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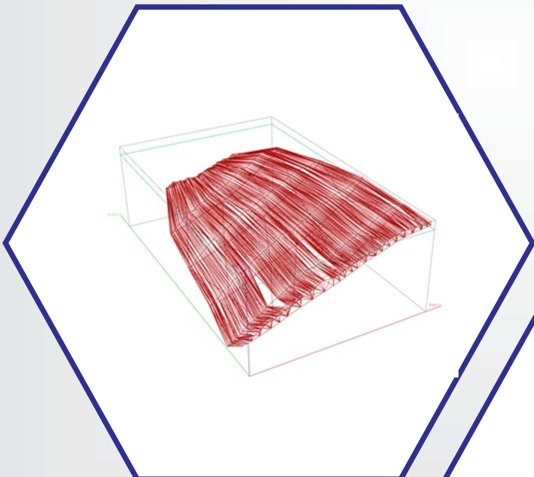

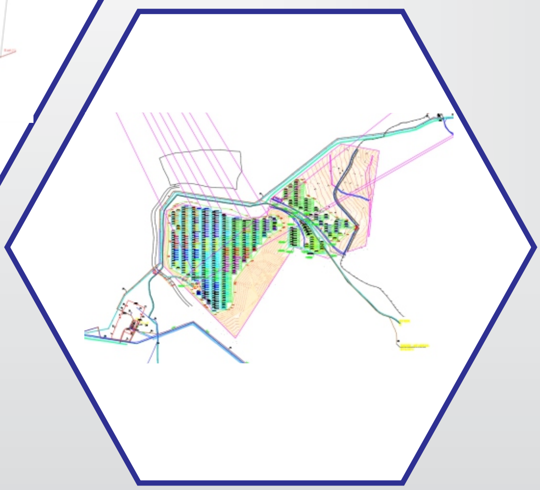

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Editor-in-chief

Dr Ana Kostov
Principal Research Fellow
Mining and Metallurgy Institute Bor
Orcid: 0000-0001-6436-9091
E-mail: ana.kostov@irmbor.co.rs
Phone: +38130/454-108; +38130/454-110

Deputy editor-in-chief

Dr Vesna Marjanović
Research associate
Mining and Metallurgy Institute Bor, Serbia
Orcid: 0000-0001-8005-5244

English Translation

Nevenka Vukašinović, prof.

Secretary of Editorial Board

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Preprinting

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19210 Bor, Alberta Ajnštajna 1
E-mail: institut@irmbor.co.rs
Phone: +38130/454-101

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Original Scientific Paper
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Aleksandra Milosavljević[*1], *Marijana Pavlov-Kagadejev*[*2], *Predrag Stolić*[**3]

THE IMPORTANCE OF DESIGN OF EXPERIMENTS[***]

Orcid: 1) https://orcid.org/0000-0003-3841-7357; 2) https://orcid.org/0000-0003-1090-6351;
3) https://orcid.org/0000-0002-2574-4765

Abstract

Design of experiments (DOE) is very meaningful and applied in various investigations from science to the industry in order to optimize the process itself. There are several such techniques and each of them has its own advantages, so it is very important to know the basics of DOE. Besides that, every problem, technology, product etc. is unique, so the knowledge about those is crucial as the first step. The most relevant fact is the dependence among variables – input factors and output responses as well as mutual connection between factors. In order to demonstrate the usability and adaptability of DOE for various purposes, some examples are given in this paper.

Keywords: *design of experiments, DOE, statistics, software*

INTRODUCTION

Design of experiments (DOE) plays a key role in science as well as industry, medicine, engineering, etc. Without a well-designed experimental plan, it is difficult to draw the reliable conclusions and make progress in research and development. It is a methodology that enables scientists and engineers to study the relationship between the input and output variables. DOE is a part of statistics which consists of planning, conducting, analyzing and interpreting tests in order to obtain relations and rules between the process factors and their responses. Besides that, the experiments are used to test laws, theories, and hypotheses. Based on the results of experiments, we can confirm or deny the certain claims. The planned experiments help in process optimization and mathematical modelling as well in order to obtain the optimized values and predict some future trends.

The first principles of DOE were postulated by Ronald Fisher in the early 1920s, who first applied it in the field of agriculture [1]. He studied how various factors such as weather conditions, soil conditions, and similar, affect yields in agriculture. Although the DOE method was first used in an

[*] *Mining and Metallurgy Institute Bor, Alberta Ajnstajna 1, 19210 Bor, Serbia,*
e-mail: aleksandra.milosavljevic@irmbor.co.rs
[**] *University of Belgrade, Technical Faculty in Bor, Vojske Jugoslavije 12, 19210 Bor, Serbia*
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agricultural context, the method has been applied successfully in the industry and all aspects of science since then. In the first time, the most common approach among all researchers was OVAT (One Variable at a Time) or OFAT (One Factor at a Time) [2]. This approach involves varying one factor over time while keeping other factors constant which requires resources and time and depends on the experience of operator. Those results are often unreliable, inefficient and may present a false process optimization. More efficient is to observe more factors at the same time in order to build the new or improved products or processes.

The fundamental principles in DOE are:

- factorial principle
- randomization
- replication
- blocking

The factorial principle shows how mu-ltiple factors (independent variables) influence a response (dependent variable). Randomization refers to the order of experiments, while replication is a rerun of complete experiments including setup. Replication increases the precision of experiment and also the signal-to-noise ratio when the noise originates from uncontrollable nuisance variables [3]. Blocking gives us an opportunity to restrict the randomization to one group of factors and later perform the other experiment with other factors. It is a method for increasing the precision removing the effect of known nuisance factors and batch-to-batch variability. So, the experiment is performed to samples of material from one batch, then to samples from another batch, and so on [3].

Over the years, the field of application of DOE has expanded and includes many areas [4 - 9]. Although foundations of DOE were posted very early, the expansion of application started from 2000. It could be noticed that DOE has the biggest role in medicine and engineering according to a number of publications which are given in Figure 1 [10].

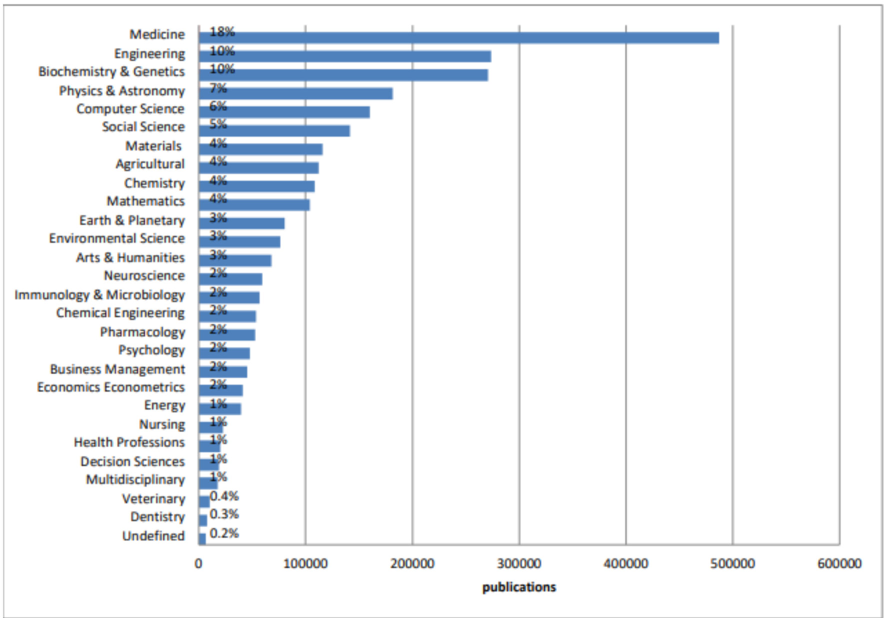


Figure 1 *An overview of the application of DOE to different scientific areas [10]*

THEORETICAL BACKGROUND OF DOE

Mathematics and statistics are found in the very theoretical basis of DOE, more precisely dispersion and regression analysis.

The basic task at the beginning is to determine the importance of the input factors (Xi) and dependence degree on the output responses (Yi) as it is shown in Figure 2.

Figure 2 *The beginning of DOE: input & output variables*

Different variants are possible: some input values - factors will significantly affect the output, while the influence of some factors will be completely negligible. Also, certain factors will have mutual dependence, so that must also be considered. Multifactorial experiment plans enable taking into account a large number of factors during research, for which there is no previous experience. After partial experiments, it is possible to eliminate those factors which are not significant from further consideration. This kind of case is the most complicated but is used when there are many unknown factors and can be described through a mathematical model:

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ij} x_i x_j + \cdots$$

In the case of a three-factor experiment, the matrix of complete experiment (full factorial design) will be as it is shown in Table 1.

Table 1 *Matrix of full factorial design (three-factor)*

No	X0	X1	X2	X3	X1X2	X1X3	X2X3	X1X2X3
1	1	1	1	1	1	1	1	1
2	1	-1	1	1	-1	1	1	-1
3	1	1	-1	1	1	-1	-1	-1
4	1	-1	-1	1	-1	-1	-1	1
5	1	1	1	-1	1	1	-1	-1
6	1	-1	1	-1	-1	-1	-1	1
7	1	1	-1	-1	1	-1	1	1
8	1	-1	-1	-1	-1	1	1	-1

More matrices could be made from this matrix for fractional factorial design. Calculations can be very complex, but various software is used for these purposes and is constantly being updated, such as SPSS, Statistica, JMP, etc.

DOE EXAMPLES

Experimental design has been refined over the years and progressed from application the basic statistical models to the specialized software for these purposes. Some of them are free, while the more demanding ones are not available to everyone. Below are some examples of created DOE using different software.

The development of new products or establishment the existing technologies is always a challenge in terms of the required funds. In order to avoid unnecessary costs that would be incurred by performing a large number of experiments, it is necessary to reduce that number to a minimum. Therefore, an example of LCD manufacturer, which is trying to satisfy a customer demand, was given using DOE to perform only those experiments that are assumed to be usable. The company needs pigment particles to be milled down to less than 200 nm so that the milling time is as short as possible, up to 5 h [11]. Detailed data for this DOE example, which was performed thanks to the use of specialized software [11], are given in Figure 11.

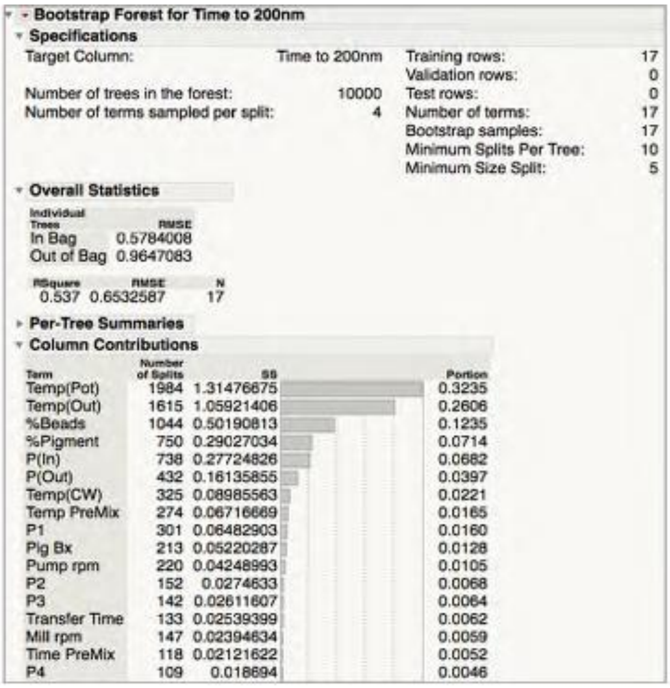


Figure 3 *Data from the 17 production runs [11]*

Within DOE, numerous calculations and graphs were provided, and the final results can be seen in Figure 4. As it can be seen in a part of diagram, the three confirmation runs showed milling times below the 5 h which was the assign at the first place [11]. In this way, DOE has proven to be very efficient in terms of minimizing the number of experiments and saving money.

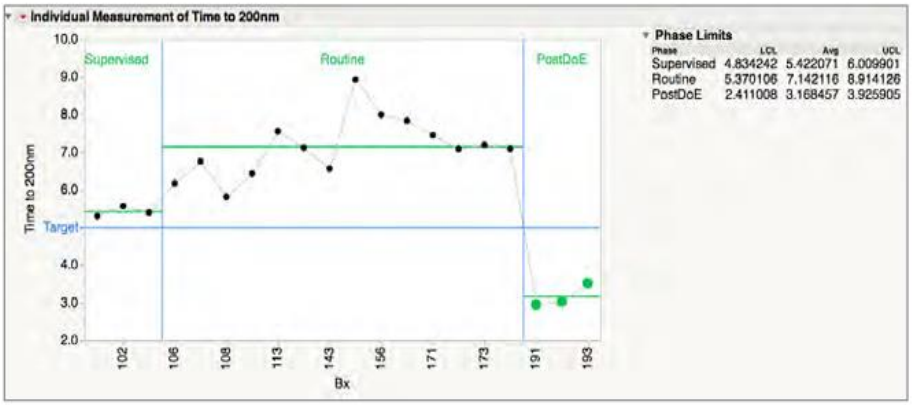
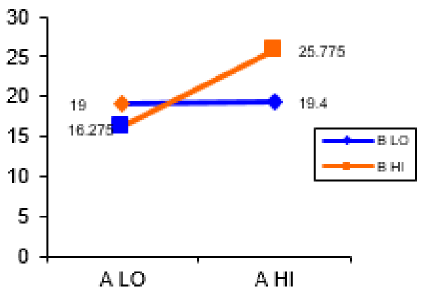


Figure 4 *Confirmation runs for DOE [11]*

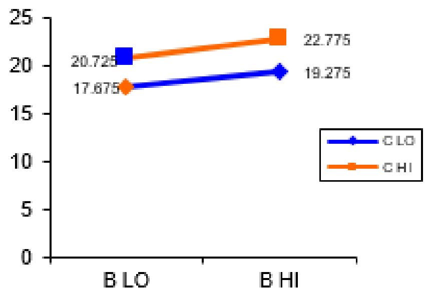
Another example, different from the previous one, without details and calculations is given in Figure 5. The difference between these two examples is in complexity and availability. From this example, the three factors and their values can be seen with the high (1) and low (-1) value for each factor, and as it can be seen in Figure 5b and 5c, there is difference in results depending on which interaction was chosen for calculation [12].

	Run Order	Boost	Moist	Cycle	AxB	AxC	BxC	AxBxC	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Avg
1	6	45	6	11	1	1	1	-1	17.9	17.6				17.75
2	8	45	6	16	1	-1	-1	1	20.3	20.2				20.25
3	1	45	10	11	-1	1	-1	1	15	14.8				14.9
4	4	45	10	16	-1	-1	1	-1	18	17.3				17.65
5	2	90	6	11	-1	-1	1	1	17.5	17.7				17.6
6	5	90	6	16	-1	1	-1	-1	21.5	20.9				21.2
7	3	90	10	11	1	-1	-1	-1	24.2	23.1				23.65
8	7	90	10	16	1	1	1	1	27.6	28.2				27.9

a)



b)



c)

Figure 5 *A DOE example: a) Factors & values; b) AxB interaction; c) BxC interaction [12]*

CONCLUSION

Experiment planning is an important aspect of any research. In that way it is important to know what we want to predict, which data are the input factors and which the outputs, what kind of relations exist between them. DOE is very powerful tool which can do more in less time.

Multifactorial experiments have a large number of factors for which sometimes there is no previous experience. With DOE, it is possible to minimize the number of experiments and to do modelling and prediction. So, DOE is useful not only for known, but also for unknown relations and factors. It helps to optimize the process and product quality as well.

DOE identifies factors which are significant and those which are not. With variation of factors and their interactions, it finds the best combination for requiring conditions.

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Original Scientific Paper
Mining

Dragana Savić[*1], *Dušan Tašić*[**2], *Katarina Milivojević*[**3], *Vanja Đurđevac*[**4]

MULTIDISCIPLINARY APPROACH TO THE ANALYSIS OF SUITABILITY THE LOCATION INTENDED FOR CONSTRUCTION THE SOLAR POWER PLANTS ON THE AREA OF A MINING WASTE DUMP[***]

Orcid: 1) https://orcid.org/0009-0002-3396-9435; 2 https://orcid.org/0000-0001-8005-9640;
3) https://orcid.org/0009-0000-1306-4044; 4 https://orcid.org/0000-0002-7973-0916

Abstract

By analyzing the world's best practices, the mining waste dumps can be turned into suitable land for location the renewable and clean energy power plants. There are several advantages that characterize these locations: they are characterized by the environmental conditions that are not acceptable for commercial or residential development. Generally, they are located near the existing roads and energy transmission or distribution infrastructure. They can be adequately zoned for renewable energy sources, provide the opportunity for employment in the urban communities and to promote cleaner and more cost-effective energy technologies, reduce the impact of energy systems on the environment (e.g. reduce the emission of harmful gases). As the solar power plants are usually built on large areas, which can lead to the changes in geological and geotechnical conditions along the project site, it is extremely important to design the appropriate geotechnical investigations to reduce or limit the geological uncertainty and determine the suitability of site for construction. In these cases, the geotechnical studies are very complex, striving for a multidisciplinary approach in analyzing the site in question for construction a solar power plant, respecting the current legislation, regulations, norms and standards.

Keywords: *solar power plants, renewable energy, geotechnics, mining waste dump*

1 INTRODUCTION

Using the publicly available information [1], the US Environmental Protection Agency (EPA) monitored the completed renewable energy projects on previously contaminated land, landfills, and mine dumps in order to identify the trends, educate stakeholders, and encourage the future development and site reconstruction. Solar power plants on landfills were a particularly attractive option for reconstruction and over time represented an increasing share in all locations intended for conversion of space (Figure 1).

[*] *Geoing Group doo, Kraljice Marije 25, Belgrade, Serbia*
[**] *Mining and Metallurgy Institute Bor, Alberta Ajnštajna 1, Bor, Serbia*
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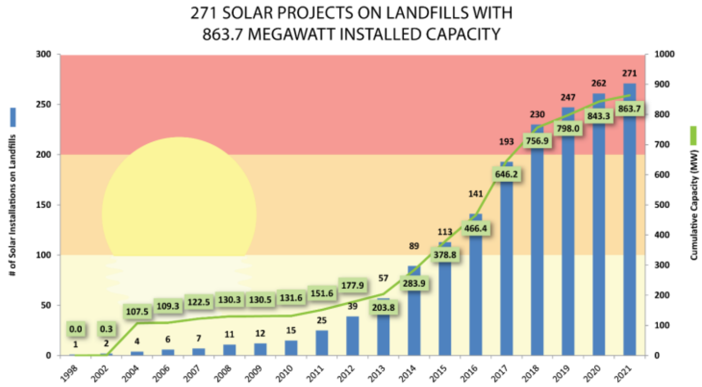


Figure 1 *Annual growth of solar installations on landfills (Source EPA) [1]*

In 2012, the solar power plants on landfills, intended for construction the renewable energy sources accounted for 39% of the total number of locations, while in 2018 that percentage was significantly higher (81%).

Regarding the potential of locations for construction the solar power plants on landfills and dumps, the ETA created a map of potential locations for their construction, available to the future Investors (RE-Powering Mapper), Figure 2 [1].

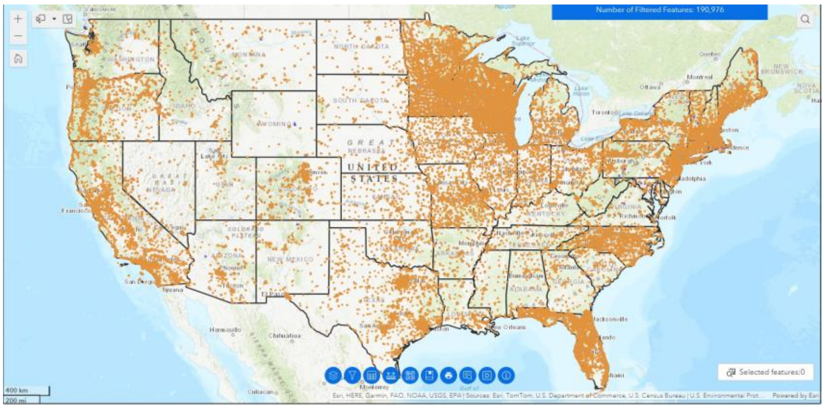


Figure 2 *RE-Powering Mapper application [1]*

The RE - Powering Mapper application enables searching:

- For multiple types of solar, wind, biomass and geothermal energy locations;
- According to several attributes including country, area, renewable energy capacity, distance to the nearest urban centers and more;
- Site Specific Screening Reports with Geotechnical Studies;
- Liaison with the EPA or state program that governs the land repurposing.

Geotechnical studies are necessary to analyze the site suitability for construction the renewable and clean energy power plants. This paper presents the recommendations for design the exploration and laboratory works, based on the latest world experience [2] (appropriate and optimal scope of geological and geotechnical explorations for the new solar power plants).

2 COMPLEXITY OF THE GEOTECHNICAL STUDY

For the new solar power installations, a good geotechnical study must bring together a range of multidisciplinary data and provide the following information:

- Geomorphological characteristics of the location, with an analysis of threats from external high water;
- Effect of high water on erosion, i.e. washing of material;
- Defining the relevant precipitation intensities for different probabilities of occurrence;
- Defining the relevant high water of torrential watercourses for occurrence probabilities of 1% and 2%;
- Defining the common meteorological parameters such as relative humidity, precipitation, temperatures, air pressure, sunshine, wind direction and intensity, wind rose, etc.;
- Defining the characteristic snow load, in accordance with the valid regulations and standards;
- Carrying out a precise zoning of the soil according to its geological and geotechnical characteristics with the delimitation of areas where photo power panels cannot be installed;
- Defining the panel funding methods: type, feasibility, limitations;
- Analyzing the aggressiveness of soil and groundwater, with an assessment the corrosiveness of foundation soil and groundwater on concrete structure, reinforcement in the reinforced concrete structure and steel structure;
- Providing data on electrical resistance of different grounding levels for appropriate designed groundings;
- Defining the geotechnical parameters of the represented soil lithotypes (soil classification, shear strength, deformability...) in which the foundations of panels will be founded;
- According to the Eurocode EC8-1, determining the type of soil at location;
- Assessment the possibility of earth excavating for the recommended type of machine for earthworks and digging trenches (providing data on depth and angle of temporary excavations);
- Determining the calculated bearing capacity and settlement for shallow foundations (foundation strips and foundation soles);
- Assessment the strength of deep foundations on piles, which is confirmed by the pull-out tests;
- Detecting and quantifying the geological hazards (risks) such as: earthquakes, watersheds, collapses, erosions, landslides;
- Defining the groundwater levels and main hydrogeological characteristics of different represented soil lithotypes;
- Determining the thermal resistance of natural soil and disposed material necessary to design the electrical trenches.

3 TYPES AND SCOPE OF MULTIDISCIPLINARY RESEARCH AND TESTS FOR GEOTECHNICAL STUDY

Research and testing methods must be carried out in accordance with the modern world trends, valid legal regulations on the type, scope and density of exploratory works and laboratory tests, providing the guidelines that can be used by the planners and designers of solar power plants, through the following stages:

3.1 Field exploratory works

- *Engineering geological mapping of the field* where the solar power plant zone should be registered and adequately displayed on the map and geotechnical sections of the following data on the field: lithological composition of the terrain and genesis, structural and textural characteristics of the field, hydrogeological phenomena, active geological processes and phenomena created in the field;
- Instrumental locating of exploratory wells, *execution of exploratory drill holes*, engineering geological mapping of the core of exploratory drill holes with sampling for laboratory-geomechanical tests, performing the standard penetration test in wells *(SPT);*
- *Performing a dynamic penetration test (DPT)* in order to obtain the soil compaction and dynamic soil resistance, through which the compressibility modules, bulk weights, undrained cohesion in clay soil and angles of internal friction in sand, gravel and clayey sand are determined by the correlation links. The dynamic penetration test is the most suitable test for evaluation the soil strength, feasibility of piling and precise zoning of the field, due to its ease of use, portability and lower cost of execution compared to the other techniques, Figure 3. The results of these tests can be correlated with the SPT test values in exploratory drill holes;

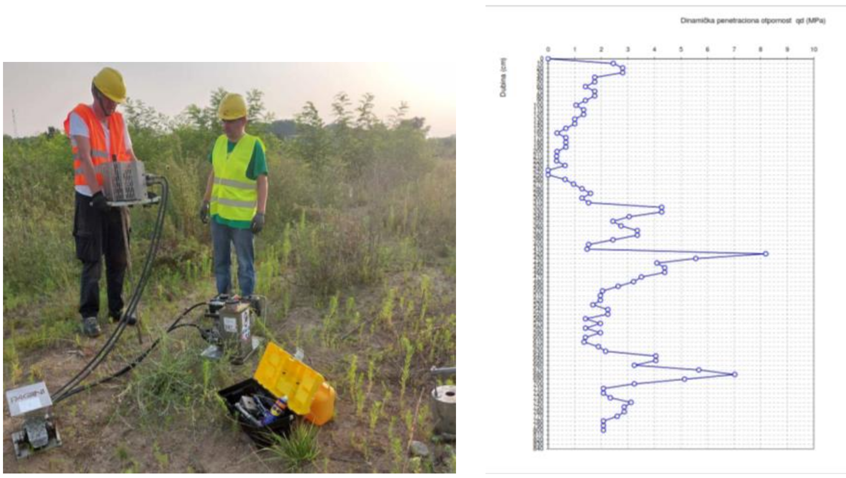


Figure 3 *Dynamic penetrometer Pagani DPM 30/20 with dynamic penetration resistance curve qd (MPa)*

- *Measuring the electrical resistance of the soil.* The most widespread and convenient technique for an electrical resistance analysis is the electrical tomography using a Venner array with 21 to 42 electrodes placed along the line [3]. With these configurations, the electrical resistivity of the soil laterally and in depth can be determined. The interpretation of these results makes it possible to create a representation of different geological units in a crosssection. Alternatively, the VES (Vertical Electrical Soundings) tests can be used, which determine the electrical resistance at a single point at various depths. This technique has been surpassed by the electrical tomography because, as stated earlier, it has the advantage of being able to make a geological interpretation over a larger area;

- *Measuring the thermal conductivity of the soil.* Thermal conductivity is the ability of soil to conduct or dissipate heat. It depends on the type of soil, humidity and temperature. In the case of electrical trenches, it is important to determine the thermal properties of the natural soil or thermal properties of the deposited material. Thermal resistance tests are carried out on the floors of the open pits, in the exploratory drill holes or exploratory excavations. This allows the thermal conductivity measurements to be performed in situ at the desired depth or at different depths. The undisturbed samples can be used for further testing in the laboratory with a range of moisture content (drying curve) or even with different temperatures [4]. The results of thermal conductivity must be followed by data for the density and moisture of sample, since these parameters largely determine the thermal properties of the soil, Figure 4.

(a) (b)

Figure 4 *Manual petrol drill Villager with power 2.2 kW (a) and heating and cooling curves on a representative sample (b)*

- *Conducting the exploratory excavations*, if it is necessary to classify the base for construction the paths/roads or to determine in detail the deformability of shallow foundations, using a dynamic plate, or an "in situ" CBR test.

The overview table 1 presents the minimum field explorations that must be carried out, depending on the size of the landfill, that is, the space intended for construction the solar power plant. The number of exploratory works should be increased or decreased depending on the local conditions (shape, slope, geology of the narrower exploration area, accessibility, existing facilities, etc.).

Any field exploratory work must be continuously controlled by a geotechnical engineer focused on the project needs and its details.

Table 1 *Recommended number of field explorations depending on the project area*

Surface (ha)	Number of exploratory excavations	Number of dynamic penetrometer test points	Number of electrical resistance test points	Number of conductivity temperature test points
<2	3-5	3-5	1-2	1-2
2-5	5-7	5-7	2-3	2-3
5-10	7-12	7-12	3-5	3-5
10-30	12-22	12-22	5-9	5-9
30-100	22-40	22-40	9-11	9-11
100-300	40-60	40-60	11-15	11-15
> 300	1 for every 5 ha	1 for every 5 ha	1 for every 20 ha	1 for every 20 ha

3.2 Laboratory testing

Laboratory tests can be divided into several groups. The purpose of testing the physical and mechanical properties of rocks and soil in the field is to obtain the physical and mechanical strength parameters, as well as deformability parameters required for the geostatic calculations.

The overview Table 2 presents the recommended number of laboratory analyses according to the number of samples:

Table 2 *Recommended number of laboratory analyses*

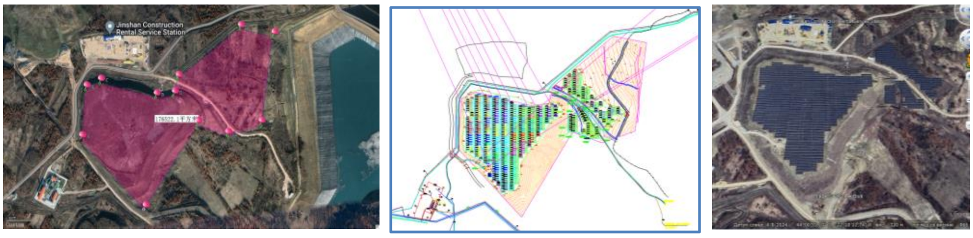
Test name	**Every 5 samples**
IDENTIFICATION TESTS	
Humidity, w (%)	5
Specific gravity, γs (kN/m^3)	5
Volumetric weight, γz (kN/m^3)	5
Granulometric composition of soil	5
Soil consistency limits - Atterberg limits	5
TEST FOR STRDENGTH DETERMINING	
Parameters of direct shear resistance - soil	0.5
MATERIAL USABILITY	
Modified proctor test	0.25
CBR index	0.25
ROCKS	
Density	0.75
Point Load Test	0.75
CHEMICAL ANALYSIS	
Content of organic and combustible matters	1
Sulfate content	1
Water aggressiveness on concrete	1
pH	1
Chloride content	1
Alkalinity/acidity determination	1
Content of soluble sulfates (in water and acid)	1
Determination of acidity according to Baumann-Gully	1

3.3 Cabinet works

Geological-geotechnical reports are directly related and can be divided into: Reports on Work Performed, Preliminary Reports and Final Reports.

4 CONSIDERATIONS AND RECOMMENDATIONS FOR THE CONSTRUCTION OF A SOLAR POWER PLANT IN THE SURROUNDINGS OF BOR

Based on the latest world experience, looking at and evaluating the hydrological, engineering geological, hydrogeological, geotechnical and chemical properties of the field, position and purpose of the solar power plant itself (Figure 5) [5], the following is significant:



(a) (b) (c)

Figure 5 *Solar power plant project from location to the construction (a, b, c)*

- Morphological characteristics of a wider site planned for construction are the result of geological processes in geological history, out o0f which the most significant are the intense tectonic effects and exogenous processes. The field on which the site in question is located is mostly flat, or with a slight slope. The absolute elevations of the field are between 342.05-345.98 meters above sea level (difference around 4.0 m);
- The field is located on the watershed of the Grčava basin, outside the effect of existing watercourses. The location is not threatened by the external high water, only by precipitation that falls on the location itself and which should be evacuated in an appropriate manner;
- According to the A. Casagrande criteria, the soil on the site is dangerous to the effects of frost;
- Adopt a minimum of 1 m for the depth of soil freezing;
- The value of snow load on the ground for location is: Sk = 2 kN/m^2;
- Dominant wind direction is from southwest to the northeast;
- Regarding the soil corrosivity, only one sample showed a high level of sulfate > 200 mg/kg, which places a field part in the middle with the medium corrosive potential;

- Relative air humidity ranges from 70%-86%, the mean value is 78%, which according to the degree of corrosiveness to steel, according to this parameter, places the location in the C4 category;
- It is recommended that the average thickness of a galvanized layer on the surface of a spiral steel pile should not be less than 80 μm, and the local minimum thickness should not be less than 60 μm;
- The field, up to the test depth (8.00 m), is built of sediments of the anthropogenic origin and Quaternary age, except for the area for construction of connection-distribution facility where the Miocene sandstones are represented;
- According to the GN-200, the sediments of anthropogenic origin and Quaternary age belong to the category III, while the Miocene sandstones belong to the category IV-V;
- On the basis of performed geophysical measurements, it can be said that the humidity at the location in question ranges from 13.5% to 31.8% to a depth of 1 m, or from 20.1% to 40% to a depth of 2 m. On the basis of performed analysis, it can be stated that the thermal conductivity values for humidity of samples from 13.5% to 22.8% range from 0.709 W/mK to 0.864 W/mK with the heating temperature range from 23.5°C to 28,7°C. Thermal conductivity values for humidity samples from 25% to 40% range from 0.894 W/mK to 1.049 W/mK with an average heating temperature range of 23.2°C to 25.6°C. The average values of electrical conductivity parameter (σ) to a depth of 1 m are about 221 ms^{-1} and 208 ms^{-1} to a depth of 2 m. Based on all the measurements, performed at location 01, the mean values of measured parameters are shown, Table 3.

Table 3 *Mean values of measured parameters*

Mean parameter values at location 01		
Parameter	Depth 1.0 m	Depth 2.0 m
Heating temperature range (°C)	23.5 – 28.7	23.2 – 25.6
Thermal conductivity range	0.759—0.969	0.821 – 1.049
Thermal conductivity	0.846	0.915
Humidityω_{mean}(%)	22.6	27.4

- On a total of 2 engineering geological profiles, the conditions prevailing in the field were interpreted;
- By analyzing and synthesizing the results from the field explorations and laboratory tests, it can be said that there are 2 quasi-homogeneous environments on tested field, separated by their genetic type (anthropogenic sediments and Quaternary deposits), more important engineering-geological properties and physical-mechanical characteristics;
- During the performing of exploratory drilling in the drill holes, no underground water was found in the field;

- Design the object at 8° MCS. According to the Eurocode EC8-1, the site belongs to the soil type D;
- The expert survey of the field did not reveal the morphological forms that would indicate the movement of earth masses, at the location and its immediate surroundings. The general conclusion is that the field in natural conditions is stable, and as such suitable for any type of urbanization with respect to the recommendations;
- In an interactive sense, by analyzing the engineering geological sections of the field, on one side, and the object on the other, the quasi-homogeneous zones were distinguished, which differ from each other in geotechnical characteristics, and the geotechnical models of the field were adopted accordingly;
- According to the calculations, for the foundation depth D_f = 1.30 m and D_f = 1.50 m and different dimensions of the foundation plates (4.05 x 5.55 m, 12.50 x 3.50 m, 10.80 x 3.50 m and 6.00 x 2.50 m), the calculated values of the bearing capacity of the foundation soil (with a buffer layer d = 10 cm) are higher than the designed loads;
- Calculation of the settlement size obtained for foundation singles is for the central point s = 0.00-4.69 cm;
- The calculated bearing capacity and settlement of the spiral steel pile is determined for different lengths and diameters of the pile. Values of the safety factor (Fs) that do not meet the stability condition are marked;
- The results of geostatic calculations of the landfill slope stability showed that the stability in relation to the shearing is ensured. The stability analysis was performed for the case of calm loading (without an earthquake) and for the case of an earthquake, where the impact of earthquake was simulated by adding the horizontal forces whose values were adopted for a specific location;
- Based on the new knowledge gained about the field, the recommendations for designers during construction and exploitation are listed, what will ensure the safety, durability and full operational usability of the solar power plant facility.

5 CONCLUSION

Evaluation the location suitability of the mining waste dump in terms of sustainability is a difficult task and should be solved comprehensively [6]. A good geological-geotechnical study is always necessary in evaluation the suitability for construction a solar power plant, providing the valid data for design, reducing risks and long-term problems during the facility exploitation. In addition to the above, it must not be forgotten the administrative needs arising from guarantees during the financing or purchase-sale process.

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Dragan Ignjatović[*1], *Lidija Đurđevac-Ignjatović*[*2], *Dušan Tašić*[*3], *Vanja Đurđevac*[*4]

COMPARATIVE ANALYSIS OF A COMPRESSIVE STRENGTH OF CONCRETE WITH AND WITHOUT MICRO-REINFORCEMENT[**]

Orcid: 1) https://orcid.org/0000-0003-2333-6853; 2) https://orcid.org/0000-0002-1113-5360; 3) https://orcid.org/0000-0001-8005-9640; 4) https://orcid.org/0000-0002-7973-0916

Abstract

The applicability and purpose of the micro-reinforced concrete is such that they are made according to the special systems and recipes with the addition of additives, fibers or additives and fibers, which should provide the concrete with the most optimal properties for each of the specific cases of use. The micro-reinforced concrete with polypropylene fibers is used for shotcrete, in the remedial mortars, for making floors, in plaster mortars, to improve the fire resistance and so on. A compressive strength is one of the physical and mechanical characteristics, that is partially mentioned in this paper.

***Keywords**: micro reinforced concrete, fibers, compressive strength*

1 INTRODUCTION

Concrete, a man-made material, is the most widely used material around the world. Following its production, a figure of about six billion cubic meters per year was reached.

The economic turnover of the concrete industry is about 35 billion dollars and employs about two million workers in the USA alone. China consumes about 40% of the world's consumption of cement, i.e., concrete [1].

In the shortest and most simplified way, it can be said that concrete is created by solidification a mixture of mineral binder, stone aggregates and water. At the same time, the mineral binders and water are active ingredients of concrete, and stone aggregates are ingredients that serve to fill the concrete mass without chemical participation. Various types of binding materials are used to make concrete, such as: cement, gypsum, lime, asphalt, epoxy resins. Depending on the type of binding material, the following are obtained: cement concrete, gypsum concrete, lime concrete, asphalt concrete, epoxy concrete, etc. Aggregates for making concrete can be natural or artificial. The most commonly used aggregates are the natural gravel and sand, crushed stone, various types of slag, etc. Stone aggregates are the concrete gravel and concrete sand, and less often artificially crushed stone. In practice, the cement concrete is mostly used. The Portland cement is used as a binder. Different additives and fibers can be present in the concrete mixture with the

[*] *Mining and Metallurgy Institute Bor, Alberta Ajnštajna 1, 19210 Bor, Serbia, E-mail: lidija.ignjatovic@irmbor.co.rs*

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aim of improving the corresponding characteristics of the concrete [2].

Today, the "special concretes" have their share in the concrete industry that are made according to the special installation systems and recipes with the addition of additives, fibers or additives and fibers, which should provide the concrete with the most optimal properties for each of the specific cases of use.

2 CHARACTERISTICS OF THE MICRO-REINFORCED STRUCTURES

The term micro-reinforced concrete usually refers to the composites, the basis of which is 0/4 mm coarse sand, coarse aggregate (up to 16 mm), binders and micro-reinforcements. How much micro reinforcement (microfibers) will be used depends on many factors, but the most important is the property of concrete [3]. Most often, this amount is in the range of 0.1-5% in relation to the total volume.

The role of fibers in concrete is multiple, but their greatest contribution is to increase the strength while simultaneously reducing the volume deformations during shrinkage [4].

Also, the addition of fibers can significantly contribute to increase the resistance of composite to wear, better adhesion at the contact of old and new concrete, increased resistance to the dynamic influences, resistance to the effects of fire and similar [5].

3 APPLICABILITY OF MICRO-REINFORCED CONCRETE

Micro-reinforced concrete is used in the structural elements where the classic reinforcement is not crucial for the safety and integrity of the structure. It is important to point out that in the load-bearing structural elements, the fibers cannot completely replace the classic reinforcement.

The basic division of fibers used for the micro-reinforcement of concrete is steel, polymer, glass and natural fibers. The most commonly used fibers are steel and polypropylene, Figure 1. The important properties of fibers are, in addition to the geometrical characteristics, tensile strength, modulus of elasticity and elongation at break. The usual technological procedures of production, transportation, installation and maintenance of concrete are possible with the micro-reinforced concrete [6].

a) b)

Figure 1 *View of fibers: a) steel b) polypropylene*

Micro-reinforced concrete with steel fibers is used in the industrial floors, prefabricated elements, for the slope stabilization, in tunnel construction, in the road slabs, airport runways, then in the parts of hydrotechnical facilities, thin shells and domes, for rehabilitation and strengthening the structures and in the structures exposed to high temperatures, shock load, seismic action or explosions.

Micro-reinforced concrete with polypropylene fibers is used for shotcrete, in remedial mortars, for making floors, in plaster mortars, to improve the fire resistance and similar.

The minimum amount of steel fibers in concrete should be 20 kg/m^3, and polypropylene 0.9 kg/m^3.

4 TESTING THE COMPRESSIVE STRENGTH OF MICRO-REINFORCED AND PLAIN CONCRETE TEST TUBES

As already mentioned in the text, the micro-reinforced concrete has the improved physical and mechanical properties, compared to the same concrete made without the micro-reinforcement. The aim of this research was to demonstrate the increase in compressive strength of micro-reinforced concrete.

The compressive strength measurement of the test tubes of both types of concrete was performed on a hydraulic press with a capacity of 3000 kN, Figure 2.

Figure 2 *Device for compressive strength measurement*

Based on the known recipe, the six test tubes with the same concrete content were made, except that in three test tubes, according to the already mentioned minimum amount of fibers, the polypropylene fibers were added, Figure 3. In addition to all the already mentioned physical properties of concrete, emphasis is placed on the compressive strength of the test tubes, i.e., ratio of compressive strength of the test tubes with and without fibers.

a) b)

Figure 3 *Concrete tubes: a) without reinforcement and b) with reinforcement*

The parameters, used in measurement the compressive strength of the concrete test tubes, are:

- Force application speed of 13.5 kN/s,
- Dimensions of the test tubes are: 150 x 150 x 150 mm.

After 28 days of care the test tubes, the following results were obtained, shown in Table 1 and Table 2:

Table 1 *Test tubes without micro-reinforcement*

Order number	Maximum breaking force [kN]	Compressive strength [MPa]
1.	875.543	38.913
2.	878.310	39.036
3.	917.888	40.795
Mean value	890.573	39.581

Table 2 *Test tubes with polypropylene micro-reinforcement*

Order number	Maximum breaking force [kN]	Compressive strength [MPa]
1.	1240.695	55.142
2.	1273.500	56.600
3.	1304.258	57.967
Mean value	1272.803	56.569

According to the obtained results of the compressive strength measurement, by addition the polypropylene fibers to the basic recipe for concrete, and according to the mentioned regulation of 0.9 kg/m^3, it can be seen that an increased compressive strength of approximately 43% was achieved.

5 CONCLUSION

After testing the compressive strength of concrete test tubes with and without micro-reinforcement, it can be seen that the fibers contribute to a significant increase of this mechanical characteristic.

In order to get a complete view of improvement the quality of micro-reinforced concrete, it is necessary to conduct a number of other physical and mechanical tests, in order to confirm their quality and use.

Therefore, such composites could be used in construction in various areas, such as: making the cement screeds, industrial floors, open concrete surfaces and similar.

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Original Scientific Paper
Mining

Dušan Tašić[*1], *Ljubiša Obradović*[*2], *Dragan Ignjatović*[*3], *Ivan Jovanović*[*4], *Divna Pacić*[*5]

PROJECT SOLUTION OF INTERVENTION MEASURES AT THE DAM OF THE "ŠAŠKI POTOK" TAILING DUMP[**]

Orcid: 1) https://orcid.org/0000-0001-8005-9640; 2) https://orcid.org/0000-0002-6715-4173; 3) https://orcid.org/0000-0003-2333-6853; 4) https://orcid.org/0009-0000-5174-3734; 5) https://orcid.org/0009-0006-2930-670X

Abstract

There was an increase in the groundwater level and increased waterlogging of the terrain at the "Šaški potok" flotation tailing dump in Majdanpek, due to a damage of drainage collector. The stability of man-made materials of the landfills is directly dependent on the position of the free water surface in the body of the landfill. The rise of the underground water level leads to a decrease in the strength parameters of the materials from which the dam is built, which reduces the safety factor of the outer slope. For the purpose of interventional lowering the high level of underground water in the main dam body of the landfill, a hydrodynamic terrain model was created and various conceptual solutions were evaluated, using the hydrodynamic analysis. A group of wells was selected as the most optimal technical solution for lowering the groundwater level below the designed elevation.

Keywords: *flotation tailing dump, high groundwater level, hydrodynamic model, group of wells*

1 INTRODUCTION

The "Šaški potok" tailing dump is located 3 km south of Majdanpek. It serves as a retention tailing dump, which receives tailings from the "Valja Fundata" flotation tailing dump in emergency cases.

For the purpose of draining the tailing dump, a drainage system of pipelines, wrapped in geotextile, was installed in the basement. During January 2024, the main collector was damaged. Shortly after that, the observation piezometers showed an increase in the underground water level, as well as an increase in the water level on the terrain surface. The last applied geological surveys were conducted in 2022. As a part of them, the hydrogeological surveys of the site in question were also carried out. Since there was a need to define a technical solution for lowering and regulating the underground water level, the continuation of numerical interpret-

[*] *Mining and Metallurgy Institute Bor, Alberta Ajnstajna 1, 19210 Bor, Serbia, e-mail: dusan.tasic@irmbor.co.rs*

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tation of the collected and presented research results with the analyses of various technical solutions was undertaken.

This paper presents the basic concept and technical solution of groundwater level regulation and expected effects of the system [1]. The aim of this paper is to present a variant of solution for lowering the groundwater level, using the method of hydrodynamic analysis

2 DEVELOPMENT OF A HYDRODYNAMIC MODEL

Due to the need to develop a technical solution for intervention defense of the dam on the accidental tailing dump, the development of a hydrodynamic (mathematical) model of this area was started [2]. The model itself was created using the finite difference method, using the MODFLOW package. The space of the hydrodynamic model is along the Y axis from 7,576,300 to 7,576,880 that is along the X axis from 4,917,240 to 4,917,602. The model has a rectangular shape with dimensions of 580×362 m, i.e. a total area of 0.21 km^2. Discretization the area of water flow was done with 5×5 m cells. The total number of cells per model layer is 8,352.

On the basis of everything stated, and from the aspect of the issued regime, it can be concluded that the largest underground water reserves are formed in the body of flotation sand with the mean value of filtration coefficient of $2.5*10^{-5}$ m/s. The depth to water ranges from about 14 to about 38 m, measured from the ground surface. The geometry of flotation sand is predisposed by the paleomorphology of terrain.

Drainage of flotation sand is artificial, that is, via a built-in drainage system. By analyzing the level of underground water and reconnaissance in the field, it can be concluded that the drainage system was very functional, from the aspect of hydrogeological profession.

The general conclusion is that a spring with a free level is formed within the flotation tailings on the entire area of retention tailing dump. The other hydrogeological collectors with different filtration characteristics are also registered, but they are sparsely distributed, so they do not significantly participate in the total reserves of underground water. Also, conditionally waterless parts of the terrain are separated, which are represented by the compact or crushed shale, andesites and clayey material.

Analyzing the conditions of recharge and drainage of groundwater, the boundary conditions were set on the hydrodynamic model that most closely describe the natural flow conditions. The applied boundary conditions are shown in Figure 1.

The so-called external boundary conditions that define the flow area and conditions of recharge and drainage and **internal boundary conditions** were used for the hydrodynamic model.

The following types were used for the external boundary conditions:

- CHD (Constant Head) – this type of boundary condition was used on the western part of the model, which simulates the constant flow of fluid into the tailing dump body;

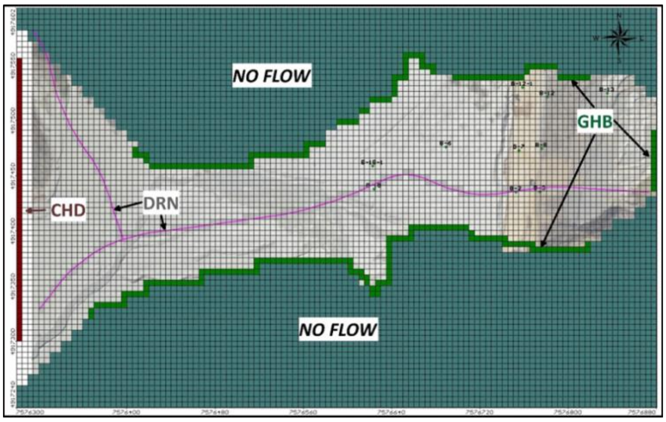

Figure 1 *Applied boundary conditions*

- GHB (General Head Boundary) – used for the northern and southern part of the model, which simulates the lateral inflow and outflow of groundwater; it was also used as a boundary condition on the east to simulate runoff to the lake;

The following types were used for the internal boundary conditions:

- DRN (Drain) which simulates runoff along the drainage collector.

By calibrating the model, this set of used boundary conditions proved to be the most reliable.

As for the filtration characteristics for the entire body of flotation sand, the mean value was used $k_x = k_x = k_z = 2{,}5\times10^{-5}$ m/s.

The calibration result of this model is shown on the hydroisohypse map and residual difference between the calculated and measured groundwater levels for the period 2022-2023, shown in Figure 2.

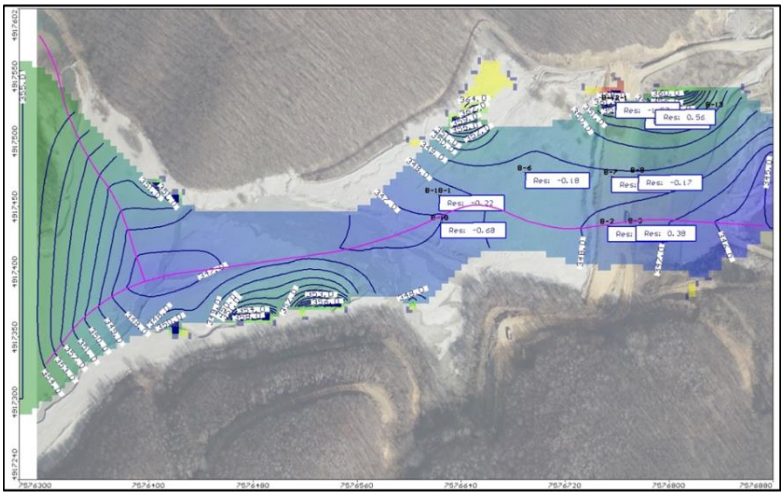

Figure 2 *Hydroisohypse map with residual difference on piezometers for the measured groundwater level based on the observation results from 2022 and 2023*

After it was observed in the field in 2024 that there was a breakdown of the drainage collector, i.e., filling of material inside the drainage itself, daily monitoring of the groundwater level on piezometers was started. A trend of increasing groundwater levels was observed on average of 4-13.5 m on the piezometers B-7, B-8 and B-18.

Based on the analysis of surface and underground water regime, and based on the ortho-photograph and measurement the groundwater level, it is completely clear that there has been a worsening of the groundwater drainage, and thus the danger of dam on the emergent tailing dump.

After that, a new hydrodynamic analysis was carried out, where the same hydrodynamic model was used, but the permeability of drainage collector was reduced. This type of calibration resulted in the following map of hydroisohypsis with the residual difference on piezometers, as shown in Figure 3.

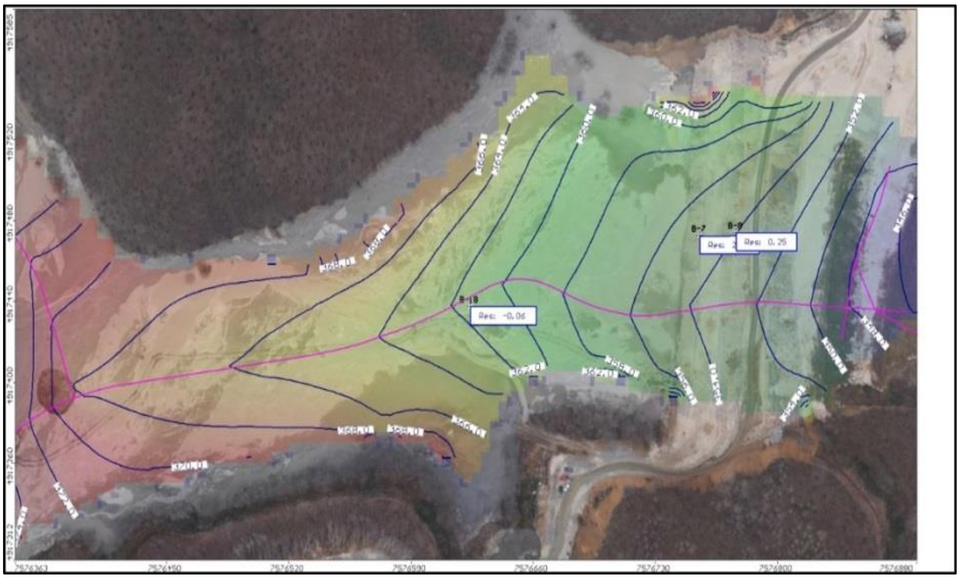

Figure 3 *Map of hydroisohypsis and residual differences based on measurements from April 2024*

Practically, the calibration of model [3] after the drainage collector failure was carried out only by reducing the filtration characteristics of the drainage collector (boundary condition of the DRN type). The model analysis showed an atrophy of the drainage collector permeability, inhomogeneous along its length, ranging from 30-70%.

The change in the groundwater level from 2022 to April 2024 is shown on the map in Figure 4.

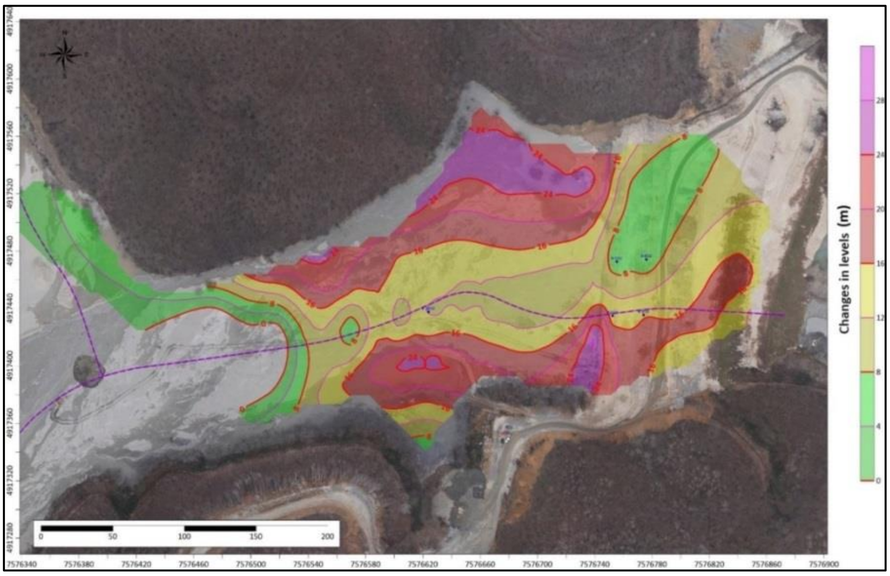

Figure 4 *Change in the groundwater level (in m) for the period November 2022-April 2024*

The highest intensity of groundwater level rise was in the part of contact between the flotation sand and parent rock, but it was also not small along the drainage collector. From all of the above, it is clear that there was a redistribution of the groundwater recharge and drainage conditions as a result of the drainage collector failure.

3 PROJECT SOLUTION OF THE INTERVENTION PROTECTION OF THE DAM

The process of changing the level of underground water was observed, after the failure drainage collector at the tailing dump. It was necessary to find a technical solution that could, in a short period of time, lower the level of underground water, as close as possible to the level before the drainage collector failure, especially immediately around the dam. On the other hand, it needs to have the ability to capture larger amounts of groundwater, if the unfavorable trend of rising levels continues.

The groundwater reduction is done in different ways, the choice of which depends on the specific geological conditions at the location. In choosing the water reduction technology, numerous factors are taken into account: conditions of groundwater occurrence, soil characteristics, thickness of aquifer, volume of drained soil, soil filtration coefficient, duration of water level reduction procedure and technological parameters of technical equipment [4].

Analyzing the different conceptual solutions, it can be concluded that the most suitable facilities for quick intervention on lowering the groundwater level and maintenance at a given elevation are a group of wells. The wells, as objects, are dimensioned so that they can respond to the problem even if the unfavorable trend of underground water level increase continues, and in terms of dam protection.

The designed position (Figure 5) and expected depth of the well are shown in Table 1.

Table 1 *Designed wells*

Well designation	Y	X	Prognostic depth (m)
EB-1	7576759	4917434	50
EB-2	7576758	4917459	52
EB-3	7576763	4917484	50
EB-4	7576734	4917459	45

The wells are dimensioned so that they have the possibility of a wide range of exploitation with capacities from 0.5 l/s to over 10 l/s depending on a further increase of the groundwater level, with the aim of maintenance the groundwater level at the given elevation.

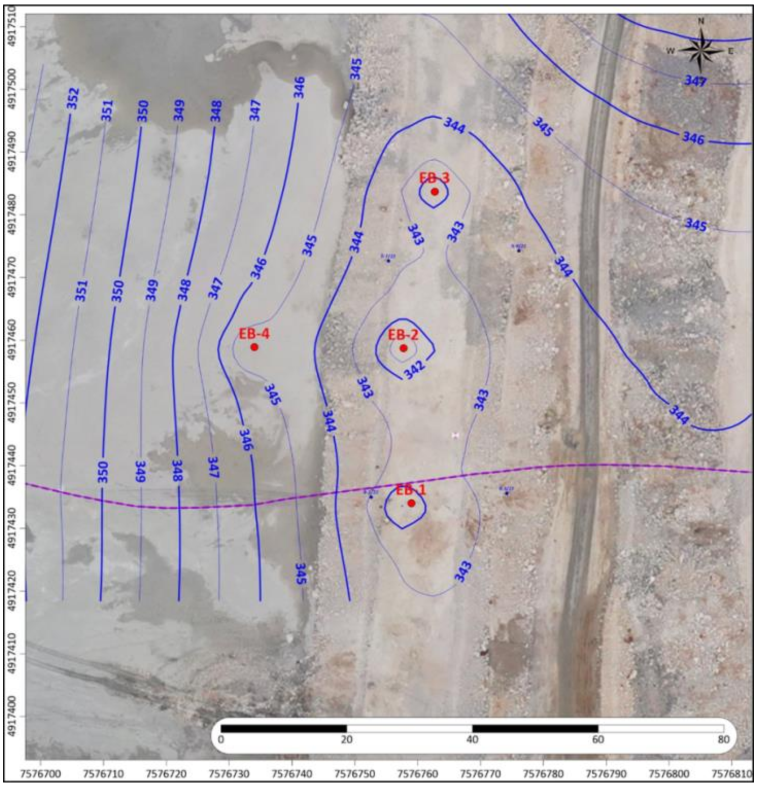

Figure 5 *Map with expected hydroisohypses after four wells are put into operation*

The expected lowering of the groundwater level after the well is put into operation is shown on the map in Figure 6.

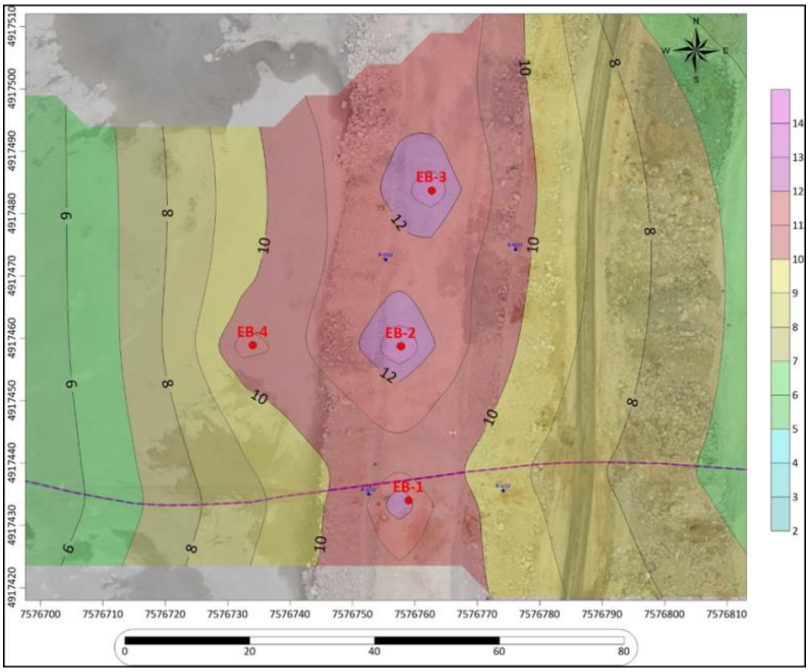

Figure 6 *Expected lowering of the groundwater level*

After construction, the contractor must use his equipment to perform the individual testing of wells and test exploitation (group test of wells), in order to procure the well pumps and electronic equipment for maintenance the level of groundwater at the given elevation after calculation the optimal capacity.

Drainage from the well should be to the nearest receiver, that is, to the pumping station. At the end of all field work, it is necessary to evaluate the technical solution [5] on the effects of dam protection, dimensioning and procurement of well pumps, electrical equipment, and water drainage to the receiver.

CONCLUSION

The predicted hydrogeological measures to lower the level of underground water were designed right next to the main dam of the tailing dump. These measures cannot replace the function of drainage collector in the entire area of the emergent tailing dump "Šaški potok", but represent the intervention measures, in order not to endanger the dam, as a result of the rise in the level of underground and surface water.

Using the hydrodynamic analysis, it was determined that in order to achieve the effects of lowering and regulating the underground water level, it is necessary to build four wells. Their position and expected effects of their installation were modeled and determined. The work presented is the basis for some of the multi-criteria optimization methods and selection the optimal variant of the groundwater defense system.

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Original Scientific Paper
Mining

Radmilo Rajković[*1], *Daniel Kržanović*[*2], *Miloš Stojanović*[*3], *Dragan Šabaz*[*4], *Ivica Vojinović*[*5]

BLOCK METHOD OF EXCAVATION WITH BACKFILLING THE EXCAVATED SPACE OF THE BOR RIVER DEPOSIT[**]

Orcid: 1) https://orcid.org/0000-0001-5905-6613; 2) https://orcid.org/0000-0003-3841-8667;
3) https://orcid.org/0000-0003-0044-5491; 4) https://orcid.org/0000-0002-1373-413X;
5) https://orcid.org/0009-0006-3658-6922

Abstract

The position of deposits and ore bodies for the underground mining in the underground mine Jama Bor, in relation to the terrain surface, old works of the Jama and Open Pit in Bor, and in relation to the mining infrastructure limits the selection of excavation methods with the applied technologies up to now. This paper presents the block method of excavation with backfilling the excavated space with the paste backfill of the Bor River deposit.

Keywords: *Bor River deposit, block method of excavation, paste backfill*

INTRODUCTION

The partially filled the old Open Pit Bor is situated above pit works and ore bodies, with the possibility of accumulating large amounts of water. The geological-mineralogical and chemical specificities of the ore sites with the goals of required productivity and economy of ore exploitation, as well as safety at work, additionally narrow a selection of mining methods. There are a settlement, roads, city and industrial sewerage and infrastructure, railway with a tunnel, cemetery, collector for several surface watercourses as well as the industrial facilities are located above the deposit of the terrain surface.

The excavation methods with caving, in addition to the characteristics of low ore utilization from the deposit, high metal depletion and environmental damages for use in the ore excavation in the underground mine Jama Bor, require large investments for relocation the buildings and infrastructure on the terrain surface or are completely inapplicable due to the risk of inflow the accumulated water [1].

The excavation methods with hydrofilling with cycloned flotation tailings have the low productivity and economy. The costs of transport and installation of backfill with drainage are high. The bearing capacity of the backfill for excavation the pillars and movement of machinery is insufficient [1].

The ore excavation using the empty space methods ensures the high capacities and productivity without ore depletion. The disadvantages of these types of methods are

[*] *Mining and Metallurgy Institute Bor, Alberta Ajnštajna 1, 19210 Bor, Serbia,*
E-mail: radmilo.rajkovic@irmbor.co.rs

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the high losses of ore in safety pillars and plates, static uncertainty and endangering the stability of entire system. By subbuilding the excavation, the economy is lost, and the problem is not solved permanently. Leaving the empty spaces in the underground mine Jama Bor is a great danger for the mine operation of and safety of employees. The disadvantages of these methods are solved by a subsequent filling of excavation with solidifying backfill. By backfilling the excavation, the system stability is ensured and enables the excavation of pillars, formed in the first phase, and achieves a high ore utilization from the deposit [1].

The ore excavation using the methods with backfilling of empty spaces with appropriate physical-mechanical and technological characteristics, in the existing conditions of location the ore bodies, layout of infrastructure and industrial plants, is solved by the underground exploitation of copper ore in the Bor deposit.

Backfilling of excavation with a high-density backfill, which has the property of hardening and then suitable load-bearing capacity, becomes a condition for selection the modern excavation methods with highly productive equipment and high capacities in an environmentally friendly way, i.e., for excavation the Borska River deposit.

EXCAVATION METHOD

A correct selection of the excavation method, as well as a strict application of the designed technology, enables the optimal technical and technological parameters to be achieved, where a care should be taken to ensure that the excavation is carried out cleanly, without leaving ore in the form of islands, edges, pillars, etc. [2]. Based on the available data on the ore body and set boundary elements in selection the excavation method, it is necessary to determine the possible excavation method in principle and to pay a special attention to the following important conditions.

- High productivity,
- Application of highly productive equipment,
- Low preparation coefficient,
- Matching the excavation geometry with the working environment,
- High degree of utilization the available ore reserves,
- Minimum depletion (dilution) of mined ore,
- Realization of designed production capacity,
- Flexibility at work,
- High safety of the employed personnel during excavation,
- Low operating costs,
- Minimum investment costs.

Taking into consideration the previous principles, analysis of the working environment and experience in the field of underground exploitation, the method of block excavation with backfilling of the excavated space was adopted [3].

Excavation preparation consists of development the excavation corridors. The number of excavation corridors to access the block is usually in a function of the block size, but in this particular case, two excavation corridors were designed (at the bottom and at the top along the block axis). The excavation corridors are permanent and reinforced with appropriate subgrade, and the minimum costs per unit of mined ore are achieved with them. Access to the block on each upper floor is required for drilling and blasting as well as filling, and on the lower floor for loading.

Division is necessary on each floor, through the floor corridors that are developed in the deposit itself, forming the sectors for the phased "attacking" the pit field, which significantly reduced the start of excavation in the pit field.

The ore knocking down in the block is carried out by crushing using the drilling and blasting. Access to the block is achieved by development the excavation corridors longitudinally in relation to a direction of deposit excavation. The first phase is to create a vertical opening (notch) between the floors that define the planned surface of the block front. The block formation is achieved by blasting a fan of boreholes between two levels, but for the initial front opening or block face, it is necessary to make an initial opening, i.e. an expansion that gives a sufficient gap for ore compensation by blasting the initial fan of boreholes. An opening or compensation chamber is usually located vertically in the block center or side at the initial strike point in the orebody. The compensation chamber is formed in the full height of block and, in this case, it connects the upper drilling corridor with the lower loading corridor.

Using the appropriate explosive charge ensures a disintegration over the entire vertical surface of the block face and formation a free surface for the next blasting sequence. The number of blasting sequences (production rings) mainly depends on the geomechanical characteristics of the working environment. That length ranges from a minimum of 30 to a maximum of 50 meters. In principle, the length of block excavation must be in a function of preserving the stability of walls. After reaching the designed block length and removing the blasted ore, that block segment is filled with backfill paste and after hardening the same according to the certain excavation dynamics in the block, the excavation continues.

In the same way, the block formation is initiated in the continuation of excavation, with the fact that care must be taken not to damage the backfill in the previous segment of block. This can be achieved by leaving a so-called clear ring (belt) between the cut-off zone in which a compensation hole is created (drilled) as well as drilling a fan of blasting boreholes. The blasting is then carried out in the order starting from the boreholes in the immediate vicinity of the drilling and ending with blasting the boreholes in the cleaning ring. This procedure ensures a minimum dilution with backfill from the previous segment of the filled block.

The shape of a designed block is achieved by blasting the rows of fans from the initial fan next to the compensation chamber, and then the block is cut from the upper to the lower floor with the other rows of fans. The blasting boreholes are blasted in sequences with a synchronized loading at the loading level. The rows of fans must be drilled parallel to each other. In this case, the vertical direction of rows of blasting boreholes in fans was chosen. The filling of fans must be fully respected to prevent the formation of oversized pieces of ore or endanger the cement paste backfill which would lead to the ore dilution of and reducing the stability of pillars. With proper blasting, the pillars remain undisturbed enabling the extraction of clean ore from the block.

The auxiliary rings consist of belts drilled parallel to the regular blasting boreholes. The purpose of the auxiliary rings is to prevent the destruction of cemented backfill mass. Experience in the world has shown that even if a part of the ore from backfill wall does not fall, it does not lead to anexcessive dilution, but prevents a great depletion in the case of blasting directly next to the backfill leading to the large deformations. However, when the backfill remains intact, a clean and complete ore extraction from the block is possible. Figure 1 presents this excavation method.

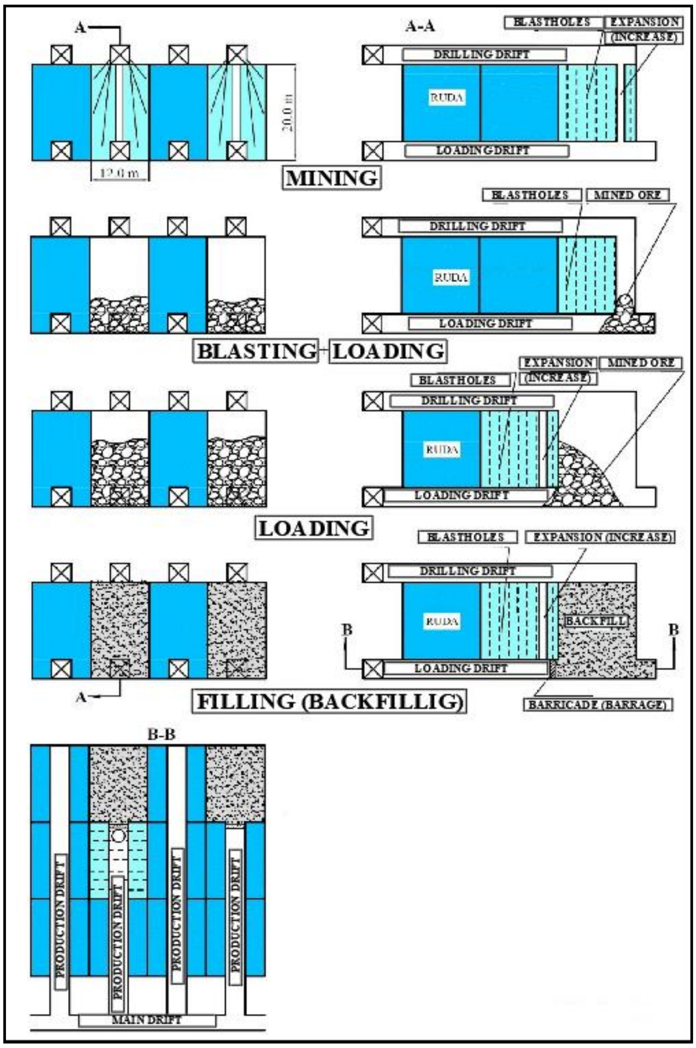


Figure 1 *Method of block excavation with backfilling the excavated area of the Borska reka deposit*

BASIC CHARACTERISTICS OF THE TECHNOLOGY OF EXCAVATION WORKS

The ore excavation by this method is carried out in the mining blocks oriented perpendicular to the ore body. The base of mining blocks is rectangular with dimensions of 12 m wide x 20 m high, and the block length depends on the width of the ore deposit, i.e., on contours of the same, so that it ranges from a minimum of 20 m to 400 m. The excavation of blocks along their length is carried out in segments (stages) from 30 m to 50 m long, depending on geomechanical characteristics in the part of ore deposit where the block is excavated [4, 5].

As soon as a certain segment is excavated to a critical length, according to data provided by geomechanics on the basis of continuous monitoring the stress conditions in the massif [6,7,8], the excavation is stopped and after the block is emptied by removing the mined ore with remote-controlled loaders, the excavation corridor is shielded that is, the loading corridor at the bottom of the block. The corridor at the very exit from the excavated block is armored by installing a suitable barricade (barrage) which, as soon as it reaches a certain level of strength, allows the backfilling of the excavated block to begin from the excavation corridor on the upper floor, which has the current function of a drilling corridor.

The distribution of backfill paste is carried out by the pipelines through the floor corridors and excavation corridor of drilling to the roof part of excavated block segment of the block and fills it up to the floor level of corridor. After filling to the level of the upper floor and hardening of backfill, the next segment of block can be continued in the established order, and until the block is excavated along its entire length. The block excavated and filled in this way represents a pillar for excavation the adjacent blocks according to the same excavation principle.

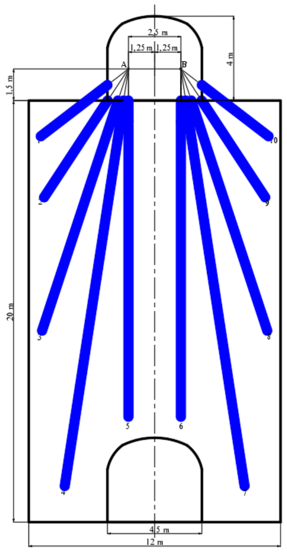
The basic procedure of this method is excavation in an open block where the size and shape of the block are limited by two levels (sub-levels). Drilling and blasting are carried out on the upper floor, and production, i.e., loading and unloading, on the lower floor. Access to the blocks is through parallel transverse excavation corridors, connected to the multi-level corridor, which is parallel to the ore deposit. This method requires moving of transport as the drilling of blocks progresses upwards, where each lower block drilling corridor for the upper block becomes a loading corridor. After filling the excavated (empty) block, the previous level of drilling becomes the next level of production, i.e., transport.

The method requires very good stability control both above the blocks and at the front due to the stress redistribution in the open sequences of block, especially if cracks and faults are present in the surrounding massif. Due to the formation of such stresses in the blocks, it is necessary to minimize the potential leaks on each (location) floor. Full coverage (insurance) is required, i.e., substructure with a suitable subgrade (sprayed concrete + anchor + mesh). In the event of a weaker working environment, the block length must be minimized in order to carry out the work safely.

The order of excavation the mining blocks is from bottom to top. The drilling level for the previous (lower) mining block becomes the loading level for the next (upper) mining block. The ore excavation in mining blocks is carried out in two phases: primary (P, every other block - pillar) and secondary (S). In the first primary phase, every other block is excavated, and the unexcavated blocks have the function of pillars, and a temporary self-supporting structure is formed. The excavated blocks in the first phase are filled with paste backfill, which after hardening the backfill become an integral part of the supporting structure. In the second secondary phase, the remaining blocks, which had the function of pillars, are excavated and, after excavation, they are filled with backfill.

There is no special preliminary preparation the bottom of blocks. A flat section of the block bottom is made by drilling and blasting the deep mine holes from the drilling corridor, where a loading corridor has already been made at the bottom. Therefore, a flat section of 4.5 m has already been formed in the middle of block and remains 3.5 m, to the left and right of the corridor, to form the bottom across the entire block width.

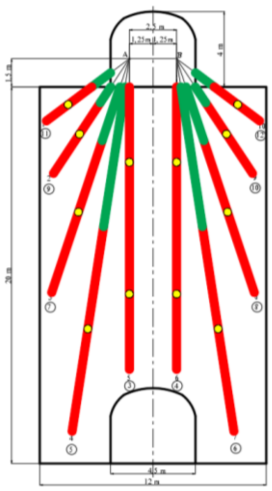
Drilling of deep exploitation drillholes, diameter of 76 mm, is carried out from the excavation corridor of the upper next excavation level in a fan arrangement in the vertical plane. The "fan" drilling is done from two centers at a distance of 2.5 m. The distance between the "fans" is 2 m. Drilling is done from top to bottom. The fans of blasting boreholes are charged with the ANFO explosive mixture. Initiation must be performed with a nonel system with boosters for the process safety. Charging of the blasting boreholes is mechanized [3]. The schemes of drilling and charging the blasting boreholes are presented in Figures 2 and 3.



Drilling table

Drillhole	Center	Length (m)	Number of bars	Angle	90°	Distance from the center
1	A	4,0	2 3/4	141	37	1,25 L
2	A	5,5	3 3/4	121	57	1,25 L
3	A	11,5	7 3/4	106	72	1,25 L
4	A	18,5	12 1/2	97	81	1,25 L
5	A	15,0	10	90	90	1,25 L
6	B	15,0	10	90	90	1,25 D
7	B	18,5	12 1/2	81	81	1,25 D
8	B	11,5	7 3/4	72	72	1,25 D
9	B	5,5	3 3/4	57	57	1,25 D
10	B	4,0	2 3/4	37	37	1,25 D

Figure 2 *Scheme of drilling the blasting boreholes*



Charging table

Drillhole	Length (m)	Charging (m)	Empty (m)	Explosives	Detonator	Amount of explosives (kg)	Buster (pcs)
1	4,0	3,0	1,0	ANFO	MS-11	12,9	1
2	5,5	4,5	1,0	ANFO	MS-9	19,4	1
3	11,5	8,5	3,0	ANFO	MS-7	36,6	1
4	18,5	11,0	7,5	ANFO	MS-5	47,4	1
5	15,0	15,0	0,0	ANFO	MS-3	64,6	2
6	15,0	15,0	0,0	ANFO	MS-4	64,6	2
7	18,5	11,0	7,5	ANFO	MS-6	47,4	1
8	11,5	8,5	3,0	ANFO	MS-8	36,6	1
9	5,5	4,5	1,0	ANFO	MS-10	19,4	1
10	4,0	3,0	1,0	ANFO	MS-12	12,9	1
							12

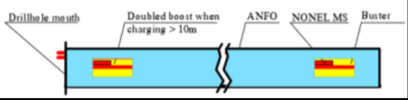


Figure 3 *Scheme of charging the blasting boreholes*

To start the ore excavation in each block, a compensation space (notch) is made in height by making a compensation shaft using the specialized ROBINS type drills or the latest EASER L Atlas Copco self-propelled sets.

The blasted ore is loaded in the loading corridors with a diesel loader with a bucket volume of 5 m^3 with remote control, and on the loading ramps it is loaded into the pit diesel trucks with a box volume of 10 m^3, which are used for transport unloading into unloading stations or mine shafts. Loaders with remote control are used for loading in blocks. Loading ramps for ore loading into trucks are made at the junction of excavation and floor corridors. Ramps are made in the multi-storey corridors with a height of 6 m [3]. Figure 4 shows a schematic representation of opening and elaboration the exploitation project above the XIX horizon.

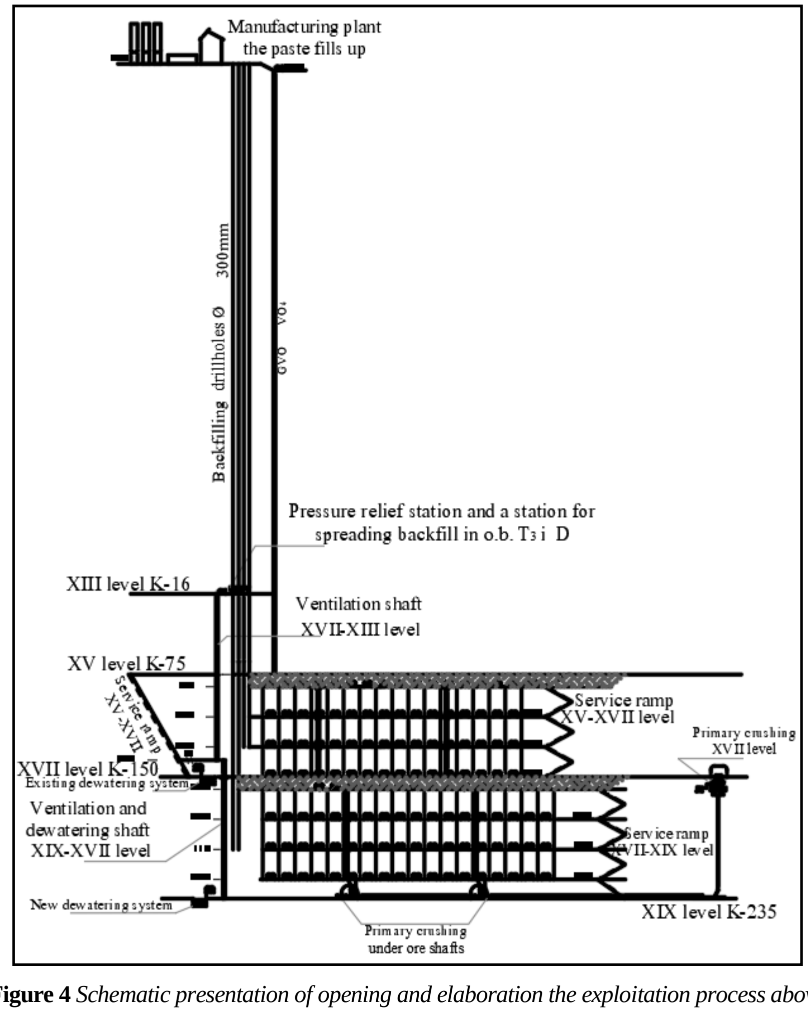


Figure 4 *Schematic presentation of opening and elaboration the exploitation process above the XIX horizon to the surface*

The excavated fields are defined by the exploitation contours of excavated blocks at the floor levels with a height distance of 20 m between floors. The exploitation contour of the mining blocks is divided into chambers with a width of 12 m, oriented transversely (east - west) in relation to the provision of the ore deposit, which is in the north - south. The numbering of chambers is unique for every three mining blocks in both mining operations. The maximum number of chambers is located on the lower excavation blocks, because they have the largest area, while some chambers are excluded on the upper excavation blocks as a result of reduction the excavation fields on them. According to the height of mining operation, the same numbering is kept for all excavation blocks vertically, regardless of the excluded chambers, due to easier monitoring the order of excavation in chambers.

FILLING THE EXCAVATED SPACE WITH BACKFILL PASTE

Backfill paste is defined as a mixture of fine binder particles and water. It contains between 72 and 85% solids by weight. The Portland cement (type 10) is the most often used as a binder. Cement is usually added in a percentage of 2 to 6%, in order to achieve the required strength. Adding slag and fly ash can partially replace cement and reduce costs. At least 15% of particles smaller than 20 microns are required in the paste mass [9].

The location for construction the plant for backfill paste productionon on the surface is above the Borska reka deposit due to as mini9mum as possible transport of backfill paste. On the ground, the location is between the rear buildings of the Sever settlement and the VO4 ventilation shaft plant for making the backfill paste and technical drillholes for backfill distribution.

The plant consists of paste thickeners, thickener feeding system, component dosing system (flocculants-binding agents), water tank, pumps for paste transport, device for density regulation, power plant, compressor, counter for measurement and regulation instruments and system management. A pipeline for delivery of flotation tailings and a pipeline for return water are being installed from the Flotation Plant Bor to the plant. The four technical drillholes are built up to the K-205 level for distribution of backfill past distribution from the level of plant for preparation of backfill pastes from the field surface to the exploitation of the Borska reka deposit. A pipeline is installed for transport of backfill paste from the plant to the drillholes.

The basic raw material for making backfill paste is the flotation tailings from the Flotation Plant Bor. The man-made RTB raw materials (slag, ash, mine waste) can be used as additives. Binding components, flocculants or cementing agents are added in the appropriate ratio to harden the backfill in a certain time and with the designed strength. Pastes are of high density, over 80% solid. A plant with a capacity of 900,000 m^3 of backfill paste in a hardened state is being built on an annual basis, with the possibility of expansion.

The floor corridors and excavation corridors at the drilling level, i.e. from the top of excavation level of each excavation level, will be used for distribution of backfill and backfilling of excavated blocks. Distribution of backfill is achieved by the pipelines from the drillholes of backfill through the floor corridors and then through the excavation corridors to the end of excavated block, where it is released by gravity into the open pit. The transport system consists of the two-by-two vertical drillholes from the field surface to the -130 or -205 level and pipeline along the floor corridors and other excavation corridors that will transport the backfill paste, Figure 5.

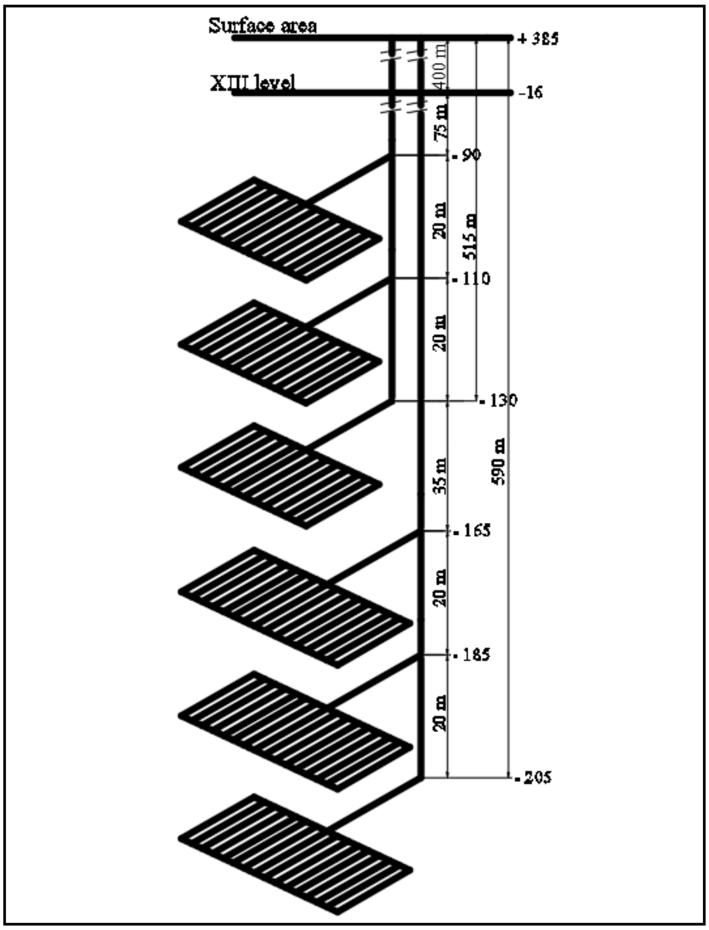


Figure 5 *Transport scheme for delivering the backfill pastes by pipelines through boreholes and corridors to the designed backfill levels*

Transport or distribution of materials in the underground mine on the floor levels out of which the backfilling or filling the excavated blocks is carried out via steel pipes installed in the ceiling of the access floor corridors.

CONCLUSION

Applying the high-capacity and high-productivity methods of excavation with the ore and overburden massif destruction, it is necessary to relocate the facilities, infrastructure, and settlements from the terrain surface, and this requires the large investment funds, a long period of realization and high initial investments. Its negative impact on the environment is evident, especially on population of the Brezanik settlement, which would have to be displaced due to the possible terrain deformation.

Continuing the underground mine production in exploitation the Borska Reka deposit, adopting the block excavation of ore with subsequent filling of the empty space with the high-density backfill and excavation the out pillars, it is possible to ensure the minimum depletion, high utilization, above all the safety of employees during excavation, compatibility the geometry of the open pit with the working environment, while preserving all the facilities, infrastructure on the terrain surface with minimizing the impact of performed underground exploitation works on the environment.

Considering the impact of exploitation method on the environment and facilities, it is minimal due to the fact that the underground method of excavation using the current method is the best way to protect the natural environment so far. This method of deposit exploitation will not affect the environment and facilities, because the proposed block excavation method with backfilling the excavation is the best way to protect the environment. Regarding the deposition of tailings, obtained by the flotation ore processing, more than 80 % of them will be used as theraw material for making backfill pastes and filling excavations in the underground mine Jama, and only a small part will be disposed on the tailing dump.

The costs of construction a tailing dump and deposition of tailings on the surface mostly cover the costs of building a plant for making the backfill pastes and costs of backfilling the excavations.

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Mining

*Daniel Kržanović[*1], Radmilo Rajković[*2], Miljan Gomilanović[*3], Nikola Stanić[*4], Aleksandar Doderović[*5]*

ECONOMIC EFFECT OF MODIFICATION THE OPTIMAL CONTOUR OF THE OPEN PIT SOUTH MINING DISTRICT MAJDANPEK, REPUBLIC OF SERBIA[**]

Orcid: 1) https://orcid.org/0000-0003-3841-8667; 2) https://orcid.org/0000-0001-5905-6613; 3) https://orcid.org/0000-0002-1209-7423; 4) https://orcid.org/0000-0002-6620-8563; 5) https://orcid.org/0000-0003-3665-6784

Abstract

The Open Pit South Mining District is a unique unit that operates within the company Copper Mine Majdanpek, which is a part of the company Serbia Zijin Copper doo (former Mining and Smelting Basin Bor Group). The capacity of the Open Pit is 9.9 million tons per year and is of a great importance for copper production in the company system. As a result of natural and technical factors, a landslide occurred on the eastern side of the open pit, so it became necessary to define a new final contour of the open pit. In this paper, the effect of modification the optimal contour of the Open Pit South Mining District on the net present value (NPV) was analyzed.

Keywords: *optimization, modification of optimal contour, NPV*

1 INTRODUCTION

The mining industry is a specific and risky industry compared to the other industries because it depends primarily on the engineer's ability to see all the issues related to the production process in terms of the number of alternatives related to the natural-technical factors, resources and quality of resources, required investments for the adopted mining technology, administrative norms and restrictions, defined by the legal acts, etc.

Design and planning of the open pits is a significant and complex problem in the mine planning. The dominant driving factor in the modern mining is to ensure that the ore body is exploited in such a way as to maximize the value realized from the mine.

In the conditions of the global market economy over the years, the necessity of forming a unique methodology for evaluation the mining projects was imposed. Profitable exploitation of mineral deposits requires a certain economic assessment and exploitation planning. First, it must be determined which part of the deposit is

[*] *Mining and Metallurgy Institute Bor, Alberta Ajnštajna 1, 19210 Bor, Serbia, E-mail: daniel.krzanovic@irmbor.co.rs*

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economical for the mine and which mining methods can be applied under the given conditions. The next step is to define the final boundary of the mine and dynamics of mining the exploitable ore reserves. The goal of these efforts is to determine the most profitable mining plan and the highest rate of return on investment [1].

The most commonly accepted goal, in the complex production systems, in the optimization of the open pit boundary is maximization the net present value of the future cash flows. To achieve this goal, the spatial association of variables in the deposit (such as the geographic location of the deposit and its geological properties) as well as the temporal association of variables (including the order in which the ore will be mined and processed) must be taken into account, and accordingly the resulting cash flow [2,3].

Optimization, reliable estimation of exploitation reserves, planning and design are realized using the Geovia Whittle™ and Geovia Gems™ software, which in the modern mining represent the standard for strategic planning and design of the open pits.

The significance of analyzing the modification of the optimal contour, depending on the natural and technical factors, is multiple and can greatly contribute to making the crucial decisions regarding the economics of the open pit mining.

2 METHODOLOGY

Modification of the optimal contour of the Open Pit South Mining District is carried out with a strict respect the geomechanical and technological factors, and at the same time, the minimum deviation from the elements of the optimal contour is sought. In this way, the conditions are created for transformation the optimal contour into the final contour.

2.1 Defining the geotechnical characteristics of the eastern side of the open pit

In the eastern part of the Open Pit South Mining District there is a landslide, which is characterized by the complex geometry and dynamics of movement.

On the basis of the engineering geological explorations, conducted at the open pit, the geotechnical profiles were defined and modeling of the sliding body was carried out. A part of the terrain with an area of 826,309 m^2 has been set aside as the unstable terrain. The material affected by the colluvial process are: a complex of medium and completely degraded slates and gneisses and medium and completely degraded andesites

Figure 1 presents a characteristic engineering-geological section of the eastern slope of the Open Pit South Mining District that shows the landslide.

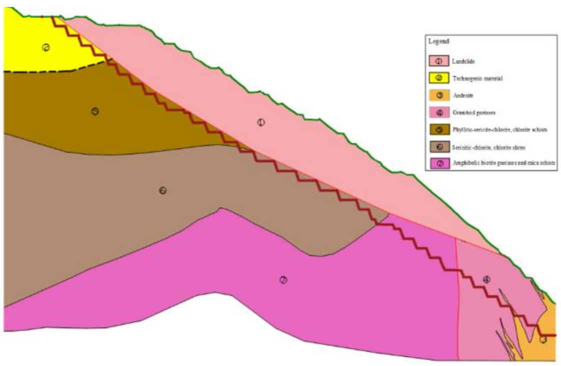

Figure 1 *Engineering geological section in the landslide zone on the eastern side of the Open Pit South Mining District*

2.2 Modeling of landslide solids in the eastern side of the open pit

The final boundary of the eastern side of the open pit was constructed on the basis of a defined landslide solid in the area limited by the terrain topography, as the upper surface and boundary of the sliding plane, as the lower limiting surface.

Solid is generated in the Geovia Gemstm software on the basis of defined vertical geotechnical profiles, which represent the closed polygons (3D rings). The solid was formed using the TIN (Triangle Irregular Network) method - it represents a triangulation with a network of irregular triangles, based on the geotechnical interpretation of landslides with vertical profiles, and the solid characteristics (solid volume, surface area (envelope), number of nodes in the formed surface, number of triangles, etc.) [4].

Figure 2 presents the generated landslide solid in the northwestern zone of the Open Pit South Mining District in the Geovia GemsTM software.

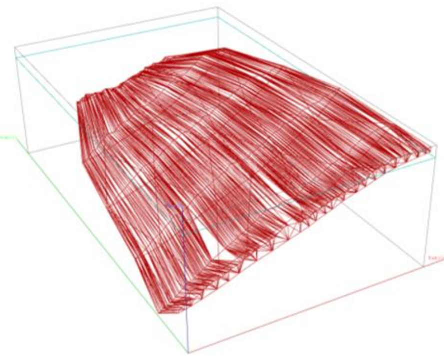

Figure 2 *View of the network of irregular triangles of the landslide solid*

Figure 3 shows the view of the landslide solid in the eastern side of the Open Pit South Mining District.

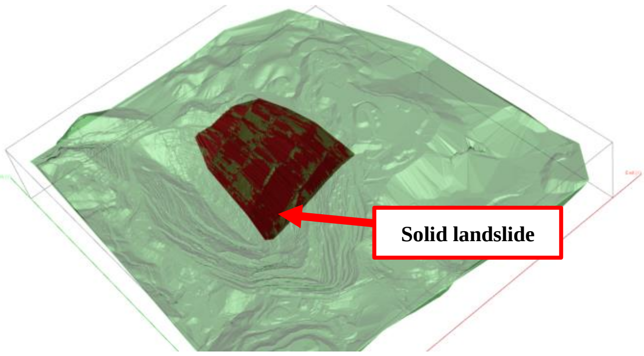

Figure 3 *3D view of the position of the solid landslide in the eastern side of the Open Pit South Mining District*

2.3 Optimal boundary of the open pit

The optimal boundary of the open pit was defined using the Geovia WhittleTM software, and based on the block model of the deposit, created by the geostatistical modeling method, Figure 4.

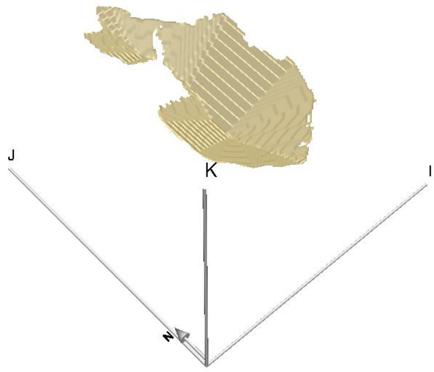

Figure 4 *Optimal contour of the Open Pit South Mining District, Geovia WhittleTM software*

2.4 Modification of the optimal contour of the eastern slope of the open pit

Modification of the optimal contour of the open pit was carried out with respecting the basic condition - to ensure a stable slope of the eastern side of the open pit. On the basis of defined conditions, the adopted geometric elements of the open pit and generated landslide solid, the final contour of the recon structed northwestern part of the Open Pit South Mining District was constructed. The final contour of the grip was constructed in the Gems software, [4].

Figure 5 presents a characteristic profile showing a deviation of the modified (final) contour from the optimal contour of the open pit.

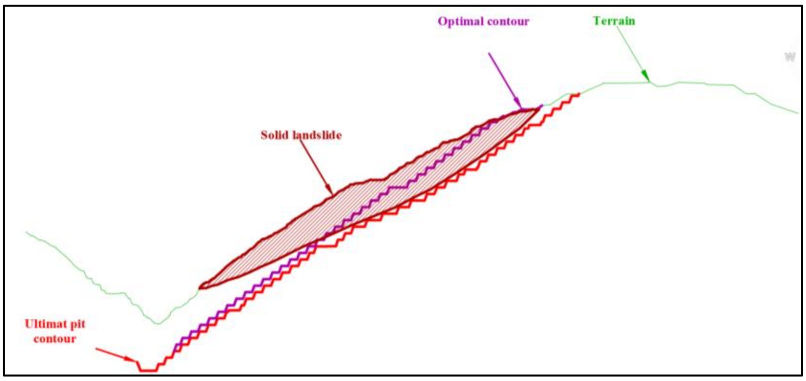

Figure 5 *View of a deviation of the modified contour from the optimal contour in the eastern side of the Open Pit South Mining District*

3 RESULTS AND DISCUSSION

Figure 6 presents the resulting graph with the economic optimization parameters, which was formed on the basis of annual production of the Open Pit South Mining District of 9.9 million tons of ore.

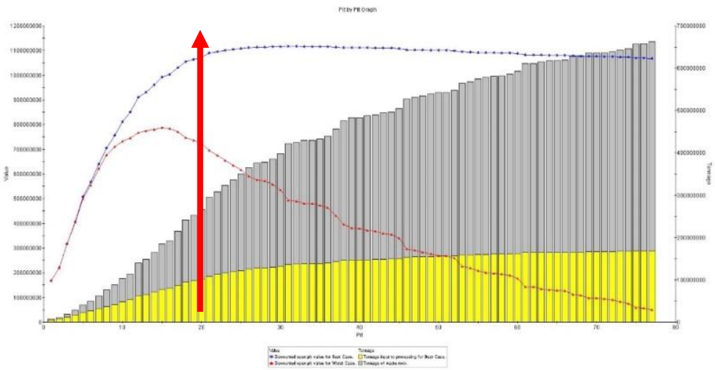

Figure 6 *Graphic presentation of the results of the Whittle economic optimization of the Open Pit South Mining District*

The maximum NPV is given by the shell of open pit no. 32, so it was chosen as the optimal contour of the Open Pit South Mining District.

Parameters of the optimal contour of the Open Pit South Mining District are shown in Table 1.

Table 1 *Techno-economic parameters of the optimal Open Pit South Mining District*

Parameter	Unit	Value
Ore	tons	124,061,159
Waste	tons	286,629,364
Overburden coefficient	t/t	2.09
Average copper content	%	0.356
Average gold content	g/t	0.189
Average silver content	g/t	1.578
NPV	$	896,643,015

A graphic representation of the final, modified contour of the Open Pit South Mining District designed in the Geovia GemsTM software, is given in Figure 7.

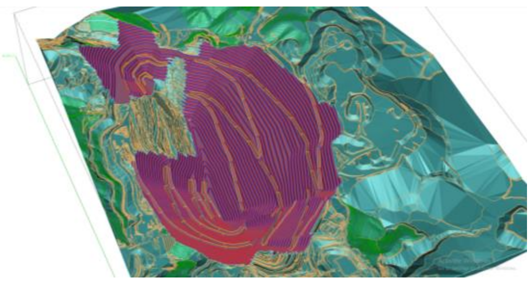

Figure 7 *3D view of the final contour of the Open Pit South Mining District*

Parameters of the final, modified optimal contour of the Open Pit South Mining District are presented in Table 2.

Table 2 *Techno-economic parameters of the modified optimal Open Pit South Mining District*

Parameter	Unit	Value
Ore	tons	124,061,159
Waste	tons	396,891,145
Overburden coefficient	t/t	3.20
Average copper content	%	0.356
Average gold content	g/t	0.189
Average silver content	g/t	1.578
NPV	$	585,932,261

On the basis of presented results, the following can be concluded:

1) The life of ore exploitation at the Open Pit South Mining District is 13.5 years.

2) 124,061,159 t of ore and 286,629,364 t of waste are captured by the optimal open pit contour. The overburden coefficient is 2.09 t/t.

3) 124,061,159 t of ore and 396,891,145 t of waste are captured by the modified optimal open pit contour. The overburden coefficient is 3.20 t/t.

4) The NPV for the optimal contour of the open pit is $896,643,015.

5) The NPV for the modified optimal contour of the open pit is $585,932,261.

4 CONCLUSION

Due to the occurrence of a landslide in the eastern side of the Open Pit South Mining District, there was a need to modify the optimal contour of the open pit in order to ensure the necessary stability for smooth development of the mining process.

Modification of the optimal contour of the Open Pit South Mining District was carried out so that the deviation from the optimal contour is minimal, i.e. to the extent that the geomechanical and technological factors are satisfied.

Due to the modification of the open pit optimal contour, the amounts of waste, which will be excavated, were increased and compared to the optimal contour, they are greater by 110,261,781 t.

The economic effect of modification the optimal contour is reflected in realization a lower NPV by $310,710,754.

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Ivan Jovanović[*1], *Dušan Tašić*[*2], *Miomir Mikić*[*3], *Vladanka Presburger Ulniković*[**4], *Novica Staletović*[**5], *Violeta Nikolić*[**6]

ENVIRONMENTAL POLLUTION WITH GASEOUS POLLUTANTS IN THE OPERATION OF MINING MACHINES AT THE OPEN PIT[***]

Orcid: 1) https://orcid.org/0009-0000-5174-3734; 2) https://orcid.org/0000-0001-8005-9640; 3) https://orcid.org/0000-0001-7659-769X; 4) https://orcid.org/0000-0001-6144-3399; 5) https://orcid.org/0000-0001-8450-5564; 6) https://orcid.org/0000-0003-0933-3197

Abstract

Atmospheric pollution at the open pits depends on the annual production and intensity of emissions the harmful gases and dust, that is, development the individual phases in overburdening and obtaining the useful mineral resources. The gas and dust emissions at the open pits occurs as a consequence of technological processes aimed at obtaining the mineral resources, most often during loading and transport operations. In addition, the pollution also depends on the terrain configuration around the open pit and climatic parameters. Therefore, it can be considered that the entire area of the open pit is a source of environmental pollution. This paper will present the results of pollution level by gaseous pollutants at the open pit, caused by the operation of mining machines.

Keywords: *gaseous pollutants, combustion, mining machinery, environmental impact*

1 INTRODUCTION

Exploitation of mineral deposits can be done by the surface or underground works. The exploitation of mineral deposits at the open pits is done by the use of a discontinuous system in most cases, which consists of several production processes - operations [1]. Considering the physical and mechanical characteristics of the deposit, it is never possible to perform a direct excavation. Mainly, the basic operations of exploitation the mineral raw materials consist of: drilling, blasting, crushing, loading and trans portation [2]. In addition to the mentioned basic mining works, the auxiliary works are also performed, which are always synchronized with the basic works.

Mining machinery is used to perform the basic mining works at the open pits: drills, excavators, trucks, bulldozers, graders and loaders [3].

The number and quantity of engaged mining machinery at the open pit depends on the designed system of exploitation of the mineral raw material, which is in

[*] *Mining and Metallurgy Institute Bor, Bor, Alberta Ajnštajna 1, 19210 Bor, Serbia, e-mail: ivan.jovanovic@irmbor.co.rs*
[**] *"Union – Nikola Tesla" University, Belgrade*
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accordance with the required capacity, physical and mechanical properties of the mineral raw material, structural parameters of the open pit and intended equipment for operation at the open pit [4,5].

In order to obtain the mineral raw materials, during the operation of mining machines at the open pit, the emissions of gaseous pollutants inevitably occur [6,7]. This most often happens during operations of loading and transport of mineral raw materials [8,9].

The intensity of pollution depends on the development of individual phases in the discovery and obtaining of useful mineral raw materials, on the configuration of the terrain around the surface mine and on climatic parameters [10]. Therefore, it can be considered that the entire area of the surface mine represents a complex source of environmental pollution.

This paper presents the results of pollution level with gaseous pollutants created during the operation of mining machines at the open pit for limestone exploitation.

2 CONCEPTS OF EXPLOITATION AT THE OPEN PIT

Exploitation of the limestone deposits is carried out by the open pit mining [11]. A discontinuous system of exploitation, consisting of several production operations, is applied.

Considering the physical and mechanical characteristics of limestone, the fragmentation is previously because a direct excavation is not possible. The blasted limestone is loaded into trucks and transported to the crusher. The auxiliary works are performed in synchronization with the basic works. The excavated humus cover is temporarily deposited on an internal landfill and subsequently used in recultivation after the end of exploitation.

The following mining machines are used to perform the basic mining works at the open pit: Atlas Copco ROC F6 drill, CAT 5080 hydraulic excavators, CAT773E trucks, CAT D9R bulldozer, CAT 12H grader and CAT 988H loader.

A discontinuous system of exploitation with the following technological phases is applied at the open pit: drilling, blasting, loading, transport and auxiliary works.

Drilling is performed with an Atlas Copco ROC F6 drill, with a drilling diameter of 90, 110 and 130 mm.

The blasted material is loaded with a Caterpillar 5080 hydraulic excavator with a normal bucket and CAT 988-wheel loader. The transportation of limestone, i.e. useful mineral raw materials, is done with the Caterpillar 773E trucks.

The entire mineral raw material from the open pit of the limestone deposit is treated as useful mineral raw material, without waste. The content of CaO is fairly uniform, and chemical composition of the mineral raw material is corrected by addition of marl and quartz sand.

The auxiliary works include the work site maintenance at the open pit and construction of a drilling platform, construction and maintenance of transport roads, maintenance of drainage facilities and maintenance of the open pit slopes, as well as the supply of machinery with fuel in the field. The following mining machines are hired for these works: Caterpillar D9R bulldozer, Caterpillar 12H grader and fuel tank truck.

The mining machines are supplied with fuel at the open pit from a gas station located outside the open pit. All vehicles except hydraulic excavators and bulldozers are supplied with fuel at the pump. The fuel is brought by tankers to the open pit and thus provides fuel for these mining machines.

3 EMISSIONS OF GASEOUS POLLUTANTS AT THE OPEN PIT

Gaseous polluting substances at the open pits are created as a result of technological processes [12-14] in order to obtain the useful mineral raw materials - limestone, during loading and transportation operations.

During drilling of boreholes, if the dedusting system is not working, the dust can enter the environment.

The open pit blasting is an occasional source of a dust-gas cloud emission. The length, width, height of the cloud, concentration and development of gases in the cloud at the open pit are affected by: the environment type, blasting methods, atmospheric conditions and quantities of explosives for one blasting.

The dust-gas cloud during blasting is created in three phases, as follows: by breaking out, that is, by being ejected from the borehole opening; by scattering, crushing, collapsing, launching and moving the mass and finally by knocking down and falling of the blasted mass; and under the effect of air shock waves and seismic earthquakes.

Upon explosive detonation, 50% of the gases created during blasting immediately go into the atmosphere, about 20% are absorbed by the crushed mass and about 30% fill the pores, cracks and empty spaces of the blasted material. The amount of gases, created during the open pit blasting, depends on the amount of explosives used.

The gaseous cloud moves in the prevailing wind direction. When the atmosphere is stable, the cloud constantly keeps rising and spreads the pollution with the air currents further through the atmosphere, and deconcentration of pollution occurs on that occasion. The impact on the environmental pollution in this situation is minimal.

Limestone is loaded with a diesel-powered hydraulic excavator and loader, with gaseous products entering the environment. During loading, the trapped gases are separated from the blasted mass and released, as well as the exhaust gases. According to the measurements, the gas emission at the open pit during the blasting operation is on average 0.25 m^3/s.

Limestone is transported by the diesel-powered trucks. During the transport of excavated mineral raw materials, the gaseous components of truck exhaust gases (carbon monoxide, nitrous gases and sulfur dioxide) reach the environment. The average gas emission for one truck according to the measurements is 0.42 m^3/s.

The diesel-powered bulldozer is used for auxiliary mining operations at the open pit. The average gas emission for the bulldozer is 0.26 m^3/s. In addition to the bulldozer, for auxiliary operations, a diesel-powered grader is also used, with the average gas emission of 0.09 m^3/s.

4 LEVELS OF ENVIRONMENTAL POLLUTION WITH GASEOUS POLLUTANTS DURING THE OPERATION OF MINING MACHINES

The level of environmental pollution with gaseous pollutants during limestone mining depends on: the intensity of emission the gaseous pollutants, climatic characteristics, terrain configuration, wind roses and protection measures taken in order to suppress or reduce the emission of gaseous pollutants during the technological operations and from degraded surfaces.

Mining machines at the open pit use a diesel fuel D2 in accordance with the standard SRPS B.H2.410/1.

During the operation of an internal combustion engine, oxygen from the air binds with hydrocarbons and other chemical compounds that make up a diesel fuel. The gas emission that occurs during the complete and incomplete combustion of fuel consists of the following components: CO, CO_2, C_nH_mO, C_nH_m, SO_2, NO, NO_2 and soot.

The concentration of gases at the open pit depends on the ratio of combustible components in the fuel, namely: carbon, hydrogen and sulfur, as well as on the corresponding fuel-air ratio.

With the fuel used, diesel D2, the sulfur concentration ranges up to one percent by weight, which is 500 ppm SO_2. The amount of air required to dilute these harmful components in the exhaust gases of an internal combustion engine depends on the concentration of those components.

In the case of liquid fuel D2, SO_2 is the dominant factor defining the required amount of air for de-concentration of gases from the open pit atmosphere, because its value of the maximum permissible concentration (MDK) is equal to 4 ppm.

The environmental quality monitoring plan defines the frequency of monitoring and measurement and the type of pollutant to be measured.

Based on the known composition of the diesel fuel D2, the known engine power of mining machines and composition of the exhaust gases of these types of engines, concentration of the emission of polluting gaseous substances for all mining machinery at the open pit for obtaining limestone was determined to be 2.256 m^3/s representing an acceptable risk for the environment.

On the basis of the obtained value, that it expected an acceptable risk for the environment, there is a low probability of occurrence an environmental aspect that causes or can cause the environmental pollution with gaseous pollutants during the operation of mining machines at the open pit. [15-19]

Based on the obtained value, there are or may be small consequences for the environment. The consequences appear or may appear as an occasional pollution of the basic environmental factors that do not exceed the MDV and MDK values. The consequences of environmental pollution can be related to the level of the open pit.

Table 1 presents the average amount of exhaust gas emissions during the operation of mining machines at the open pit per one operation of the technological process. The total concentration of emitted polluting gaseous substances is 2.256 m^3/s.

Table 1 *Concentration of polluting gaseous substances at the open pit*

Type of equipment	Manufacturer	Type	No. of units	Total gas emission m^3/s
Drill	Atlas Copco	ROC F6	1	0.146
Hydraulic excavator	Caterpillar	5080	1	0.25
Loader	Caterpillar	988	1	0.25
Truck	Caterpillar	773E	3	1.26
Bulldozer	Caterpillar	D9R	1	0.26
Grader	Caterpillar	12H	1	0.09
Total			**8**	**2.256**

5 ENVIRONMENTAL PROTECTION MEASURES AGAINST THE NEGATIVE EFFECTS OF GASEOUS POLLUTANTS DURING THE OPERATION OF MINING MACHINES

The environmental pollution during exploration at the open pit results from the operation of engaged mining machines, as well as during blasting operations.

The environment quality in the vicinity of the open pit also depends on the environmental protection measures taken during the exploitation of mineral raw material - limestone.

Gaseous polluting substances, created by the operation of mining machinery and blasting operations at the open pit, diffuse together with the air currents into the atmosphere and are deconcentrated.

The environmental pollution with gaseous pollutants - exhaust gases such as CO, NOx, SO_2 from internal combustion engine machines, cannot significantly affect the environment because the gases diffuse.

The concentration of gases in the air is not expected to be higher than MDK in the environment. Therefore, no special protection is foreseen, except for the regular maintenance and regular technical control the composition of exhaust gases from machines with the internal combustion engines, as well as the use of diesel fuel of a constant content.

Considering the expected level of acceptable risk, the mandatory protection measures that are taken are:

- Carrying out the periodical testing of the environment in order to control the realized effects of applied protection measures.
- Reduction the amount of gases during blasting is achieved when the impact cartridges are placed at the bottom of the bore hole, which affects the increased efficiency of blasting, and a smaller amount of gases is emitted.
- Mandatory use of the original explosive packages.
- Monitoring the concentration of gaseous substances in the air.

The owner of the open pit is obliged to monitor the indicators of emissions, that is, the indicators of the impact of activities on the environment and indicators of the effectiveness of applied measures to prevent the occurrence or reduce the level of pollution. The quality plan defines the frequency of measurements and type of pollutant to be measured.

6 CONCLUSION

Gaseous pollutants that occur at the open pits during the operation of mining machines arise as a consequence of technological processes aimed at obtaining the mineral raw materials, during blasting, loading, transport, crushing operations, as well as due to the effect of natural factors - terrain configuration, climate parameters, winds.

Mining machines at the open pit use a diesel fuel D2 in accordance with the prescribed standards. During the operation of an internal combustion engine, oxygen from the air binds with hydrocarbons and other chemical compounds, included in the composition of diesel fuel.

The concentration of gases at the open pit depends on the ratio of combustible components in the fuel, namely: carbon, hydrogen and sulfur, as well as on the corresponding fuel-air ratio.

Based on the known composition of diesel fuel D2, engine power of mining machines and composition of the exhaust gases of these types of engines, the concentration of emission the polluting gaseous substances for all mining machinery at the open pit for obtaining limestone was determined to be 2.256 m^3/s.

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Telephone: +381 (0) 30/435-164; +381 (0) 30/454-108

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