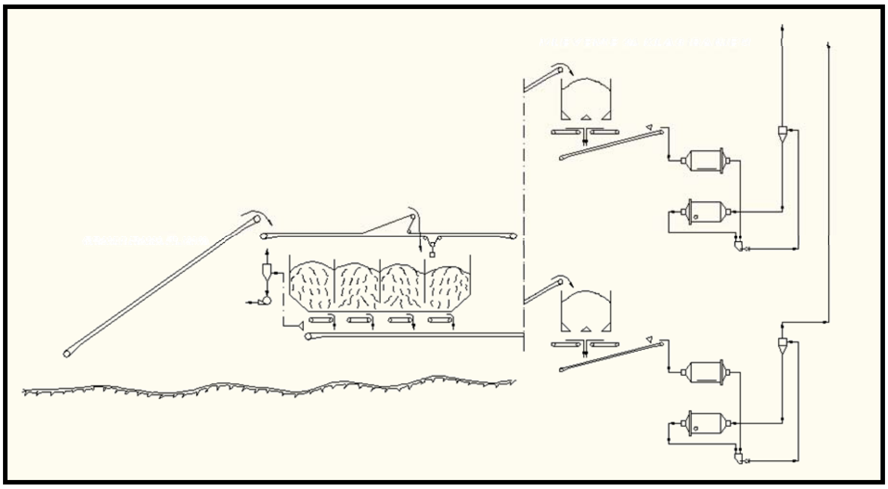

Fig. 8. *Slag comminution process after slag granulation*

It is expected that the continuation of work on said project, through experiments in the industrial conditions, can achieve the grain-size distribution of granulated slag at the level of grain size distribution of inlet into ball mill what would create the conditions such that the final result is far finer grinding product. Decrease in grain size of ground slag increases copper recovery in concentrate [2,3].

CONCLUSION

The proposal of this solution is the exemption of grindingprocess by the slag granulation process from the slag comminution process in the industrial conditions. If during slag disharge in the industrial conditions, the slag would be granulated by directed jet of water into the jet of hot slag and as such cooled, it would have much lower size range. **The advantage of this solution is that a simple cheap procedure would avoid costly crushing stage and inlet into grinding would be finer, therefore it should be expected that the grinding product is finer to that is proven by better copper recovery in the flotation concentrate.** In this case, the technological scheme of slag comminution process would consist only of grinding.

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KOMITET ZA PODZEMNU EKSPLOATACIJU MINERALNIH SIROVINA UDK: 622

UDK:622.87(045)=861

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POTENCIJALNE BOLESTI I OPASNOSTI KOD RUDARSKE PROFESIJE[*****]

Izvod

Rudarska profesija je veoma teška, puna potencijalnih prirodnih opasnosti a takodje i opasnosti od pojava raznih bolesti prilikom eksploatacije mineralnih sirovina: metala, nemetala, uglja, nafte, kao i kod rada sa mašinama u raznim stenskim naslagama koje sadrže razne sastojke štetne za rudare pri radu i u kontaktu sa njima.

Od početka rudarenja i daljim razvojem civilizacije, pored dobiti u procesu eksploatacije, učinjene su i mnoge štete zbog narušavanja prirode, zagadjenja radne i životne sredine. Zato je danas postao imperativ vodjenja ,,održivog razvoja'', što znači da se prirodna bogatstva ne smiju više eksploatisati nekontrolisano i prekomerno zbog ugrožavanja života na celoj planeti.

Rudari rade u veoma nepovoljnim uslovima, gde je velika dubina, tesan prostor, prašina, štetni gasovi, slaba ventilacija, zagadjene vode, slabo osvetljenje, zarušavanja stena i mnoge druge iznenadne i nepredvidjene opasnosti. Zbog toga rudari imaju svoje specifične profesionalne bolesti, a obolevaju i od drugih opštih, široko rasprostranjenih bolesti.

Veliki je zadatak naučnika, istraživača rudarske i medicinske struke da uoče pojave bolesti, prepoznaju njihov uzrok, preduzmu preventivne mere za sprečavanje njihovog daljeg širenja i uvedu efikasno lečenje.

U ovom radu data je kratka analiza glavnih profesionalnih bolesti kod rudara i neki parametri koji odredjuju nivo opasnosti. U našoj literaturi vrlo je malo obradjivana ova tema na ovako pregledan način.

Ključne reči: *profesionalna oboljenja, prevencija, zaštita životne sredine, koncept održivog razvoja.*

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[*****] *Ovaj rad obuhvata deo istraživanja u okviru naučnog projekta - teme br. TR 33029, koju, kao deo Programa tehnološkog razvoja, finansira Ministarstvo obrazovanja i nauke Republike Srbije, a čiji su realizatori Rudarski institut doo Beograd i Rudarsko-geološki fakultet Univerziteta u Beogradu.*

I. UVOD

U rudarstvu se primenjuju uglavnom tri načina eksploatacije mineralnih sirovina: dubinsko (jamsko), površinsko i bušotinsko. Mineralne sirovine koje se eksploatišu su: metalične (Au, Ag, Cu, Fe, Pb, Ar…), nemetalične (so, gips, glina…) i fosilne (ugalj, nafta, gas…) Kaže se da metali čine kičmu civilizacije, a ugalj, nafta i gas čine energiju i krvotok civilizacije.

Od samog početka rada (i sada) u rudarstvu su postojali veoma teški uslovi, kako u procesu eksploatacije tako su i socijalno-ekonomski uslovi bili skoro uvek nepovoljni. Ne kaže se uzalud da je rudarski rad- hleb sa 7 kora.

U početku rudarenje je bilo robovski rad, a sa napretkom tehnike i nauke, pojedini procesi rada su mehanizovani i automatizovani sa težnjom uvodjenja tzv.„inteligentnog rudnika'', gde je rad mnogo olakšan, a broj ljudi u procesu rada sveden na minimum. Rudarski rad je častan i plemenit poziv i struka.

Teški uslovi u eksploataciji mineralnih sirovina ogledaju se u sledećem:

- rad pod veštackim oskudnim svetlom,
- pojava visokih temperature sa porastom dubine eksploatacije,
- pojava i prodori gasa metana (CH_4) koji je veoma eksplozivan i izaziva velike katastrofe i rušenja pri eksploziji dovodeći do velikih ljudskih gubitaka i materijalnih dobara,
  - pojave požara u rudnicima i trovanja sa ugljenmonoksidom (CO),
  - pojave gasa ugljendioksida (CO_2) opasnog za gušenje i u malim koncentracijama,
  - prodor gasova i stenskog materijala u rudarske prostorije,
  - prodori voda u rudarske prostorije (podzemne i površinske)
- pojava i manifestacije povećanog jamskog pritiska i njegovog ekstremnog oblika „gorski udari'' koji su razorni i uzrokuju velike ljudske i materijalne štete,
- pojave drugih gasova kao azotni oksidi kod miniranja i drugih procesa,
- velika degradacija zemljišta i naselja oko rudnika i njegovo zagadjivanje, i gubitak obradivih površina,
- zagadjivanje voda, biljki i celog ekosistema.

Rudarskom eksploatacijom, pored koristi, degradiraju se ogromne površine zemljišta i zagadjuje životna sredina, što izaziva ogromne ekološke probleme čak i na planetarnom nivou.

Najnoviji koncept rudarske eksploatacije je koncept „održivog razvoja“, gde su predvidjene mere da se profitabilna eksploatacija može vršiti samo uz potpunu zaštitu radne i životne sredine, svodjenjem degradacije zemljišta i imisije štetnih gasova i produkata na minimum. Na taj način i profesionalne bolesti kod rudara mogu biti smanjene.

II. RUDARSKE PROFESONALNE BOLESTI

II.1. ZAGAĐENJA VAZDUHA

II.1.0. OPASNOSTI ZA PLUĆA, UHO, GRLO, NOS

Glavne profesionalne bolesti kod rudara pogađaju pluća. Tu spadaju: silikoza, antrakoza, berioza, ultramarinoza, manganokonioza, aluminoza (boksitna) pneumakonioza, antrakoza, sideroza, uranopneumonikoza i dr. Ove bolesti uglavnom nastaju od udisanja finih prašina i aerosoli pomenutih minerala i stena. Dalje, razne vrste gasova truju ili oštećuju rudarska pluća: ugljen-monoksid, ugljen-dioksid, sumpor-vodonik, sumpor-dioksid, azotni gasovi, isparenja pri raznim procesima oksidacije i upale jamske građe, uglja, metana, ugljene prašine, pirita, pirhotina, sumpora, nafte i gasa, trafo ulja, poliuretana, upale eksploziva, eksplozije metana, ugljen-monoksida, paljenja eksploziva. Ako tome, dodamo alkohol, i duvanski dim, dimove i izduvne gasove radnih mašina na pogon dizel motorima, onda je to već previše za rudarska pluća. Razni polutanti i duvanski dim, štetno utiču na rudareva pluća više nego kod drugih građana.

Cilj prevencije bio bi smanjenje imisije zagađivača vazduha u organizam čoveka.

Najvažnije je da se smanji koncentracija bilo koje prašine, gasa, ili dima, i da se u svakom slučaju primenjuju zaštitne (preventivne) mere koliko god je maksimalno moguće: bušenje minskih rupa sa vodenim ispiranjem, vodene barijere pri utovaru rude i stene (jalovine), korišćenje robotizovanih mašina i ličnih zaštitnih sredstava.

Pneumokonioze

II.1.1. Silikoza. Silikoza je jedna od hroničnih fibroznih plućnih bolesti i nastaje dugim udisanjem anorganskih prašina. To je pre svega slobodni silikat (silicijum dioksid), kao najčešći izazivač iste.

Da bi se čovek razboleo potrebno je duže izlaganje prašini (2-22 godine). Postoje brojne profesije u kojima nastaje silikoza. Osim rudarenja u tvrdim silikatnim stenama, peščarama i slično, silikozu izazivaju i peskarenje, livački radovi, proizvodnja abraziva, i sileks obloga, spomenika, ukrasa (rozete), stepenica, kamenih mostova, obloženih ploča, keramike, stakla (duvački radovi, brušenje kristala). Za dijagnozu je bitna istorija izlaganja prašini da se primete karakteristične promene iks-zracima (rendgen): bilateralne module fibroza, brežuljkasta limfadenopatija, pa i povratnih respiratornih infekcija, kada se javlja tuberkoloza (silikotuberkuloza). Na osnovu Ph nalaza i plastične slike određuju se stadijumi silikoze: I, II, III.

Prvi znaci pneumokonioze su tegobe slične astmi i slabi kašalj sa neznatnim lučenjem sluzi. Dalje nastupaju poremećaji rada srca i opšta slabost, razvija se enfizem, stvaraju se bronhistazije tuberkoloznog porekla.

Kod silikoze oboljevaju oba plućna krila, a kod tuberkoloze često samo jedno, i to vrh njegov.

Dispneja (otežano disanje) pri naprezanju je opšta pojava/smetnja, razvija se kašalj, najpre suv, a kasnije postaje produktivan, često sa krvavom prugastom pljuvačkom. Može se pojaviti jaka, povremeno fatalna hemoptiza (pljuvanje krvi) i obilnije krvarenje iz pluća.

Dijatometska zemlja, talk, grafit, kaolin i slični proizvodi izazivaju neku vrstu silikoze.

II.1.2. Azbestoza. Azbestoza je posledica udisanja azbestne prašine i sa silikozom je najopasnija pneumokonioza. Vrlo je kancerogena, tako da se u određenim slučajevima dobije rak pluća, plućne maramice, bronhija ili trbušne maramice. Istraživanja su pokazala da nije samo azbest opasan, već i arsenovi minerali, berilijum i njegova jedinjenja, kadmijum i njegova jedinjenja, šestovalentni hrom, katran i kameni ugalj, čađ. Zbog opasnosti jedno vreme je bila skoro totalno zabranjena upotreba azbesta u industriji, ali je odskora ipak ponegde dozvoljena (za kočione uređaje, npr.).

II.1.3. Ugljena prašina (antrakoza) i metan. Ugljena prašina stvara antrakozu, kako u rudarstvu uglja, tako i kod gradskog stanovništva. Ista izaziva gubitak prirodne boje pluća (oboji ih u crno) i otežava disanje, a uz napredovanje bolesti (fibroza, dispnea, otežano disanje) može se dobiti i silikoza.

Ugljena prašina u rudnicima uglja može pod određenim uslovima da eksplodira. Pali se i to kod kamenog uglja na temperaturi 350-450^{0}C, a kod mrkog uglja na 25-400^{0}C. Ako u jami ima i metana, koji se pali na 600^{0}C, onda je mešavina potpuno katastrofalna. Inače, sam metan je najopasniji kad ga u jamskoj atmosferi ima između 4,5 i 14,5%, kada može da eksplodira, pri čemu dostiže temperaturu u 1650^{0}C, pa se uz tu eksploziju može zapaliti i ugljena prašina, a i još neki gasovi (etan). Najsnažnija je eksplozija kada u jamskom vazduhu ima 9,6% metana. Osim stradanja ljudi i imovine od udaljenog talasa, strada se i od povratnih talasa, a naročito od plamena i raznih otrovnih gasova koji se udišu (ugljen monoksid i dr.). Osim masovnih fatalnih slučajeva, kod eksplozije posebno dolazi do strašnih oštećenja pluća i disajnih puteva, kao i opekotina kože.

II.1.4. Manganokolioza. Javlja se pri eksploataciji i preradi manganovih ruda i kako su tu često i razni silikatni minerali, dobija se i silikoza.

II.1.5. Sideroza. Javlja se pri eksploataciji i preradi gvozdenih ruda, bušenju metala i elektrolučnom zavarivanju. Gvozdeni oksidi i sam metal gvožđe izazivaju crvenu (oksidi) i crnu (metali) obojenost pluća. Crveni tip vodi fibrozi, a crni tip je skoro redovno udružen sa silikozom.

II.1.6. Aluminoza. Boksitna pneumokonioza ili aluminoza javlja se pri eksploataciji i preradi boksita, pa često izaziva fibrozu, otežano disanje (sipnju) i spontani pneumotoraks.

II.1.7. Berlioza. Nastaje kao bolest pluća pri eksploataciji berilijumovih minerala i samog metala, a naročito kod mašinske obrade i upotrebe berilijumskih legura i keramike u elektronici i industriji svemirskih letilica. Elastično tkivo se ošteti i izaziva dispneu, ali se javljaju i nodule slične bronhijalnoj pneumoniji.

II.1.8. Ultramarinoza. Nastaje pri obradi dragog kamena ultramarina i izaziva teško disanje i sipnju.

II.2. TROVANJA I GUŠENJA OD GASOVA

To su profesionalna trovanja uglavnom preko pluća.

II.2.1. Ugljen monoksid (CO). To je gas bez boje, mirisa, ukusa i jako je otrovan. Slabo je rastvorljiv u vodi. Sagorljiv je. Kad smeše od 13-75% sa vazduhom može da ekslodira ako se zapali. Otrovno dejstvo počinje sa 0,048%. Kod koncentracije 0,11 do 0,34 mg/l u vazduhu izaziva glavobolju i malaksalost, kod 1,1 do 2,5 mg/l u vazduhu ako se zadržavamo 30-60 minuta nastaje smrt; kod 2,5 do 4,0 mg/l čovek gubi svest posle nekoliko udisaja, a to znači posle jednog do dva minuta, i nastupa teški stepen trovanja. Kod 4,6 do 5,7 mg/l smrt nastupa u toku 5 minuta. Ako je iznad 5,7 mg/l, smrt je trenutna.

Ponekad su rudari u jamu nosili sa sobom kanarince u kavezu. Ove divne ptičice mnogo brže podlegnu trovanju i kad to rudar primeti, napušta radilište.

Inače, ugljen monoksid nastaje pri svakom nepotpunom sagorevanju (nedovoljno kiseonika), a u jami je to od požara u rudnicima uglja; naročito kod požarnih pregrada, zatim kod miniranja uz upotrebu eksploziva sa pozitivnim bilansom kiseonika, kao i kod eksplozije metana i ugljene prašine.

II.2.2. Ugljen dioksid (CO_2). Gas bez boje, sa slabim kiselastim ukusom i mirisom. Specifična težina mu je 1,52 i zato je uvek u najnižim delovima rudarskih prostorija. Kod tri procenta u vazduhu, disanje se ubrzava i udvostručuje, kod 2 do 5% nastaje opšta malaksalost, glavobolja i ubrzani rad srca, pa i obamrlost.

Kod 20-25% u vazduhu nastaje smrt gušenjem, tj. u većim količinama deluje otrovno i tretira se kao otrovni gas. Ima ga u pećinama, bunarima, pa treba biti oprezan.

Ugljen-dioksid nastaje od oksidacije drvene građe, radom bakterija. Može se javljati u svim jamama, jer ga ima u mnogim stenama Zemljine kore odakle postepeno prodire i u jamske prostorije.

II.2.3. Sumpor oksidi (SO_2). Sumpordioksid je gas bez boje, oštrog mirisa i ukusa. Veoma je otrovan, jako razara sluzokožu naročito očiju. Kod 0,05% u vazduhu opasan je po ljudski život. Nastaje kod sagorevanja sumpora i njegovih jedinjenja, a u jami naročito od sagorevanja sulfida, posebno pirita. Inače svaka sulfidna ruda postepeno pomalo oksidiše i stvara se sumpor dioksid. Poznate su upale pirita u sipkama u jami RTB-a Bor gde se stvorio sumpor dioksid od koga je umrlo više ljudi.

II.2.4. Sumpor vodonik (H_2S). To je gas bez boje sa karakterističnim mirisom na pokvarena jaja. Otrovan je i nadražujuće deluje na sluzokožu očiju i disajnih organa. Kod sadržaja 0,1 do 0,2% u radnoj sredini i atmosferi uopšte, brzo izaziva smrt.

II.3. ZAGAĐENJA OD PRAŠINE, BUKE I VIBRACIJA

II.3.0. OŠTEĆENJA UHA, GRLA, NOSA, KOŽE

Rad u zaprašenoj sredini može da ošteti uho, nos, grlo i kožu. Uho može da bude oštećeno toliko da dođe do gubitka sluha (gluvoće). Neke traume mogu izazvati pucanje bubne opne, a uz to ide hronična upala pluća.

Osteoskleroza nastupa i ranije usled prašine, buke i sl. Inače sve rudarske mašine: za bušenje minskih rupa, za kopanje, za utovar, pa i za transport proizvoda jaku buku, tako da se uši moraju štititi, pored prašine, i od buke, korišćenjem posebnih specijalnih štitnika.

Buka se deli na tri vrste ili klase, i to:

- prva klasa, nisko učestala buka sa 90 do 100 decibela,
- druga klasa, srednje učestala buka sa 85 do 90 decibela
- treća klasa, visoko učestala buka, sa 75 do 85 decibela.

Tabela. *Buka mašina i drugih sprava*

Naziv mašina	db
Avion pri poletanju	120
Bušači čekić Pop muzička grupa	113-120
Utovarna mašina	105
Pneumatska rotaciona bušilica	110
Ventilator	87
Kamion, motocikl, podz. železnica	113
Prezauzeta raskršća	75
Izvan kuće, blizu autoputa	70
Bučna kancelarija	55
Bučna ulica, kroz otvoren prozor	52
Buka u pozadini tihe zone	48
Tiha soba za sedenje	44
Šum drveća	40
Radio studio	37
Pustinja	22

Nos, pored prašine napadaju i trideset rinovirusa, a mnogo utiče i okolina: hladnoća, razna isparenja, te pojava upala sinusa nije retkost.

Grlo, takođe pati od prašine, pa imamo suvo grlo. Kako su rudari stalno u nekoj vlazi dolazi do infekcije grla, kao i razne upale, krajnici. Štetno utiče i isparenje ulja za podmazivanje mašina, gasova i isparenja od rada dizelmotora u jami.

Koža je često očišćena od prašine, zapuše se lojne žlezde i dođe do dermatokonioze. Kožu oštećuju nafta i njeni derivati, i naravno vlaga. U humidnim oblastima dolazi do pojave ojeda (interrigo), koju izaziva efekat kvašenja, zbog toplote, vlage i trenja. Razne infekcije kože od stafilokoka ili streptokoka izazivaju interrigo, čireve, epizepelas. Gljivične infekcije kože takođe nastaju. Ima i parazitnih infekcija, naročito od šugavca i nesnosnog svraba. Na koži se javljaju i tumori, kod kože je čest i sarkom (maligni tumor).

II.4. ZAGAĐENJA OD NAFTE

II.4.0. NAFTNI IZVORI – mogu biti remetilac zdravlja i izvori zdravstvenih opasnosti.

Dokazani trovač pluća su zapaljeni naftni izvori, a naročito za vreme ratnih dejstva, jer tada ne gore samo nafta i gas već ko zna još kakve hemikalije, otrovi, bojni otrovi, osiromašeni uranijum. Dugo disanje dima od ovih požara izaziva glavobolju, muku, bol kože, zapaljenja pluća, astmu.

Usled korišćenja osiromašenog uranijuma dolazi do poremećaja u životnim sokovima, naročito u spermi muškaraca, što dovodi do rađanje dece sa određenim poremećajima ili sindroma Golden Hair (asimetrija glave i kičmenog stuba); nedostatak jednog uha, jednog oka; poremećen probavni trakt, nemože da se jede, nema debelog creva i eliminacija otpadnih materija se obavlja kroz otvor na stomaku; oštećene glasne žice; pati se od hidrocelije, a to je skupljanje tečnosti u mozgu koju treba stalno drenirati, deformisane ruke i noge; rupa u srcu; krvni poremećaji slični hemofiliji; nerazvijeni ušni kanali...

U slučaju požara koriste se zaštitne gas maske, a kod ratnih dejstava treba ljude povući sa naftnih polja, a radove obustaviti.

II.5. MINIRANJE KAO NOSILAC RIZIKA PO ZDRAVLJE

II.5.0. MINIRANJE

Mnogi rudarski podzemni objekti se grade uz upotrebu različitih eksploziva. Tom prilikom može doći i do požara, a redovno se proizvode ogromne količine štetnih i opasnih gasova: ugljen monoksid, azot-monoksid, azot-dioksid, sumpor-vodonik, živine i olovne pare...

II.5.1. Azot monoksid. Gas bez boje, malo teži od vazduha, rastvara se u vodi. U vazduhu prelazi u azot dioksid.

II.5.2. Azot dioksid. Gas smeđe boje, teži od vazduha, rastvara se u vodi i prelazi u azotnu kiselinu.

Mehanizam dejstva oksida azota objašnjava se njihovim jakim oksidacionim dejstvom na tkivo organizma, deluje prodirući kroz kožu i izazivaju pneumoniju, apscese pluća, upalu sluzokože nosa i bronhija, emfizem pluća, hipotonija, opšta slabost, anemija, delovanje oksida azota nastupa odmah.

Sadržaj oksida azota u vazduhu od 0,125 mg/l izaziva kašalj, 0,20 do 0,30 mg/l i pri kratkotrajnom delovanju opasno je po život. Mnogo su opasniji od ugljen monoksida.

Pri miniranju u sulfidnim mineralima i pri korišćenju štapina, stvaraju se sumpor-vodonik i sumpor-dioksid.

II.5.3. Pare olova i žive. Živine i olovne pare nastaju u malim količinama pri upotrebi detonatorskih kapisli i električnih detonatora, u kojima se inicijalno punjenje sastoji od živinog fluminata i olovnog oksida. Ove pare kod trajnijeg delovanja mogu izazvati hronično trovanje centralnog nervnog sistema, organa za varenje i bubrega.

Postoje maksimalno dozvoljene koncentracije otrovnih gasova (MDK) u vazduhu koji se stvaraju pri miniranju.

Kod razmatranja žive treba dodati da je gornja dozvoljena granica sadržaja žive u hrani 0,5 delova na milion. Međutim u ribama Amazonije, gde se zlato iz peskova vadi amalganizacijom i otpad baca u reke nađeno je 1,1 pa čak 3,81 u ikri.

Trovanje živom može da izazove slepilo, gubitak sluha, gubitak koordinacije, smetnje u govoru, nervna oboljenja (teška drhtavica), ispadanje zuba (rudari obično na radu u jami žvaću slaninu).

Živa prodire kroz pluća udisanjem

živinih para (pri zagrevanju amalgama živa ispari a zlato ostaje), kroz sluzokožu usta i preko kože. Trovanje može biti akutno, kada dolazi do poremećaja rada creva sa teškim prolivima, poremećajem rada bubrega sa anurijom; onda ulceracija desni, drhtanje ruku, teški bronhitis, upala pluća.

Prevencija se pažljivo izvodi rukovanjem, bez direktnog kontakta sa živom i korišćenjem maski. Inače postoji genetički izmenjeno drvo koje upija živu iz zagađenog tla, kao i bakterija koja čini bezopasnim jednog od najopasnijih zagađivača-živu.

II.6. OPASNOSTI OD OPEKOTINA

II.6.0. OPEKOTINE

Oštećuju kožu ali i pluća. Težina opekotine se ceni dubinom prodora u kožu:

- prvi stepen, kada se javlja crvena koža, ili siva; ne računa se kod procene ukupno opečene površine kože,
- drugi stepen, znači dublji prodor u kožu, i
- treći stepen znači prostrano uništenje kože, kao najteži stepen opekotine, koja ugrožava život.

Posebna oštećenja kože nastaju kad se pri izradi okana i drugih objekata naiđe na slanu vodu.

Uz opekotine ide inhalacija dima, prevrućeg vazduha, udisanje plamena, što skoro redovno dovodi do smrtonosnih oštećenja pluća.

II.7. OPASNOSTI OD TUBERKULOZE

II.7.0. TUBERKOLOZA

Zbog napornog rada u rudarstvu i teškog života (siromaštvo) dolazi i do pojave tuberkoloze česte socijalne bolesti. Ona se širi putem kašlja, ispljuvka obolelog, nevidljivih kapljica i inficiranih predmeta. Slaba ishrana, manjak proteina i vitamina, pogoduju razvoju tuberkoloze.

II.8. OPASNOSTI OD ZAMORA

II.8.0. ZAMOR

Zamor, malaksalost, slabost, umor i letargija najčešće su uzrokovani sa opštim faktorima, kao što su prenaprezanje, slaba fizička kondicija, nepravilan odmor, primetna debljina, nepravilna ishrana i emocionalni problemi. Da pomenemo neki od organskih uzroka zamora:

- endokrini poremećaji: adisonova bolest, hipotiroidizam, dijabetes,
- neurološki poremećaji: mystenia gravis (teško oboljenje mišića),
- infektivne bolesti: hepatitis, tuberkoloza, bruceloza, infektivni endokarditis, crveni paraziti,
- hematološki poremećaji: anemija, infektivna mononukleoza,
- collagen poremećaji: reumatoidni artritis, sistemski lupus (lišaj koji razjeda, eritematoza,
- rak, bilo koji,
- droge, toksini, alkohol, sedativi i trankvilajzeri, otrovi životne i radne sredine

II.9. RADNE MAŠINE NA DIZEL POGON U JAMI KAO NOSIOCI ZDRAVSTVENOG RIZIKA

II.9.0. RADNE MAŠINE NA DIZEL POGONU

Gasovi i pare koje ispuštaju mašine posle sagorevanja nafte štetni su po zdravlje rudara, naročito na respiratorni trakt, pa se zato posebnim propisima reguliše upotreba tih mašina, prečišćavanje izduvnih gasova i naročito kontrola ispravnosti instalacija.

Glavni sastojci izduvnih gasova su: ugljen dioksid, ugljen monoksid, aldehidi, oksidi sumpora (zato se traži gorivo čisto od sumpora), azotni oksidi, čađ. O opasnostima nekih od ovih gasova već je bilo reči.

Akrolein je bezbojna lako isparljiva tečnost, neprijatnog mirisa. Dolazi u vazduh u vidu akroleinske pare. Teži je od vazduha 1,9 puta. Lako se rastvara u vodi. Veoma je otrovan. Boravak u atmosferi sa svega 0,008% akroleina stvara skoro nepodnošljivo nadraženje sluzokože, a koncentracija od 0,014% je već smrtonosna. Maksimalno dozvoljena koncentracija je 0,1 ppm odnosno mp u kubnom metru vazduha.

Formaldehid je bezbojan veoma otrovan gas, deluje jako razrdražujuće na organe za disanje i nervni sistem. Specifična težina je 1,04 kg/m^3. Lako je rastvorljiv u vodi. Početna štetna koncentracija je od 0,007%, a opasnost počinje kod 0,018%. Maksimalno dozvoljena koncentracija 0,8 ppm odnosno 1 ppm po metru kubnom vazduha.

Sve treba držati pod kontrolom dobrom ventilacijom (uz redovnu kontrolu izduvnih gasova, merenja i više puta u smeni).

Upotreba rudarsko-građevinskih mašina na zagađenim gradilištima traži kabine za radnike sa kondicioniranjem vazduha uz neophodno filtriranje i odvajanja štetnih gasova, prašine i smrada.

Posebna zaštita je potrebna u rudnicima uranovih minerala kada se uz adekvatnu zaštitu koriste i odgovarajući roboti. I ovde pojačana ventilacija rešava probleme Redovna merenja ozračenosti su normalna i od velike važnosti.

II.10. NEKI PSIHIČKI FAKTORI KAO IZVORI OPASNOSTI

II.10.0.STRAH I STRES

Rudarski posao je izuzetno opasan. I to svaki dan. To se ne priznaje, ali stresa ima. Kažu da rudari piju alkohol da smire živce - jednu čašicu pre odlaska u jamu, a posle izlaska iz jame pet - da zahvale sudbini.

II.10.1. Stres i sindrom „sagorevanja na poslu“

To je iscrpljenje emotivne, psihičke i fizičke energije ili motivacije, koje nastaju kao rezultat produženog izlaganja stresu. Ovaj sindrom karakterišu tri glavne grupe simptoma iscrpljenosti i neefikasnosti. Pojavljuju se učestale glavobolje, koštani ili mišićni bolovi, smanjenje ili povećanje apetita, povećana potreba za spavanje ili nesanica, razdražljivost i nervoze. Zbog hronične izloženosti stresu opada imunitet i javljaju se češće infekcije, a naročito organa za disanje, pa i do dijabetisa i do oboljenja srca i krvnih sudova.

Vremenom ovaj sindrom može dovesti do ozbiljnih mentalnih ili somatskih poremećaja. Alarmirana od hipotalamusa (deo mozga), hipofiza (žlezda u glavi) luči transmitere koji preko krvi stižu do nadbubrežnih žlezda... Kora nadbubrežne žlezde proizvodi hormone stresa (kortizol, dok se u srži istih formiraju adrenalin i noradrenalin). Ako je dostignut određeni nivo koncentracije hormona stresa u krvi, to kod zdravih ljudi sprečava njegovo dalje lučenje. Ako je ovaj kružni proces regulacije poremećen, nivo hormona stresa u krvi ostaje trajno visok, sa poznatim posledicama po zdravlje.

Tako imamo tri stepena iscrpljenosti koji pokazuju određene poremećaje:

Prvi stepen-prvi znaci iscrpljenosti su: poremećaji sna, bolovi, zujanje u ušima, poremećaj srčanog ritma, pojačana radna aktivnost, smanjena radna sposobnost, razdražljivost i preosetljivost.

Drugi stepen-iscrpljenosti uzima maha. Ponašanje se menja, sve se vrti samo oko posla. Tu su: agresivni ispadi, slepi akcionizam, povlačenje od prijatelja i porodice, osećanje nemoći, problemi sa koncentracijom i pamćenjem.

Treći stepen, sagorevanje na radu su: radna efikasnost i životna radost nestaju, duh i telo idu ka potpunoj iscrpljenosti: potpuna apatija, sklonost samoubistvu, depresiji, preti infarkt.

III. ZAKLJUČAK

Proizvodi rudarske delatnosti koji se dobijaju eksploatacijom mineralnih sirovina uvek su kroz istoriju civilizacije bili značajni za ceo svet. Zato su i određeni vremenski periodi po tome i nazivani kao: kameno doba, bakarno, bronzano, gvozdeno, atomsko doba.

I pored sadasnjeg ogromnog napretka u tehnici i tehnologiji eksploatacije uvođenjem mehanizovanih i automatizovanih procesa pri radu, težak i opasan rad rudara uzrokuje niz profesionalnih bolesti specifične za ovu ljudsku delatnost.

Osim, u referatu nabrojanih profesionalnih bolesti, rudari su i u stalnoj opasnosti i od zarušavanja stena, prodora opasnih štetnih gasova, prodora površinskih i podzemnih voda, čestih požara, jamskih pritisaka i gorskih rudara (mali zemljotresi) i dr.

Rudarskom eksploatacijom, pored dobiti, degradiraju se i ogromne povrsine zemljišta i zagadjuje životna i radna sredina, što izaziva ogromne ekološke probleme čak i na planetarnom nivou.

Ogromni su zadaci pred rudarskom i medicinskom strukom; kako na adekvatan način smanjiti nepovoljan razvoj profesionalnih bolesti kod rudara i kako adekvatno i pravilno prići izvodjenju rudarske eksploatacije sa što manje šteta.

Od nedavno u svetu (i kod nas) usvojen je najnoviji koncept rudarske eksploatacije tzv. „koncept održivog razvoja'' gde su predvidjene mere i postupci da se profitabilna eksploatacija može vršiti samo uz potpunu zaštitu radne i životne sredine, svodjenjem na minimum degradaciju zemljišta i imisije štetnih gasova i produkata eksploatacije i prerade mineralnih sirovina. Primenom novog koncepta održivog razvoja eksploatacije biće smanjene i profesionalne bolesti kod rudara, kao i ugroženost i ekološka opasnost za celi svet.

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POSSIBLE DISEASES AND DANGERS WITH THE MINING PROFESSION[*****]

Abstract

Mining profession is very difficult, full of potential natural dangers, as well as of the risk of catching various diseases while exploiting raw materials of metals, non-metals, coal, oil and gas, and when working with machines in various rock layers which may contain ingredients harmful to the miners who are in contact with them.

Since the start of mining and further development of civilization, in addition to profit in the process of exploitation, there has been made a lot of damage due to violations of nature and environmental pollution and work environment. Nowadays it has become imperative to keep sustainable development, which means that natural resources must not be exploited without any control because of the risks to life on our planet.

Miners work in very adverse conditions, in great depth, narrow space, dust, harmful gases, poor ventilation, contaminated water, poor lighting, caving rocks and many other sudden unpredictable dangerous.

Therefore, miners suffer from specific occupational diseases, as well as from other general, widespread diseases.

The major task of scientists, researchers, mining and medical professionals is to recognize these diseases, identify their cause, and take measures to prevent their spreading and to introduce effective treatments.

This paper presents a brief analysis of major occupational diseases in miners and some parameters which determine level of risk. In our literature, this issue has not been previously discussed in such an obvious way.

Key words*: professional diseases, prevention, protection of the working and living environment, concept of the sustainable development*

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INTRODUCTION

Three ways of exploitation the mineral resources are applied in mining underground (pit) surface and borehole. Mineral resources that are exploited are: metallic (Au, Ag, Cu, Fe, Pb, Ar ...), non-metallic (salt, gypsum, clay ...) and fossil (coal, oil, gas ...) It is said that metals are the backbone of civilization, and coal, oil and gas are the energy and circulation of civilization.

From the very beginning (and now) there were very difficult conditions in mining, both in the process of exploitation so the socio-economic conditions were almost always negative. It is not said in vain that the mining operation is a bread with seven crusts.

Initially, mining was slave labor, and with the progress of science and technology, individual work processes are mechanized and automated with the introduction of the so-called "Inteligent Mine, where the work is much easier, and the number of people in the work process is minimized. Mining work is honorable and noble calling and profession.

Difficult conditions in the exploitation of mineral resources are the following:

- Working under poor artificial light
- The emergence of high temperature with increasing depth of exploitation
- The appearance and breakthroughs gas methane (CH_4), which is very explosive and cause a major catastrophe and destruction leading to the explosion of a large human losses and material goods
- The fire in the mines and poisoning from carbon monoxide (CO)
- The phenomena of gas carbon dioxide (CO_2) to suppress dangerous even in small concentrations
- Expansion of gases and rock material in mining areas
- Penetration of water in mining areas (ground and surface)
- The emergence and manifestation of increased pit pressure and its extreme forms, "rock hits" that are destructive and cause great human and material damage
- The emergence of other gases like nitrogen oxides in mining and other process
- Large land degradation and villages around the mine and its pollution, and loss of arable land
- Pollution of water, plants and entire ecosystem.

Mining exploitation, in addition to benefits, the vast areas of degraded land and pollutes the environment, causing huge environmental problems even on a planetary scale.

The newest concept of mining exploitation is the concept of "sustainable development", where the measures envisaged to profitable exploitation can only be made with full protection of labor and environment, reduction of land degradation and emission of harmful gases and fluids at minimum. By this way, the occupational diseases in miners can be reduced.

II. MINING OCCUPATIONAL DISEASES

II.1. AIR POLLUTION

1.0. DANGERS FOR LUNGS, EARS, THROAT, NOSE

The main occupational disease in miners affect the lungs. This includes: silicosis, antracosis, beriosis, ultramarinosis, manganoconiosis, aluminosis (bauxite) pneumaconiosis, antracosis, siderosis, uranopneumonicosis. These diseases usually result from inhalation of fine dust and aerosols of these minerals and rocks. Further, various types of gas poison or damage the lungs of miners: carbon monoxide, carbon dioxide, hydrogen sulfide, sulfur dioxide, nitrous gases, vapors in various processes of oxidation and inflammation of the pit material, coal, methane, coal dust, pyrite, pyrhotine, sulfur, oil and gas, transformer oil, polyurethane, inflammation of explosives, explosion of methane, carbon monoxide, burning explosives. If this, add alcohol, and cigarette smoke, exhaust fumes and business machines to drive diesel engines, it is already too much to the lungs of miners. Various pollutants and cigarette smoke, adversely affect the miners lung more than other citizens.

The aim of prevention was to reduce the emissions of air pollutants in the human body.

The most important thing is to reduce the concentrations of any dust, gas, or smoke, and that in any case apply protective / preventive / measures as far as the maximum possible: Drilling holes with mine water irrigation, water barriers in loading ore and rock / overburden / the use of robotic machinery and personal protective equipment.

Pneumoconiosis

II.1.1. Silicosis. Silicosis is a chronic fibrotic lung disease and is caused by inhalation of inorganic dust long. It is primarily free silica (silicon dioxide), the same as the common cause.

Longer exposure to dust (2-22 years) is a possible reason for man illness..There are many professions in which silicosis occurs. In addition to mining in hard silicate rocks, sandstone, etc., causing silicosis and blasting, foundry work, the production of abrasives and silex linings, monuments, decorations (roses), steps, stone bridges, coated plates, ceramics, glass (brass works, grinding of crystals). For the diagnosis is an important history of exposure to dust, to observe the characteristic X-ray changes (x-ray): bilateral modules fibrosis, hills and lymphadenopathy and recurrent respiratory infections, tuberculosis occurs when (silico tuberculosis). Based on the findings of Ph and plastic images, the stages of silicosis are determined: I, II, III.

The first signs of pneumoconiosis were asthma-like symptoms and weak cough with little secretion of mucus. Continue to perform cardiac disorders and general weakness, emphysema develops, creating the bronho stasi of tuberculous origin.

In silicosis, both lungs are affected and with tuberculosis often only one, and its top.

Dyspnea (shortness of breath) at a stress is a common phenomenon/nuisance, a cough is developed, initially dry and later becomes productive, often striped with bloody saliva. Strong, occasionally fatal hemoptysis (spitting blood) and higher bleeding from the lungs may appear.

Diatometic earth, talc, graphite, kaolin and the like products cause some kind of silicosis.

II.1.2. Asbestosis. Asbestosis is the result of inhaling asbestos dust and with the pneumoconiosis silicosis is the most dangerous. It is carcinogenic, so that in some cases getting lung cancer, lung tissue, airways, or peritoneum. Studies have shown that asbestos is not only dangerous, but also minerals arsenic, beryllium and its compounds, cadmium and its compounds, hexavalent chromium, and coal tar, soot. Because of the danger, at one time, it was almost totally banned the use of asbestos in industry, but more recently still allowed in some places (for example - brake devices.).

II.1.3. Coal dust (antracosis) and methane. Coal dust creates antracosis, both in the coal mining and the urban population. The same causes loss of the natural color of the lungs (both of them in black) and difficult breathing, and with disease progression (fibrosis, dyspnea, shortness of breath) silicosis may be also obtained.

Coal dust in the coal mines may, under certain conditions, explode. It fires at the stone coal at temperatures 350-450oC, and the brown coal at 25-400oC. If in the pit there is methane, which fires at 450oC then the mixture was completely devastating. Otherwise, methane is the most dangerous when it is in the pit atmosphere between 4.5 and 14.5%, when it can explode, where the temperature reaches 1650oC, and with the explosion might ignite the coal dust, and some other gases (ethane). The most powerful was the explosion in the pit when the air has 9.6% methane. In addition to the suffering of people and property away from the waves, and suffers a wave of feedback, especially from the flame and various noxious gases that are inhaled (carbon monoxide, etc.). In addition to massive fatal cases, the explosion is especially terrible damage to the lungs and respiratory tract, and skin burns.

II.1.4. Manganocoliosis. It occurs at the exploitation and processing of manganese ore and how they are t various silicate minerals, silicosis is also obtained.

II.1.5. Siderosis. It occurs in exploitation and processing of iron ore, drilling metal and arc welding. Iron oxides and iron metal cause red (oxides) and black (metals) staining of the lungs. Red type results into fibrosis, and the black type is almost always associated with silicosis.

II.1.6. Aluminosis. Bauxite pneumoconiosis or aluminosis occurs in the exploitation and processing of bauxite, and often causes fibrosis, difficulty breathing (wheezing), and spontaneous pneumothorax.

II.1.7. Berlioz. It appears as the lung disease in the exploitation of minerals and beryllium metals, and especially in the machining and use the beryllium alloys and ceramics in the electronics industry and spacecraft. Elastic tissue is damaged and causes dyspnea, but also appear similar to bronchial pneumonia nodule.

II.1.8. Ultramarinosis. It occurs in the processing the precious stone ultramarine and causes shortness of breath and wheezing.

II.2. Poisoning and suffocation from gases (CO_2). These are professional poisoning mainly through the lungs.

II 2.1 Carbon monoxide (CO). This gas is colorless, odorless, taste and very toxic. It is poorly soluble in water and combustible. In the mixture of 13-75% with the air it can explode if ignited. Toxic effects begin to 0.048%. At concentrations of 0.11 to 0.34 mg/l in the air causes headache and malaise, with 1.1 to 2.5 mg / l in the air if we spend 30-60 minutes, the death occurs, at 2.5 to 4.0 mg/l a man loses consciousness after a few breaths, that is, after one to two minutes, and the performance level of severe poisoning. At 4.6 to 5.7 mg / l the death is within 5 minutes. If it is above 5.7 mg/l, the death is instantaneous.

Sometimes the miners in the pit carry the canaries in a cage. These beautiful birds succumb to poisoning more quickly when a miner notices it, he lives the job site.

Otherwise, carbon monoxide resulting from incomplete combustion of any (insufficient oxygen), and in the pit from the fire in the coal mines, particularly in the fire barrier, then the blasting using explosives with a positive balance of oxygen, and the explosion of methane and coal dust.

II.2.2. Carbon dioxide (CO_2). It is a gas without color, with low acidic taste and smell. The specific weight is 1.52 and it is always in the lowest parts of the mine rooms. With three percent in the air, the breathing speeds up and doubled, and with 2 to 5% of the general malaise, headaches and increased heart rate, and even numbness occur.

In 20-25% of the air choking death occurs, that is large quantities of toxic effect and it is treated as a toxic gas. It is found in caves, wells, so be careful.

Carbon dioxide is produced from the oxidation of wood by the work of bacteria. It can occur in all pits, as it is present in many rocks of the Earth crust out of which it gradually penetrates into the pit rooms.

II.2.3. Sulfur oxide (SO_2). Sulphur oxide is a gas without color, smell and sharp taste. It is very toxic, very destroys the lining of the eyes in particular. At 0.05% in the air, it is dangerous to human life. It occurs in the combustion of sulfur and its compounds, especially in the pit of burning sulfur, especially pyrite. Otherwise, each sulfide ore gradually oxidizes and produces sulfur dioxide. Inflammation of pyrite in the pit of RTB Bor are known, where sulfur dioxide was created from which more people died.

II.2.4. Hydrogen sulfide (H_2S). It is a colorless gas with a characteristic smell of rotten eggs. It has toxic and irritant effect on eyes and mucous membranes of the respiratory organs. In the content of 0.1 to 0.2% in the working environment and atmosphere in general, causes rapid death.

II.3. POLLUTION FROM DUST, NOISE AND VIBRATIONS

3.0. DAMAGE OF EAR, THROAT, NOSE AND SKIN

Working in a dust environment can damage ear, nose, throat and skin. The ear can be damaged so much that comes to hearing loss (deafness). Some trauma can cause cracking of the tympanic membrane, and this entails a chronic inflammation of the lungs.

Osteo sclerosis appears more earlier due to dust, noise and so on. Otherwise, all mining machinery for: drilling the blast holes, digging, loading and transportation of products produces a large noise, so that the ears must be protected, in addition to dust, and noise, using the special protectors.

Noise is divided into three types, or classes, namely:

- •first-class, low frequent noise from 90 to 100 decibels,
- •second class, high frequent noise from 85 to 90 decibels
- •third class, high-frequent noise, from 75 to 85 decibels.

Table 1. *Noise of machines and other devices*

Machine name	db
Plane takeoff	120
Drilling hammer Pop music group	113-120
Loading machine	105
Pneumatic rotary drill	110
Fan	87
truck, motorcycle, subway	113
Busy crossroads	75
Outside the house, near the highway	70
Noisy office	55
Noisy street, through the open window	52
Noise in the background of quiet zone	48
Quite living room	44
Rustle of trees	40
Radio studio	37
Desert	22

Nose, in addition to attacking the dust, is also attacked by thirty rhinoviruses, and the environment has a lot of influence: cold, different vapors and the occurrence of sinusitis that is not uncommon.

Throat, also suffers from dust, so there is a dry throat. As the miners are at constant moisture, it leads to a throat infection, and various infections, the tonsils. It is also adversely affected by the vapor of machine lubricating oil, gases and vapors from the work of diesel-motors in the pit.

Skin is often free of dust, the sebaceous glands are clogged and there is dermatoconiosis. Skin is damaged damage by oil and its derivatives and, of course, the humidity. In the wet areas, the rash (interrigo) appears, caused by the effect of wetting due to heat, moisture and friction.

A variety of skin infections, caused by staphylococcus or streptococcus, causes the interrigo, sores and epizepelas. Fungal skin infections also occur. There are also parasitic infections, particularly of mange and unbearable itching. Appear on the skin and Also tumors appear on the skin, and sarcoma (malignant tumor) is common in the skin.

II.4. POLLUTION FROM OIL

4.0. OIL WELLS – can be health disturbers and sources of health hazards.

The proven poisoners of lungs are the burned oil wells, especially during war operations, because the oil and gas do not only burn, but who knows other chemicals, poisons, toxic weapon, depleted uranium. Long breathing of smoke from these fires causes headache, nausea, skin pain, pneumonia, asthma.

The use of depleted uranium leads to disturbances in the juices of life, especially in the sperm of men, what leading to the birth of children with specific disorders or syndrome the Golden Hair (asymmetry of the head and spinal column), lack of one ear, one eye, abnormal digestive tract, cannot be eating, no colon and waste elimination of waste matters is carried out through an opening in the abdomen; damaged vocal cords; suffers from hydrocelia, and that is the fluid collecting in the brain that must be constantly drained, deformed hands and feet, hole in the heart, blood disorders like hemophilia ; underdeveloped ear canals ...

In the case of fire, use the protective gas masks, and in the war people should be withdrawn from the oil fields, and stop the work.

II.5. BLASTING AS THE BEARER OF THE RISK TO HEALTH

5.0. BLASTING

Many underground facilities in the mines are constructed with the use of different explosives. On that occasion, it can cause a fire, and regularly huge amounts of harmful and hazardous gases are produces as well as: carbon monoxide, nitrogen monoxide, nitrogen dioxide, sulfur, hydrogen, mercury and lead vapor...

II.5.1. Nitrogen monoxide. a colorless gas, slightly heavier than air, soluble in water. In the air, it passes into nitrogen dioxide.

II.5.2. Nitrogen Dioxide. a brown gas, a little bit heavier than air, soluble in water and it transfers into nitric acid.

The mechanism of action the nitrogen oxides is explained by their strong oxidizing effect on the tissues of the body, acting penetrating through the skin and they cause pneumonia, lung abscesses, inflammation of the mucous membranes of the nose and bronchi, pulmonary emphysema, hypotonia, general weakness, anemia, and the effects of nitrogen oxides occur immediately.

The content of nitrogen oxides in the air to 0.125 mg/l causes coughing, from 0.20 to 0.30 mg/l and at the short-term action, it is dangerous to life. They are much more dangerous than carbon monoxide.

In blasting in the sulphide minerals and the use of sticks, they form the hydrogen sulfide and sulfur dioxide.

II.5.3. Lead and mercury vapors. Mercury and lead vapors are generated in small quantities when using detonating caps and electric detonators, in which the initial charge consists of mercury fulminates and lead oxide. These vapors in the lasting effects can cause the chronic poisoning of central nervous system, digestive system and kidneys.

There are maximum allowable concentrations of toxic gases (MPC) in air that are produced during mining.

When considering mercury, it should be added that the upper permissible limit of mercury content in the food is 0.5 parts per million. However, in the fish of the Amazon, where gold is mined by amalgamation and the waste is dumped in the river, it was found 1.1 and even 3.81 in the spawn.

Mercury poisoning can cause blindness, hearing loss, loss of coordination, speech problems, nerve disorders (severe tremor), loss of teeth (usually the miners in the pit chew bacon).

Mercury enters the lungs through inhalation of mercury vapor (when heating the amalgam, mercury evaporates and the gold remains), through the mouth mucosal and through the skin. Poisoning can be acute, when intestinal disorders with severe diarrhea, kidney dysfunction with anuria, then ulceration, teeth gums, trembling hands, severe bronchitis and pneumonia appear.

Prevention is carefully performed by handling without direct contact with mercury and using masks. Otherwise there is a genetically altered wood that absorbs mercury from polluted soil, as well as the bacteria that makes harmless one of the most dangerous pollutants – mercury.

II.6. RISKS OF BURNS

6.0. BURNS

It damages the skin and lungs. The severity of burns is estimatedby the depth of penetration into the skin:

- first degree, when the skin appears red, or gray; not be included in estimating the total burned area of skin,
- second degree, which means deeper penetration into the skin, and
- third degree means a vast destruction of the skin, as the worst degree of burns, life-threatening.

Special skin damage caused during preparation of shafts and other facilities encountered in salt water.

Inhalations of smoke, over hot air, breathing of fire go with burns, which almost always leads to fatal lung damage.

II.7. RISKS OF TUBERCULOSIS

7.0. TUBERCULOSIS

Hard work in mining and hardship (poverty) lead to frequent occurrence of tuberculosis, often social ills. It is spread through coughing, sputum of patient, and the invisible droplets of infected objects. Poor nutrition, lack of protein and vitamins are suitable for development of tuberculosis.

II.8. RISKS OF FATIGUE

8.0 FATIGUE

Fatigue, malaise, exhaustion, and lethargy are often caused by the general factors, such as overstrain, poor physical fitness, abnormal relaxation, apparent thickness, inadequate nutrition and emotional problems. Here are mentioned some of the organic causes of fatigue:

- endocrine disorders: Addison's disease, hypothyroidism, diabetes,
- neurological disorders: mystenia gravis (severe disease of muscle),
- infectious diseases: hepatitis, tuberculosis, brucellosis, infectious endocarditis, red parasites,

- •haematological disorders: anemia, infectious mononucleosis,
- •collagen disorders: rheumatoid arthritis, systemic lupus (eczema, which erodes), erythematosus,
- • cancer, any type,
- • drugs, toxins, alcohol, sedatives and tranquilizers, poisons living and working environment.

II.9. OPERATING MACHINES ON DIESEL DRIVE IN THE PIT AS CARRIERS OF HEALTH RISKS

9.0. OPERATING MACHINES ON DIESEL DRIVE

Gases and vapors emitted by the machine after combustion of oil are harmful to the health of miners, especially the respiratory tract, and therefore special regulations governing the use of those machines, exhaust system and in particular control of the installations.

The main components of exhaust gases are carbon dioxide, carbon monoxide, aldehydes, sulfur oxides (because it requires a clean fuel sulfur), nitrogen oxides, soot. The dangers of some of these gases have already been discussed.

Acrolein is a colorless easily volatile liquid, unpleasant odor. It comes into the air in the form of acrolein vapors, heavier than air 1.9 times, easily soluble in water and very toxic. Staying in the atmosphere with only 0.008% acrolein generates almost unbearable irritation of mucosa, and concentration of 0.014% is fatal. Maximum allowable concentration is 0.1 ppm or mp in a cubic meter of air.

Formaldehyde is a colorless highly toxic gas, with exasperating effect on respiratory organs and nervous system. Specific gravity is 1.04 kg/m^3. It is easy soluble in water. Its initial harmful concentration is 0.007% and the risk starts at 0.018%. Maximum allowable concentration is 0.8 ppm or 1 ppm per cubic meter of air.

Everything should be kept under control by good ventilation (with a regular control of emissions, measurements of several times per shift).

The use of mining and construction machinery on contaminated construction sites requires cabins for workers with air conditioning and necessary filtration and separation of gases, dust and odors.

Special care is needed in the mines of uranium minerals when the robots are used with adequate and appropriate protection. Here, the increased ventilation solves problems. Regular measurements of radiation are normal and of great importance.

II.10. SOME PSYCHIC FACTORS AS THE SOURCES OF DANGER

10.0. FEAR AND STRESS

Mining business is extremely dangerous even every day. It is not recognized, but there is a stress. Its is said that the miners drink alcohol to calm nerves-a glass before going into the pit, and after leaving the pits five glasses to thank destiny.

II.10.1. Stress and syndrome of "burning on the job"

It is emotional exhaustion, mental and physical energy or motivation, that result from prolonged exposure to stress. This syndrome is characterized by three main groups of symptoms of exhaustion and inefficiency. Frequent headaches, bone or muscle pains, decrease or increase of appetite, increased need for sleep or insomnia, irritability and nervousness appear. Due to the chronic exposure to stress, the immunity decreases and infections occur more frequently, especially respiratory organs, including the diabetes and t heart and blood vessels diseases.

Over time, this syndrome can lead to serious mental or somatic disorders. Alarmed by the hypothalamus (part of the brain), pituitary gland (a gland in the head) transmitters secreted by blood that reaches the adrenal glands. Bark adrenal glands produce stress hormones (cortisol, whereas in the same form the core of adrenaline and noradrenaline). If the concentration reached a certain level of stress hormones in the blood, it prevents its further secretion of healthy people. If this circular process regulation is disturbed, the level of stress hormones in the blood remains permanently high, with the known health consequences.

So we have three degrees of exhaustion, which show certain disorders:

- The first degree - the first signs of exhaustion are: sleep disturbances, pain, tinnitus, impaired heart rate, increased business activity, reduced working ability, irritability and hypersensitivity;
- The second degree - exhaustion takes hold. The behavior is changed and all is just about work. Those are the aggressive outbursts, blind activism, withdrawal from friends and family, sense of powerlessness, problems with concentration and memory;
- The third degree, burning on the job, is: working efficiency and joy of life disappear; the mind and body go towards complete exhaustion: complete apathy, tendency to suicide, depression, and heart attack threatens.

III. CONCLUSIONS

Products of mining activity, obtained by exploitation of mineral resources have always been through the history of civilization significant for the whole world.

That is why the time periods were specified in that and called as: the Stone Age, Brass, Bronze, Iron, Atomic Age.

Despite enormous progress in the current techniques and exploitation of technology introducing the mechanized and automated processes at work, a difficult and dangerous work of miners causes a series of diseases specific for this human activity.

In addition to the enumerated occupational diseases, the miners were in constant danger from rock demolitions, infiltration of dangerous pollutants, penetration of surface and ground water, frequent fires, underground and mountain pressures (small earthquakes) and others.

Mining exploitation, in addition to profits, and degraded the vast areas of land and pollution the work environment, also causes a huge environmental problems even on a planetary scale.

The enormous tasks are ahead of mining and medical profession, in order to adequately reduce the adverse development of occupational disease in miners and to perform adequately and properly the mining operation with minimum damage.

Recently in the world (and here) was adopted the latest concept of mining exploitation, so-called the “concept of sustainable development" where the measures and procedures are predicted for profitable exploitation only with the full protection of labor and the environment, minimum land degradation and emission of harmful gases and products of exploitation and processing of mineral raw materials. Using the new concept of sustainable development exploitation will also reduce the occupational diseases in miners, as well as vulnerability and ecological threat to the whole world.

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UNAPREĐIVANJE ELEKTROKINETIČKOG UKLANJANJA Pb, Zn I Ni IZ JALOVINE**

Izvod

U ovom radu je ispitivana mogućnost primene pulsne elektrokinetičke tehnike u cilju uklanjanja Pb, Ni i Zn iz jalovine. Ispitivan je uticaj trajanja ON i OFF intervala u okviru ciklusa. Utvrđeno je da primenom pulsne tehnike pri odnosu ON/OFF intervala od 3/1 dolazi do postizanja veće efikasnosti uklanjanja Pb nego pri konvencionalnom tretmanu. Elektrokinetička remedijacija se može koristiti u svrhu uklanjanja metala iz jalovine koji se nalaze u mobilnom, dostupnom obliku, a koji i predstavljaju najveću pretnju po životnu sredinu. Dodatno, primena pulsne tehnike povećava efikasnost uklanjanja metala iz jalovine.

Ključne reči: *elektrokinetička remedijacija; jalovina; unapređivanje; teški metali*

1. UVOD

Jalovina je material koji nastaje nakon procesa izdvajanja korisne frakcije rude. Nakon separacije jalovina se odlaže i, s obzirom da sadrži visoke koncentracije teških metala kao i da se na odlagalištima akumulira dugo vremena, može ispoljiti brojna neželjena dejstva na životnu sredinu. Pored toga što spiranjem sa odlagališta može doći do uticaja na vodne resurse (površinske i podzemne vode), jalovina može ispoljiti negativne efekte na okolnu floru i faunu kao i na kvalitet vazduha emitovanjem finih čestica. Zbog navedenog od velike je važnosti iznalaženje rešenja ovog problema. Jedan način je da se procesom remedijacije jalovina stabilizuje.

U proteklih dvadesetak godina intenzivna je primena elektroremedijacije u cilju uklanjanja teških metala iz različitih tipova

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čvrstih medijuma. Elektrokinetička (EK) remedijacija podrazumeva primenu slabe jednosmerne struje posredstvom elektroda koje su uronjene u medijum što rezultuje mobilizacijom i ekstrakcijom naelektrisanih i nenaelektrisanih supstanci [1,2]. Elektrokinetički proces čini skup nekoliko pojedinačnih procesa: elektroliza, elektromigracija, elektroosmoza (i hemijska osmoza), elektroforeza, proces difuzije kao i niz geohemijskih reakcija. Kao posledica elektrolize vode u anodnom delu, generišu se H^+ joni čime se snižava pH vrednost, dok se u katodnom delu formiraju OH^- joni tj. povećava se pH vrednost. Elektromigracija podrazumeva kretanje jona koji su slobodni i vrši se ka odgovarajućoj elektrodi u zavisnosti od oblika u kome se joni nalaze. Elektroosmotski protok podrazumeva kretanje vode pod dejstvom električnog polja i to usled naelektrisanja na površini čestica sa kojima je u kontaktu.

Do sada je u manjoj meri ispitivan elektrokinetički tretman jalovine [3,4], mada budući da se na ovaj način vrši uklanjanje metala odnosno može se sprečiti spiranje teških metala iz jalovine u vodne sisteme i difuzija u okolno zemljište, ova tehnika može biti široko primenjivana u svrhu prečišćavanja jalovine.

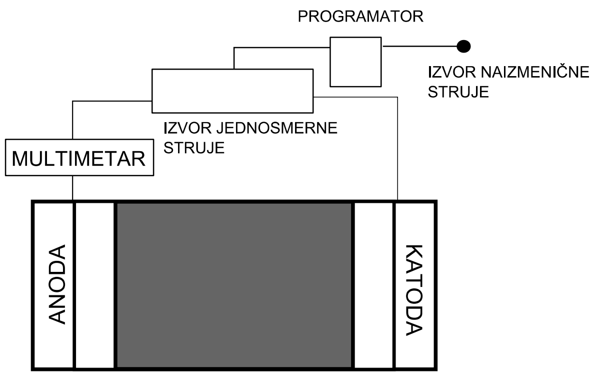
Kako bi se pospešila elektroremedijacija do sada je razvijen niz tehnika (koje ne podrazumevaju dodatak agenasa u sistem) kako u cilju poboljšanja ekstrakcije kontaminanata iz medijuma [4-6] tako i u svrhu smanjenja troškova tretmana [7-9]. Jedna od tehnika koje se primenjuje u cilju zadovoljenja oba gore navedena zahteva je pulsna tehnika [10-13]. Princip pulsne tehnike je da se određeni period jednosmerna struja propušta kroz medijum (ON), dok se na određeni period zaustavlja propuštanje struje kroz medijum (OFF). Primenom jednosmerne struje difuzioni dupli sloj se polarizuje što dovodi do promene u migraciji naelektrisanja [13]. Takođe, primenom jednosmerne struje javljaju se elektromigracija i elektroosmoza koji ograničavaju proces rastvaranja jonskih vrsta odnosno difuzije [10]. U toku OFF intervala, bez primene struje ili uz primenu naizmenične struje, dolazi do: a) depolarizacije difuzionog duplog sloja i b) prevazilaženja difuzionog gradijenta koji se javlja u toku primene jednosmerne struje. Kao posledice navedenog su intenzivnija ekstrakcija i desorpcija odnosno rastvaranje pri čemu dolazi do povećanja sadržaja jona dostupnih za migraciju [12,13]. Ovo je uzrok značajnog povećanja gustine struje primenom napona nakon OFF intervala. Primenom OFF intervala smanjuje se potrošnja električne energije, a time i troškovi tretmana. Do sada ispitivani su uglavnom uticaji broja ciklusa ON/OFF u cilju tretmana sedimenta i zemljišta, dok nije ispitivan uticaj trajanja ON i OFF intervala u okviru ciklusa. Ovaj uticaj je bitan sa aspekta potrošnje energije, a u cilju održanja/unapređenja efikasnosti procesa.

U ovom radu je ispitivana mogućnost primene pulsne elektrokinetičke tehnike u cilju tretmana jalovine sa visokom koncentracijom Pb, Zn i Ni. Ispitivan je uticaj trajanja ON i OFF intervala u okviru ciklusa.

2. EKSPERIMENTALNI DEO

Merenje pH vrednosti vršeno je u supernatantu koji preostaje nakon mešanja jalovine i dejonizovane vode (jalovina: voda=1:5) u toku 1 h pomoću SenTix®21 elektrode i pH-metra (340i WTW). Praćenje struje u toku tretmana vršeno je pomoću multimetra. Kapacitet kisele neutralizacije (eng. Acid neutralizing capacity, ANC) je određivan titracijom sa hlorovodoničnom kiselinom prema Gran metodi. Kapacitet katjonske izmene (eng. Cation exchange capacity, CEC) određivan je metodom zamene sa NH_4^+ jonima. Procedura za hemijsku ekstrakciju u cilju određivanja pseudo-ukupnog sadržaja metala u jalovini vršena je prema USEPA 3051a metodi. Analiza sadržaja metala vršena primenom Atomskog apsorpcionog spektrometra (plamena tehnika) (PerkinElmer, AAnalyst 700) u skladu sa USEPA 7000b metodom. Klasifikacija jalovine pre i nakon tretmana vršena je prema *EPA 2009* [14] i *Waste Classification Guidelines 2009* [15].

Konvencionalna EK tehnika vršena je pomoću uređaja koji je prikazan na Slici 1. Kao anoda i katoda korišćene su grafitne pločice dimenzija 10 x 5 x 1 cm. Za sprovođenje konvencionalnog eksperimenta programator je bio isključen i ovaj eksperiment je označen kao E1.



Sl. 1. *Prikaz elektrokinetičkog uređaja*

Program ON/OFF intervala u okviru ciklusa (1 ciklus/h) dat je Tabeli 1. U toku eksperimenata održavan je gradijent napona od 1 V/cm . Ekperimenti su trajali 7 dana. Na kraju eksperimenata uzorak jalovine je podeljen na 5 jednakih delova. Svaki deo je označen kao normalizovano rastojanje od anode (z/L: z = rastojanje od anode, L = dužina odeljka za uzorak): 0,1, 0,3, 0,5, 0,7 i 0,9. pH i pseudo-ukupna koncentracija metala su mereni u početnom uzorku kao i u uzorcima nakon tretmana na svakom definisanom rastojanju.

Tabela 1. *Eksperimentalni uslovi*

Oznaka eksperimenta	Odnos ON/OFF intervala
E1	-
E2	1/3
E3	1/1
E4	3/1

3. REZULTATI I DISKUSIJA

U Tabeli 2 su date karakteristike jalovine korišćene u eksperimentima.

Niske vrednosti AND i CEC ukazuju na mogućnost lakog prostiranja kiselog fronta koji se u toku tretmana formira u okolini anode. Prostiranje kiselog fronta omogućava rastvaranje i desorpciju metala sa čestica (Acar i Alshawabkeh 1993). Može se uvideti da se jalovina može klasifikovati kao opasan otpad prema sadržaju Pb, Ni i Zn na osnovu EPA 2009 odnosno prema sadržaju Pb prema Waste Classification Guidelines 2009.

Tabela 2. *Karakteristike jalovine*

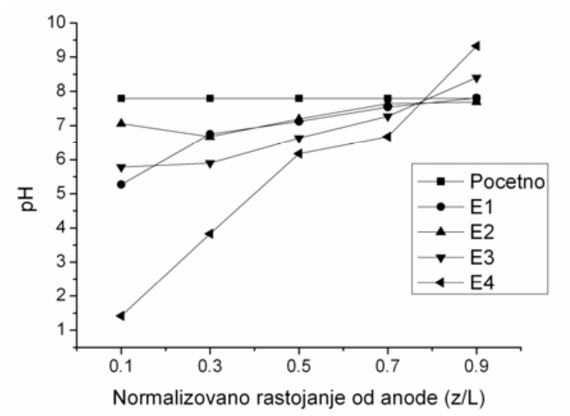
Parametar	Vrednost	Granična vrednost[1]	Granična vrednost[2]
pH	7,80	-	-
ANC (meq/100g)	4,75	-	-
CEC (meq/100g)	0,75	-	-
Pb (mg/kg)	1184	300	400
Ni (mg/kg)	126	60	160
Zn (mg/kg)	1038	200	-

[1]*Prema EPA 2009*

[2]*Prema Waste Classification Guidelines 2009*

3.1. Promene pH vrednosti jalovine nakon EK tretmana

Na Slici 2 je prikazana promena pH vrednosti jalovine nakon EK tretmana. Najznačajnije sniženje pH vrednosti kao i prostiranje kiselog fronta je postignuto nakon E4, što je posledica difuzije formiranih H^+ jona u toku OFF intervala kao i elektromigracije H^+ jona u toku ON intervala. Iz istog razloga dolazi do značajnijeg povećanja pH vrednosti u okolini katode. Povećanje pH vrednosti u okolini katode rezultuje taloženjem hidroksida metala [2].



Sl. 2. *Promene pH vrednosti jalovine nakon EK tretmana*

3.2. Distribucija Pb, Zn i Ni u jalovini nakon EK tretmana

Efikasnosti uklanjanja metala nakon EK tretmana dati su u Tabeli 3. Uviđa se da nije došlo do uklanjanja Zn, dok je Ni uklonjen iz jalovine nakon svakog tretmana u značajnom procentu. Na uklanjanje Pb iz jalovine primena pulsne tehnike je imala veliki uticaj. Pri eksperimentu sa najkraćim trajanjem ON intervala procenat uklonjenog Pb je neznatan, dok je Ni pri istom uklonjen 96%. Uviđa se porast efikasnosti uklanjanja Pb sa povećanjem trajanja ON intervala dok je istovremeno efikasnost uklanjanja Ni pokazala trend opadanja. Ovo je posledica promene transportnog broja koji opisuje doprinos jona metala ukupnoj električnoj provodljivosti. Iako Pb ima visoku jonsku pokretljivost, Ni je većoj meri podleže elektromigraciji što je najverovatnije posledica oblika u kom se nalazi. Jedino u mobilnom, dostupnom obliku metali mogu podleći elektromigraciji i biti uklonjeni. Povećanje efikasnosti uklanjanja Pb od E2 do E4 eksperimenta je posledica: a) difuzije jona Pb u toku OFF intervala, b) prostiranja kiselog fronta kroz sistem što je uslovilo desorpciju jona metala i rastvaranje kao i c) dovoljnog trajanja ON intervala za elektromigraciju [10]. Dakle, primenom pulsne tehnike postiže se čak i veća efikasnost nego prilikom konvencionalne tehnike. Ovo ukazuje da se primenom manje količine električne energije može postići čak i veća efikasnost. Zn nije uklonjen usled kombinovanog uticaja velike koncentracije Ni koja je bila dostupna za migraciju kao i velike jonske pokretljvosti desorbovanih jona Pb, a u vezi sa transportnim brojem. Konačno, željena krajnja koncentracija metala u jalovini postignuta je samo za Ni.

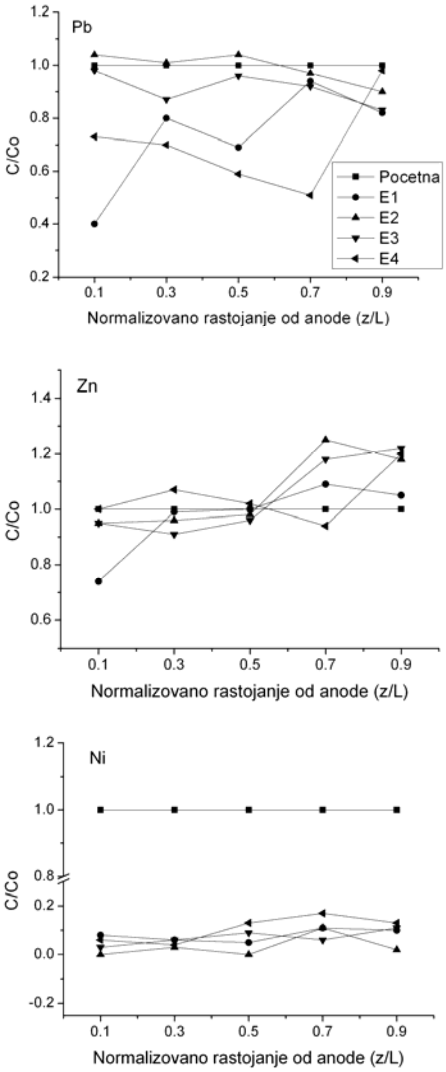
Tabela 3. *Efikasnosti uklanjanja metala nakon EK tretmana*

Oznaka eksperimenta	Pb (%)	Zn (%)	Ni (%)
E1	27	2,5	92
E2	0,7	0	96
E3	8,9	0	93
E4	30	0	89

Na Slici 3 prikazana je distribucija Pb, Zn i Ni u jalovini nakon tretmana na različitim rastojanjima od anode. Može se primetiti da je procenat uklonjenog Ni približno jednak na svim normalizovanim rastojanjima. S obzirom da je pH vrednost na z/L=0,1 i 0,3 niska (Slika 2) očekivan je veći procenat uklanjanja sa ovih rastojanja. Ipak, postignute vrednosti se mogu objasniti difuzijom jona Pb u toku OFF intervala. Akumulacija u okolini katode posledica je povećanja pH vrednosti u ovom regionu (Slika 2).

4. ZAKLJUČAK

U ovom radu je ispitivana mogućnost primene pulsne elektrokinetičke tehnike u cilju tretmana jalovine sa visokom koncentracijom Pb, Zn i Ni. Ispitivan je uticaj trajanja ON i OFF intervala u okviru ciklusa. Utvrđeno je da primenom pulsne tehnike pri odnosu ON/OFF intervala od 3/1 dolazi do postizanja veće efikasnosti uklanjanja Pb nego pri konvencionalnom tretmanu. Dakle, primena pulsne tehnike povećava efikasnost uklanjanja metala iz jalovine. Iako je željena krajnja koncentracija metala u jalovini postignuta je samo za Ni na elektrokinetički tretman može se posmatrati kao poželjan tretman s obzrom da se njegovom primenom uklanja mobilna, dostupna frakcija metala, a koja može ispoljiti negativna dejstva po životnu sredinu.



Sl. 3. *Distribucija Pb, Zn i Ni u jalovini nakon EK tretmana*

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Ljiljana Rajić, Svetlana Ugarčina Perović**[*]

ENHANCING THE ELECTROKINETIC REMOVAL OF Pb, Zn AND Ni FROM TAILINGS**

Abstract

In this study, we investigated the possibility of using pulse electrokinetic technique to treat tailings with high concentrations of Pb, Ni and Zn. The effect of ON and OFF intervals duration within the cycle was investigated. It was found that application of pulse technique with ON/ OFF interval of 3/1 resulted in significant acid front propagation and achieved greater Pb removal efficiency than the conventional treatment. It can be concluded that the application of pulse technique increases the metals removal efficiency from the tailings. Electrokinetic remediation can be used for removing mobile, available metals from tailings which has the greatest influence to the environment.

***Key words**: electrokinetics remediation; tailings; enhancing; heavy metals*

1. INTRODUCTION

Mine tailings contain high concentrations of chemicals and elements that are of concern to the environment. Mine tailings are transported as pulp form to specially conditioned sites called tailing ponds. Mine tailings, not only have a damaging effect on hydro resources by the natural leaching of chemicals, but also generate effects on flora and fauna, and serious effect on the air quality by generation the fugitive emissions of fine particles. It becomes necessary to find solutions to mitigate the impact of mine tailings on the environment. One aspect for the solution to the problem is to give stability to the mine tailings by the heavy metal remediation processes. Electrokinetic (EK) remediation involves the application of weak direct current through electrodes that are immersed in the medium resulting in mobilization and extraction of charged and uncharged substances [1,2]. Electrokinetic process involves several individual processes: electrolysis, electromigration, electroosmosis (and chemical osmosis), electrophoresis, diffusion process and series of geochemical reactions. As the result of water electrolysis in anodic region, H^+ ions

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generate thus lowering the pH value, while in the cathode region, pH value increases due to OH^- ions formation. Movement of ions to the opposite charged electrodes is the electromigration. Electroosmotic flow involves the movement of water under the influence of electric field due to the charge on the surface of particles with which it is in contact. So far, electrokinetic treatment of tailings was not widely studied [3,4], but since this technique can prevent heavy metals entering in water systems and diffusion into the surrounding soil, it can be applied for tailings treatment. In order to enhance the electroremediation, a range of techniques was developed (which do not include the addition of agents in system) improving the extraction of contaminants from the medium [4-6] as well as reducing the cost of the treatment [7-9]. Technique, that meets both of the above requirements, is the pulse technique [10-13]. The principle of pulse technique is that the certain period when direct current passed through medium (ON), that is followed by the period where no current passes through medium (OFF). Applying direct current diffusion, double layer is polarized, what leads to a change in charge migration [13]. Also, during direct current application, the electro migration and electro osmosis are limiting dissolution and diffusion of ionic species [10]. During OFF interval, without using electricity, the following appears: a) double layer depolarization and b) overcoming the diffusion gradient. As a conseqence, the intensive desorption or dissolution appears so the content of available ions for migration increases [12,13]. This causes a significant increase in current density by the use of applying voltage after OFF interval. Using OFF intervals reduces the power consumption and thus cost of treatment. So far, influences of ON/OFF cycles number was studied, while the impact of duration of ON and OFF intervals, within the cycle, were not investigated. This influence is important in terms of energy consumption for maintenance/improvement the process efficiency.

In this study, we investigated the possibility of using the pulse electrokinetic techniques for tailings treatment with high concentrations of Pb, Zn and Ni. The duration effect of ON and OFF intervals within the cycle was investigated.

2. EXPERIMENTAL CONDITIONS

The pH of tailings was measured on pH meter (340i, WTW). The pH measurements of tailings were carried out in deionized water (tailings: water = 1:5) by SenTix®21 electrode. The ammonium acetate method was used to measure cation exchange capacity (CEC). Acid neutralizing capacity (ANC) was measured and calculated according to the Gran method. Electric current was measured by multimeter. The protocol for chemical extraction for determination the pseudo-total metals content in tailings was performed in accordance with the USEPA Method 3051A. Analyses of metals were carried out using Flame Atomic Absorption Spectrophotometry (PerkinElmer, AAnalyst 700) in accordance with USEPA method 7000b. Tailings classification before and after treatments was made according to *EPA 2009* [14] and *Waste Classification Guidelines 2009* [15].

EK treatments were carried out in electrokinetic setup, shown in Figure 1. Anode and cathode were graphite (10x5x1 cm). During conventional treatment, the programmer was turned off (E1).

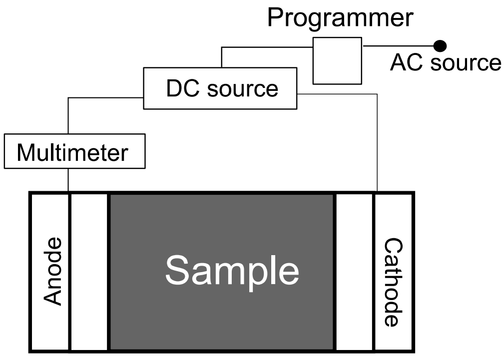

Fig. 1. *Diagram of elektrokinetic setup*

ON/OFF programme during one cycle (1 cycle/h) is given in Table 1. During experiments voltage gradient was 1 V/cm. Duration of experiments was 7 days. At the end of the process, the tailings sample was divided into five parts. Each part was assigned as the normalized distance z/L (z = distance from the anode, L = sediment bed length) from anode: 0.1, 0.3, 0.5, 0.7 and 0.9. The pH and metals pseudo-total concentrations of initial tailings sample and in each of its sections were measured.

Table 1. *Experimental conditions*

Experiment assignation	ON/OFF intervals ratio
E1	-
E2	1/3
E3	1/1
E4	3/1

3. RESULTS AND DISSCUSION

Tailings characteristics are shown in Table 2. Low ANC and CEC indicate that acid front in tailings can be easily formed. Acid front formation enables dissolution and desorption of metals from particles [2]. Tailings can be ascribed as hazardous according to Pb, Ni and Zn based on EPA 2009 [14] and according to Pb based on Waste Classification Guidelines 2009 [15].

Table 2. *Tailings characteristics*

Parameter	Value	Limit value[1]	Limit value[2]
pH	7,80	-	-
ANC (meq/100g)	4,75	-	-
CEC (meq/100g)	0,75	-	-
Pb (mg/kg)	1184	300	400
Ni (mg/kg)	126	60	160
Zn (mg/kg)	1038	200	-

[1]*According to EPA 2009*

[2] *According to Waste Classification Guidelines 2009*

3.1. Changes of tailings pH values after EK treatments

Changes of tailings pH values after EK treatments are shown in Figure 2. The most evident pH value decrease appeared after E4, which is a consequence of H^+ ions diffusion during OFF interval as well as the electromigration of H^+ ions during ON interval. Due to the mentioned processes pH increase in cathode region appeared. Alkaline conditions in the cathode region cause metals precipitation and accumulation [2].

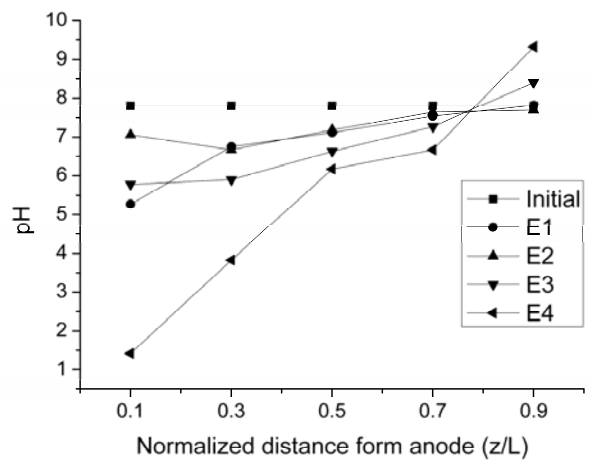

Fig. 2. *Changes of tailings pH after EK treatments*

3.2. Distribution of Pb, Zn and Ni in tailings after EK treatments

Overall metals removal efficiencies after EK treatments are given in Table 3. No Zn was removed from tailings while Ni was removed in high percentage. Pb removal from tailings was highly influenced by pulse technique. During E2 Pb was insignificantly removed while 96% of Ni was removed. With ON interval duration increase, Pb removal efficiency increased while Ni removal efficiency showed downtrend. This is a consequence of transport number changes which indicates a metal ion contribution to the conductivity. Although Pb has high ion mobility, Ni mainly subject to electromigration. This is a consequence of the form in which Ni appeared in tailings. Only mobile, available forms of metals can migrate into electric field. Removal efficiency increasing of Pb from E2 to E4 experiment is the result of: a) Pb ions diffusion during OFF interval, b) acid front propagation through the system which caused the dissolution and desorption of metal ions, and c) optimum ON interval duration for electromigration [10]. So, using the pulse technique, higher efficiency is achieved than conventional techniques, and the electric power consumption is reduced at the same time. Zn was not removed due to the combined impact of high concentrations of Ni, which was available for migration and large Pb ion mobility with respect to the transport number.

Table 3. *Overall metals removal efficacies after EK treatments*

Experiment assignation	Pb (%)	Zn (%)	Ni (%)
E1	27	2.5	92
E2	0.7	0	96
E3	8.9	0	93
E4	30	0	89

Distribution of Pb, Zn and Ni in tailings, after treatment at different normalized distances, is shown in Figure 3. Ni is equally distributed among the tailings. Since pH value is low at z/L=0.1 and 0.3 (Figure 2), higher Pb removal efficiency was expected. Pb behaviour can be explained by diffusion of Pb ions during OFF intervals. Removal efficiency from cathode region is a consequence of pH value increase (Figure 2) which caused an accumulation.

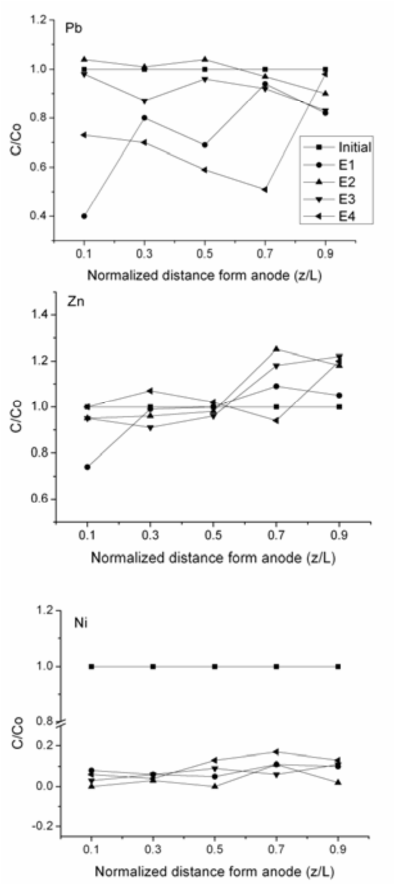

Fig. 3 *Distribution of Pb, Zn and Ni in tailings after EK treatments*

4. CONCLUSIONS

In this work, we investigated the possibility of using the pulse electrokinetic technique for removal of Pb, Zn and Ni from tailings. The influence of ON and OFF intervals in cycle was investigated. It was noticed that after pulse technique, where ON/OFF intervals ration was 3/1, more Pb was removed than after conventional treatment. So, the pulse technique improves the metals removal efficacy. In our work, only Ni was removed to the limit values.

Although only mobile, available metal fraction are removed after electrokinetic treatment, it can be used for tailings treatment since this metal fraction mainly affect environment.

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PRERADA SEKUNDARNIH SIROVINA NA BAZI PLEMENITIH METALA**

Izvod

Ispitana je mogućnost prevođenja nerastvornih ostataka metala platinske grupe (PGM), dobijenih u procesima reciklaže sekundarnih sirovina, u oblik pogodan za dalji tretman radi dobijanja čistih platinskih metala. Pirometalurškom preradom nerastvornih PGM ostataka različitog porekla, pripremane su bakarne anode sa sadržajem plemenitih metala do 2 mass % koje su zatim elektrolitički rafinisane. Hemijska karakterizacija anoda pokazala je da se sadržaj PGM kreće u granicama od 1.11 do 1.24 mass %. Rafinacija anoda rađena je u bakarnom sumporno kiselom rastvoru čiji hemijski sastav odgovara uslovima standardne elektrolize bakra, sadržaj Cu u elektrolitu: 35 - 45 g/dm^3*, koncentracija* H_2SO_4 *u opsegu od 160 do 180 g/dm*^{3}*, na postrojenju poluindustrijskih razmera koje je projektovano na osnovu zahteva tržišta za preradu cca 360 kg anodnog bakra/anodnoj operaciji. Raspored elektrolitičkih ćelija, šinski razvod kao i cevni razvod za anodni mulj, omogućavaju da svaka ćelija može da radi pojedinačno. Na osnovu hemijske analize i mase anodnog mulja utvrđeno je da je u anodni mulj prešlo 99 mass % PGM metala pri čemu je sadržaj Pt+Pd+Rh bio 21.24 mass %. Na osnovu sitovne analize utvrđeno je da je u anodnom mulju 80 % čestica sitnijih od 20 µm. Daljim tretmanom anodnog mulja primenom standardnih hemijskih procesa, moguće je izdvojiti metale PGM grupe u čistom metalnom obliku tako da ova vrsta prerade može da bude ekonomski i ekološki opravdana.*

Ključne reči: *sekundarne sirovine, PGM metali, prerada.*

1. UVOD

Platinsku grupu metala (PGM) čini šest sledećih metala: platina, paladijum, rodijum, iridijum, rutenijum i osmijum. Proizvodnja PGM u svetu naglo se povećala tokom 20-og veka što se je odrazilo na povećanje oblasti primene ovih tehnološki važnih metala. Kombinacija osobina: hemijska inertnost, otpornost prema visokim temperaturama kao i katalitička aktivnost omogućava primenu ovih metala kod katalizatora u automobilskoj, hemijskoj i naftnoj industriji. Primenu nalaze i u elektronskoj industriji, u stomatologiji i medicini, juvelirstvu. Komercijalno, iz ove grupe od 6 metala, najveći značaj imaju platina i paladijum (1,2). S obzirom na sve veći značaj ovih metala,

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potrebno je da proizvodi od PGM odgovaraju zahtevima za primenu u određenoj oblasti (3).

Iako se metali ove grupe generalno nalaze zajedno, mineralni depoziti PGM su veoma retki. Platinska grupa metala se u prirodi nalazi najčešće vezana za nikl ili bakar i širok spektar manje rasprostranjenih elemenata kao što su olovo, telur, selen i arsen. Tehnički i komercijalni zahtevi usmereni su na razdvajanje PGM grupe od drugih metala i razdvajanje unutar grupe u cilju dobijanja pojedinačnih metala visoke čistoće, ostvarivanja visokog prinosa i visokog stepena izdvajanja [4,5].

Razvoj industrije u svetu doveo je do povećenja količina sekundarnih sirovina koje se u novije vreme sve više koriste kao polazna sirovina za proizvodnju mnogih metala. Sekundarni materijali uglavnom sadrže visoki procenat metala pa se iz tog razloga velika pažnja poklanja razvoju tehnologija za njihovu preradu, a u cilju izvlačenja metala do proizvoda visoke čistoće. Primena savremenih tehnologija omogućava znatno smanjenje količina otpadnih materijala, smanjenje troškova tretiranja otpadnih voda i gasova, smanjenje potrošnje energije. Rezultati različitih istraživanja kao i tehnologije razvijene na osnovu postignutih rezultata, nalaze praktičnu primenu u procesima reciklaže.

U radu je ispitivan stepen rastvorljivosti bakarnih anoda kod kojih je sadržaj plemenitih metala bio maksimalno 2 mass %, količina i sastav anodnog mulja, kvalitet katodnog taloga. Cilj je da se elektrolitičkom rafinacijom ovih anoda nerastvorni ostaci PGM metala, nastalih u različitim procesima prerade, prevedu u formu pogodnu za dalji tretman. Dobijanjem čistih metala (Pt, Pd i Rh) ovakav način tretiranja nerastvornih ostataka PGM metala postao bi ekoločki opravdan i ekonomski isplatljiv [6].

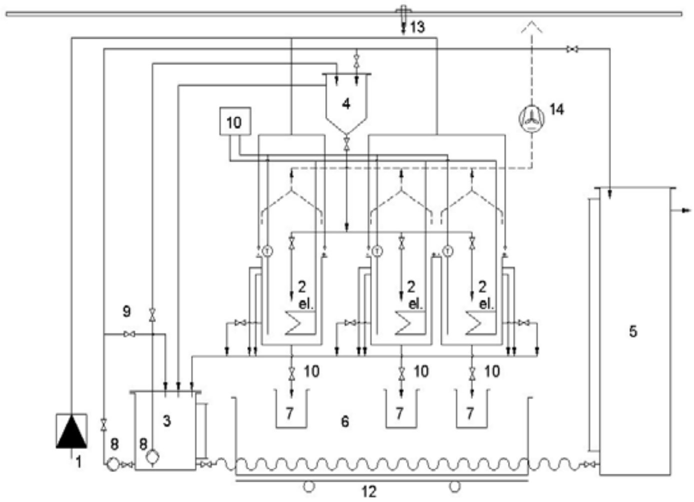
2. EKSPERIMENTALNI DEO

Bakarne anode korišćene za proces elektrolitičke rafinacije u cilju prevođenja platinskih metala u anodni mulj, pripremane su od katodnog bakra i nerastvornih ostataka metala platinske grupe (Pt, Pd, Rh). Odnos masa katodnog bakra i nerastvornih ostataka metala platinske grupe preračunavan je tako da zbirni sadržaj plemenitih metala iznosi do maksimalno 2 mas.%. Pripremljeni rastop je izlivan u odgovarajuće čelične kalupe a anode nakon hlađenja pripremane za proces elektrolize.

Za određivanje sadržaja Pt, Pd, Rh, Sb i Si u anodama i anodnom mulju korišćen je atomski apsorpcioni spektrofotometar, FAAS PERKIN ELMER 403.

Tokom procesa elektrolize merene su vrednosti jačine struje (A), napona na ćeliji (V), i temperature elektrolita (^{o}C). Gustina struje taloženja održavana je u granicama 130-140 mA cm^{-2}. Jednosmerna struja obezbeđena je sa spoljnjeg izvora jednosmerne struje karakteristika I max. 150 A, U max. 10 V. Polazna katoda je od katodnog bakra čistoće 99.95 % Cu. Vreme trajanja anodnog perioda tokom svakog eksperimenta bilo je 648 h i bilo je uslovljeno zahtevom za prevođenje maksimalne moguće količine plemenitih metala u anodni mulj.

Eksperimenti su urađeni na novom poluindustrijskom postrojenju koje je specijalno dizajnirano [7] za potrebe provere rezultata laboratorijskih ispitivanja (Slika 1). Osnovni delovi poluindustrijskog postrojenja su: 1. strujni snabdevač, 2. elektrolitička ćelija, 3. komercijalni rezervoar, 4. napojni rezervoar, 5. skladišni rezervoar za elektrolit, 6. prihvatni rezervoar za elektrolit, 7. posude za prihvat anodnog mulja, 8. pumpa za transport elektrolita, 9. elektrolitni razvod, 10. sistem za merenje i regulaciju temperature elektrolita, 11. muljni razvod, 12. uređaj za podni transport, 13. kran, 14. ventilator. Oprema je izrađena od hemijski otpornih materijala.



Sl. 1. *Tehnološka šema poluindustrijskog postrojenja za elektrolitičku rafinaciju anoda sa povećanim sadržajem plemenitih metala – Linija I*

Elektrohemijska ćelija je pravougaona, od PP materijala, unutrašnjih dimenzija L×W×H: 800×600×380 mm. Radna zapremina elektrolita u jednoj ćeliji iznosi maksimalno 150 dm^3, a ukupna zapremina u sistemu od tri ćelija 600 dm^3.

Hemijski sastav elektrolita (Pt, Pd, Rh) određen je ICP metodom, na simultanom optičkom emisionom spektrometru sa indukovano kuplovanom plazmom, SPECTRO CIROS VISION, sadržaj Cu u elektrolitu određen je elektrogravimetrijskom metodom a sadržaj H_2SO_4 volumetrijskom metodom.

Za određivanje granulomertijskog sastava primenjena je metoda prosejavanja (sitovna analiza) od 200 do 20 µm na siste-mu sita TYLER, DENWER viseći vibro sistem.

3. REZULTATI I DISKUSIJA

3.1. Hemijski sastav anoda

Hemijska analiza pokazala je da je sadržaj Pt+Pd+Rh za sve uzorke bio ispod 2 mass % i to minimalna vrednost je bila 1.11 mass % a maksimalna vrednost 1.24 mass %. Sadržaj Cu predstavljao je razliku do 100 mass %.

3.2. Elektrolitička rafinacija bakarnih anoda sa povećanim sadržajem PGM

I Eksperiment

Za elektrolitičku preradu korišćeno je 6 bakarnih anoda ukupne mase 156 kg (2 ćelije). Proces je trajao 27 dana i to I katodni period: 13 dana a II katodni period: 14 dana. Organizacija elektroda u ćelijama je: katoda – anoda – katoda, tako da su u svaku ćeliju ulagane po 3 anode. Međuelektrodno osno rastojanja iznosilo je 80 mm, cirkulacija elektrolita: jedna izmena zapremine ćelije na 2÷2.5 h.

Jačina struje održavana je u opsegu od 150 do 160 A, temperatura elektrolita u granicama 53-57^{0}C, sadržaj Cu u elektrolitu: 35 - 45 g/dm^3, koncentracija H_2SO_4 u opsegu od 160 do 180 g/dm^3, koloidi: vodeni rastvor tiouree i želatina (4 g želatina + 4 g tiouree u 2 l vode) dodavani su tokom 24 h u sistem.

Tokom procesa meren je napon na svakoj ćeliji pojedinačno. Napon na ćeliji 1 kretao se u granicama: 320 - 360 mV a na ćeliji 2: 325-370 mV.

Dobijeni katodni bakar bio je čistoće 99,99 % Cu a stepen prelaza plemenitih metala u anodni mulj iznosio je 99 mass. %.

II Eksperiment

Eksperiment je urađen na sve tri elektrolitičke ćelije i ostaloj pratećoj opremi od koje se sastoji postrojenje. U ćelije je uloženo po 4 anode i 5 polaznih katoda kako je predviđeno projektnom dokumentacijom. Masa 12 anoda iznosila je 319,7 kg. Kao i kod I eksperimenta, proces je trajao 27 dana i to I katodni period: 13 dana i II katodni period: 14 dana. Vreme trajanja procesa bilo je uslovljeno maksimalno mogućim rastvaranjem anoda u cilju prevođenja što veće količine plemenitih metala u anodni mulj.

Jačina struje održavana je u opsegu od 150 do 160 A, temperatura elektrolita u granicama 53-57^{0}C, sadržaj Cu u elektrolitu: 35 - 45 g/dm^3, koncentracija H_2SO_4 u opsegu od 160 do 180 g/dm^3, koloidi: vodeni rastvor tiouree i želatina (6 g želatina + 6 g tiouree u 2 l vode) dodavani su tokom 24 h u sistem.

Napon na ćeliji 1 kretao se u granicama: 240 - 285 mV, na ćeliji 2: 245-290 mV a na ćeliji 3: 250-290 mV. I kod ovog eksperimenta dobijeni katodni depozit bio je čistoće 99,99 % Cu a raspodela plemenitih metala u anodni mulj iznosila je 99 mass. %.

ZAKLJUČAK

Elektrolitičkim tretmanom bakarnih anoda sa sadržajem PGM do 2 mass % nerastvorni ostaci platinske grupe metala prevedeni su u anodni mulj koji predstavlja sirovinu pogodnu za dalji hemijski tretman radi dobijanja čistih platinskih metala.

Na novom poluindustrijskom postrojenju kod koga svaka ćelija predstavlja posebnu tehnološku celinu, moguće je ispitivanje rastvorljivosti bakarnih anoda različitog hemijskog sastava.

Na osnovu hemijske analize i mase anodnog mulja iz svake ćelije pojedinačno, utvrđeno je da je u anodni mulj prešlo 99 mass % PGM pri čemu je sadržaj Pt+Pd+Rh zbirnog uzorka bio 21.24 mass %. Rezultati sitovne analize anodnog mulja pokazali su da se radi o jako sitnom materijalu pogodnom za dalji tretman primenom standardnih hemijskih procesa tako da je metale PGM grupe moguće izdvojiti u čistom metalnom obliku čime ova vrsta prerade može da bude ekonomski i ekološki opravdana.

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UDK: 546.9:658.567(045)=20

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RECYCLING OF SECONDARY RAW MATERIALS BASED ON PRECIOUS METALS**

Abstract

This work gives the study of possibility the transfer of insoluble residues of platinum group metals (PGM)s, obtained in the process of recycling of secondary raw materials into a form suitable for further treatment to obtain the pure platinum metals. By pyrometallurgical treatment of insoluble PGMs residues of different origin, the copper anodes, containing precious metals to 2 wt.%, were prepared and then electrolytically refined. Chemical characterization of anodes showed that PGMs content ranges from 1.11 to 1.24 wt.%. Anode refining was carried out in copper sulfur acid solution whose chemical composition corresponds to the conditions of standard copper electrolysis, Cu content in electrolyte: 35-45 g/dm^3, H_2SO_4 concentration in the range of 160 to 180 g/dm^3, on the semi industrial scale plant that is designed on the basis on market demands for processing of approximately 360 kg of anode copper/anode operation. Arrangement of electrolytic cells, rail and tube distribution for anode slime allow that each cell can operate individually. Based on chemical analysis and mass of anode mud, it was found that the anode slime shifted 99 wt.%. of PGMs where the content of Pt + Pd + Rh was 21.24 wt.%. Based on the sieve analysis, it was revealed that the anode slime contains 80% of particles finer than 20 µm. By further treatment of anode slime, using the standard chemical processes, it is possible to separate PGMs in pure metal form such as that this type of treatment can be economically and environmentally justified.

***Key words**: secondary raw materials, PGM, treatment*

1. INTRODUCTION

Six metals, platinum, palladium, rhodium, iridium, ruthenium and osmium, forms the platinum-group metals (PGMs). The world-wide production of the PGMs has increased dramatically over the last century and reflected to the increased fields of use these technologically important metals.

Their unique combination of features: the chemical inertness, refractoriness as well as the catalytic activity enables their use as catalysts in the automotive, chemical, and petroleum-refining industries. They are also used in electrical and electronic industry, dentistry and medicine and jewelry. Com-

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mercially, platinum and palladium (1, 2) are the most important from this group of six metals. Regarding to their increasing importance, the high quality products of PGMs is required to meet demands in the certain field of use [3]. Although the metals of this group are generally found together, the mineral deposits of PGMs are very rare. PGMs generally occur in the nature associated usually with nickel or copper and a wide range of minor elements such as lead, tellurium, selenium and arsenic. Technical and commercial requirements are directed to the separation of PGMs from other metals and separation of each other inside the group aimed to obtaining the individual high purity metals, achieving high yield and high percentage of recovery [4,5]. Development of industry in the world has led to increase in the amounts of secondary raw materials that are recently increasingly used as the starting raw material for production of many metals. Secondary materials mainly contain high percentage of metals and, due to this reason, a great attention is paid to development of technologies for their treatment in order to recovery metals of high purity. The use of modern technologies significantly reduces the amount of waste material, reducing the costs of waste water and gas treatment and reducing the energy consumption. The results of various investigations, as well as developed technology on the basis of realized results, have found practical use in the recycling process.

This paper investigated the degree of solubility of copper anodes in which the precious metal content was up to 2 wt.%, the amount and composition of anode slime, quality of cathode deposits. The aim is to transfer the insoluble of PGMs residues, formed in different treatment processes, into a suitable form for further treatment using the electrolytic refining. Obtaining the pure metals (Pt, Pd and Rh), this type of treatment the insoluble PGMs would become environmentally justified economically cost effective [6].

2. EXPERIMENTAL PART

Copper anodes, used for electrolytic refining process in order to transfer the platinum metals in anode slime, were prepared from cathode copper and insoluble residues of platinum group metals (Pt, Pd, Rh). Mass ratio of cathode copper and insoluble residues of platinum group metals was calculated such that the summary content of precious metals is up to maximum of 2 wt.%. Prepared solution was casted into suitable steel molds, and anodes, after cooling, were prepared for the process of electrolysis.

For determination Pt, Pd, Rh, Cr and Si content in anodes and anode slime, the atomic absorption spectrophotometer Perkin Elmer FAAS 403 was used.

During electrolysis process, the values of current intensity (A), cell voltage (V) and electrolyte temperature (^{o}C) were measured. Deposition current density was maintained within the limits of 130-140 mA cm^{-2}. Direct current was supplied from an external source of DC with characteristics of I max. 150 A, U max. 10 V. Starting cathode was of cathode copper purity 99.95% Cu. Time of anode period during each experiment was 648 h and it was conditioned upon a request to transfer maximum possible quantity of precious metals into anode slime.

Experiments were carried out on a new semi-industrial plant which was specially designed [7] for the needs of checking the results of laboratory tests (Figure 1). Basic parts semi-industrial plant plants are: 1 power supplier, 2 electrolytic cell, 3 commercial tank, 4 supply tank, 5 storage tank for electrolyte, 6 receiving tank for electrolyte, 7 dishes for acceptance the anode slime, 8 pump for transport of electrolyte, 9 electrolyte distribution, 10 system for measuring and regulation of electrolyte temperature, 11 slime distribution, 12 device for floor transport, 13 crane, 14 fan. The equipment is made of chemically resistant materials.

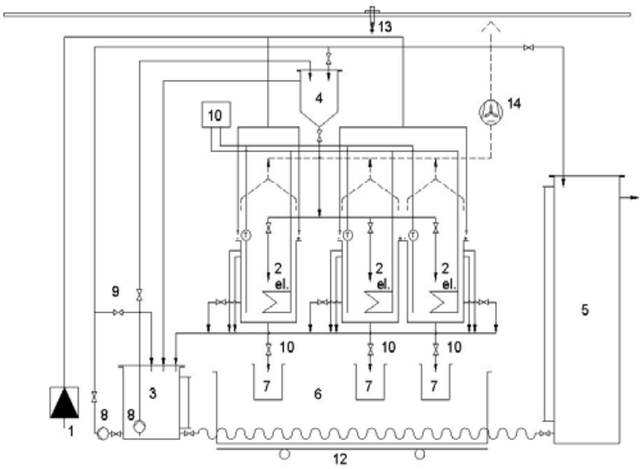

Fig. 1. *Technological scheme of semi-industrial plant for electrolytic refining of anodes with increased content of precious metals – Line 1*

Electrochemical cell is rectangular, made of PP material, with internal sizes L×W×H: 800×600×380 mm. Working volume of electrolyte in one cell is maximum of 150 dm^3 and total volume in the system of three cells is 600 dm^3.

Chemical composition of electrolyte (Pt, Pd, Rh) is determined by the ICP method on simultaneous optical emission spectrometer with induced coupled plasma, SPECTRO CIROS VISION; Cu content in electrolyte is determined by the electrogravimetric method and H_2SO_4 content by the volumetric method.

The sieving method (sieve analysis) of 200 to 20 µm was used for determination the granulometric composition on the system of sieves TYLER, DENWER hanging vibrating system.

3 RESULTS AND DISCUSSION

3.1 Chemical content of anodes

Chemical analysis shown that Pt+Pd+Rh content for all samples was below 2 wt.% and minimum value was 1.11 wt.%, but value was 1.24 wt.%. Cu content was a difference to 100 wt.%.

3.2 Electrolytic refining of copper anodes with increased content of PGMs

I Experiment

Six copper anodes, total weight of 156 kg (2 cells) were used for electrolytic refining. Process lasted 27 days as well as the I cathode period: 13 days, and the II cathode period: 14 days. Organization of electrodes in the cells is: cathode - anode - cathode, so that 3 anodes were inserted into in each cell. Inter-electrode axial distance amounted to 80 mm; electrolyte circulation: one change in cell volume at 2÷2.5 h.

Current intensity was maintained in the range of 150 to 160 A; temperature of electrolyte within the limits 53-57^oC; Cu content in electrolyte: 35-45 g/dm^3; concentration of H_2SO_4 in the range of 160 to 180 g/dm^3 ; colloids: aqueous solution of thiourea and gelatin (4 g gelatin + 4 g of thiourea in 2 l of water) were added for 24 h in the system.

During the process, the voltage was

measured on each cell individually. Voltage on the cell 1 varied within the limits: 320 to 360 mV and on the cell 2: 325-370 mV.

The obtained cathode copper was purity of 99.99%, and a degree of transfer the precious metals into anode slime was 99 wt.%.

II Experiment

The experiment was carried out on all three electrolytic cell and the rest of the supporting equipment that makes up the plant. Four anodes and five starting cathodes were inserted into the cells as provided by the project documentation. Mass of 12 anodes was 319.7 kg. As with the I experiment, the process lasted 27 days as well as the I cathode period: 13 days and the II cathode period: 14 days. The process time was conditioned to maximum possible dissolution of anodes in order to transfer as large as possible quantities of precious metals into anode slime.

Current intensity was maintained in the range of 150 to 160 A; temperature of electrolyte within the limits 53-57°C; Cu content in electrolyte: 35-45 g/dm^3; concentration of H_2SO_4 in the range of 160 to 180 g/dm^3 ; colloids: aqueous solution of thiourea and gelatin (6 g gelatin + 6 g of thiourea in 2 l of water) were added for 24 h in the system.

Voltage on the cell 1 varied within the limits: 240 - 285 mV; on the cell 2: 245-290 mV, and on the cell 3: 250-290 mV. And in this experiment, the obtained cathode deposit has purity of 99.99% Cu, and distribution of precious metals in anode slime was 99 wt. %.

4. CONCLUSIONS

By electrolytic treatment of copper anodes containing PGMs to 2 wt.%, the insoluble residues of platinum group metals were tramsfered into anode slime that is a suitable raw material for further chemical treatment in order to obtain the pure platinum metals.

On a new semi-industrial plant in which each cell presents a separate technological unit, it is possible to investigate the solubility of copper anodes with different chemical composition.

Based on chemical analysis and mass of anode slime from each cell individually, it was found that 99 wt.% PGMs was transferred into anode slime while Pt + Pd + Rh content of aggregate sample mass was 21:24%. The results of sieve analysis of anode slime showed that it is a very fine material suitable for further treatment using standard chemical processes so that PGMs can be extracted in pure metallic form by which this type of treatment can be economically and environmentally justified.

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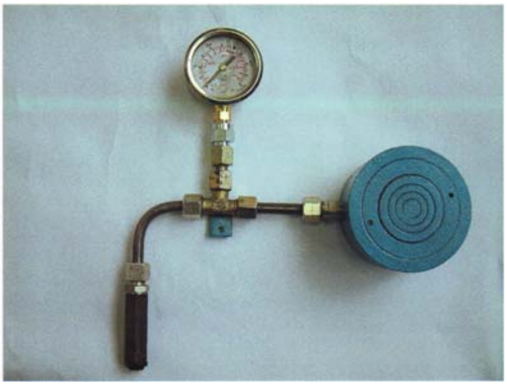

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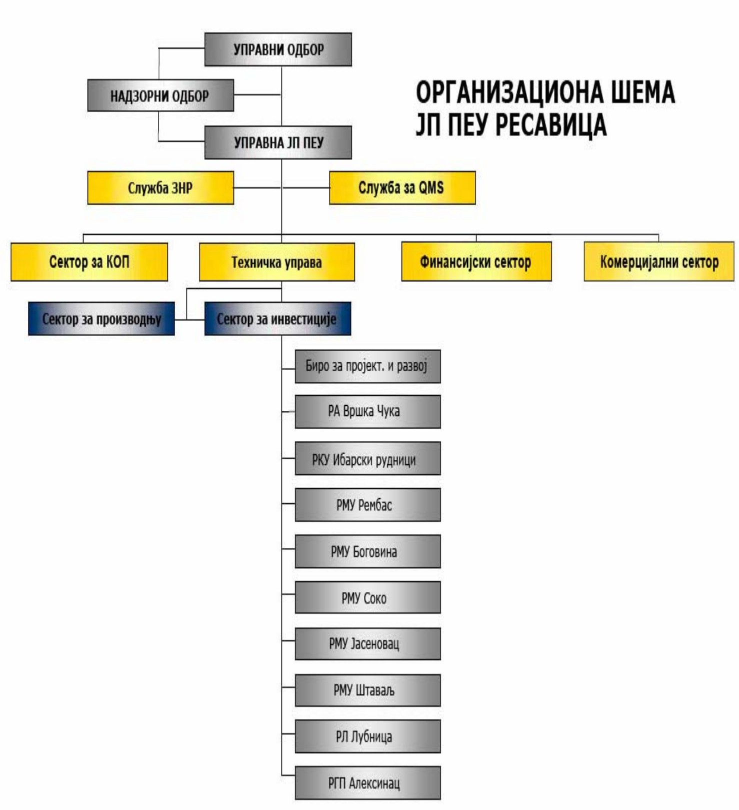

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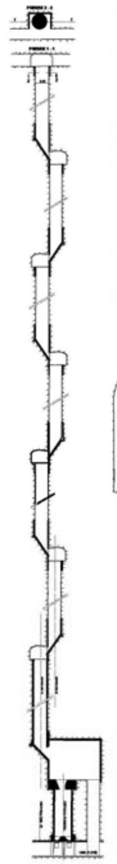

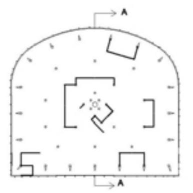

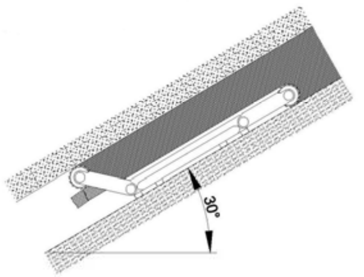

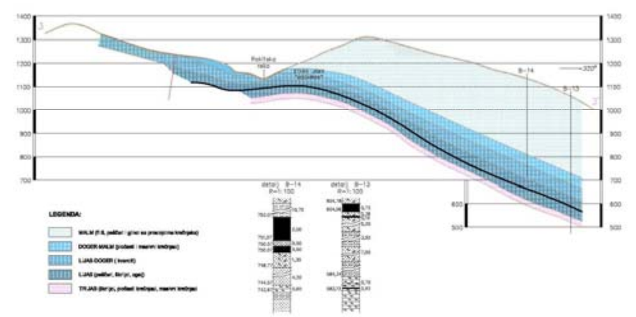

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[1] B.A. Willis, Mineral Procesing Technology, Oxford, Perganom Press, 1979, str. 35. *(za poglavlje u knjizi)*

[2] H. Ernst, *Research Policy*, 30 (2001) 143–157. *(za članak u časopisu)*

[3] www: http://www.vanguard.edu/psychology/apa.pdf *(za web dokument)*

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[1] Willis B. A., Mineral Procesing Technology, Oxford, Pergamon Press, 1979, pg. 35. (for the chapter in a book)

[2] Ernst H., Research Policy, 30 (2001) 143–157. (for the article in a journal)

[3] www: http://www.vanguard.edu/psychology/apa.pdf (for web document)

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Acknowledgement is given where appropriate, at the end of the work and should include the name of institution that funded the given results in the work, with the name and number of project, or if the work is derived from the master theses or doctoral dissertation, it should give the name of thesis / dissertation, place, year and faculty where it was defended. Font size is 10, italic.

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We are thankful for all authors on cooperation