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Original Scientific Paper
Geomechanics

Dušan Tašić[*], *Vanja Đurđevac*[*], *Dragan Ignjatović*[*]

GEOMECHANICAL CHARACTERISTICS OF SMELTING SLAG FROM THE DEPOT IN BOR[**]

Abstract

During the geotechnical research at the RTH flotation tailing dump in Bor, the environment representing the so - called "anthropogenic layers" of smelting slag was singled out in the engineering geological materials of the field. It is a petrified, semi-metallic material, which forms layers in the field or is spread in a loose state. This paper presents the results of geomechanical and chemical tests, as well as the SEM analysis of samples of this material.

Keywords: *smelting slag, geomechanical parameters, rock mass, SEM analysis*

INTRODUCTION

Technogenic copper deposit "Depo sljake 1" - Bor , was created as a "by-product" of one of the phases of the pyro - metallurgical process of copper obtaining. Namely, according to Janković (1960, pp. 331-333), the process of pyrometallurgical processing of sulfide ore and copper concentrate consists of several stages. The first stage is roasting and eventual agglomeration (concentrate). A certain sulfur content is left in the obtained semi-product, which is different, depending on the character of further processing and can vary within wide limits. The second stage is melting, which can be done in a flame or pit (jacket) furnaces. As a result of melting, a copper calcine enriched with copper sulfide is obtained. The content of copper in calcine ranges from 20 to about 80%. Most often, the copper calcine contains 40-50% Cu. Copper calcine has the property of dissolving some precious metals contained in the ore and/or concentrate (gold, silver, platinum group of metals). As the specific mass of copper calcine is significantly higher than the specific mass of slag, their separation during discharge from furnace is facilitated.

SMELTER SLAG

The northwestern edge of the RTH flotation tailing dump in the area of dam 1 rests on the deposited man-made deposits - smelting slag. It is a petrified mass, semi-metallic, of low strength, and occurs in the form of thinner broken layers or in the form of aggregates with fractions the size of coarse gravel.

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Figure 1 *Smelter slag – Core from exploration drill-holes B-5/21 i B-3/21*

In the drill hole B-5/21, a layer of these deposits with a thickness of about 20 m was drilled. It was observed that the core is hollow, pseudo-layered in texture and mostly compact, so this environment can be treated as a rock massif, and the samples taken for geomechanical tests of this environment are treated as the rock material. The following results were obtained:

- bulk weight
  γ = 30.08 (kN/m^3)
- uniaxial compressive strength
  σ_p= 19.8 (MPa)
- elasticity module
  $E_{(50)}$=19450 (MPa)
- Poisson coefficient
  υ= 0.27.

Smelter slag can also occur in the form of loose coarse-grained material (observed in in drillhole B-3/21 and by mapping the field surface. In this case, the cohesion of this material would be 0, and the angle of natural holding of material, determined by earlier tests, would be φ = 32-37°.

The physical and mechanical parameters of this environment, based on the results of sample testing, fund data and direct assessment of the environment state, are:

- bulk weight
  γ = 30 (kN/m^3)
- angle of internal friction
  φ = 34° (for material as rock mass)
  φ = 37° (incoherent material)
- cohesion
  c = 240 (kN/m^2) (for material as rock mass)
  c = 0 (kN/m^2) (incoherent material).

In addition to the physical and mechanical properties of slag, the SEM analysis was also carried out on a sample from depot 1. The results are shown in Figure 2.

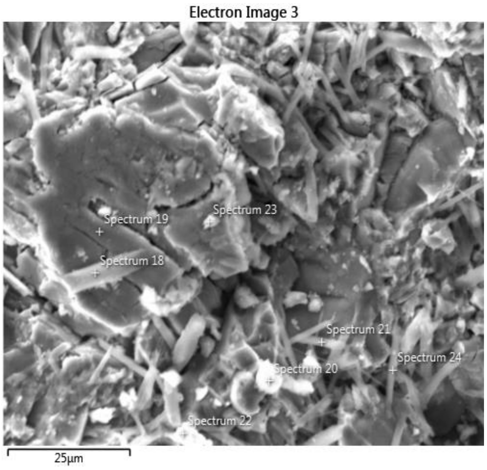

Figure 2 *Analyzed spectra by the SEM-EDS analysis of a slag sample (magnification 1.300×)*

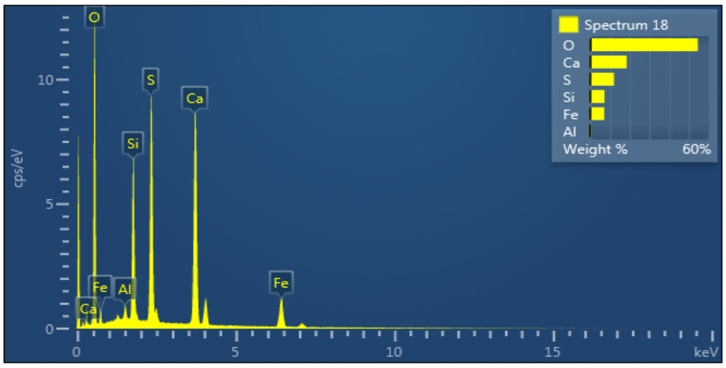

Figure 3 *Results of spectrum analysis for point 18*

Table 3 *Chemical composition of analyzed spectra by the SEM-EDS analysis (sample from Depo 1)*

Spectrum	O	Mg	Al	Si	S	K	Ca	Fe	Cu	Zn	Total %
Spectrum 18	54.48		0.67	7.26	12.03		18.44	7.11			100
Spectrum 19	31.79	0.65	1.59	21.17			17.09	27.71			100
Spectrum 20	39.18			7.39	0.79		2.16	49.32	1.16		100
Spectrum 21	56.90		0.90	9.69	8.03		14.77	9.71			100
Spectrum 22	44.43		2.06	16.28	1.27	0.29	7.71	27.95			100
Spectrum 23	46.63		1.44	14.02	9.24		8.69	14.71		5.27	100
Spectrum 24	49.02		0.42	3.25	16.87		23.26	7.18			100

Test results of the Depo 1 slag sample show the following mineral composition: fayalite, gypsum/anhydrite, pyroxenes, wollastonite, copperite, chalcopyrite, hematite and sphalerite. Fayalite and gypsum/anhydrite are the dominant mineral phases. Pyroxene most likely occurs at the base of sample on which the other mineral phases belong. The results are shown in Figures 2 and 3 and in Table 1.

CONCLUSION

The conducted tests of smelting the slug material yielded the results of geomechanical test of material: bulk density of 30.08 kN/m^3, uniaxial compressive strength of 19.80 MPa, elasticity module 19.45 GPa and Poisson ratio υ = 0.27. Fayalite and gypsum/anhydrite are the dominant mineral phases.

Further laboratory physical-mechanical, chemical and mineralogical tests of this artificial creation will provide more precise parameters needed for its eventual exploitation and possible application in various branches of the economy.

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Original Scientific Paper
Mining

Aleksandar Milijanović, Nikola Stanić*, Saša Stepanović*, Miljan Gomilanović**

COMPARATIVE ANALYSIS OF GEOMECHANICAL VERIFICATION THE SLOPE STABILITY IN THE ZONE OF PREVENTIVE MAINTENANCE HALL OF THE COAL MINE PLJEVLJA**

Abstract

During the geomechanical verification the stability of mining facilities, it is necessary to correctly select the calculated values of the rock material properties from an engineering point of view. In order to complete the previous steps, the starting point is data collection from the open pit. This characterizes the demanding work that is put before the engineers, all with the aim of forming a quality database within which the various characteristics of rock mass, covered by the open pit, are collected and analyzed. Based on this, it is possible to adopt the calculation values of the rock material properties, all with the aim of obtaining the relevant data for the slope stability analysis using different groups of methods. This paper presents a comprehensive analysis of determination the safety factors in a part of the Hall for preventive mechanical and electrical maintenance at the Potrlica open pit. Considering the state of working slope in the position of the Hall for preventive mechanical and electrical maintenance, the system of cracks, as well as the presumed faults that occur in the mentioned zone, it is necessary to include in the analysis different groups of methods for verification the safety factor of analyzed working slope. The application of different analysis methods creates an opportunity for a comparative analysis of the obtained safety factors, which is a direct indicator of the state of analyzed working slope.

Keywords: *geomechanical stability check, Pljevlja coal mine, finite element method, limit equilibrium methods*

1 INTRODUCTION

Bringing the slope to a stability state with an appropriate safety factor is a complex technical-technological and geomechanical undertaking that is put before the engineers. An important aspect in understanding the complexity of mechanical behavior of rocks is knowledge of the influencing factors and processes that lead to the slope instability. For the purposes of defining the value of geomechanical properties, it is necessary to include a number of parameters that directly and indirectly affect the slope condition [1]. On the basis of the performed laboratory and field research, the set of processed and obtained data provides the necessary conditions providing the input parameters for formation the geomechanical model [1].

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Based on the research results, the calculation values of the rock material properties will be selected for geomechanical verification the slope stability [1].

On an example of the open pit Potrlica of the coal mine Pljevlja (Figure 1), specifically for the area in the western part, in the area of the Hall for preventive mechanical and electrical maintenance (Figure 2), both the influence of established geomechanical parameters and tectonics present on that area can be analyzed on the stability of formed slopes. The slope state in the part of the Hall for preventive maintenance is characterized by the crack systems and fault zones, a complex structure of engineering-geological units, and the entire area can be characterized as a complex from a geomechanical point of view. Due to the occurrence of cracks, which indicate the existence of processes that lead to the slope instability, it is necessary to perform a geomechanical stability verification on the basis of which the state of analyzed slope will be monitored.

Figure 1 *Open pit Potrlica of the coal mine Pljevlja (October 2022)*

Figure 2 *Slope of the system of open pit working levels in the area of the Hall for preventive maintenance*

2 GEOMECHANICAL CONDITIONS IN THE HALL ZONE

Defining the geomechanical conditions of the slope in the zone of the Hall for preventive maintenance is a key factor in preparing the stability analysis calculation. Defining the influencing factors on the analyzed slope, all the necessary conditions for defining data are acquired related to:

- Geology of the narrower area, characterized by a contact of marl and clay, clay and coal, marl and coal, marl and limestone and coal and limestone. In addition, there are also different types of marl, limestone and clay where the deposit conditions have changed and where the structure has been disturbed in relation to the condition that existed during the formation of deposit itself. Although the area in question was explored with a fairly dense network of drillholes that were made in order to define the structural structure of the deposit layers and geomechanical characteristics, due to its complexity, it cannot be studied at a sufficient level because it implies an irrationally dense network of exploratory drillholes and a large volume of field and laboratory testing and research. The initial assumption is that the weakened contact zones between different engineering-geological structures can be represented by the presence of those materials that show the lowest values of strength parameters.
- Tectonics, characterized by the presence of crack systems. Tectonic processes in the deposit after its creation led to the destruction of original structure. During exploitation, by unloading and creating the free surfaces in places that are predisposed to the tectonic processes, the open cracks appeared and phenomena that indicate processes that lead to the instability of formed individual working slopes and systems of working slopes. Prospecting, exploration works and geological mapping determined the primary directions and inclinations of cracks and fault zones.
- Engineering geological environments are characterized by the presence of a large number of geological and engineering - geological structures (units). The geomechanical characteristics of these units were determined in different periods of exploration and exploitation of the deposit, and the determined values of the geomechanical parameters are mostly the result of laboratory tests and are in a wide range. The engineering-geological characteristics of the environment of the rock masses of the Potrlica deposit are of the primary importance within the framework of the analysis that will be carried out. [2] As such, the following engineering-geological units were exposed in the open pit area: quaternary, marl, interlayered clays, coal, podine clays and limestone.
- Geomechanical parameters of the working environment are characterized by the values that move within wide limits, irregularly spatially distributed sampling points on the surface and depth of the deposit, and insufficient reliability for this phase of the open pit mining.

- Adopted values for the calculation. On the basis of an insight into the available documentation of the Coal Mine Pljevlja and presented data, obtained by the exploration works and certain laboratory test, the values on the basis of which the statistical processing of data was performed were taken. The statistical processing of data on the available set of values determined the relevant parameter values, which were adopted for the geomechanical stability check on the basis of reliability.

3 GEOMECHANICAL VERIFICATION OF THE SLOPE STABILITY IN THE ZONE OF THE HALL FOR PREVENTIVE MAINTENANCE

The analysis of safety factor calculations was performed on 8 characteristic profiles (Figure 3). The emphasis of the F_s value verification was only in the area of the Hall for preventive maintenance. The reason for the geomechanical stability verification in the mentioned zone is the appearance of cracks on the ground surface, foundations of the Hall and on the open level profiles. The presence of cracks indicates processes that can lead to the instability of the mentioned part of slope.

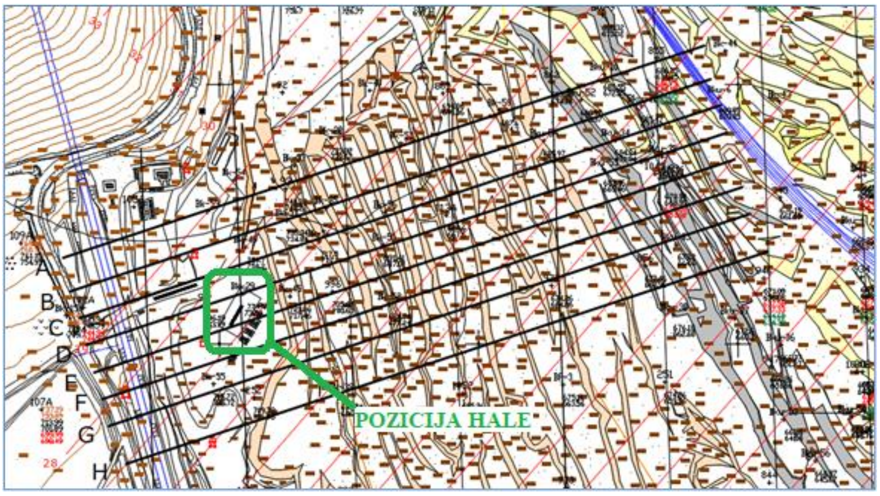


Figure 3 *Position of the cross section for verification the slope safety factor in the Hall area*

Positioning of the cross-sections was done so that, to the greatest extent possible, they were perpendicular to the direction of the system of working levelz, to include the completed works on the coal exploitation in the foothill and position of the regulated bed of the Ćehotina river.

The initial analyzes of the working slope stability in a part of the Hall were carried out using the limit equilibrium methods, based on the use of lamellas, for circular failure and predisposed (plane) failure of the slope. For the needs of more precise results in the disturbed zone of the rock mass such as in the Pljevlja basin, the application of the finite element method (FEM) will present an approach to the analysis of the working slope stability that is more appropriate to the nature of the prevailing rock mass, marl.

The finite element method represents a group of methods from the set of numerical modeling. The advantages of the FEM application are primarily in accuracy, versatility and requiring much smaller prior assumptions, especially regarding the fracture mechanism that can occur. The challenge for engineers is the system complexity in a part of the working slope near Hall, and based on the complexity of the state, the rock massif represents a type of problem that should ideally be studied using the finite element method.

On the basis of such study, the conditions were created to break the current balance applying the FEM to the moment for monitoring the development of fracture, including the fracture itself caused by shearing. The factor of safety in the FEM slope stability analysis is determined from the ratio of shear strength of material and shear strength required to achieve the equilibrium. The presented F_s is characterized in exactly the same way as with the traditional methods of limit equilibrium, and the obtained safety factor can still be defined as the ratio of maximum and realized moments. The basic methodology for determining the FEM safety factor implies the application of the shear strength reduction technique. The failure criterion is the Mohr-Coulomb.

The application of the Shear Strength Reduction (SSR) technique in the slope stability analysis using the finite element method is a simple way to systematically study and determine the Strength Reduction Factor (SRF) or the value of safety factor (F_s) by which the slope leads to the limit state of failure [3].

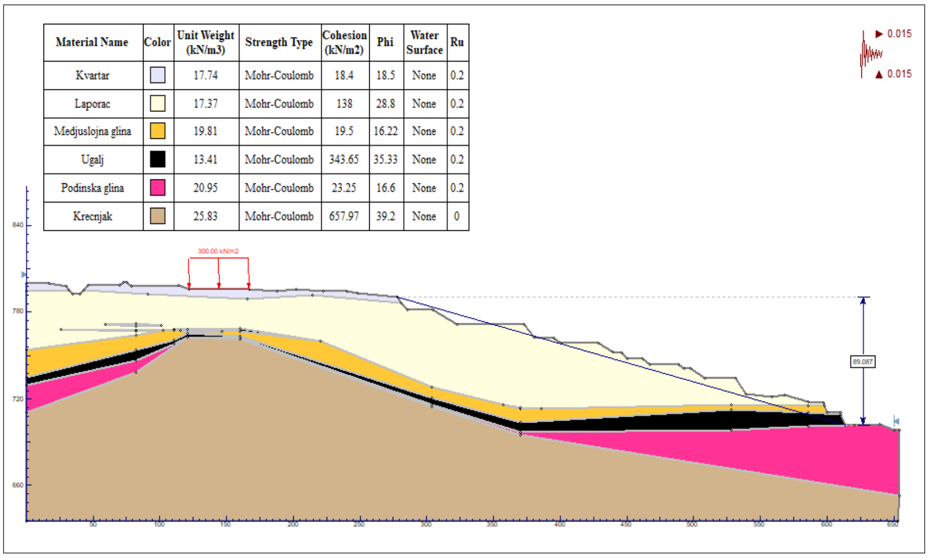
The physical problem of the slope model is numerically modeled in such a way that the entire analyzed area is divided into elements. The suitability of application the finite element method is reflected in its adaptability to solve the problem of geomechanical stability in conditions of pronounced tectonics and non-linear material properties such as occur in the Pljevlja basin.

Calculation of the safety factor on the formed geomechanical models of slopes on the characteristic cross sections and for the adopted parameters of the working environment was carried out using the software packages "Slide" and "Phase2" from the company Rocscience Inc.

The Rocscience Inc. "Slide" is an in-plane slope stability analysis software. It can be used for the design or analysis of natural and artificially formed slopes (slopes of embankments, levels of open pits, dumps and landfills, slopes of ditches and embankments and free or additionally stabilized walls). The program enables analyzing the stability by self-generated or user-defined sliding surfaces. Sliding surfaces can be circular, flat or a combination of these surfaces. The Slide program package within its graphic editor enables modeling of the tested objects as well as different ways of displaying the calculation results and interpretation of individual calculation elements [4].

The Slide program package also enables the positioning of an arbitrary or determining the position of sliding surface with the minimum value of safety factor. The Rocscience Inc "Phase2" is a software adapted to verify the behavior of elasto-plastic media based on their stress state using the finite element method. It is used both for the analysis of voltage conditions of the working environment in the existence conditions of the underground exploitation facilities as well as open pits. It serves to solve a number of engineering problems, such as the construction of stable slopes at the open pits, stable underground exploitation rooms, in construction for foundations and construction the retaining walls and other ways of stabilizing the base and slopes, etc. [5]. One of the advantages of this software is a relatively simple user interface and numerous ways of visualizing the results, which enables their easier interpretation.

Geomechanical verification the slope stability of the system of working levels was performed for all 8 shown profiles, and in this work, Figure 4, Figure 5, Figure 6, Figure 7 and Figure 8 show a characteristic view of calculations on profile D. All calculations were done for circular, predisposed sliding planes and planes under the maximum shear stress. The adopted coefficient of seismicity in both horizontal and vertical directions is 0.015.



Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kN/m2)	Phi	Water Surface	Ru
Kvartar		17.74	Mohr-Coulomb	18.4	18.5	None	0.2
Laporac		17.37	Mohr-Coulomb	138	28.8	None	0.2
Medjuslojna glina		19.81	Mohr-Coulomb	19.5	16.22	None	0.2
Ugalj		13.41	Mohr-Coulomb	343.65	35.33	None	0.2
Podinska glina		20.95	Mohr-Coulomb	23.25	16.6	None	0.2
Krecnjak		25.83	Mohr-Coulomb	657.97	39.2	None	0

Figure 4 *Geomechanical model of the existing slope on the cross section D-D*

The geomechanical model of the slope was defined on the basis of data from exploration works and laboratory tests on a profile and parameters determined by the valid study [6], [7], [8]. The load of Hall was taken with a value of 300 kN/m^2 and many times exceeds the real load of the Hall. It follows that the impact of the Hall loading is taken with a significant safety margin. The stability analysis of the system of working slopes in the Hall area was carried out using the method of A. W. Bishop and Yanbu, which belong to the group of limit equilibrium calculation methods. For these needs, the program package "Slide" version 6.0 of Rocscience Inc. was used. The aforementioned program package is the property of the Mining and Metallurgy Institute Bor.

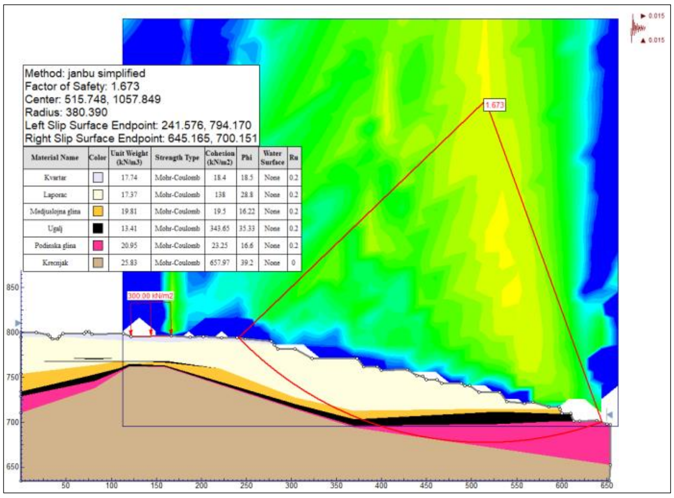


Figure 5 *Minimum safety factor and critical sliding plane for the Mohr-Coulomb failure criterion and limit equilibrium methods for circular sliding plane according to the Yanbu method*

The formed slope model is mainly built by the engineering-geological units of quaternary, marl, clay, coal, interlayered clay and limestone. In order for the stability analysis to include the slope as a whole, it is necessary to position the center of sliding circles, which provides all the prerequisites for interpretation the sliding circles and verification the safety factor of the analyzed slope.

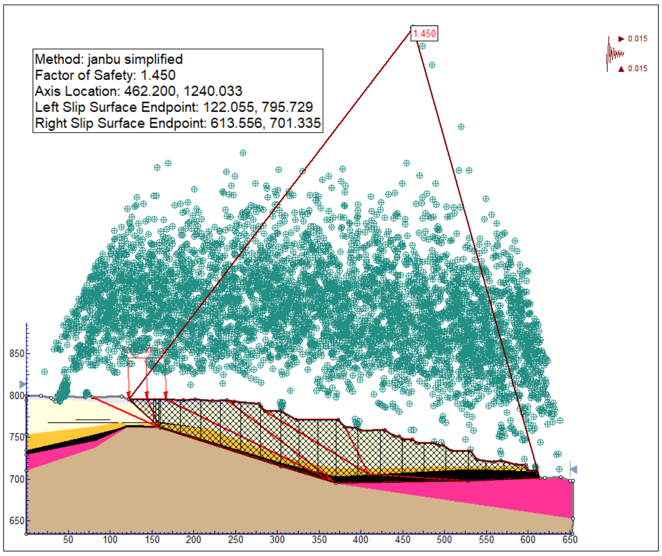


Figure 6 *Minimum safety factor and critical sliding plane for the Mohr-Coulomb failure criterion and limit equilibrium methods for the predisposed sliding plane according to the Yanbu method*

In addition to the limit equilibrium method, the analysis of stability in the Hall zone was also carried out by the FEM. For the purposes of calculating F_s according to this method, the software package "Phase2" from Rocscience Inc. was used. The aforementioned program package is the property of the Mining and Metallurgy Institute Bor.

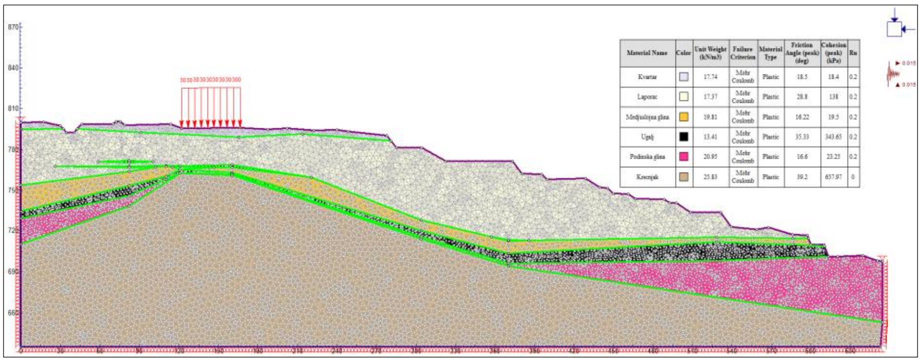


Figure 7 *Geomechanical model of the existing slope on the D-D cross section for calculation using the finite element method*

The boundary conditions of the model according to the FEM should emphasize that the medium is incompressible in the boundary zones of the model. Model boundaries can be defined by different axis constraints. By limiting the model with an engineering approach, the surface is divided into a certain number of elements. Size of an element, i.e., the number of nodes, should be adapted to the smallest dimensions of the engineering-geological environments represented in the model. Interpretation of the FEM calculations can be given in several ways, the most commonly used being the display of horizontal displacements and maximum shear stresses.

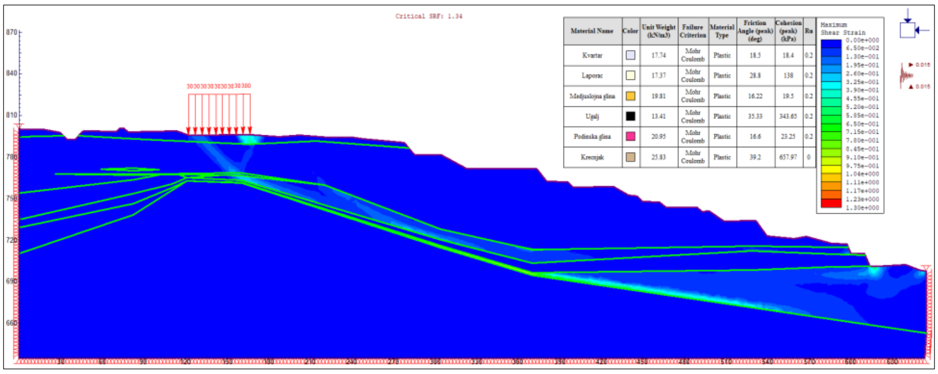


Figure 8 *Minimum factor of safety and critical sliding plane for the Mohr-Coulomb failure criterion and finite element methods*

The analyzed condition of the slope and obtained safety factors using different groups of methods indicate that the slope can be characterized as stable. The reason for geomechanical stability verification using different groups of methods is reflected primarily from the engineering point of view and initial assumptions by visual observation the working slope. The slope stability analysis was performed for different forms of sliding surfaces, which took into account all the possibilities of forming sliding surfaces at the contact of engineering-geological units.

The geomechanical stability verification using the circular shape of sliding surface indicates that the obtained sliding circles do not pass on the contact parts of the engineering-geological environments, characterized as the critical places, and therefore the obtained values of safety factors are slightly higher. For the slope stability analysis for a flat fracture of the sliding surface, the obtained safety factors indicate that the engineering assumptions at the contact of different engineering-geological environments were taken with reliable foundations. The care should be taken here since it cannot be claimed with certainty, based on the engineering assumptions that the critical surfaces were correctly defined. Predisposed sliding planes are constructed so that they include both the entire slope and partial parts of the slope, as well as passing through materials with the lowest strength parameters, where the obtained safety factors for the sliding planes show regularity in the spatial arrangement, and the minimum value is not at the border of that space. For the purposes of this analysis, the given fracture plane on the critical surfaces and obtained safety factors indicate that there is a greater possibility of occurrence the slope sliding at the contact between the layers.

With the complex structure of the rock mass as it was created in the Pljevlja basin, the author's engineering approach has emphasized the geomechanical stability verification according to the FEM due to the possibility of analyzing the parts that have been disturbed by force. Based on such impacts, the rock material has been disturbed, where the disturbed rock material can be characterized as crushed. As a result, cracks and microcracks appeared at the contact of such structured material, and in some areas real faults, lenticular clay and other structural changes occurred. Such a description of the state of the rock massif indicates that the original formations suffered severe tectonic changes, which led to various deformations under the impact of all-round pressures. This is how the formations of artificial contacts between marl and limestone were created, on the basis of which the state of the slope was best analyzed by the FEM.

Applying of this method, according to the general structure of material, the software itself can determine the weakest places within the model (profile), i.e., within the massif itself, and based on that to predict where it can, i.e., where it is expected to break, based on the stress state and characteristics, that is the resistance parameters of the material. After the completed analysis using the FEM, the initial assumptions of engineers have turned out to be good, where the obtained safety factors for the analyzed part of slope are significantly lower than during the analysis using the methods from the limit equilibrium groups. The results of the obtained safety factors of all 8 characteristic cross sections for different shapes of sliding surfaces and analysis by different methods are given in Table 1.

Table 1 *Results of geomechanical stability check using different groups of methods*

Shape of sliding surface	Circular		Predisposed plane		By maximum shear stresses
Method	Bishop	Janbu	Bishop	Janbu	FEM
Cross section A-A	1.637	1.592	1.333	1.29	1.33
Cross section B-B	1.835	1.792	1.504	1.464	1.24
Cross section C-C	2.147	2.022	1.841	1.829	1.26
Cross section D-D	1.747	1.673	1.494	1.45	1.34
Cross section E-E	1.799	1.752	1.553	1.507	1.28
Cross section F-F	1.637	1.592	1.396	1.357	1.23
Cross section G-G	1.835	1.792	1.504	1.464	1.39
Cross section H-H	2.046	1.979	1.557	1.513	1.47

Based on the presented results of stability calculations using the group of limit equilibrium methods and finite element method, the obtained safety factors for analysis the system of working slopes in the Hall area were calculated for the case of maximum expected seismic activity. The stated values of the safety factor indicate that in the event of occurrence the seismic tremors and tremors from blasting, the stability of working slope is not threatened on the basis of the analyzed model.

According to the results for the analyzed slope condition, under the influence of seismic coefficient (ks = 0.015), the safety factor meets the stability criterion, $F_s \geq 1.15$. Based on the previous analysis, it can be concluded that the system of working levels in the area of the Hall for preventive mechanical and electrical maintenance, according to the analyzed models, is stable with a safety factor that is above the minimum prescribed by the Rulebook. The appearance of the comparative safety factor curves is shown in Figure 9.

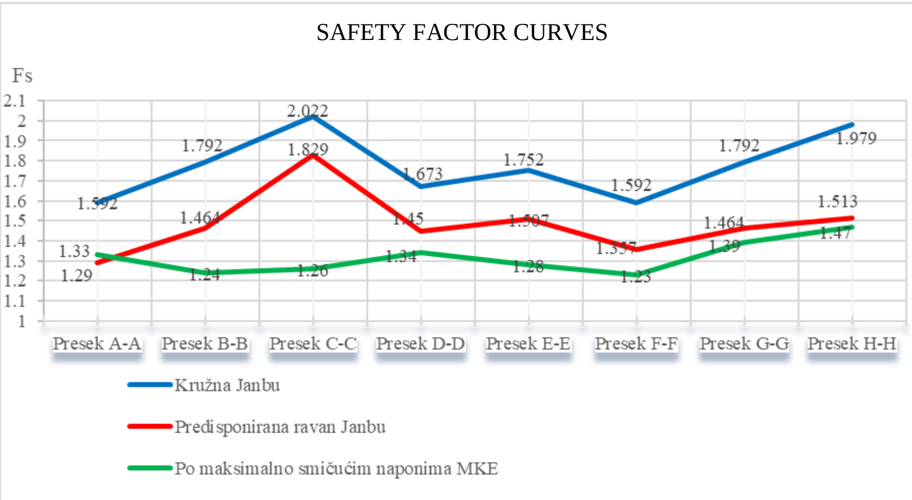


Figure 9 *F_s curve using different methods for geomechanical stability verification*

Based on the interpreted safety factor curves for the analyzed sections, a comparison of the obtained F_s can be performed using different groups of methods. From Figure 9, as a final engineering consideration the advantages of applying the finite element method for the analysis of geomechanical stability verification, it is reflected in the fact that during calculation the finite element method, the software analyzes the maximum shear stresses at the critical contact of engineering geological environments. The obtained safety factors can be taken as the values with greater reliability, which puts the engineering conclusions of the safety side at a higher level.

4 CONCLUDING CONSIDERATIONS

State of the system of working slopes in the area of the Hall for preventive mechanical and electrical maintenance is a consequence of the need for a geomechanical check the stability of slopes due to the appearance of crack systems and assumed fault zones. Complexity of this analysis is reflected in the changed environments in terms of lithology, position of the Hall, as well as appearance of cracks in the zone of the Hall foundation. Through a detailed analysis of application different groups of methods, the safety factor values were obtained, which indicate that the analyzed condition of slope is stable. At the same time, from the group of numerical modeling methods, application of the finite element method (FEM) is an advantage compared to the traditional limit equilibrium methods because during the analysis it is not necessary to make any assumptions in advance regarding the shape and position of the sliding surface, lamellar lateral forces and their directions.

Applying the FEM, the state of stress, deformation and corresponding shear strength in the rock material can be calculated very precisely. Development of the fracture mechanism itself can be very general and does not have to be a simple circular or logarithmic curve. The finite element method can also be applied to the fractures that occur as a result of spalling, rock material that behaves as brittle materials, rock material with variable parameters, which is also the case for analysis the system of working slopes at the open pit "Potrlica" - Pljevlja.

In the further development of works at the open pit "Potrlica" in the analyzed area, it is necessary to relieve the slope and thereby increase safety in the Hall area. The relief of slope can be done increasing the number of levels and reducing the height in the analyzed zone, and in this way all relevant parameters will be satisfied on the basis of which the condition of slope stability will be fulfilled. The reason for this is the multitude of crack systems that are a direct consequence of post-struggle tectonics. In order for the slope to be considered stable, it is necessary to verify the stability by at least 2 methods, where after the analysis, it is necessary that the obtained safety factors meet the minimum values prescribed by the regulations.

Through the control check, it can be concluded that a better knowledge of the working environment is needed, on the basis of which the calculated safety factors will be obtained with a greater reliability. Due to this reason, it is necessary to carry out the regular checks with visual observations of the slope and periodic calculation of safety factors, which will have as an indicator that the condition of analyzed working slope is stable and meets the values of minimum safety factors prescribed by the Rulebook.

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Original Scientific Paper
Geomechanics

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STOPE STABILITY ANALYSIS IN ROOM-AND-PILLAR MINING METHOD USING CEMENTED PASTE BACKFILL***

Abstract

Significant economic and environmental advantages can be expected using cemented paste, especially in mining as a backfill for room-and-pillar excavated method. But, it is necessary to investigate the behaviour of cemented paste backfill within mine stope. In this paper will be presented results of stress-strain analysis of stope stability in room-and-pillar excavation method, before and after backfilling with cemented paste on a model developed in a plane (2D) with corresponding boundary conditions. This model was developed in order to analyze stress-strain stability of the room-and-pillar system in excavating block with included loading and drilling corridors. Model was analyzed before and after backfilling. This excavation method will be applied in "Borska Reka" mine, Bor, Serbia.
Keywords: *cemented paste, backfill, room-and-pillar method, stope stability analysis*

INTRODUCTION

Development and application of filling for underground facillities has undergone its development over past three decades in the world. The mining industry was particularly interested in this technology due to a reduction of costs associated with the filling of large underground facilities. In addition to the basic application, filling, construction of pillars and so on, one more important aspect should be taken into consideration, which is the storage of large quantities of tailings underground (up to 60%). This is especially important for the preservation of the environment, especially if the tailings are chemically aggressive (acidic, basic). Back-fill consists of a dehydrated flotation tailing and up to 7% of a binder, such as Portland cement, fly ash, high-pressure furnace slag or a combination of these binders [1], [2], [3].

Canadian scientists Mostafa Benzaazou and Tikou Belem have made a special contribution to the study of the characteristics of various types of filling, obtained by combinations of flotation tailings and binders. In their work *Mechanical behavior of cemented paste backfill* [23], these scientists described the mechanical properties of the backfill obtained from two different types of flotation tailings from polymetallic ores, with increased sulfur content in them. Physico-mechanical properties (specific mass, granulometric composition, uniaxial compressive strength and triaxial testing) were examined on nine different recipes (combination flotation tailing + binder + water) [23], [13].

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Similar researches have been carried out all over the world. Researches are based on the study of various pasta recipes, with different materials, such as: alkali-activated blast furnace slag [4], sulphide-rich mill tailings [10], maple-wood [15], super-fine unclassified tailing [21]. Tests that were carried out on so-obtained pastas are: determination of physical [9], [19], mechanical [14], [17], [21], and rheological properties [8]. Analysis of these properties was performed on 2D and 3D mathematical models [16], [5].

Many of mentioned tests were carried out in Laboratories of Mining and Metallurgy Institute Bor, in purpose to determine the best recipe for cement paste backfill, which will be used in a sublevel stopping method in ore body Borska reka. After determination of the recipe, five models were created for analyzing the stability of underground facilities. Only two of them will be present in this paper, as characteristic models for analyzing stress state in the corridors, before and after they have been filled with cement paste backfill.

It is also very important to monitor the behavior of the surrounding rocks during and after the excavation has been completed [24].

PHYSICAL-MECHANICAL CHARACTERISTICS OF ADDOPTED CPB

Underground cemented paste backfill (CPB) is an important component of underground stope extraction. As mining operations progress, paste backfill is placed into previously mined stopes to provide a stable platform for miners to work on and ground support for the walls of the adjacent adits by reducing the amount of open space that could potentially be filled by a collapse of the surrounding pillars.

CPB, presented in this paper, is a result of tests, which were carried out in the laboratories of Mining and Metallurgy Institute Bor. Basic material for CPB was flotation tailings, together with cement and water. Researches showed that the best results were achieved with CPB which consists of 5% cement, 24% water and 71% noncycloned flotation tailings. In terms of consistency, this CPB belongs to a group of materials with liquid consistency. The binding time is longer than 12 hours. From graph, Fig. 1, it can be seen that the basic condition for uniaxial compressive strength (UCS) of 1.0-1.5 MPa, after 28 days, is fulfilled. Beside the proper physical and mechanical characteristics, this backfill also meets the economic parameters [12], [18].

VERIFICATION OF ADOPTED RECIPES IN THE MODEL

Stability analysis of the isolated stope (chamber – drilling corridor - filling of the excavation with backfill)

In order to analyze the stability of the main corridor, whose dimensions are 4.5 x 4.0 m, a model was constructed in which was analyzed stress-strain state of rock massif around it, as shown in Fig. 1.

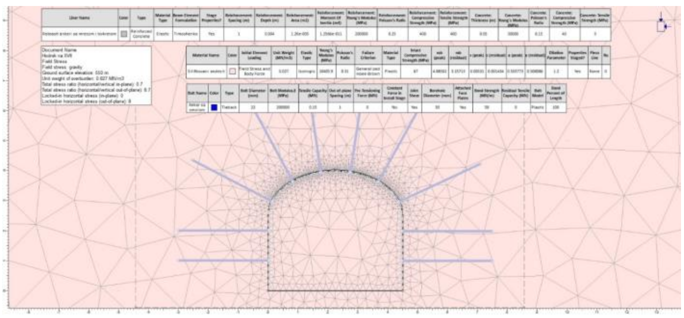

Figure 1 *Construction of the Model for stability analysis of the main corridor*

In such working environments, when plastic deformation of the rock massif is occurring in the excavation environment, only anchoring should not have a major impact on the strength factor and the plasticity zone. However, anchoring, in combination with mesh and sprayed concrete, significantly reduces the number of broken finite elements that will be shown in further analysis.

The excavation chamber, which will be dug up with parallel or fan boreholes, is divided in five segments. Each segment is 4m long, since the height of the transverse corridors is 4 m. The model itself is shown in Fig. 2.

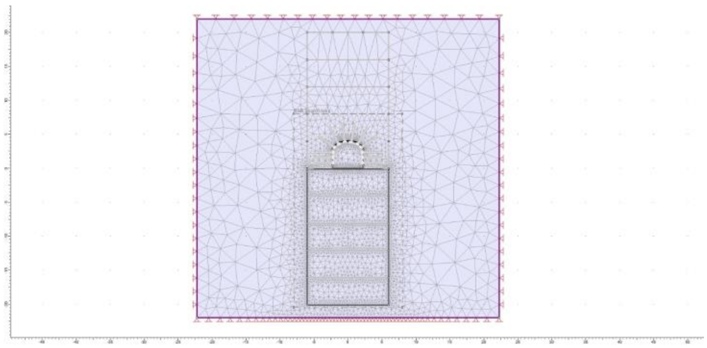

Figure 2 *Model of excavation developing of the chamber – drilling corridor*

The purpose of this model is to analyze the stability of the system drilling corridor - open chamber. It is necessary to be seen what kind of stress appears and whether such a system can be statically balanced and under what conditions.

This is very important because in the next stage, when the works are raised for one floor, the drill corridor will have the function of the loading corridor, which means that the stability of this corridor must be preserved until the moment of closing the chamber and the time required to achieve the full carrying capacity of the paste backfill.

In order to determine how the corridor with an anchor, mesh and sprayed concrete is behaving in such situation, the stress-deformation analysis and the results are presented in Fig.s 3, 4, 5 and 6.

With mounting of anchors through the contour of the corridor, the following values of stress on the anchor and displacements along the depth of the massif were obtained.

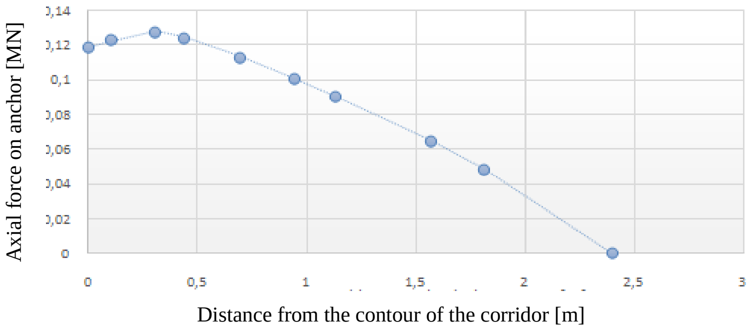

Figure 3 *Graph of changes of axial load on the built-in anchor in the rock massif by the contour of the corridor in the zone of elastic deformations*

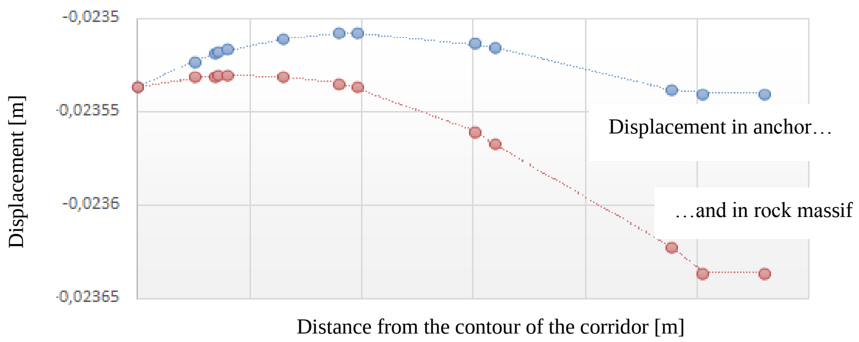

Figure 4 *Graph of displacement in anchor and rock massif by the contour of the corridor in the zone of elastic deformations*

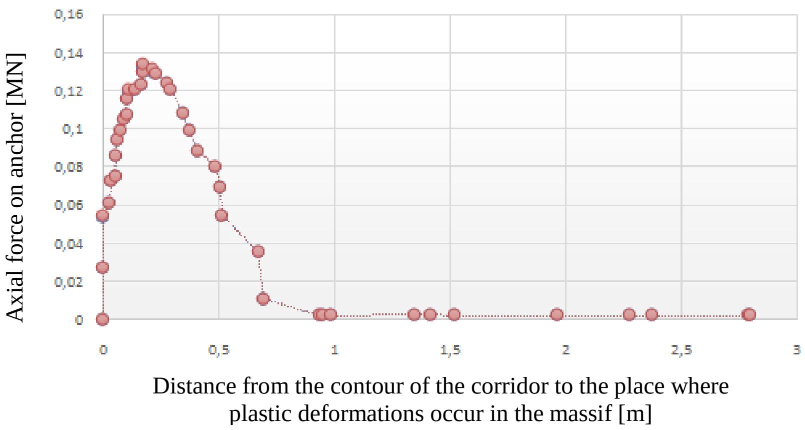

Figure 5 *Graph of changes in axial load in the anchor when plastic deformations occur in the massif through contour of the corridor*

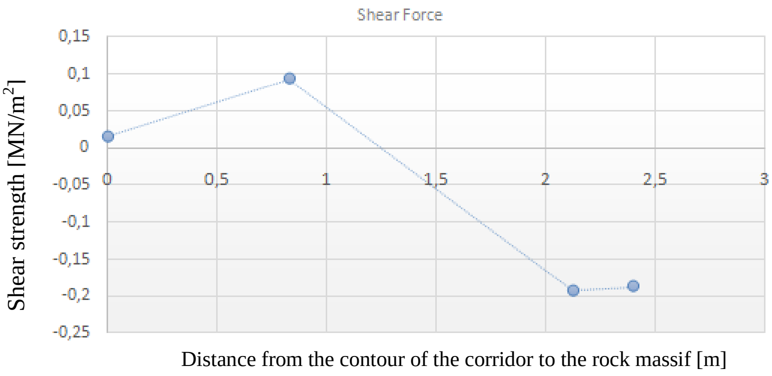

Figure 6 *Graph of changes in shear strength, by length, on the built-in anchor in rock massif over the contour of the corridor*

Plasticification of a rock massif in the surroundings of corridor does not mean that the corridor itself will collapse. The broken material may still have significant strength which will limit the size of the plasticized zone in relation to the width of the corridor. In this case it is noticeable that this zone can be up to one meter, taking into account the quality of the rock massif, depth of the corridor and pressure. Plastification can be manifested only as a few cracks or as a "peeling" of the contour of the corridor in a smaller extent.

During closing the chamber, time required filling the chamber on one side and the time required for solidification of the paste up to reach the final load parameters must be taken into account.

It was tried to be simulated in the model. The results show that number of finite elements in the side of chamber, in which the safety factor is less than 1, is reduced. It is interesting that, when the chamber is fulfilled to its final height, the hardening of the last level of paste results in strains in the floor of the corridor and that zone remains in the plastic deformation zone. It is important that this zone no longer has an impact on the overall stability of the excavation - the chamber + the drill corridor. The plasticization zone switched from the primary pillar from the rock massif to the contact zone of the secondary pillar, created from paste backfill.

The question arises: how does this system behave in the vicinity of the nearest stope?

For this reason, the isolated chamber system in the excavation block was developed as the next model that could answer this asked question.

Stability analysis of the isolated excavation system chamber - loading and drilling corridor

First of all, it is necessary to determine the behavior of the rock massif during the formation of the trial excavating block, especially the stability in the pillars during chamber opening. Development of the model through 15 phases is simulated, which includes various variants in the dynamics of preparation and opening of the trial excavation.

In the first phase was simulated making of the loading and drilling corridors with a distance of three widths of the pillar and without supporting.

In the next phase was observed the case of excavating chambers from the level of the drilling corridor, which are also without supporting, Fig. 7. It can be concluded that there is no interaction between these chambers.

A zone of plasticity is shown in Fig. 8, when there is a beam formation above the chamber, in case the corridors are secured by sub structuring system. The next phase analyzes making of preparation chambers in the middle pillar between the chambers, located at a distance of three widths of the pillars.

The next few phases show different variants of preparation to determine the mutual dependence, shown in Fig.s 9 and 10.

However, if we have the simultaneous opening of two chambers between pillars of hardened paste, Fig. 11, we can expect great instability in pillars, which would jeopardize preparation and opening of the next sublevel. Fig. 12 shows that, when the work is carried out on the higher floor and we are standing on the hardened paste, we have a completely stable system.

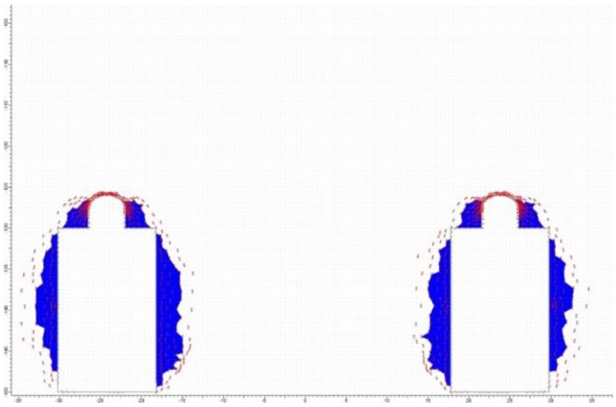

Figure 7 *Plasticization zone during opening the chamber (non-supported corridors)*

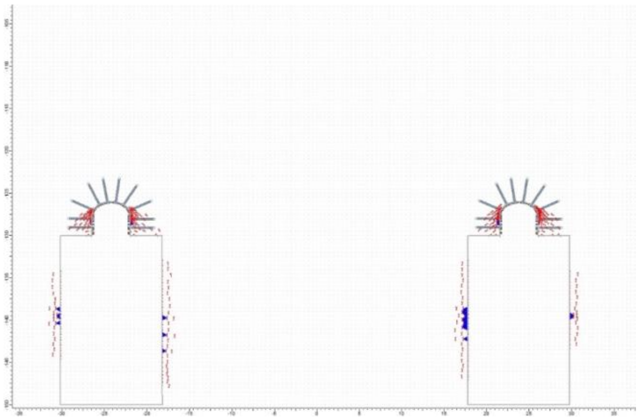

Figure 8 *Plasticization zone at the opening of the chamber (supported corridors with the anchor system + mesh + sprayed concrete)*

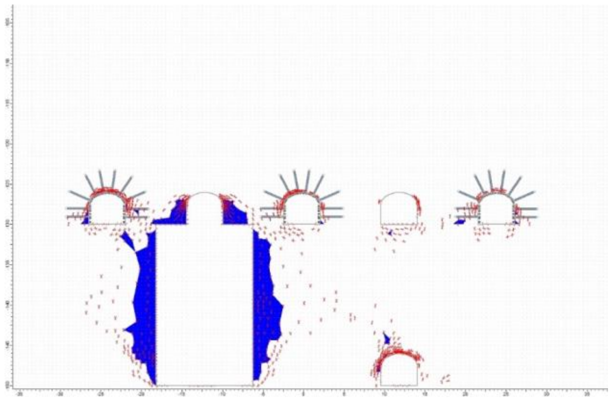

Figure 9 *Plastic deformation in fulfilled primary pillars with backfill, during opening the chamber without supported corridor*

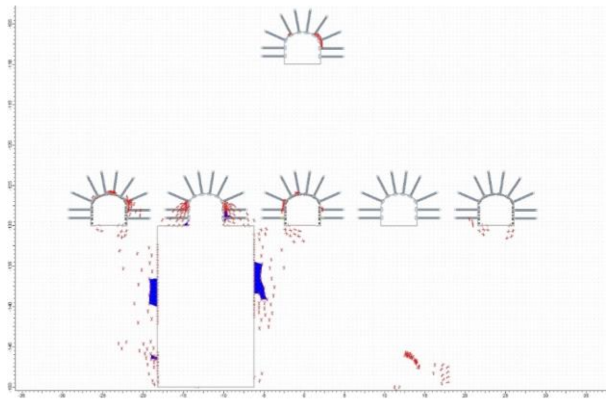

Figure 10 *Plastic deformation in fulfilled primary pillars with backfill, during opening the chamber with supported corridors with the anchor system + mesh + sprayed concrete*

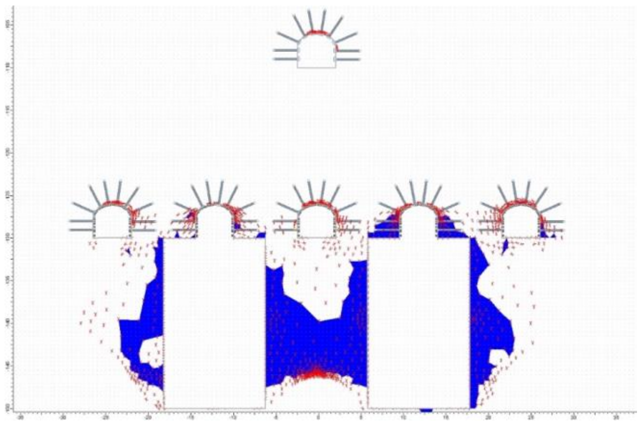

Figure 11 *Simultaneously opening of two chambers between pillars made of hardened backfill and supported drilling corridors*

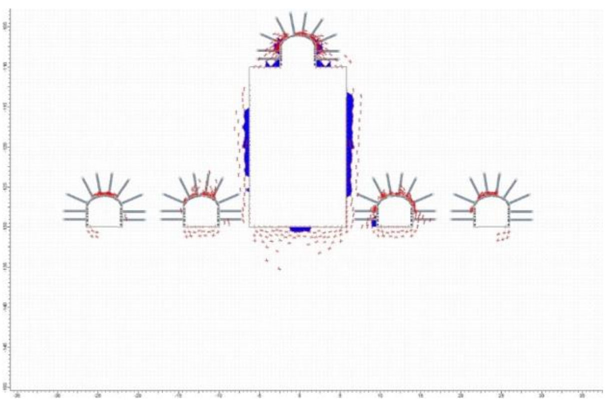

Figure 12 *Drilling corridor opening with chamber on the next sub level, with primary and secondary pillars of hardened backfilling located under them*

CONCLUSIONS

Reviewing the results of numerical analyzes (only plasticization zones are interpreted), it can be said that the security pillars will break along whole section, although its width is 12 meters, when the pillars are made in the room-and-pillar chamber system, regardless of whether is a pillar of a rock massif or a hardened paste.

The state of deformation, plasticity zone and progressive fracture, which can occur in the pillars, can be controlled by proper dynamics of preparation and opening. Works on the construction of corridors, both for loading and drilling, should be avoided in the pillars, beside the open chambers.

It is also a conclusion that the simultaneous opening of every second chamber, in a vertical plane analysis, poses a major problem for stability of pillars. As a measure for overcome of this problem, it is recommendded to accept a larger distance in simultaneous opening of chambers, in order to prevent negative impact of open chambers on one another.

After fulfilling of these chambers, the analysis shows that there is no increase in deformation, but on the contrary, the plasticization zones are in the range of acceptable, above all because of application of insurance system in the drilling corridor.

At the same time, the filled chambers perform relaxation of the primary horizontal stresses in its direction of affect.

Since this is only a 2D analysis and it is difficult to take out the right conclusions without analyzing the complex 3D model, models that provide interpretation of stability in the horizontal cross-section must also be analyzed, and therefore analyze the boundary length of the chamber.

Nevertheless, it can be concluded that the adopted recipe of cement paste backfill fulfilled its purpose. This means, it can be used as a good material for creating artificial pillars for support.

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Original Scientific Paper
Mining

Radmilo Rajković, Daniel Kržanović*, Miomir Mikić*, Emina Požega**

REHABILITATION OF THE LANDSLIDE AT THE "LANDFILL 3" IN THE ZONE OF THE ČUKARU PEKI FLOTATION TAILING DUMP**

Abstract

The "Landfill 3" was formed at the location of the flotation tailing dump "Čukaru Peki", where the earthen material, created during the dam construction of the flotation tailing dump was placed. A part of the deposited material and substrate at this landfill has slipped that endangers the local road and "Kusak" stream at the landfill foot. That is why this landslide needs to be rehabilitated.

Keywords: *"Čukaru Peki", landfill, landslide, rehabilitation*

INTRODUCTION

The "Čukaru Peki" copper and gold deposit is located in the central part of East Serbia. The exploitation field of the hydrothermal Cu-Au system "Čukaru Peki" is located about 6 to 8 km in the south of the town of Bor. According to the mine development and transport plan, as well as the selected location for depositing the flotation tailings, in combination with the topographical conditions, the location of the mineral processing plant was selected on the south side related to the deposit, and northeast of the portal of the transport decline. Based on the field research, taking into account technology, economics, construction conditions, environmental protection and other aspects, the flotation tailing dump is located in the east of the processing plant, in a natural valley 4 km away from the flotation plant.

The earthen material is placed on the "Landfill 3" as a product of ground excavation for the purpose of a dam construction for the flotation tailing dump. With the formation of this landfill, in 2021, there was a soil breach on the slope on which the landfill is located, what caused sliding of the clay substrate and deposited material, Figure 1. The moving material interrupted the local road and flow of the nearby "Kusak" stream at the bottom slopes and formed a smaller accumulation.

The cause of landslide activation is the unfavorable geometry of landfill and overloading of the base on which it rests, which caused the ground to break. The slide has covered an area with approximately size of 190 x 260 m.

As a result of pressure of the activated technogenic material and deluvial clays on the lower part of research area affected by the slide, a zone of pronounced surface deformations appears, as a result of large lateral pressures. Deformations appear in the form of accumulation of material and cracks

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on the ground, which completely changed its natural geometry. The zone is developed in the middle of deluvial clays covered with humus and must be subjected to the rehabilitation measures.

The design solution is to achieve the permanent stability of endangered slope changing the geometry, and to break through a new route of the riverbed to dry out the artificially created dam.

Figure 1 *Landslide on the "Landfill 3"*

GEOTECHNICAL RESEARCH

The purpose of geotechnical research is to provide data on the spatial distribution and more important physical-mechanical parameters of all engineering geological members that participate in the construction of this space. Based on these data, with the use of adequate software, it will be possible to find out whether the designed works contribute to the stability, as well as to what extent they can be carried out, so that the stability is not threatened.

A total of eight exploratory drill holes were drilled, the accompanying field works were carried out and an optimal number of samples were taken for the laboratory geomechanical tests.

As part of field research and creation of geological-geotechnical documentation, the following field investigations were carried out:

- Engineering geological mapping of the field
- Exploratory drilling
- Standard penetration tests Engineering geological mapping of the drillhole cores
- Taking samples for the laboratory geomechanical tests
- Laboratory geomechanical tests

The following engineering geological media were identified on the investigated field:

- Medium 1 – Colluvium
- Medium 2 – Technogenic material
- Medium 3 – Deluvial clays
- Medium 4 – Clay siltstones, claystones and sandstones.

Seven geotechnical profiles were defined on the site. Calculation parameters were determined for stability calculation for each working medium, as well as the level of underground water on profiles [1]. The values of calculation parameters for stability calculation are shown in Table 1, the characteristic geotechnical profile is shown in Figure 2.

It is assumed that the thickness of the activated material in the central part is up to 23 m. By mapping the field, a frontal scar visible along its entire length was observed, with a jump of an average of 2 m, with a clearly visible plane along which the movement occurred. The deposited material and part of deluvial clays were affected by sliding.

Table 1 *Values of calculation parameters for stability calculations*

Work medium	Cohesion, kN/m^2	Angle of internal friction, °	Density, kN/m^3
Medium 1 – Colluvium	16	11	18
Medium 2 – Technogenic material	17	12	18
Medium 3 – Deluvial clays	22	20	19.2
Medium 4 – Clay siltstones, clays and sandstones	155	20	19.5

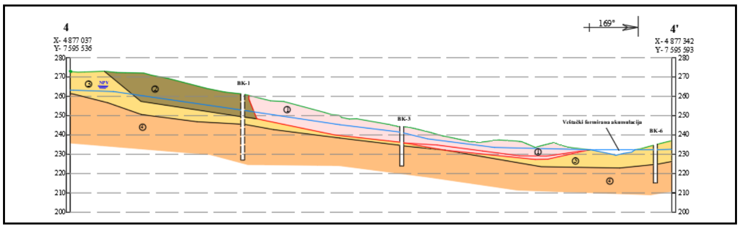

Figure 2 *Characteristic geotechnical profile*

Based on the geotechnical profiles, a 3D model [10-13] of the field and landfill was made in the Gems program, Figures 3 and 4.

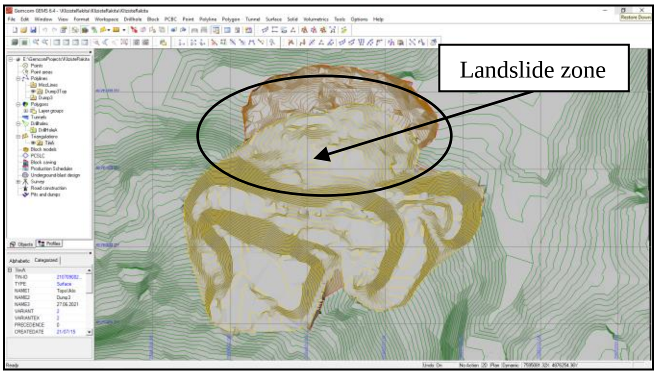

Figure 3 *2D view of the field and landfill model*

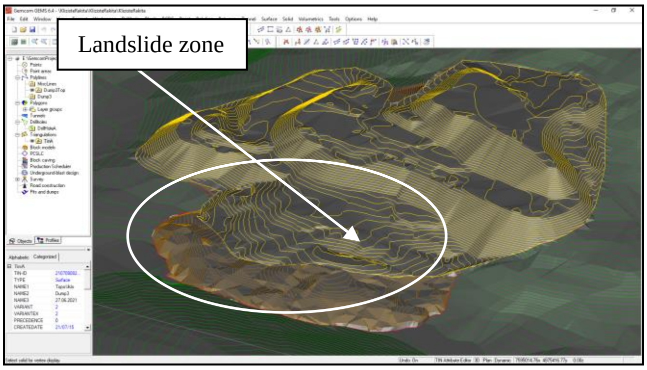

Figure 4 *2D view of the field and landfill model*

A stability calculation was performed on six geotechnical profiles [2]. Figure 5 shows the output interface of the Slide program in which the stability calculation of the existing state was made [4-9]

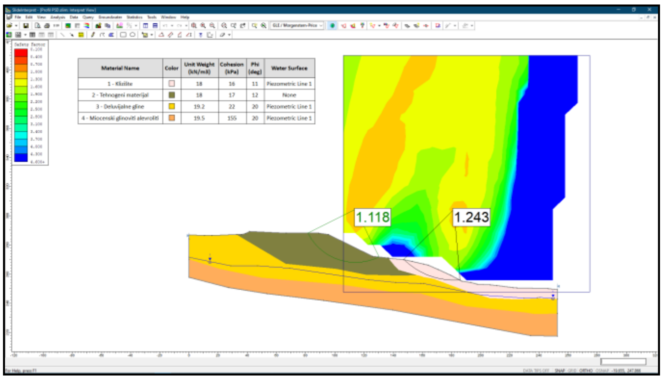

Figure 5 *Calculation the existing landfill state stability in the Slide program*

Analyzing the calculation results of the existing state stability of the landfill, the areas were determined where the safety coefficient is below the legal minimum [3]. The values of safety coefficients of the existing state confirm that rehabilitation of certain parts of the landfill is required. Figure 6 shows the areas of "Landfill 3" that require rehabilitation.

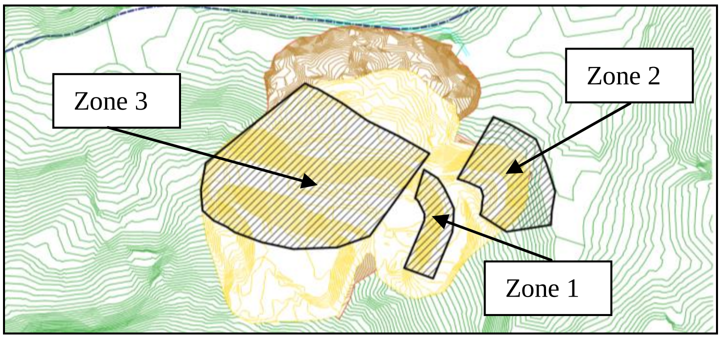

Figure 6 *Rehabilitation areas of the "Landfill 3"*

LANDSLIDE REHABILITATION

Rehabilitation of the landfill critical areas will be carried out by transferring the dumped material from higher elevations towards the base of the landfill, whereby the slope angles will be softened as much as is necessary to satisfy the legal minimum for the stability condition [3].

The material transferred to the foot of the landfill is ballast, which has a positive effect on stability. Work on transferring the deposited material from higher elevations towards the base of the landfill will be done with bulldozers.

The protection of the landfill from water from the catchment areas from which it gravitates towards it during atmospheric precipitation will be carried out by the construction of channels.

Analyzing the slope angles that meet the legal minimum from the aspect of stability, the construction of a 3D model [10-13] of the landfill after rehabilitation was carried out, Figures 7 - 9.

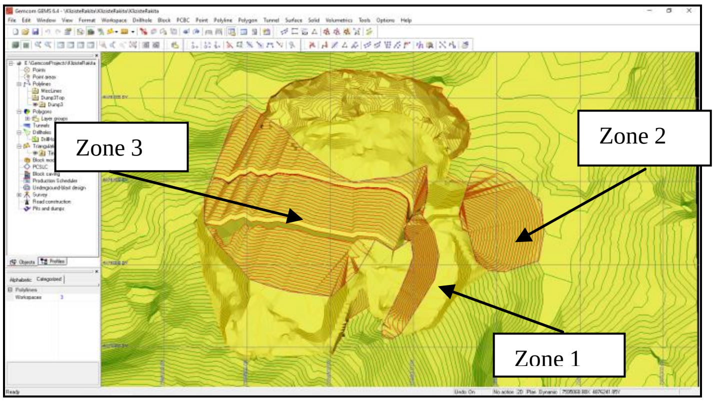

Figure 7 *2D view of the field and landfill model after rehabilitation*

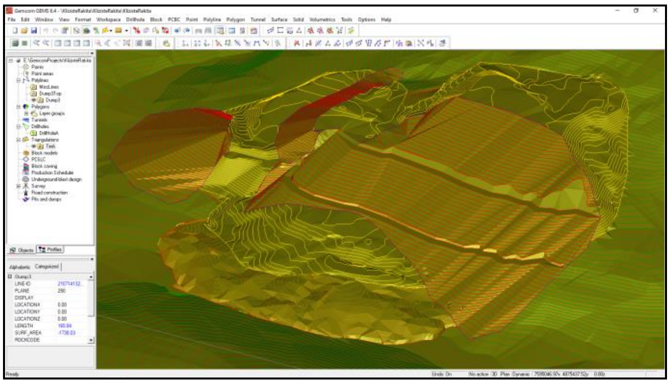

Figure 8 *3D model of the rehabilitated landfill - view from the northwest*

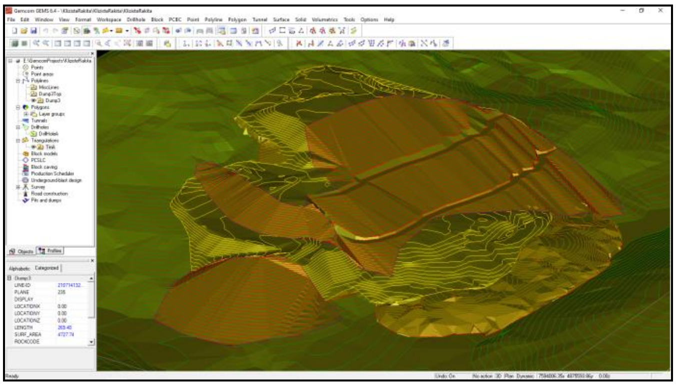

Figure 9 *3D model of the rehabilitated landfill - view from the northeast*

The general angle of slope of the rehabilitated zone 1 is 24°. The general slope angle of the rehabilitated zone 2 is 18°. The general angle of slope of the rehabilitated zone 3 is 14°.

In order to protect the local road whose route passes under rehabilitation zone 3, two bench levels will be built at the levels k+267 m and k+252 m, Figures 7 - 9.

In order to protect the landfill from water from the catchment areas from which it gravitates during atmospheric precipitation, the construction of two channels with sedimentation tanks for settling the solid particles before discharge into natural watercourses is planned: the first channel from the western side of the landfill and the second channel from the southern side of the landfill, Figure 10. Water from both channels, they are taken to a sedimentation tank, from where, after solid particles have settled, they are discharged into the "Kusak" stream.

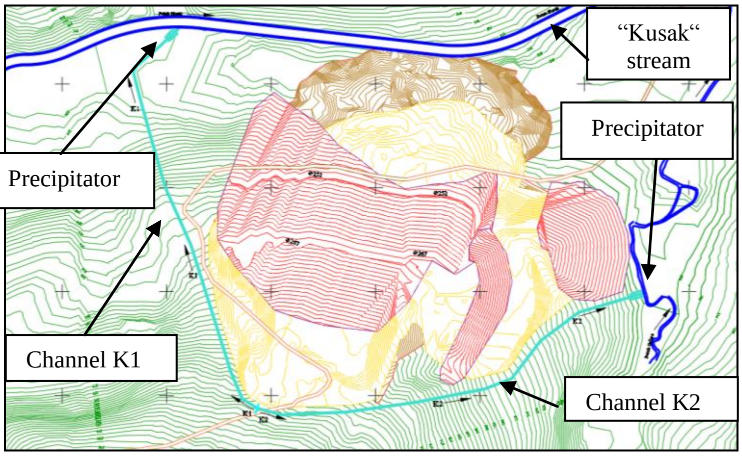

Figure 10 Location of the drainage channel

The stability calculation of the landfill after rehabilitation was done on the same geotechnical profiles and with the same calculation parameters, used to calculate the existing state stability of the landfill [2].

Figure 11 shows the output interface of the Slide program in which the stability calculation of the rehabilitated state was performed [4-9].

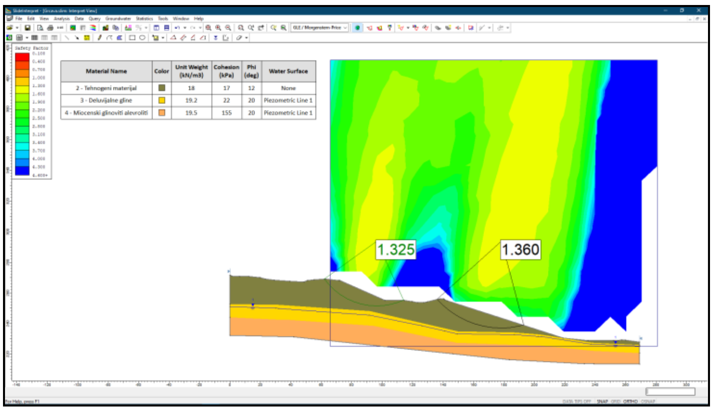

Figure 11 *Stability calculation of the rehabilitated landfill in the Slide program*

Analyzing the calculation results of the landfill stability after rehabilitation, the conclusion is that the legal minimum value of the stability coefficient of F_s = 1.30 for soft rocks on the landfill is met [3].

CONCLUSION

In order to ensure the "Landfill 3" stability, i.e., to rehabilitate the consequences of landslides on the landfill, a part of the deposited masses must be removed from the higher parts of the landfill. Before defining the remediation concept and scope of work, the geotechnical tests of the landfill base and deposited material were carried out in order to determine the stability parameters, structure of base and areas of the landfill to be rehabilitated.

In order to keep the costs of removing these masses as minimal as possible, these masses are not transported outside the location of the "Landfill 3" but are moved to its lower parts. These amounts constitute an additional ballast in the lower parts of the landfill, which has a positive effect on stability.

The designed solution for the landslide rehabilitation ensures the permanent stability of the landfill in accordance with legal regulations.

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ASSESSMENT OF DUST EMISSION AT THE LIMESTONE OPEN PIT "MILOJEVIĆ BRDO"**

Abstract

The basis of emission assessment at the Open Pit "Milojević Brdo" is to define the dust distribution depending on the wind influence and dust emitters. This paper presents the data for equipment engaged at the open pit. Through an analytical approach, the total emission of dust emitted by the mining equipment and aeolian erosion in the area of the open pit was determined. The results of this analysis represent a prediction of the state of dust impact on the environment during the exploitation process at the open pit.

Keywords: *dust emission, maximum allowed concentration, emission limit value, open pit mining*

1 INTRODUCTION

The Open Pit "Milojević brdo" of limestone as a technical-building stone is located in the southwest of Čačak on the northwestern slopes of the Jelica Mountain. The exploitation life of the surface mine is 42 years. The maximum annual exploitation capacity is 150,000 tons. The exploitation takes place discontinuously at the Open Pit "Milojević brdo". The exploitation consists of: preparatory work, drilling and blasting, gravity transport, loading of blasted material, crushing and classification (obtaining the final products), loading of final product.

2 MATERIAL AND METHOD OF OPERATION

The production of mineral resources is usually associated with the management and manipulation of significant quantities of materials not found in the other industrial areas. In addition to the significant consumption of energy necessary in the production of mineral raw materials, there are also significant impacts on the environment, i.e., the environmental factors of exploitation [1].

The European Environment Agency (EEA) estimates that 80-90% of the urban population in Europe is currently exposed to the particulate matter and ozone levels that are higher than recommended by the World Health Organization (WHO) [2]. This is particularly pronounced in the areas with a high intensity of industrial activity, as it is the case at the open pits.

Considering the mining equipment and technological units at the Open Pit "Milojević brdo", it can be concluded that the impact of individual mining operations is

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different when talking about local or general dust emissions. Table 1 shows the impact of individual operations as well as the assessment of percentage participation of the certain technological operations [3].

Table 1 *Review the impact of individual operations as well as an assessment the percentage participation of the certain technological operations*

Technological operation	Nature of pollution	Share in air pollution (%)
Drilling of boreholes	Local	5
Blasting	Wider zone	15
Gravity transport	Local	15
Limestone loading into the crusher	Local	5
Primary crushing	Wider zone	15
Final product loading	Local	10
Auxiliary works at the landfill	Local	5
Eolian erosion	Wider zone	30

Dustiness in the surroundings of the working equipment is intensively changed with the humidity, but the indicators of this impact are strongly related to the type of rock material in which the mining works are performed.

As an intensive pollutant, there is the raising of deposited dust - "eolian erosion", which on average produces about 30% of the total pollution, and it is possible that it is significantly more. This situation occurs at wind speeds greater than 2 m/s. The emission of individual work tools is of an experimental nature, and is usually calculated separately for each type and the obtained value is marked with N0 (mg/s).

$$N = N_0 \exp(\alpha \frac{Q - Q_0}{Q}), \text{ (mg/s)}$$

For a point source, the intensity of release of harmful substances into atmosphere of the open pit can be determined by the relation:

$$I = Q * N, \text{ (mg/s)}$$

Intensity of release the harmful substances for several different sources, and in relation to the open pit:

$$E = \Sigma I_u + \Sigma I_s \text{ , (mg/s) respectively}$$

$$E = \Sigma I_t + \Sigma I_e + \Sigma I_P + \Sigma I_s, \text{ (mg/s)}$$

The total intensity of release the harmful substances (dust or gases) of one group of sources also depends on the simultaneous operation of these sources. For the corresponding point sources, the total intensity is:

$$IT = \Sigma A_i K_i I_{ti} \text{ , (mg/s)}$$

If the work of source is variable in intensity, then the coefficient is:

$$K_i = \frac{A_i (I_{max} - I_{mi})}{A_0 * I_{max}}$$

The dust emission (E) resulting from the "eolian erosion", the surface of exposed, blasted or deposited materials of different grainsize distribution and humidity on the surface, can be calculated:

$$E = E_s F, \text{ (mg/s)}$$

During the technological process, the following emitters can be present at the same time Table 2:

Table 2 *Type of dust emitter*

Type of dust emitter	Total emission (mg/s)
One drilling rig	600
Bulldozer (gravity transport)	1500
One excavator (loading to the crushing plant)	1000
One excavator (loading to the crushing plant)	1000
"Eolian Erosion"	5160
Total superimposed emission in the process of exploitation	**9.260**

Suppression of dust during the operation of mining equipment at the open pit can be successfully carried out by wetting the blasted mass in the summer, watering of roads and effective maintenance of dedusting devices during drilling of bore holes. Applying the complex protection measures, the stated total dust emission from the open pit can be reduced by up to 90%. Then the dust immission from the open pit in the most unfavorable case for the environmental protection would amount to: **E=926 (mg/s).**

This data was used to calculate the impact of open pit dust on the environment. An increased presence of dust is expected only in extremely dry periods. It can be objectively said that the the case of simultaneously operation of all machines is technologically practically impossible, so the calculation refers to the most unfavorable conditions of dust impact.

Assessment of dust emission in the mineral processing process

During the technological process of mineral processing, the sources of air pollution with suspended particles are:

Dotted

- Loading of out-of-mine limestone into a mobile crusher
- Dumping place from crusher to the mobile screen
- Loading of finished fractions into transport vehicles,

Linear

- belt conveyors on a vibro screen,

Superficial

- open landfills of finished fractions +0 - 63 mm, 31.5 - 63 mm and 0 - 31.5 mm.

The assessment of this emission is a function of wind speed, material properties, grain size distribution, and surface area of the open landfill of finished products. The primary sources are technological equipment and machinery in operation, and the secondary sources are all active surfaces (open landfills and internal roads), which, under the impact of wind, emit the floating fractions from deposited dust into the air. Calculation of the total emission assessment is done according to the methodology of comparison with similar plants for crushing and sieving and the results are given in the following Table 3.

Table 3 *Results of assesmeng calculation of the total emission*

Dust source	Concentration (mg/m^3)	Emission (mg/s)
Loading basket of the primary crusher	100	50
Primary crushing	100	200
Conveyor belt from the crusher to the vibro screen	300	230
Vibro screen	100	2,500
Transporters for finished aggregates	100	230
TOTAL	**700**	**3,230**

Assessment of the total dust emission when there is no dust removal system is: 3,230 mg/s. This emission can be reduced by up to 95% of the total emission applying the technical protection measures, such as dry dusting or sprinkling with water, belt conveyors and spillways, covering with removable vibro screen covers, etc.). In that case, the dust emission from the mineral processing process would amount to: **Er≈ 150 (mg/s).**

The assessment of emissions from the open landfills is a function of wind speed, material properties, grain size distribution and surface area of the open landfill, so here the emission can be assessed on the basis of the following relationship:

E = Es x F = 2 x 240 = 480 (mg/s)

(Es = 5 mg/sm^2 at V = 4 m/s)

Assessment of this emission is given only at a wind speed of 4 m/s, at higher speeds the emission rises sharply. As informative data, the emission at a wind speed greater than 15 m/s is given, but it is noted that this type of emission is very rare, and that it does not have a decisive impact on air pollution in the environment: Es > 500 mg/cm^2.

Dust emissions from the open landfills can be reduced up to 20 times applying the technical protection measures, such as wetting or covering with a demountable cover. In that case, this emission would amount to:

E = 480/20 = 24 (mg/s), at V = 4 (m/s)

The total dust emission from the exploitation and preparation of limestone would amount to

E (dedusting+preparation) = 926 mg/s + 150 mg/s + 24 mg/s = **1100 (mg/s)**

3 RESULTS AND DISCUSSION

Introduction of the system of environmental standards (ISO 14000) implies the development of an environmental protection management system as a means of achieving and systematically controlling the level of performance in the area of environmental protection [4].

The maximum concentration of dust is located on the axis of the main direction of wind blowing, and at a point at a distance X (m) from the source, it can be determined by the formula:

Depending on the pattern of air flow in the pit, which depends on the pit configuration, the direction and speed of wind, the dust concentration at the edge of pit will also depend.

Thus, the formulae for its determination are given in the literature:

at flow scheme:

$$C_{xl} = \frac{10\Sigma q_i}{\Psi x_{sk}\ L_k W_s} + C_0\ , (mg/m^3)$$

at recirculation scheme:

$$C_{xl} = \frac{15\Sigma q_i}{\Psi x_{sk}\ L_k W_s} + C_0\ , (mg/m^3)$$

The dust sedimentation outside the pit is carried out on the wind axis on the surface that has the shape of a rectangle with surface, (P = 1m * x). Lateral scattering of dust, depending on the turbulence coefficient Ψ, is not significant, so the equation of surfaces on the wind axis can be observed in the shape of a rectangle of length, x. The total dust sedimentation from the pit edge to the isoline of the natural dust background of the area (C_o = 0.01 mg/m^3), is obtained by the formula:

$$I = \frac{(C_{sl} - C_0) W_s\ F3600 * 24}{I_i}\ , (m),$$

If this formula is saved by the rectangle length x, in the wind direction, the range of immissions of the certain given values, I_i, within the zone from the dust source to the isoline of natural concentration background. This gives the range points, x_i, of the certain sizes of occasional emissions, I_i, which, when connected with lines for various wind directions, represent the dust isolines around the pit contour:

$$I = \frac{(C_{sl} - C_0) W_s\ 3600 * 24}{I_i}\ , (m),$$

How much the air pollution will be in a certain direction during the year depends on the amount of wind in that direction.

On the basis of the percentage of wind frequency, f, that is, the number of days d, of wind blowing in certain directions in a year, the isolines of average daily emissions for a year can be determined by the formula:

$$x_i = \frac{(C_{sl} - C_0) W_s\ F3600 * 24F}{I_i}\ , (m),$$

$F = d_f/365$

The upper values of the average immissions of the total precipitable substances for populated areas are 450 (mg/m^2/day) for one day, and 200 (mg/m^2/day) for a calendar year, determined by the Regulation on Amendments to the Regulation on Monitoring Conditions and Requirements for the Air Quality ("Official Gazette of RS", Nos. 11/2010, 75/2010 and 63/2013) [5].

When it comes to the data on frequencies and wind speeds according to the sides, the data from the meteorological station Kraljevo was used.

Based on the analyzed data from the meteorological station, the predominant wind direction is west (200‰) and east (172.8‰), then northwest (137.0‰) and south (123.3‰). Winds blow most rarely from the north (65.8‰).[6]

From the downloaded data for wind speed and wind frequencies according to the world standards, the following calculations can be made:

- dust emission range for dangerous concentrations above MDK (*maximum allowed concentration),*
- range of occasional daily GVI (*immission limit value)*
- range of mean annual GVI

Based on calculations, the range of air pollution concentrations in the vicinity of the Open Pit "Milojević brdo" above MDK and GVI is given in Table 4.

Table 4 *Range of concentrations of air pollution concentrations in the vicinity of the Open Pit "Milojevića brdo"*

Ord. No.	Name of size and units	N	NE	E	SE	S	SW	W	NW
1	Mean speed, W_s (m/s)	1.44	1.16	2.44	2.68	1.56	1.34	2	2.44
2	Frequency of wind direction, (‰)	65.8	68.5	172.6	117.8	123.3	115.1	200.0	137.0
3	No.of days per annum, 18	24	25	63	43	45	42	73	50
4	Coefficient Ұ	0.655	0.537	1.075	1.176	0.705	0.613	0.890	1.075
5	L_t, (m)	264	378	284	235	264	378	284	235
6	X_{sk}, (m)	284	235	264	378	284	235	264	378
7	C_0, (mg/m^3)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
8	q, (mg/s)	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100
9	C_{xl}, (mg/m^3)	0.388	0.497	0.087	0.081	0.311	0.334	0.147	0.103
10	Range X(m) C>0,12	**344**	**443**	**70**	**64**	**273**	**294**	**124**	**85**
11	Range X(m) C>0,07	41	56	22	14	62	62	46	21
12	Range, l 100, (m)	**470**	**488**	**162**	**164**	**405**	**375**	**237**	**196**
13	Range, l 200, (m)	235	244	81	82	203	187	118	98
14	Average annual. L 100, (m) ann.	**30.9**	**33.4**	**28.0**	**19.3**	**50.0**	**43.1**	**47.3**	**26.9**
15	Average annual L 200, (m) annum	15.5	16.7	14.0	9.7	25.0	21.6	23.7	13.4

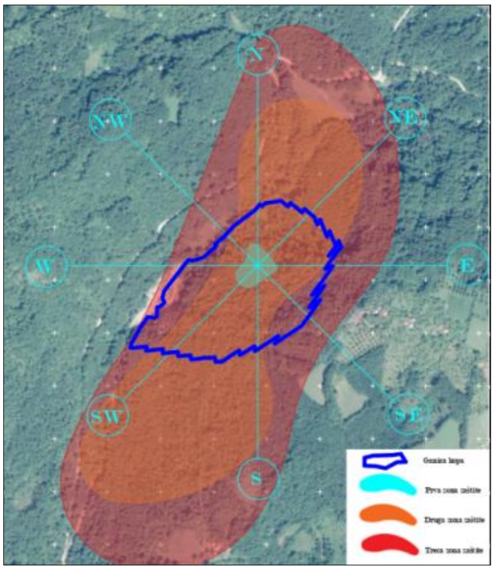

Figure 1 *Interpretation the range of air pollution concentrations in the vicinity of the Open Pit "Milojević brdo"*

The following can be seen from Table 4 and Figure 1:

The first protection zone (marked in blue) refers to the range of average annual permissible values of total sediments. The range of the average annual permissible values of the total precipitation amounts to the maximum of 50 m with a southerly wind, directed to the north, then 47.3 m with a westerly wind, directed to the east, and 43.1 m with a southwesterly wind, directed to the north-east. Other ranges of the average annual permissible values of the total sediments have significantly lower values. These ranges are located within the limits of the exploitation field.

The second protection zone (marked in orange) refers to the range of occasional permissible values of the total sediments; its greatest width is 488 m toward the southwest when the northeast wind blows. The next range of occasional daily permissible total precipitation values of 470 m is when the north wind blows.

The range of harmful concentrations of the total suspended particles above MDK on certain profiles depends on the direction and speed of wind with constant dust emission and reaches a the maximum value of 443 m when the wind blows from the northeast. When the calculated values for all wind directions are combined, an isoline is obtained, which is marked in red in Figure and refers to the range of air pollution concentrations of the total suspended particles above MDK. It is also **the third dangerous zone** of the soil around the open pit.

4 CONCLUSION

In order to establish the functional dependence of dust distribution in the area of the open pit and its immediate surroundings as a function of the input parameters, it is necessary to view the entire system as dynamic, which requires a conti-nuous monitoring of the input parameters and the results of dust measurement in the specific area. In this way, it is possible to form a model of impact on the environment quality.

This paper presents one approach to the model of distribution the dust particles in the area of impact the mining works at the Open Pit "Milojević brdo". The ultimate range and spatial distribution of dust emission is determined on the basis of the main impact factors, namely:

-dust emissions,

-distances from the place of emission,

- speed and direction of air currents.

The model for predicting the concentration and spread of dust in the function of mentioned parameters determines the degree of impact the mining operations on the environment in the vicinity of the open pit and determines the type and extent of protection measures required to reduce this impact to the permitted limits.

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Original Scientific Paper
Mining

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OVERVIEW OF APPLICATION THE SOFT COMPUTING METHODS IN THE FIELD OF MINING IN OUR COUNTRY AND IN THE WORLD**

Abstract

Application of the Soft computing in the mining industry is of great importance. This paper shows only a part of the published scientific and professional articles on application the Soft Computing methods in our country and in the world in the field of mining. Originally, the Soft Computing methods arose from the need to analyze the complex processes and problems in a quick and simple way with relatively little knowledge of the influencing parameters. Considering that the mining problem is related to numerous and largely insufficiently investigated influential factors, the soft computing methods are widely applied in this area and their application leads to an improvement in understanding the mutual influence of natural and technical-technological factors in the processes of exploitation, selection and maintenance of the basic and auxiliary mining equipment, the impact of mining operations on the environment, social environment and other aspects of mining activities.

Keywords: *Soft computing, Fuzzy logic, ANN, mining*

INTRODUCTION

The Soft Computing (SC) represents a new and innovative approach to the construction of intelligent systems. By definition, the Soft Computing is an approach to computing that mimics the extraordinary ability of the human mind to conclude and learn in an environment of uncertainty and imprecision. [1]. The Soft Computing methods that are most widespread include: fuzzy logic and artificial neural networks, but the evolutionary algorithms, rough sets, decision trees methods are used less frequently, support vector machines, genetic algorithms are used less frequently.

The Soft Computing Techniques are a reliable tool to help in the design, development and operation of intelligent systems that have the ability to adapt, learn and act independently. In addition, these techniques allow the designer of the process model to take advantage of the knowledge accumulated in the system being modeled (in the form of linguistic or in the form of other data), to continuously learn from operational experience and to take advantage of the capabilities of intelligent algorithms for the process optimization [2]

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The advantages and disadvantages of the most commonly used SC methods are given in Figure 1.

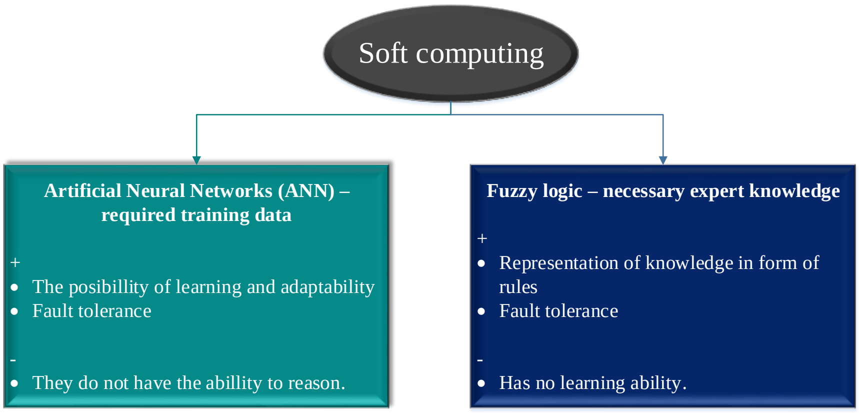

Figure 1 *Advantages and disadvantages of the SC methods*

LITERATURE REVIEW

In this review paper, the works with the application of Soft Computing in mining are presented. In recent years, the Soft Computing has been increasingly used in mining. The largest number of works is related to the process of blasting, the field of mechanization in mining, environmental impact assessment, etc. On the other hand, the application of numerous methods from the field of Soft Computing enables the aforementioned problem to be successfully analyzed, and the analysis results reflect the previous expert experiences and results of experimental measurements in a good way. To assess the success of the application of these methods, a prior knowledge of behavior the analyzed systems and processes is necessary. Its verification is performed by comparison the experienced and experimental data with the analysis results using one of the Soft Computing methods. Every specific issue isolated from a broad domain of mining, whether it is about the complex technical systems, natural or technological processes, can be analyzed using one of the Soft Computing methods, and most often, several methods can be applied to one problem or their mutual combination or combination with one of the other methods from the field of operational research. Furthermore, an overview of works in our country and in the world with the application of Soft Computing is presented.

In the paper entitled "Predicting the Availability of Continuous Mining Systems Using the LSTM Neural Network" [3] Gomilanovic M. and other authors deal with the development of a model for predicting the availability of continuous mining systems using the artificial neural networks. The idea of this paper is to improve the analytical approach for determining the availability of continuous systems. The data on which the model was developed are related to the I ECC system at the Open Pit Drmno Kostolac. The aim of this work is to improve the model for predicting the availability. Based on the values of test statistics *RMSE, MAE* and R^2 in this paper, it is concluded that the model obtained using an artificial neural network has a higher predictive power compared to the analytical approach. At the end of the work, a simulation is created showing the availability range of continuous coal system.

Gomilanović M. and other authors in the paper entitled "Determining the Availability of Continuous Systems at Open Pits Applying Fuzzy Logic" [4] present a model for determining the availability of continuous systems at the open pit using the fuzzy logic, fuzzy inference system. The applied model was formed on the basis of partial indicators of availability. This model is based on an expert system for assessment the availability of continuous systems at the Open Pit Drmno. Partial indicators that make availability are reliability and ease of maintenance. The Fuzzy compositions used for integration the partial indicators are the max-min and min-max compositions. This model for determining the availability has a role to help the responsible persons at the open pit in planning and controlling the exploitation, adopting the maintenance strategy, and all with the aim of stable production and cost reduction. The presented model can be used as a tool for rapid assessment the availability of the complex technical systems.

Ivezić D. and others, in the paper entitled "A Fuzzy Expert Model for Availability Evaluation" [5], analyze the availability concept of the mining machines. In this paper, an expert phase model was created that analyzes and integrates the reliability, convenience of maintenance and functionality of three types of bulldozers that work at the open pit within the Electric Power Company of Serbia. Based on the evaluation results, a comparison of bulldozers was made. In this paper, conclusions are given that can be useful for improving the convenience of maintenance, logistics and purchase the new machines.

Tanasijevic M. and others in the paper entitled "A Fuzzy-Based Decision Support Model for Effectiveness Evaluation - A Case Study of the Examination of Bulldozers" [6] define the effectiveness as a com prehensive concept and measure of the usability level of the observed technical system. This paper presents the analysis and structuring of partial indicators. A model has been developed for their synthesis to the level of effectiveness. The paper used indicators of a hybrid nature, such as the measured values and expert evaluations. A phased reasoning model for their processing and integration into effectiveness is presented. This concept enabled the evaluation of technical system in terms of making decisions about the remaining possibilities and optimizing the life cycle costs. The efficiency evaluation model is applied on an example of bulldozer auxiliary machines. In this paper, two approaches are given. The first approach is based on the expert evaluations, and the second approach is based on the measurement and statistical data processing.

In the paper entitled "Study of Dependability Evaluation for Multi-hierarchical Systems Based on MaxMin Composition" [7] Tanasijević M. et al. present a model of safety of functioning the complex technical systems that includes the partial indicators of reliability, convenience of maintenance and logistic support for maintenance. Partial indicators of safety of functioning are defined as linguistic variables. In this work, the max-min composition was applied to determine the safety of functioning. A concept for synthesis the performance safety of the functioning of individual components in a complex technical system is proposed.

In the paper entitled "Multi-criteria Approach for Selecting Optimal Dozer Type in the Open-Cast Coal Mining" by Janković I. et al. [8], an analysis of the availability and lifetime costs of dozers is provided. The parameters taken into analysis in this work are as follows: technical, economic, exploitation and survey. Since tthe calculated data are not mutually measurable (more precisely, they cannot be compared with each other), a mathematical method with the multi-criteria approach AHP (method of analytical hierarchical processes) was used. In addition to the fact that it is a traditional method, the authors have shown that it is possible to reach results that show their advantages and disadvantages when choosing mechanization through the multi-attribute consideration. The presented method showed that with a minor adjustment of the parameters, it can be applied to all auxiliary machines.

In the paper entitled "Adaptive Neuro-Fuzzy Prediction of Operation of the Bucket Wheel Drive Based on Wear of Cutting Elements" by the author Miletić F. et al. [9], a model made as a combination of artificial neural networks and fuzzy logic, so-called the ANFIS (Adaptive Neuro Fuzzy Inference System) is presented. The main goal of this work is to determine the dependence of how the wear of the cutting elements affects the operation of rotary excavator drive.

In the paper entitled "Applying the Fuzzy Inference Model in Maintenance Centered to Safety: Case Study - Bucket Wheel Excavator" by Jovančić P. et al. [10] the safety-focused maintenance according to the adaptive fuzzy inference model is promoted, which has online adaptation to operating conditions. The input parameters for this model are indicators of the service quality of the analyzed engineering system: reliability, maintainability, consequence, severity and observability of fai-lures.

In the paper entitled "A Hybrid Artificial Bee Colony Algorithm-Artificial Neural Network for Forecasting the Blast-Produced Ground Vibration" [11] by Taheri K. et al., a hybrid model for predicting the explosion-induced ground vibrations is presented in the Miduk copper mine Iran using a combination of the artificial neural network with the ABC (artificial bee colony). The predicted values of ground vibration using this model were compared with several empirical models. Model results were compared with the available data using the mean absolute percentage error, root mean squared error and coefficient of correlation R^2.

Wang J., Yang JB. and Sen P. in the paper entitled "Safety Analyzes and Synthesis Using Fuzzy Sets and Evidential Reasoning" [12] provide a methodology for safety analysis the complex engineering system with a structure that can be decomposed into hierarchical levels. This methodology uses the fuzzy logic to describe each failure, and then the fuzzy inference is used to synthesize the information thus obtained to assess the safety of the entire system. The parameters of failure probability, failure severity and failure consequence probability are used for the failure analysis. These parameters are described by the linguistic variables, characterized by the function of belonging to the defined categories. In this paper, a practical engineering example is given that shows the proposed safety analysis and synthesis methodology.

Das A. et al., in the paper entitled "Development of a Blast-Induced Vibration Prediction Model Using Artificial Neural Network" [13], develop an ANN model for the blast vibration prediction using the 248 data records collected from three coal mines with different blasting conditions. It was found that the correlation coefficient between the measured peak particle velocity (PPV) and the output of model is 0.96, and the average error percentage is 11.85. The output of the ANN model was compared with the output of three empirical models widely used to predict the PPV. The correlation coefficient between the PPV predicted by the empirical model and the measured PPV data was 0.63, and the relative error percentage was 38.47. This result shows the superiority of the ANN model compared to the empirical models.

Khandelwal M. et al., in the paper entitled "Application of Soft Computing to Predict Blast-Induced Ground Vibration" [14] provide an assessment of the ground vibration using the ANN (artificial neural network). The neural network architecture consists of 3 layers. The first layer or input layer consists of 2 neurons, the second layer or hidden layer consists of 5 neurons and the third output layer has one neuron. For training and testing, the 130 records were used at the Singareni Collieries Open Pit Coal Mine of Kothagudem, Andhra Pradesh, India. The 20 new records were used for validation. The results were compared on the basis of determination coefficient and mean absolute error between the monitored and predicted PPV (peak particle velocity) values.

When it comes to the application of artificial neural networks in the modeling of flotation processes, Al-Thyabat considered the effect of three input parameters (mean grain diameter in the input pulp, collector dose and flotation machine impeller rotation speed) on utilization and quality of the concentrate obtained by the process of flotation concentration of Jordanian phosphates. For this purpose, the author studied the suitability of different architectures of multilayer perceptrons and came to the conclusion that the most suitable network architecture is [3-9-11-5-9-2] (with 4 hidden layers), giving the smallest mean square error. The results of simulations realized using the ANN showed that the optimal utilization and quality of concentrate are 92.97% and 83.47%, respectively. The optimal values of parameters that give the mentioned results are: mean grain diameter 321.28 μm; collector consumption 735.4 g/t and impeller speed 1225.25 min^{-1}[15].

Lal B. et al., in the paper entitled "Prediction of Dust Concentration in Open Cast Coal Mine Using Artificial Neural Network" [16] developed 3 models for predicting the concentration of dust particles at different locations far from the pollution source. These models were developed using the Multilayer Perception Network and learning was performed with the help of back-propagation algorithm. Data for training and testing the network were collected in the field at the Karanpura coal mine, Jharkhand in India. The following are used as inputs in these models: meteorological data (wind speed, dispersion coefficients, precipitation, cloudiness and temperature), geographic data and emission rate. Each model has a different number of inputs, and the output (dust concentration) is the same for all three models. Based on the performance of all three models, it was concluded that the model number 3 is better than the models 1 and 2.

Petrović D. et al., in the paper entitled "Fuzzy Model for Risk Assessment of Machinery Failures" [17] provide an algorithm for implementing the negative risk parameters into a synthesis model for assessing the risk level of machinery used in mining. Fuzzy logic theory in combination with the statistical method was applied to analyze the time image of the state of the observed machine. Fuzzy logic is represented through the fuzzy proposition and fuzzy composition models. Using these tools, the symmetric fuzzy sets were applied in relation to the classes and fuzzy inference in the calculation outcome. The convenience of the proposed model is the possibility of using numerical and linguistic data in the risk assessment model. The proposed risk assessment model, using the fuzzy logic inference and min-max composition, was applied to the Lokotrack LT 1213S mobile crusher of the Open Pit Ladna Voda in Petrovac on Mlava.

In the paper entitle "Fuzzy Expert Analysis of the Severity of Mining Machinery Failure" Petrović D. et al. [18] show the concept of failure severity analysis, one of the risk indicators. The consequences are observed through the negative effects that dismissal has on a machine, the health and safety of the employees, working environment and environment. Repairing the consequences of dismissal requires the additional financial investment, which negatively affects the company operations. In order to prevent this, it is necessary to introduce a risk-based maintenance policy, where the risk assessment would include all the negative consequences of a risky event. A phased expert model of failure severity assessment, based on the harmful effects of failure, is proposed. The negative effects of machine failure were analyzed, such as the time required for repair, possibility of injury at the workplace as a result of t failure, and impact of failure on the environment. This approach to the assessment the severity of failure allows a comprehensive insight into this risk indicator. The model was applied on an example of failure of hydraulic subsystems of a mobile crusher "Lokotrack LT1213S" of the Open Pit Ladna Voda.

CONCLUSION

The positive trend in application the soft computing methods in the field of mining recently indicates the broad possibilities of analyzing various technical, technological, chemical, physical and other processes, as well as complex technical and natural systems. With the increase in application of these methods, better planning, design, prediction of system behavior and optimization of process parameters are possible. On the other hand, some of the methods are more often applied in this area compared to the others. Thus, the application of Fuzzy logic is the most present in the analyzed papers, followed by the application of the method of artificial neural networks, while the others are significantly less present. Among the less frequently applied, hybrid methods are the most represented, which try to reduce the influence of negative features of the soft computing methods.

The mentioned soft computing methods are equally successfully applied to both simple and complex technical systems and to the technical-technological processes from exploitation, through the processing of mineral raw materials to modeling the impact of mining operations on the environment. This characteristic distinguishes soft computing methods as methods that will be increasingly applied in the future, especially in the complex conditions of mine-environment interaction, technical system-maintenance and technological system-parameter optimization. The main advantage of application of these methods, apart from the possibility of wide application, is that the analysis can be carried out in conditions when the influencing parameters cannot be precisely determined or not all important parameters that influence the behavior or the relationship between different systems can be identified.

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Original Scientific Paper
Environmental in Mining

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ANALYSIS OF THE WORKING ENVIRONMENT CONDITIONS IN THE FUNCTION OF WATER DRAINAGE INTO MASSIVE AT THE QUARRY VELIKI KRIVELJ**

Abstract

The conditions of the open pit drainage are usually very complex and, as a rule, insufficiently researched. When it comes to the exploitation of technical stone, especially limestone, the working environment is characterized by the crack porosity, and the present system of cracks and faults, apart from being in a complex relationship with each other, is characterized by greater or lesser water permeability as a function of the size of crack openings, type of material with which they are filled and degree of filling. As a result of exploitation works, the seismic impact that occurs as a result of blasting at the open pit, change in stress conditions due to the excavation and filling of the openings of existing cracks by the formation of transport roads and working plateaus at the open pit itself and during exploitation, the working environment conditions are changed, affecting the selection and functioning of drainage system of the open pit. Due to a number of affecting factors and their changes during exploitation, the selection and achievement of high efficiency of the open pit drainage system is a complex task. When it comes to testing the possibility of applying the water drainage from the open pit into surrounding rock massif, in order to achieve the expected high efficiency and safety of the drainage system, the working environment characteristics must be well known. This paper presents an analysis of application the conditions of the Kriveljski Kamen open pit drainage system by mine water drainage into massif [1]. This type of system was analyzed as a part of development the limestone exploitation project at this open pit with the basic idea of creating a reliable and economical system for protecting the open pit from water in the conditions of extremely high rainfall.
Keywords: *open pit, dewatering, technical stone, working environment*

INTRODUCTION

For an efficient exploitation process, it is necessary to define an open pit protection system against water that gravitates towards the contour of the open pit, but also water that directly reaches the contour of the open pit.

As with all other operations that are carried out on exploitation and drainage, a large number of factors affect it [2]. In practice, these factors can be divided into mining and natural. The mining factors are the product of exploitation process and reflected in the newly created terrain configuration, areas that need to be protected from water and arrangement of mining facilities. The natural factors are a

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consequence of the natural conditions that prevail in the narrower and wider area of the deposit. Therefore, they can be divided into climatic, tectonic, hydrological and hydrogeological [3]. Depending on all the mentioned parameters, as well as the connection of their impacts, the choice of drainage method also depends.

The condition of the working environment has a significant impact e on the choice of drainage system. During the preparation of the project documentation, the idea of evacuating water through the massif, into subsequently constructed drillholes of a larger diameter, was proposed. The positive and negative sides of this method will be explained through the analysis of the influential factors applied to a specific open pit.

WORKING ENVIRONMENT

According to the terrain configuration, the deposit belongs to the mountain type (Figure 1). The terrain within a contour of the ore body slopes steeply to the south. The maximum height difference in the deposit is about 110 m, counting from the highest elevation of the terrain, about 668 m in the northern part, to the lowest elevation, about 558 m (level 560), in the central part of the deposit.

Figure 1 *Kriveljski kamen limestone deposit*

The deposit has an irregular, elongated shape in plan, the longer axis in the NW-SE direction is about 460 m, and the shorter one is about 175 m. The area of the deposit is about 70,000 m^2.

The considered limestone open pit was initially developed as a high type open pit. After a certain time, the deep levels would be developed. The deepening of the deep levels is foreseen in further development of works. In this way, the conditions for organizing the open pit protection from water become more complex.

Two categories of natural factors, terrain configuration and hydrogeological characteristics of the working environment, have the greatest impact on selection the drainage method. Depending on the position of exploitation object in space, size, slope and type of surfaces that gravitate towards and from the objects, the amount of water coming into the contour of the open pit will also depend [4].

The structural, tectonic and hydrogeological characteristics of the massif in which exploitation is carried out affect how much water that reaches the catchment area will reach the open pit contour, as well as how much water that reaches the open pit contour will flow into massif.

Based on the available data, the Kriveljski Kamen limestone deposit is made of light gray to dark gray limestone ($K_1^{3,4}$) and white to light gray Upper Cretaceous (K_2^3) and Paleogene (Pg) marbles. [5] There is no surface overburden within the deposit and the following lithological units have been identified:

a) Ore mass:
- layered and massive limestones ($K_1^{3,4}$)
- marbles (K_2^3)
- marbles (Pg)
- marbled limestones (K^{23}) and (Pg)

b) Interlayered waste:
- quartz diorite porphyrite (Laramie granitoids Pg);

c) Floor waste:
- augite-horblende and horblende andesites of phase II (αah)

The limestone structure is microcrystalline or pelitomorphic to microcrystalline, and textures are homogeneous, breccia and homogeneous to stylolitic. The rock is interspersed with numerous cracks and fissures, which are filled with carbonate binder. Cracks, fissures and veins often give the rock a breccia character, and the rock most often cracks along them. The marble structure is heteroblastic to mosaic, and texture is homogeneous. Cracks and styloliths are a common phenomenon that are irregularly concentrated.

Quartz diorite porphyrite is an interlayered overburden in the deposit and occurs in the form of dykes (strings and irregular bodies). The interlayered overburden was found in the northwestern part of the deposit in drillhole B-6 and is 7.50 m thick. Drillhole B-7 also drilled quartz diorite porphyrite about 5 m thick, within which drilling was stopped. Drilling was also stopped in drillhole B-6 (3.50 m) in quartz diorite porphyrites.

The floor waste is made of augite-horblende and horblende andesites of the phase II (αah). It was found in the exploratory drillholes in the southeastern and eastern part of the deposit. Augite-horblende and horblende andesites of the phase II belong to volcanics of the second phase and belong to andesite basalts; they crystallized from drier lavas without significant presence of water.

Two systems of disjunctive elements were distinguished on the explored terrain. These two systems, based on statistical data collected from the field, are perpendicular to each other, while their planes are mostly subvertical.

The longitudinal system has a general direction of extension NW-SE with general elements of 240/80 dip. The transverse system of rupture elements takes the general direction of extension NE-SW, with general elements dipping 170/75. Both fracture systems are followed by the systems of shear cracks parallel to the fracture zones.

A striking structure was noted in the eastern part of the deposit. The structure belongs to the Bor fault zone. The fault zone belongs to a longitudinal system of ruptures along which limestones, altered rocks and marbles are more intensively crushed. This rupture partly represents the boundary between andesite and marble and Cretaceous sediments.

The following figures show a typical geological section of the deposit (based on the geological map on a scale of 1:100,000) - Figure 1, Geological plan of the deposit (view of the geological plan on a scale of 1:1000) - Figure 2, and characteristic geological sections of the deposit (based on the geological map on a scale of 1:1,000) – Figure 3.

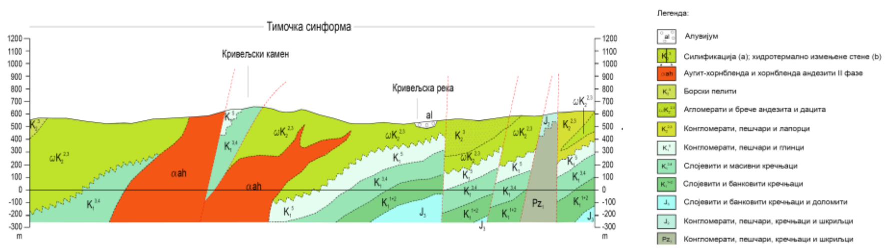

Figure 2 *Characteristic geological section of the deposit*

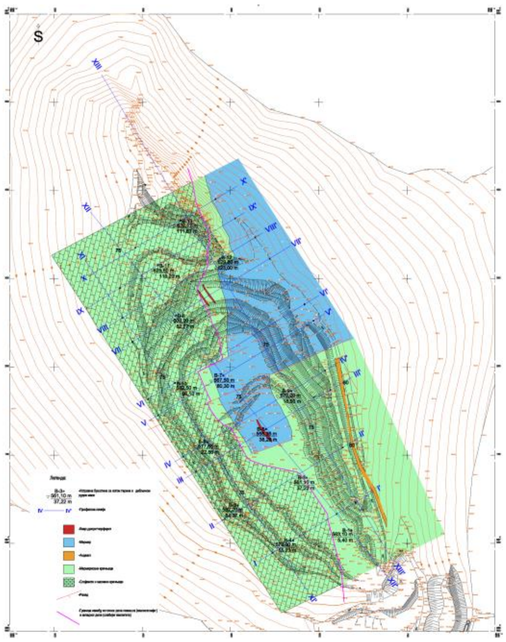

Figure 3 *Geological plan of the deposit*

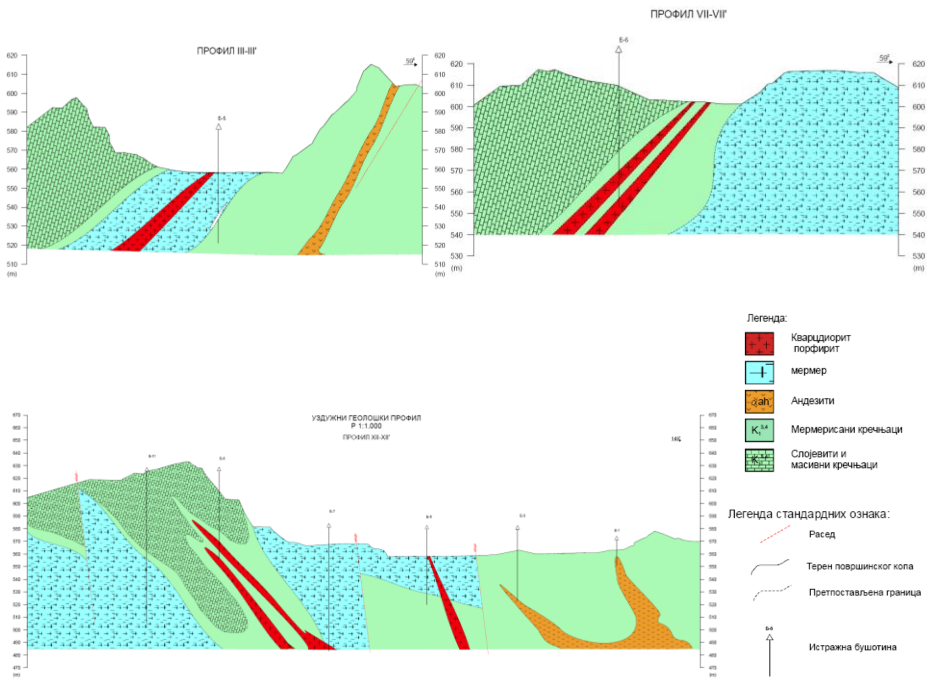

Figure 4 *Characteristic sections of the deposit*

From the viewpoint of hydrogeological factors, limestones are characterized by a low compactness. They have features of the fissure-caverous type, with tectonic fracture along the faults. Along the caverns and fault lines, which are usually filled with the products of decomposition the original base mass, it is possible for water to penetrate into the deeper parts of the deposit. Marbles are more compact, and also fractured along the fracture surfaces. The biggest impact on water permeability is cracking of the rock masses, type of porosity and degree of filling the cracks, as well as the abundance of source.

On the basis of collected information and data, the limestone and marble deposits of Kriveljski kamen in the hydrogeological sense are made up of the following lithological units:

- well permeable, and
- weakly permeable

Well permeable rocks include limestone and marble, as well as their varieties. These sediments build up the deposit.

Weakly permeable rocks are represented by andesites that occur in the southeastern part of the deposit and represent the basement. Weakly permeable rocks also include quartz diorite porphyrites, which represent the interlayered overburden. They occur in the form of dykes in almost negligible quantities that could affect the hydrogeological characteristics in the deposit.

In the case of more intense alteration, which is related to the surface parts, andesites and quartz diorite porphyrites represent the water permeable rocks, which are most often eroded by the surface water courses.

There are no permanent or occasional watercourses in the deposit area. In the immediate vicinity of the deposit, there are two hydrogeologically significant watercourses, which flow about 900 m from the north-eastern border of the deposit, i.e., west of the contour of open pit. Both watercourses can be used as a receptacle for drainage of collected water. Other water flows in the vicinity of the deposit are occasional and do not have a torrential character. The terrain drainage from collecting areas is gradual.

ANALYSIS OF TECHNICAL AND TECHNOLOGICAL FACTORS

In addition to the structural-geological, hydrogeological and morphological characteristics, the technical-technological factors that affect the selection of open pit protection system from water were considered [6]. At the same time, for the selection of drainage system, the following were singled out as important factors:

- The system should be as simple as possible and suitable for maintenance during the exploitation phase.
- The working environment is represented by limestones and marbles with high values of strength parameters, and for the construction of objects in such material, it is necessary to hire a special equipment that can perform mechanical fragmentation of material. Due to this reason, the objects are formed as the stationary as possible.

Considering the characteristics of working environment, the proper functioning of drainage system is important in conditions of extremely high rainfall or periods of sudden snow melting, since the moderate rainfall does not call into question the slope stability or cause longer interruptions of exploitation and processing process.

The existing level berms below the level of 600 m in the central part of open pit currently do not provide enough space for a channel construction and safe operation and movement of equipment and to ensure a sufficient width of berm for the road and channel, and a larger scale reconstruction of the slope is necessary. The previous system of water protection was based on the organized collection of water at the lowest elevation and centralized evacuation outside the boundary of open pit [7].

COMPARISON OF SOLUTIONS

Drainage of collected water from the open pit contour can be realized in several ways by receiving water through channels and taking water to the recipients and evacuating water to the recipients with a pump-pipeline system. This type of system is common for dewatering the open pits.

In special cases, it is possible to use the hydrogeological characteristics of massif, its fissure porosity, existence of the old underground structures, hydraulic connections of the working environment with surface recipients in order to evacuate water from the open pit into massif or recipients connected to it.

The classic drainage system is characterized by large initial investments necessary for purchase the equipment and construction of drainage facilities. Also, this method of dewatering entails the operational costs related to the occasional dislocations of pumping stations and pipelines and electricity consumption. [8] The volume of work that is carried out outside the contour of open pit during the construction of channels and installation of pipelines to the recipients can also be significant. During water evacuation from the open pit to the surrounding area, in addition to fulfilling all environmental conditions, it is necessary to take into account the interests of local community.

A water drainage system via drill holes, wells or surface water shafts works so that collected water by the system of drainage or surface channels is conducted to the well and then infiltrates into the soil/rock. This system is used most often in cases of:

- when there are already old facilities - wells that have dried up due to a drop in the water level in collector due to over-exploitation or change in recharge condition
- when there are old underground exploitation facilities that are in such condition that they can drain or receive surface water in the appropriate capacity
- when there is a hydraulic connection between the working environment and recipients on the surface through which water is evacuated, and
- when it can be considered that the capacity of collector, where water from the open pit is evacuated, is unlimited.

The use of existing facilities is beneficial because it reduces drainage costs and makes the system itself simpler. Since such facilities do not exist at the open pit, the new ones would have to be built.

In addition to the above, this group of drainage systems can also include those in which the pumped water is used for irrigation of surrounding area or in the function of maintaining the level of underground water in wider area, which is damaged by the existing depression of the open pit. Also, in this case, it is necessary that the environment into which water infiltrates has the appropriate hydrogeological characteristics so that the pumped water can be returned within the geological structures within which the water level has decreased [9].

In the case of introduction of such system, water would be collected from the area of open pit in a designed water reservoir. The collected water from reservoir, after settling the solid fraction, would be poured towards a well with a larger diameter - a well through which water would be fed into massif.

As an illustration of this system, the underground and surface water protection system of the open pits Žuta prla – Višnjica and Brskovo in Montenegro, which is currently being designed, can be mentioned. In the area where the open pits will be developed, there are the old mining works that drain higher parts of massif. It is planned to build a well, which would establish a hydraulic connection between the terrain surface, that is, the open pit, and underground rooms. Since these rooms have not been in operation for a long time and there is no possibility of their revision, the open pit protection system against water next to the water evacuation wells also foresees the existence of pumping plants and pipelines with a capacity that meets the requirements of the Rulebook and in conditions where there is no drainage through the underground rooms at all. Introduction of the reserve system is a request made by the investors based on their international experience in solving this problem.

In order for such a system to function, there must be appropriate conditions, that is, there must be some fault zone, that is, a space characterized by the crack porosity and water permeability, to which water would be conducted by the drillholes/wells. Water permeability essentially depends on the size of openings of cracks and fissures, as well as the degree of their filling.

In this connection, the geological Project Study of the deposit in question states that:

1. "The rock is intersected with numerous cracks and fissures, which are filled with carbonate binder."
2. "Cracks, fissures and veins often give the rock a breccia character, and the rock most often cracks along them."
3. "Cracks and styloliths are common and irregularly concentrated."
4. "Quartzdiorite porphyrite is an interlayered overburden in the deposit and occurs in the form of dykes (strings and irregular bodies). The floor waste are made up of augite-horblende and horblende andesites of the phase II (αah). Augite-horblende and horblende andesites of the phase II belong to volcanics of the second phase and belong to andesite basalts, they crystallized from drier lavas without significant presence of water."
5. "The fault zone belongs to a longitudinal system of ruptures along which limestones, altered rocks and marbles are more intensively crushed. This rupture partly represents the boundary between andesite and marble and Cretaceous sediments."

CONCLUSION

The terrain configuration and characteristics of the massif ensure a rapid outflow of water that reaches the area of deposit, but also contributes to the loss of a part of water in massif. However, the loss of water in massif as the main method of drainage cannot be relied upon. In cases of precipitation of lower intensity and duration, it is possible to expect that water that reaches the mine contour will swell into massif, while in the case of precipitation of greater intensity and duration, this is not possible. With the increase in duration of rainfall, after a certain time, the massif becomes saturated with water, so the initial outflow of water from the deposit surface is significantly reduced, and in the end all the water ends up in the contour of open pit. This type of drainage requires time, which is not always available in certain situations. Drilling of drillholes for drainage of water collected in the contour of open pit, in situations of prolonged rain of high intensity, the massif would be significantly loaded with water and effect would be the same as the natural water drainage.

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Original Scientific Paper
Mining, Preparation of Mineral Raw Materials

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AUSCULTATION OF THE RTH FLOTATION TAILING DUMP IN BOR WITH REFERENCE TO THE STABILITY OF DAMS AND DYKES AT THE TAILING DUMP**

Abstract

The RTH flotation tailing dump, located in the old open pit RTH in Bor about 500 m southeast of the Flotation Plant, has been in continuous operational work since 1985. The flotations tailing dumps are important mining facilities that are constantly changed during their exploitation period. Due to the changes occurring in the tailing dump during its exploitation, it is necessary to perform a continuous technical and technological surveillance - auscultation in order to collect parameters in real time to predict the phenomena, which will enable the normal exploitation of tailing dump. This paper presents the current state of the flotation tailing dump RTH, based on the auscultation monitoring program, carried out in the period August 2020 to February 2021. As for the normal exploitation of the flotation tailings dump in safe and stable conditions, a special attention is paid in this paper to the stability analysis of the dams I and II, as well as the sand dyke between them.

Keywords: *auscultation, monitoring, tailing dump, dam stability*

1 INTRODUCTION

The flotation tailing dump in the area of the old open pit RTH (the tailings dump is named after the mine) has been in operation since 1985, and according to the project: MAIN MINING PROJECT OF THE NEW FLOTATION TAILING DUMP IN THE EXCAVATED SPACE "RTH", CI, June 1984. The above-mentioned project envisaged a filling height of the tailing dump of K+350 m above sea level, with the possibility of further upgrading the tailing dump.

The tailing dump has the shape of an ellipse with the approximate direction of central axis east-west, Annex 1. The Dam I is built of hydrocyclone sand; it closes the tailing dump from the northwest side, towards the old dump and slag dump. The Dam I rests on a high planer with its left side (viewed downstream through the valley of the former Bor river), and with its right side on the smelter slag disposal site, from where it passes into the peripheral embankment with which it forms a functional unit. To the southeast of the tailing dump, there is a waste disposal site from the old open pit of the ore body "H", which separates the tailing dump from the Oštrelj road and Bor - Zaječar railway. In addition to the mine overburden that was deposited there (which has an inhomogeneous granulo-

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metric composition), this space was also used to dispose of ash, garbage, and other waste material.

The Dam II was built on this part of the hydrocyclone sand. Viewed down the valley of the former Bor River, the Dam II extends on its left side towards the high planer, passing into the peripheral embankment, so at the point of connection with the planer, it reached the designed height of K+378 m above the sea level. From the north, north-east and east sides, the tailing dump is closed with a high planer with an elevation of over K+400 m above the sea level, On the south, south-west and west sides are the main railway line and road that comes in a form of circle of the RTB facilities, which are protected from the RTH tailing dump by a perimeter embankment, built of the hydrocyclone sand.

Figure 1 *Flotation tailing dump RTH, GoogleEarth source, taken on April 9, 2021*

2 OBSERVATION METHODOLOGY OF DAMS AND EMBANKMENTS

Inspection of dams and embankments is carried out in accordance with the Serbian Standard SRPS U.C5.020, the application of which is a mandatory for all dams and embankments with height higher than 15 m, starting from 1980. Observation of high dams in the natural environment requires a multidisciplinary approach, and is achieved through the following aspects:

- visual observation of the visible surfaces of dams and immediate surroundings where the dam is founded,
- and registration of all changes on those surfaces;
- geodetic observation of benchmarks at the characteristic points of embankment and foundation of the dam;
- measurement of the underground water level and piezometric pressures with the free-level piezometers or manometers;
- measurement of the quantity and quality of leachate at collection points - measuring profiles and in drainage systems;

- measurements with special devices for registration the earthquake ground movements;
- measurements with special instruments installed under the surface of the dam body and foundations (measurements of expansions, displacements, total and pore pressures, and temperature);
- registration of hydrometeorological parameters (temperature, precipitation, runoff, winds, relative humidity, etc.).

The aforementioned observations have the common goal of providing the necessary insight into behavior of an object, environment in which the object is located, and the immediate surroundings, from the moment of design, during the object construction, its exploitation and, if necessary, after the end of exploitation and closure of the object.

Based on the observation data, the following is done:

- checking whether the conditions foreseen by the project are fulfilled or not;
- acquiring knowledge about behavior of the object within the conditions foreseen by the project;
- taking the additional monitoring, remediation, or insurance measures (for the endangered area) if some measured values are less favorable than the values provided by the project, and if it is determined that this endangers the object or object surroundings.

2.1 Visual observations

Visual observation is aimed at a direct observation of occurrences and phenomena related to the exploitation conditions, infiltration regime, and tailing dump stability [3]. The obligation of visual observation is daily and is not limited to a part of the day, shift, etc. All workers employed at the tailing dump are subjected to the obligation of vi-sual observation, including the leading supervisory and technical staff of the Copper Flotation Plant in Bor. This observation monitors the dynamics of construction the embankments, condition and functionality of piezometers, operation of drainage system, operation of hydrocyclone batteries, size of the sedimentation lake, evenness of filling the tailing dump, etc. According to the results in the field and conducted measurements, the MMI Bor prepares the periodic reports. During auscultation work, a special attention should be paid to the following phenomena:

- deformations of the basic terrain or external and internal slopes in certain parts of the tailing dump as well as the dam itself and perimeter embankment;
- appearance of springs, ponds, or wet zones;
- occurrence of suffosion phenomenon;
- occurrence of erosion;
- size of the sedimentation lake, its height, and position;
- uniformity of filling and reached the height of tailings accumulation

2.1.1 Occurrence of the phenomenon of suffosion

Suffosion is a phenomenon by which the infiltration currents move the smallest particles of material without moving the basic skeleton of coarse-grained material. By washing out small particles, the volume of interstitial space increases, and thus the permeability and rate of infiltration. Intensification of the suffusion phenomenon can lead to the creation of larger voids in the mass, followed by uneven settlement of embankments and dams on the tailing dump. This can have unforeseeable consequences if not detected in time. Detection of this phenomenon is possible by visual observation and control of suspended particles in the underground and leachate water. If the occurrence of suffusion is determined, the urgent measures must be taken to rehabilitate the flotation tailing dump. During the tour of the RTH tailings in the period February 2020 - August 2021, no occurrence of suffusion was observed on the dams and embankments, except in a part where the reservoir abuts a high planar, and it has been occurring occasionally for years. Periodically, when the amount of water in the storage lake increases and it rests directly on the slope of the high plan (due to unevenly deposited mining debris, there are a large number of cracks and caverns), there is a sinking of water and partly mud, which through the cracks and cracks on the old TIR collector to this collector, they go into the watercourse of the Bor River, and it is additionally polluting. As soon as the loss of water in the storage lake was noticed by throwing several jumbo bags in the area of the leakage, it was temporarily stopped. A permanent solution to this problem will be given through the project of shielding the old TIR collector with a waterproof concrete plug so that losses of this nature will be under control in the future.

2.1.2 Occurrence of erosion

Erosion at the RTH flotation tailing dump is a daily phenomenon and can be internal or external, and occurs as a daily phenomenon due to the effect of air currents or atmospheric precipitation on the dam crown, as well as on the internal and external slopes of dams and embankments [1]. Internal erosion is more dangerous because it is not visible until it appears on the external slope, and then the condition is already critical. It is characterized by appearance of springs and ponds and removal of material from the flotation tailing dump. External erosion can be under the influence of wind and heavy rains, as well as a consequence of sudden snow melting. Internal erosion occurs as a result of wind and precipitation effects, as well as water from the storage lake, which in the PPS zone directly rests on the internal dam slope.

Wind erosion, as in the previous period, has the most harmful effect on the geometry of dams and embankments. Figure 2 shows the embankment on untreated part of the tailing dump between PPS and Dam 2, where a damage caused by the wind daily to the RTH tailing dump is best seen, taken in 2021. The material is removed from the dam crown and stored outside the tailing dump area. This significantly disrupts the designed geometry of the dam and embankment. During the material removal from the dam crown, large depressions up to 3 meters deep are created, what significantly threatens the dam stability. The embankment has changed its designed height and cross-section, and the embankment crown is not of designed width leading to a reduction in the safety coefficient of that section, because the designed ratio of embankment height and water in the embankment body have changed.

Figure 2 *Detail of the endangered part of the embankment between PPS and Dam II, flotation tailing dump RTH, 2021*

Figure 3 shows a part of Dam II where, due to erosion, the first overflow of water and sludge occurred over Dam II into the surrounding area on 01/29/2021, which could have caused very serious problems at the flotation tailing dump. The quick re sponse of employees at the tailings dump stopped the overflow of sludge, which was quickly localized and stopped. This part of embankment is highly threatened by the wind erosion, and here urgent interventions are necessary in terms of correcting the geometry of embankment in accordance with the current technological project, in order to prevent the harmful consequences that further erosion of the embankment can cause for the stability of this part of embankment, as well as the entire flotation tailing dump RTH as a unique mining facility. In order to rehabilitate the dam crowns and embankments at the flotation tailing dump and bring their geometry to the designed geometry, the Investor concluded a contract with MMI Bor for the development of the DMD of the overhang the flotation tailing dump RTH, within which Volume II.1: Technical Design of Dam Rehabilitation will be prepared, and bring it to the designed state according to the valid technological project.

Figure 3 *Completely eroded crown of the Dam 2 where the first serious overflows where the observed water and silt over the crown and downstream slope were recorded on January 29, 2021*

2.1.3 Uniformity of filling the accumulation space of the flotation tailing dump

The evenness of the filling of the storage area in the case of the RTH tailings pond is directly affected by the position of storage lake and location of the floating pumping station, which was not placed at the designed location, provided in the current Technology Project from March 2008 [2]. The position of the floating pum-ping station in the current conditions of exploitation at the RTH flotation tailing dump is shown in Figure no. 4 as location 1 or PPS1, while the designed location is shown as location 2 or PPS2. The images were taken during regular auscultation during the annual auscultation period. The current position of the PPS has a great effect on the inner slope stability of the embankment. Due to the proximity of the PPS embankment, the area around the PPS is exposed to the erosive action of water on the embankment. Sand particles are washed away, thus the body of the embankment and internal slope, which leads to flaking of embankment and separation of individual parts. Increasing the water level in the lake, flaking i.e., separation the parts of embankment is more and more pronounced. This reduces the weight of embankment, which directly affects the slope stability and increase the groundwater level in the body of embankment. After rehabilitation the embankment crown and armoring the old inactive TIR collector, it will be possible to move the PPS to the designed location next to Visoki Planir [4].

Figure 4 *Existing and designed location of the floating pumping station, tailing dump RTH*

2.2 Stability verification on characteristic profiles at the RTH tailing dump

Calculation the stability of the RTH flotation tailing dump was performed on profiles 2/1, 4/2, 8*/1, and 9/1, considering that water was registered only in them according to the measurements submitted by the Boric flotation technical service. The geodetic condition of the dams was recorded on February 1, 2021 by the geodetic service ZIJIN Bor. The position of the profile was chosen on the basis of position of the exploratory drill holes through the dams and installed piezometers. The position of analyzed profiles is shown in Figure 5 and Table 1. Table 2 presents the physical and mechanical parameters of flotation tailings, and Table 3 presents the physical and mechanical parameters for disposed mine waste [5].

Table 1 *Position of analyzed profiles*

Profile	X1	Y1	X2	Y2
2/1	7 589 877	4 881 499	7 590 157	4 881 394
4/2	7 589 937	4 880 906	7 590 004	4 880 986
8*/1	7 590 589	4 880 608	7 590 414	4 881 080
9/1	7 590 446	4 881 111	7 590 777	4 880 659

Table 2 *Physical and mechanical parameters of the flotation tailing dump*

Profile	Volumetric weight, kN/m^3	Cohesion, kN/m^2 , (zone 1/zone 2)	Angle of internal friction, ^{o} , (zone 1/zone 2)
2/1	22,28	0/15	25/20
4/2	20,45	0/15	25/20
8*/1	14,37	0/15	25/20
9/1	17,88	0/15	25/20

Table 3 *Physical and mechanical parameters for deposited material at the mine disposal site*

Work environment	Cohesion, kN/m^2	Angle of internal friction,°	Volumetric weight, kN/m^3
Deposited waste	10.00	30.00	20.00

Table 4 *Physical and mechanical parameters of the substrate*

Work environment	Cohesion, kN/m^2	Angle of internal friction,°	Volumetric weight, kN/m^3
Degraded andesite	50	27	20

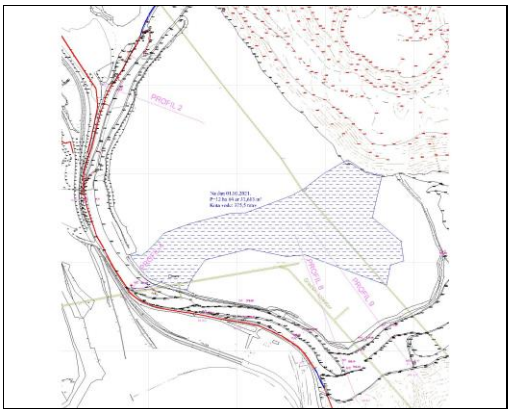

Figure 5 *Position of the analyzed profiles*

To define the underground water level, the data on water level in the installed piezometers for analyzed profiles submitted from the flotation plant in Bor, the measurements from 02/09/2021 were used. The stability calculation was done with the SLIDE v6.0 program from ROCSCIENCE [6]. The stability calculation is carried out under the limited equilibrium conditions, according to the Yanbu method. The effect of groundwater on stability was modeled on the basis of measured water levels in the piezometers and the level of water mirror in the tailing dump. Calculation of stability according to the analyzed profiles for constant static loads and dynamic loads for seismicity coefficient KS = 0.13 is shown in Figures 6 and 7 for profile 4/2, while the calculation results are shown in Table 5.

Table 5 *Summary of the stability coefficient of general slopes according to the Yanbu method*

Profile	F_s static	F_s dynamic
2/1	1.846	1.231
4/2	**1.036**	**0.783**
8*/1	2.955	1.926
9/1	**1.112**	**0.868**

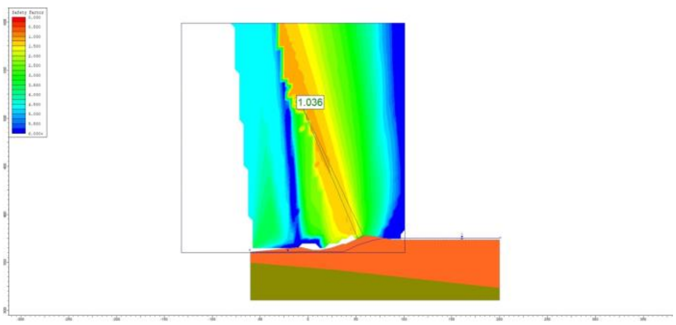

Figure 6 *Stability coefficient by profile 4/2 for static loads, Yanbu method*

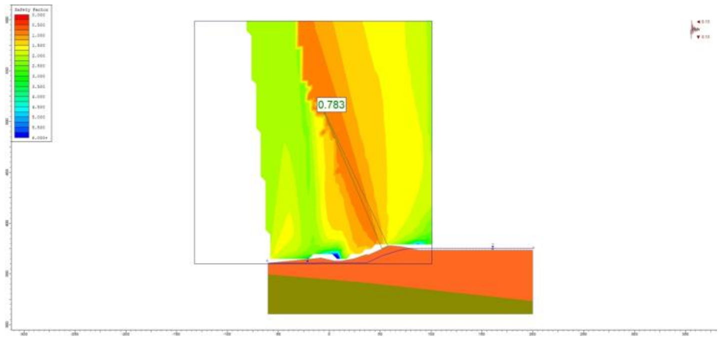

Figure 7 *Stability coefficient by profile 4/2 for dynamic loads, Yanbu method*

By comparison the obtained safety coefficients of the flotation tailing dam with the minimum permitted coefficients, according to the current standard for dams (SRPS U.C5.020), which for embanked dams over 15 m in height is a minimum of F_s = 1.50 in the case of permanent static loading, i.e. F_s = 1.00 in the case of an occasional dynamic load for occurrence the earthquake, it can be concluded that for profiles 4/2 and 9/1, the values for both coefficients (for static and dynamic loads) are significantly below the prescribed minimums.

3 CONCLUSION

Based on the above, the conclusion is that it is necessary to take the remedial measures in the profile zone 4/2 and 9/1 (in the area of pumping station, i.e. the water mirror), primarily by lowering the groundwater level and removing the water mirror from the inner slope of the flotation tailing dump embankment, as well as bringing the geometric elements of the dam, i.e. the mine disposal site in the zone of profile 9/1 into the designed parameters. Also, related to the stability of the RTH tailings dams, it is necessary to constantly monitor all changes on the dams: the occurrence of cracks, landslides, and subsidence, occurrence of percolating water, as well as the geodetic recording of the dams in the event of aforementioned occurrences, to timely observe all important changes on the endangered analyzed profiles.

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