# PROCEEDINGS

## OF THE XV INTERNATIONAL CONFERENCE OF THE OPEN AND UNDERWATER MINING OF MINERALS


**June 3-7, 2019**
**Varna, Bulgaria**



**SCIENTIFIC AND TECHNICAL UNION OF MINING, GEOLOGY AND METALLURGY**
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***Dear Ladies and Gentlemen,***
***Dear colleagues,***

On behalf of the National organizing committee I have the pleasure to greet all of you for participation in the XV International conference of the open and underwater mining of minerals. The conference has become a significant scientific forum, traditionally hosted by the Scientific and Technical Union of Mining, Geology and Metallurgy.

More than 30 years have passed since the first conference on open mining of minerals and stability of the slopes in mines, which proved the prestige of this already traditional forum. Underwater mining was also included, as a thematic area of particular importance.

Conducting the conference is also important for countries with developed mining industry. This forum is a platform of experts, scientists and industrialists from all over the world that allows discussions to be held on the new technological developments and production methods in the mining industry. Mining, scientific and technical aspects of the sustainability of mining activities as well as their social impact will also be discussed during the conference. In this context, besides discussing scientific and technical issues, the main goal of the conference is to create new opportunities for business development.

I would like to congratulate you and to wish you good health, professional and scientific success. Thank you for your participation which contributes to the success of the conference.

I wish you all fruitful work and good luck!

**Prof. DSc Eng. Tzolo Voutov**

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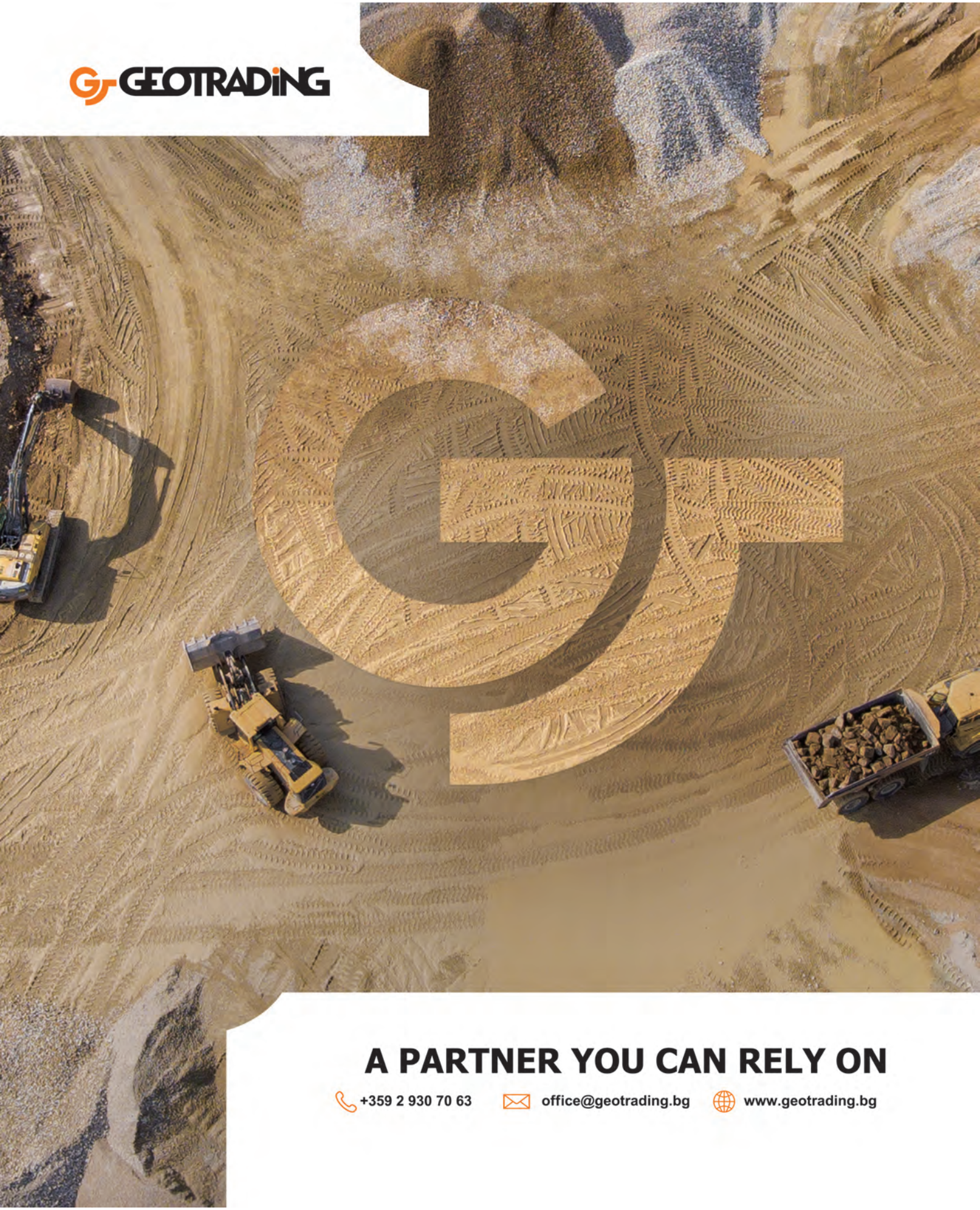

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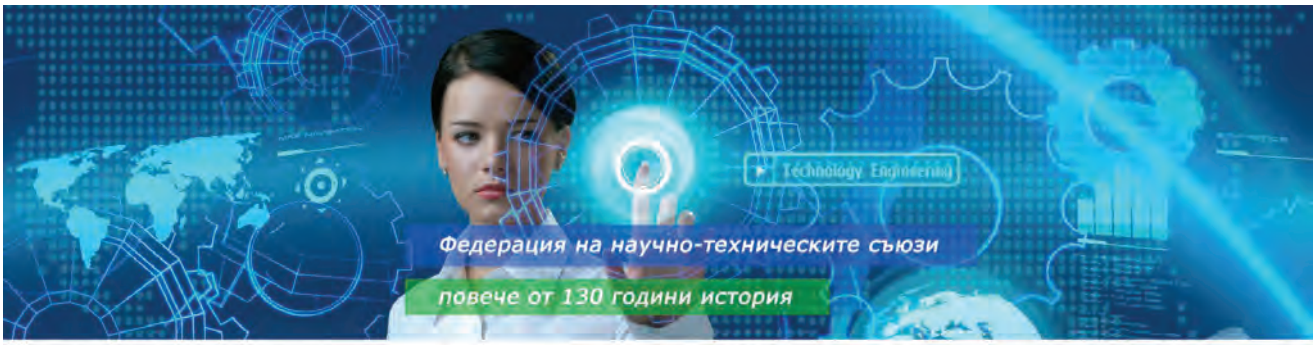


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**A. Innovations in the construction and operation of opencast mines and quarries.**
**B. Modern technologies and facilities in underwater mining of minerals.**
**C. Drilling and blasting activities and safety techniques for open mining of minerals.**
**D. Drainage and stability and consolidation of the slopes in mines, quarries and waste dumps.**
**E. Quality management. Economic efficiency in open and underwater mining.**
**F. Protection and reclamation of environment during and after mining activities.**
**G. Information technologies in geological and mining activities.**
**H. Innovations in electrification, automation, mechanization and repair.**
**I. Advanced technologies in mineral processing and leaching.**
**J. Mining legislation. Qualification and specialization of the experts in open and underwater mining.**

# THE STABILITY OF THE WORKING AND FINISHING SLOPES IN THE COAL MINE "BROD-GNEOTINO" AT THE MUNICIPALITY OF NOVACI

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***ABSTRACT***
*The "Brod-Gneotino" coal deposit is located on south-west of the Republic of North Macedonia, near the city of Bitola and about 10 km south of the deposit "Suvodol". According to the engineering - geological regionalization of the terrain, the rock masses in the deposit are grouped in the part of the various lythogenetic units, or it is characterized by the presence of several engineering-geological groups of rock masses. Based on the overall performed investigations and explorations, statistical analysis was made on the results of the physical - mechanical examinations and were obtained calculation values necessary for designing of the slope stability. The calculation of the stability is according the method of Bishop (with the software SLIDE 7.0), method that is based on the conditions of boundary equilibrium. Safety coefficients are adopted according the " Rulebook on Technical Norms for Surface Exploitation of deposits of Mineral Raw Materials for slope stability on open pit and Landfills", with Fs ≥ 1.1 for local working unburdened slopes, Fs ≥ 1.15 for system of working slopes and burdened working slopes and Fs ≥ 1.3 for final slopes.*
***Key words:*** *open pit, landslide, sanation, geological, geomechanical and hydrogeological research, stability of the terrain*

## INTRODUCTION

The area of the deposit "Brod-Gneotino" is located about 10 km south of the deposit "Suvodol", which represent its northern border, while on the south side is situated the deposit "Zivojno". On the eastern side, the border is the edge of the Pelagonia basin, and towards the west the boundary of the deposit is open and undefined due to the large depth of the coal layers (more than 250 m). The geomechanical analysis of the stability for this site was carried out on the basis of an existing fund of data for geomechanical and hydrogeological parameters, from the existing documentation for the coal deposit "Brod-Gneotino", for which statistical parametric analysis was performed.

## GEOLOGICAL FEATURES

As an integral part of the Pelagonija basin, the deposit "Brod-Gneotino", from the aspect of its geological structure, has all the characteristics specific to the sedimentation environment of the basin, i.e. as the deposits "Suvodol" and "Zivojno". In the geological structure of the deposit Brod Gneotino are present Precrambrian crystalline rocks, Neogene and Quaternary sediments.

***Lithological - stratigraphic composition of the site***

Paleorelief, as well as the eastern part of the basin (the edge part), is composed of Precambrian gneisses and mikashists, Paleozoic quartz - graphite shists, phyilites and slates. The coal deposit is located in the zone of contact of the Precambrian crystalline rocks and Neogene to upper Pliocene sediments. Transgressively and discordantly on them lie Neogene and Quaternary sediments.

Neogene sediments are divided into the following facies:

- Basal (floor facies)
- Productive coal formation and
- Roof sedimentary complex

***Productive coal formation*** is a heterogeneous sedimentary complex, composed of a facies of grey - greenish heterogeneous dusty sands and a large number of coal layers and coal clay.

## ENGINEERING - GEOLOGICAL CHARACTERISTICS

According to the engineering geological regionalization of the terrain, the rock masses are grouped in the part of the various lithogenetic units: unbound rock masses, weakly bound rock masses, tightly bound semi-rocky masses and petrified rock masses. From the current scale of investigations and analyzes, more precisely from the engineering geological mapping of the terrain and mapping of the core from the investigated boreholes, it can be concluded that the terrain that covers the coal deposit "Brod-Gneotino" is characterized by the presence of several engineering-geological groups on rock masses.

**Unbounded rock masses** This group includes the roof Quaternary sediments that are composed of varieties of dusty sands, finegrained sands and gravels. **Weakly bound rock masses** are present in the various lithogenetic units, as well as the deluvial sediments, which are represented by clay - terra rossa with low to medium plasticity, as well as in the subproductive creations in the form of coal clay. **Tightly bound semi-petrified to poorly bound rocky masses.** This engineering-geological group refers to tripoli. **Tightly bound semi-rocky masses.** In this engineering-geological group is coal. **Tightly bound petrified rocky masses** where belong gneisses and micaschists, which appear on the east side of the deposit.

## HYDROGEOLOGICAL FUNCTION OF LITHOLOGICAL MEMBERS

According to the hydrogeological function of the aquifers, there are: hydrogeological collectors (sands), hydrogeological insulators (tripoli and clays) and hydrogelological complexes (dusty sand, sandy dust, etc.).

According to the hydrodynamic characteristics i.e. the hydraulic conditions, in the aquatic environments are distinguished aquifers with a free level of underground waters and, deeper for the phase of exploitation, aquifers with a groundwater level under pressure (artesian and subartesian well). According to the hydrodynamic character of the groundwater level, well with free level (roof - k), and deeper in the exploitation stage, wells at a pressure level (first interlayer - M1, second interlayer - M2 and floor - p).

## GEOMECHANICAL CHARACTERISTICS OF THE UPPER LAYER

Lithuanian members of the Brod-Gneotino PC are mainly divided into 5 zones. The delineation in five zones, which is done according to the geological structure of the investigated terrain and the stratigraphic position of the lithological members, as a terminology is adopted starting from the first investigative works to the last. However, for the stability analysis for obtaining more reliable data, the geomechanical soil layers are separated each layer individually and seven types of soil materials are identified:

- GW, GP, GFs (sandy gravels);
- SP, SW (gravely sands);
- TR (tripoli);
- MI, ML (dust, low to medium plastic);
- SFs, SFc (sands and clayey sands);
- OI, OH (organic clay with medium to high plasticity);
- J (coal).

## SELECTION OF PARAMETERS FOR GEOMECHANICAL CALCULATIONS

It is indisputable that the choice of the values of the geomechanical parameters of the materials is one of the most complex and sensitive tasks in the geotechnical analysis of the stability in the mine design, so in determining them, all the available research and testing bases should be used to obtain what possible reliable and relevant data. However, the values obtained are characterized by the layers from which the samples are taken, the manner and the procedure of the investigations, the concept of excavation because it affects the treatment of ambient conditions in simulating the tests, the hydrogeological condition in situ and eventually recommended measures that will influence to change it, engineering - geological features on the terrain as tectonics etc., i.e. it represents a complex that is harmonized with the provided mining and technological concept for exploitation of the deposit.

The adopted strength geomechanical parameters from the performed parametric analysis for the soil materials from the PK Brod-Gneotino are shown in the following table:

*Table 1. Adopted strength geomechanical parameters for PK Brod-Gneotino*

| No. | Type of material | Geomechanical mark | c (kN/m$^2$) | φ ( ° ) | γ (kN/m$^3$) |
|---|---|---|---|---|---|
| 1 | Sandy gravels | GW, GP GFs | 0,0 | 33,00 | 21,00 |
| 2 | Gravely sands | SP, SW | 0,0 | 28,00 | 20,10 |
| 3 | Tripoli | (TR) | 31,35 | 19,63 | 15,62 |
| 4 | Dust, sandy - clayey | MI, ML | 24,63 | 16,11 | 18,62 |
| 5 | Sands, clayey - dusty | SFc, SFs | 8,00 | 17,65 | 18,74 |
| 6 | Coal clay - organic | OH, OI/OL | 25,00 | 14,20 | 16,96 |
| 7 | Coal | (J) | 50,00 | 24,00 | 12,67 |
| 8 | Deposited material | (N) | 6,00 | 17,00 | 15,00 |
| 9 | Disintegrated material | | 0,00 | 10,00 | 14,00 |

## DETERMINATION OF CUTTING ELEMENTS OF EXCAVATION MECHANIZATION

The machinery for excavation of roof sterile mass in the PK Brod-Gneotino consists of two BTO (excavator - conveyor - depositor) systems. Rotary excavators SRs 2000 for excavation of a roof sterile mass in the next period of 5 years are foreseen to work only in a height block. Even though these excavators have the option of direct excavation of the slag with sub-bench, no excavation will be performed with sub - bench, since it is necessary for the excavators to accelerate their progress, in order to meet the requirement for the required annual quantity of coal.

The main sterile bench is defined at a height of 20 m. Although the rotary excavators have the possibility of higher bench, however, for the environment in which they will excavate at the PK Brod-Gneotino, in order to have no problems with geomechanical stability, as the most suitable height of the main bench is 20 m. According to the characteristics of the rotary excavators SRs 2000 for excavation of a 20 m high level, the excavation is done in three cuts.

On the following pictures are shown the cuttings for frontal and lateral excavation slope for the SRs 2000 rotary excavators.

Graphical construction on the frontal slope

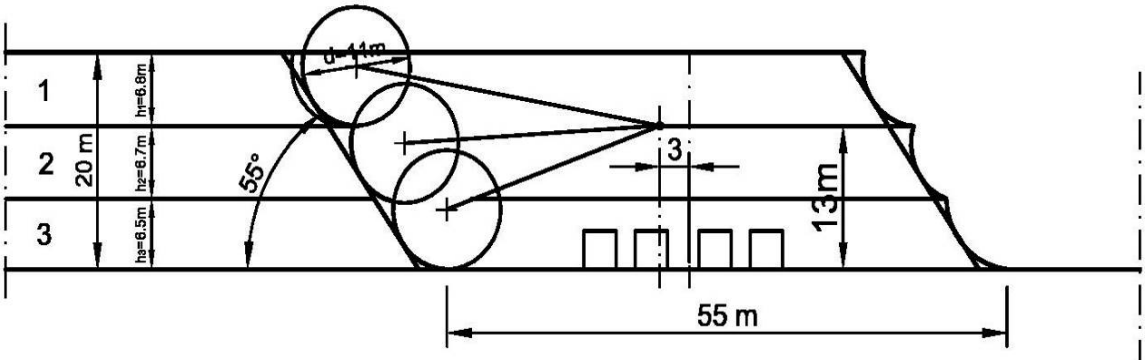


*Figure 1. Cutting elements for frontal slope*

Graphical construction on the lateral slope

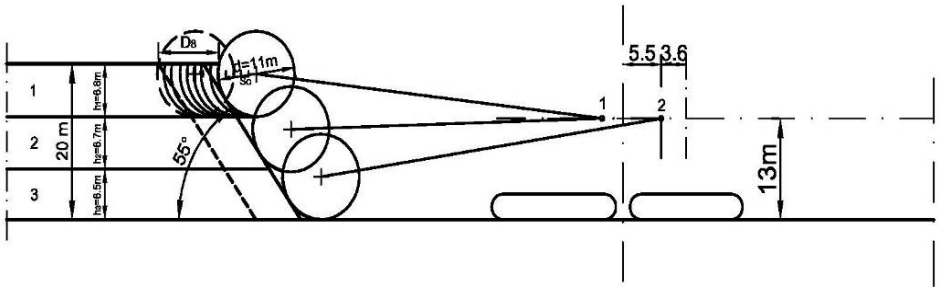


*Figure 2. Cutting elements for lateral slope*

## CALCULATION OF THE STABILITY OF THE GENERAL SLOPES OF THE OPEN PIT FOR SURFACE LAYER AND COAL

The geomechanical analysis of the stability for the final slope is performed for 2 (two) characteristic profiles: 11 and 12 on the west side of the pit, 3 (three) characteristic profiles: 10, 11 and 12 on the east side of the pit, or a total of 5 (five) characteristic profiles.

The geomechanical stability analysis is performed with characteristic circular-cylindrical slip surfaces according to the Bishop method, taking into account the specificity of the stability problem. When analyzing the stability of the east and west sides of the mine, the possibilities of the computer package for stability SLIDE 7.0 were used, or, the analysis was performed for multiple possible sliding plains with an automatic search for the minimum reliability coefficient (1000 iteration cycles). The locations of the characteristic sliding plains are set to end in characteristic places, and the choice of them is how to obtain minimum safety coefficients, approaching the actual state of the terrain, for the given geological, hydrogeological, geomechanical and geometric boundary conditions. The obtained results (the lowest reliability coefficients) of the performed stability analysis for the general slopes are shown in the following table for different $r_u$ and the general slope.

The analysis of global stability for the profiles on the west side is performed as for the final slope Fs>1.3, with the variation of the ratios of the pore pressure for different presence of groundwater, for the defined slopes according to the mining and technological concept of excavation. Final general slopes are designed so that the minimum safety coefficients are greater than 1.3 for $r_u$ = 0.1 (in the presence of water and the appearance of the pore pressures), as can be seen from the obtained results.

*Table 2. Analyses of the general pit slopes*

| side | profile | plain | $r_u$=0.0 | $r_u$=0.1 | $r_u$=0.2 | α (°) |
|---|---|---|---|---|---|---|
| west | 11-11 | B_11-01 | 1.567 | 1.401 | 1.235 | $\alpha_3$=16.56 |
| | | B_11-02 | 1.594 | 1.421 | 1.248 | |
| | 12-12 | B_12-01 | 1.688 | 1.518 | 1.348 | $\alpha_3$=15.81 |
| | | B_12-02 | 1.815 | 1.630 | 1.445 | |
| east | 10-10 | B_10-01 | 1.570 | 1.420 | 1.270 | $\alpha_3$=15.48 |
| | | B_10-02 | 1.461 | 1.329 | 1.198 | |
| | | B_10-03 | 2.195 | 1.980 | 1.766 | |
| | 11-11 | B_11-01 | 1.897 | 1.728 | 1.558 | $\alpha_3$=13.68 |
| | | B_11-02 | 1.413 | 1.307 | 1.198 | |
| | 12-12 | B_12-01 | 2.019 | 1.836 | 1.653 | $\alpha_3$=18.12 |
| | | B_12-02 | 1.514 | 1.381 | 1.247 | |
| | | B_12-03 | 1.885 | 1.756 | 1.624 | |

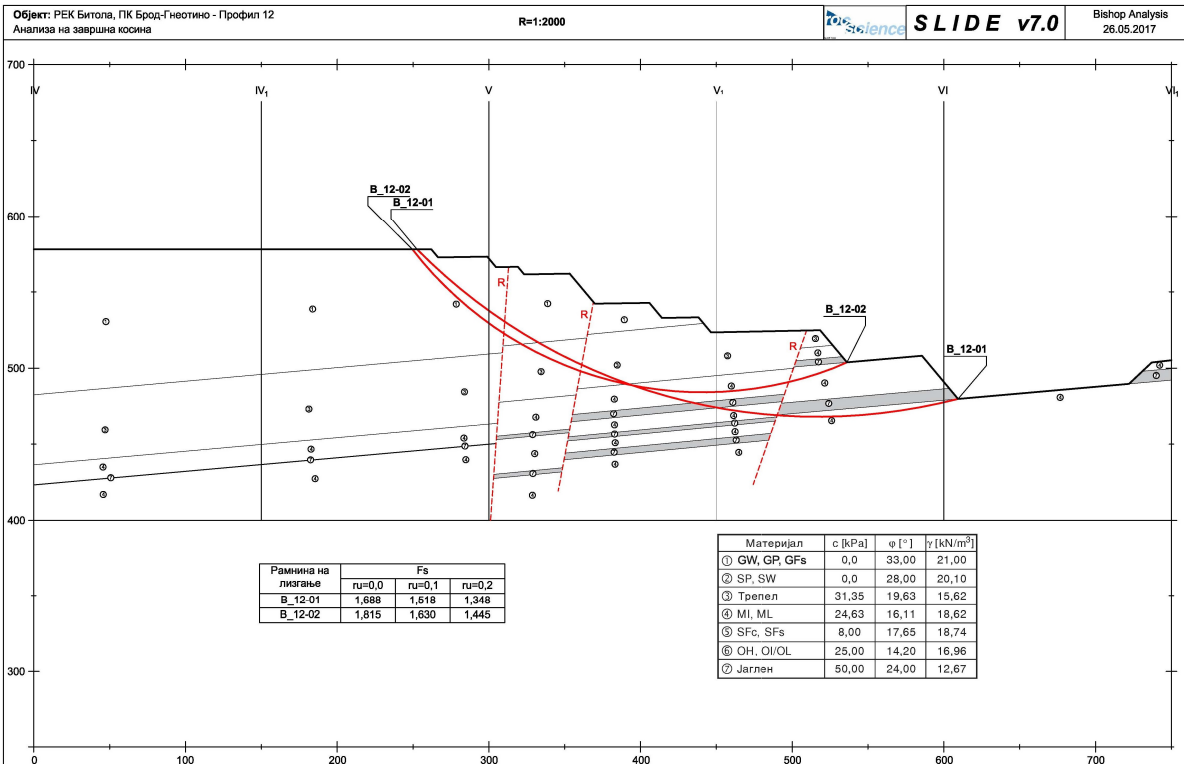


*Figure 3. Verification of the final slopes of the profile*

## CONCLUSIONS

A global and local analysis of the stability for unloaded and burdened working slopes has been performed per year for excavation, external and internal landfill. For excavation, the geomechanical stability analysis was performed on the characteristic profile VI for five years of exploitation. For the external landfill, the stability analysis was performed for I and II BTO systems, where I BTO was analyzed for two years of deposition, while II BTO was analyzed for five years of deposition. For the internal dumping site, the geomechanical stability analysis is performed for the characteristic profile R for five years of deposition.

From the calculations for the stability of the basement of the external landfill for the maximum height of 90 m, it has been found that the basis is satisfactory in terms of stability.

The obtained coefficients of safety for the working and the final slopes in the pit are within the limits of the prescribed coefficients in accordance with the "Rulebook on Technical Norms for Surface Exploitation of deposits of Mineral Raw Materials for Slope Stability of open pit" for $r_u$ = 0.1, pressure will be achieved with the envisaged drainage measures. While the reliability ratios at $r_u$ = 0.2 are simulated to show the negative impact of the increased presence of water, and the negative impact will be avoided by applying the drainage measures, indicating that the drainage should function properly.

The treatment of the slopes as working or finishing depends on the mining and technological concept of exploitation as to how long the slope will be, so it is important to define the time component from the aspect of the available and provideed mechanization for performing the works for a certain period of time, and of course it should also take into consideration the undertaken drainage activities that will directly affect the degree of drainage, i.e. the finishing and working angles of the slopes.

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