GEOTECHNICAL ASSESSMENT OF THE BENCHES IN THE ELATZITE OPEN PIT MINE AFTER BLASTING

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ABSTRACT. The geotechnical assessment of the mine slopes is part of the monitoring of controlled blasting performed at the „Elatzite" Open-pit Mine in the design of the final geometry of the mine board. The structural integrity and geometry of the benches formed by the blasting as well as their long-term stability are analysed. An essential part of this assessment are the specific recommendations for blasting designs that take into account the influence of geological and technological factors on the design of the benches for each area of the mine pit. The publication deals with 12 types of deviations from the design geometry of the slopes and three types of violations of their structural integrity.

Keywords: geotechnical assessment, open pit mine

ГЕОТЕХНИЧЕСКА ОЦЕНКА НА ОТКОСИТЕ НА РУДНИЧНИТЕ СТЪПАЛА В РУДНИК „ЕЛАЦИТЕ" СЛЕД ПРОВЕЖДАНЕ НА ВЗРИВНИ ДЕЙНОСТИ

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РЕЗЮМЕ. Геотехническата оценка на рудничните откоси е част от мониторинга на контролираните взривните дейности, извършвани в рудник „Елаците", при оформянето на крайната геометрия на рудничния борд. При извършването ѝ се анализира структурната цялост и геометрията на рудничните стъпала, получени в следствие на взривните дейности, както и дългосрочната им устойчивост. Съществена част от тази оценка е изготвянето на специфични препоръки към проектите за взривни работи, отчитащи влиянието на геоложките и технологичните фактори, върху дизайна на рудничните стъпала за всяка една зона от рудничния котлован. В публикацията са разгледани 12 типа отклонения от проектната геометрия на откосите и три типа нарушения на структурната им цялост.

Ключови думи: *геотехническа оценка, открит рудник*

Introduction

Ellatzite Open-pit Mine belongs to the company Ellatzite-MED AD (part of the GEOTECHMIN Group), that specializes in producing copper-gold and molybdenum concentrates. It is situated in the ridge parts of the Northern flank of stara Planina near the town of Etropole. It is situated about 60 kilometers east from Sofia, in the northern foot of Etropolska Baba Peak (1 787 m). The topography of the region of the deposit is typically mountain like, from elevation 840 m to elevation 1510 m. It is connected to the town of Etropole via 14-kilometer long asphalt road, providing access all year long, as well as to the towns of Ztatitza and Pirdop via Zlatitza Passage (fig. 1).

The region of the pit consists of three main rock types:

- Paleozoic metamorphic complex (phyllite, stphilitriped and spotted schists, hornfels);
- Paleozoic granodiorites and concomitant strings of dike rocks;
- Upper cretaceous granodiorite, diorite and и quartz monodiorite porphilite rocks, intervening the two upper complexes.

Fig. 1. Locatoin of Ellatzite Open–pit Mine

The geometry and stability of the pit walls depends on the geological factors, the factors connected with the design of pit benches and the blasting activities in the present publication we will mainly consider the geotechnical estimation of the controlled blast works and their impact on the geometry and stability of the pit benches.

The influence of the different factors is specific for each area of the pit and this is why it is necessary to be taken into account when preparing blast designs. One of the possible approaches to reduce this influence is the use of specific techniques of controlled blasting, such as: different timing, different hole diameters and spacing, variety in the quantity of explosives, stemming length etc. With the help of the controlled blasting one can achieve the steepest possible angles of the single or double benches and safe digging and clearing of the mine mass is guaranteed. It allows to keep the strength and structural integrity of the pit walls, minimizes the technogenic cracks in the rock body, situated right next to the blasted mine mass and achieves the project geometry of the pit bench.

Too much damage on the wall can be described as the impact of blast activities gone beyond the planned blast area or crack distribution in the rock body outside the deflecting line. In the scope of the blast field there is an expectancy of about 80% reduction of the rock strength (Peterson, 2001). This strength reduction can be distributed outside the area of the blastfield over some weak structures (contacts, faults and cracks) (Krolikowski, 2015). In addition to the vibrations, the movement caused by gas swelling of the rock body and pressure changes have equal probability to affect the shearing strength along the cracks. Reducing the shearing strength benefits the movement along them which leads to possibilities of creating slide surfaces and wedge rockslides. The reduction of the rock strength is caused by the blast mechanics thorough the outcoming vibrations and by the gas expansion. Overdamaging the rock integrity can often lead to violation of the wall stability of pit benches and mine mass downfall (Hoek, 2007).

Methods

When making geotechnical assessment of the pit bench walls after controlled blasting activities in Ellatzite Pit, the geotechnical experts document and analyze the state of integrity of the walls, situated in right next to the blasted mine mass, and the achievement of the project geometry of the pit bench. The characteristics of the deformations after blasting is based on the information achieved by the special mapping and analysis according to the methods of Cebrian (2017), Marshall-Mohr (2005), Rock-mass ratings system (RMR –

Table 1.

Level of deformations	Cracks and blocks	Slope angle and rock body status	Excavation and loading and wall geometry
1. Level – Slight deformations	The cracks are closed and the stowage is still intact	Slope angle >75° The pre-split holes are clearly seen on the wall. There is no damage and there is minimal technogenic cracking by the blasts.	Traces of bucket teeth of the excavator in softer rocks. Excavation and loading material to the prject gowl line going through the center of the pre-split holes
2. Level – Moderate deformations	The weak stowing material of the cracks has been broken. Very rare occasions of block movement and the cracks are slightly open	Slope angle from 65° to 75°. The slope is smooth, some of the pre-split holes can be seen. There is slight break and a little technogenic cracking of the wall by blasting	Excavation and loading material slightly behind the project gowl line going through the center of the pre-split holes. Bucket teeth of the excavator grind noisily over the rock
3. Level – High deformations	Some of the blocks are moved and the cracks are wide/open	Slope angle from 60° to 65° The slope is relatively smooth. Minimal break, moderate technogenic and visible radial cracking by the blasts	Excavation and loading material up to 1.5 м behind the project gowl line going through the center of the pre-split holes.
4. Level – Very high deformations	Thick net of open cracks and some blocks are lose and moved	Slope angle from 55° to 60° Uneven slope with smal breaking and highly cracked wall in depth	Excavation and loading material до 3 m behind the project gowl line going through the center of the pre-split holes.
5. Level – Extreme deformations	The blocks are moved and highly lose and reoriented. Large open cracks with visible damage from blasting	Slope angle < 55° Very uneven slope highly broken and open technogenic cracks in the wall	Excavation and loading material more than 3 m behind the project gowl line going through the center of the pre-split holes.

Bieniawski (1989) and ISRM (1981), modified 6/98), Mining Rock-mass ratings system (MRMR – Laubscher (1990)) и Q-slope (Bar & Barton, 2018). It is also a very important part of the process of creating a stable and economically efficient profile of the mine.

The scope of geotechnical assessment includes the following tasks:

- check up right after blasting, as well as mapping, photographing and describing the deformations (parallel cracks) behind the deflecting line;
- five-stage quality assessment of the deformations along the slope of the benches (Cebrian, 2017, changed) as a result of blasting according to three criteria for excavating the blasted ore (table 1);
- mapping, photographing and description of the deformations along the benches after excavation of the ore mass;
- geodesic survey of the achieved upper and toe crests of the benches after digging the blasted ore and comparison with their designed locations in search of inaccuracies;
- update of the bench plans for the strength and structure of the rock body in the areas where the next blasting activities are about to take place;

- preparation of recommendations for better efficiency of the blasting activities in problematic zones and areas.

In the high hypsometrical levels of Ellatzite mining is done by working of a single bench with 15 m height. In depth (going into harder rocks) those benches become double. Due to the big variety of rock types with wide diversity of physio-mechanical properties, there are specific designs for every different area or elevation. They are structured in different sections, each with a title of their own if possible. Each statement should contain: thesis and hypothesis of the research, applied methods, main results achieved and discussion. The conclusion should not match completely the resume.

In Figure 2 there is an examplary situation of blasthole pattern. You can see a combination of pre-split row, stab row, or as often called - short buffer row, buffer row as well as three production rows.

The production rows, depending on the physio-mechanical properties of the rocks, can be vertical, with diameters 142, 165 or 250 mm and 16 m length, and the rest of the holes are with diameter 142 or 165 mm, with variable length and inclination. Depending on the length of the resistance line in the bottom of the wall, however, the production holes can be drilled with inclination. Stab holes are 9 m long and the buffer ones – 19 m. They are left without stemming (air deck), with the upper few meters remaining empty. The combination of different types of pre-split, stab and buffer holes is a main element for controlling the blastwork and is essential for maintaining the structural integrity of the ore bench and reducing the deformations and damages of its final board.

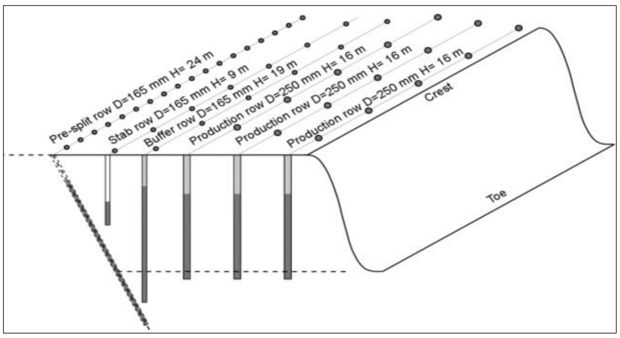

Fig. 2. Example of a blast pattern in Ellatzite Mine

Results

The summarized results from the geotechnical assessment of the bench walls after performing controlled blasting activities are illustrated with 12 examples for different wall geometries. The difference of the geometry before designed and real bench wall after excavating the blasted material is due to the combination between the strength characteristics and the structures (faults, cracks) of the rock body. The angle between these structures and the wall, as well as the design blasting parameters, are shown in Figure 3 and in Table 2.

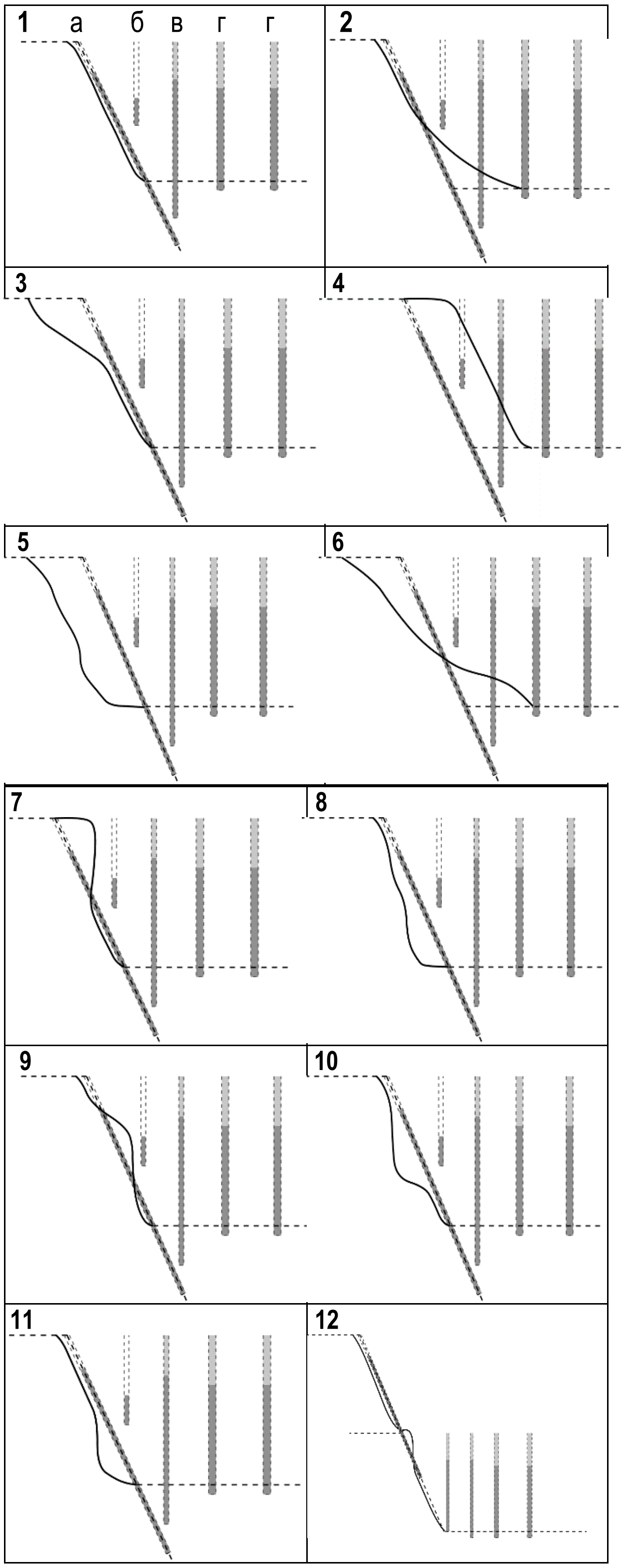

Fig. 3. Grafical representation of the 12 examples for the achieved pit wall compared to designed (Cebrian, 2017 с with cnanges) Legend: designed wall geometry of the bench; —— achieved wall geometry after excavation; а – pre-split hole; б – stab hole; в – buffer hole; г – production holes. Dark grey color shows the explosive material, light grey – stemming.

Description of the twelve examples for achieved geometry of the pit wall profile compared to the design, after finishing with excavation and loading:

- Example 1. The board matches the design – this can happen when there is some damage from blasting level 1 or 2, which means slight to moderate. There is no need for minimal modification of the next project for controlled blasting in the examined area. This is the prevailing type of geometry of the actually achieved walls and it is observed with all rock types;
- Example 2. The toe of the real slope is in front of the project one – this happens in very rare occasions and mainly with vertical change of the lithology in the bench or when there are horizontal or slightly inclined tectonic breaks that screen the blasting energy. The harder rock at the toe of the slope has remained unbroken. There is a need to increase the blasting energy. In this example, the space between the buffer row and the production holes is correct. The necessary changes for the next projects might be some of the following:
  - o increase of the charge in the buffer road;
  - o decrease of spacing between buffer row holes;
  - o moving the buffer row closer to the pre-split holes.

Table 2.

Rock types/Example	1	2	3	4	5	6	7	8	9	10	11	12
Phyllite	X		X		X							
Shists	X		X		X		X		X	X		
Hornfels	X	X	X		X	X						X
Quarz monodioritr porphyrites	X	X	X		X	X			X	X		
Granodiorites	X			X		X	X	X			X	X

- Example 3. The crest of the actual slope is behind the project one – this happens when there is some damage from blasting level 3 to 5, which means high to extreme. This is observed at slopes with cracks wit slight inclination going inside the wall, as well as in layered types of rock (phyllite and shists). It is necessary to decrease the energy in the upper part of the area of project slope. Usually this geometry happens because of some unfavorable geological structures and/or excessive energy in the stabilizing buffer row, as well as too much subdrilling from the upper bench. The slope toe is in the right position that is why the location of the buffer row should not change. In this case the downfall could be avoided through:
  - o increasing the no stemming interval (decreasing the length and quantity of explosive respectively) of the stab and buffer rows;
  - o decreasing the load of explosives only in the stab row;
  - o increasing the distance between the stab row and the pre-split holes;
  - o increasing the spacing in the stab and buffer rows, as well as increasing the burden between those two rows;
  - o double decked charge (divided) in the stab and buffer rows with two independent levels and blasting of the upper charge 80 - 100 ms before the lower one, i.e. formation of two separate, independent blasts in the upper and lower level.
- Example 4. The actual slope is in front of the design one – this happens when the rock body strength is not reduced enough due to the high rock strength or the insufficient blast energy. It is necessary that the energy from the blast in the design slope area is increased. The design might be corrected through narrowing the distance between stab and buffer row and the pre-split holes equal to the difference between the project and the actual wall crest, and reducing the time delays between the rows.
- Example 5. The real slope is far behind he designed one – this happens when there is some damage from blasting level 3 to 5, which means high to extreme. This can be observed in benches with highly damaged tectonic areas, mainly in phyllite and shists. It is necessary to reduce the energy from the blasting to be reduced. This can be achieved (contrary to the example above) through increasing the distance between the stab and buffer rows and the pre-split equal to the difference between the actual and designed wall crest, as well as through increasing the time delays between the rows.
- Example 6. The real slope in its upper part is behind the designed one, and in its lower part is in front – this happens when there is some damage from blasting level 3 to 5, which means strong to extreme. These are pretty rare in our mine. Almost every time they are due to gravitation processes of the type slide along slope cracks and faults. It is necessary for the accumulated energy to be reduced in the upper part and increased in the lower part. The design of the following blast works must be modified for fragmentation improvement in the lower part of the bench while at the same time reducing eventual damages in the upper part. In this case it is necessary to use the following steps for improvement of blasting activities:
  - o reduce of spacing in the buffer row;
  - o increase the charge in the buffer row;
  - o increase the distance of the stab row and reduce the distance of the buffer row to the pre-split holes;
  - o double deck the stab row and the buffer row in two independent levels and blasting the upper deck slightly before the lower, for example 25 ms.
- Example 7. The actual slope in its upper part is before the designed – this can happen when the upper part of the slope the rock strength is not reduced enough due to the better rock strength of the upper part of the rock body, change of the lithology in depth. It is necessary that the released energy in the upper part to be increased. This can be achieved through the following:
  - o increasing the charge of the stab row;
  - o increasing the charge in both stab and buffer rows;
  - o reducing the distance between the stab row and pre-split holes;
  - o reducing the spacing between stab row holes.
- Example 8. The actual slope is with a bigger angle and its lower part is behind the designed one – this can happen with really hard rocks or when there are tectonic faults with sinking angle larger than 65^{o} towards the air slope. It is necessary that the energy released with the blasting of the lower parts of the

designed slope to be reduced as well as some changes in the buffer row through:

- o reducing the charge in it;
- o increasing the spacing;
- o increasing the distance between it and the pre-split holes.

- Example 9. The actual slope's middle part is in front of the designed one – this can happen when there is a lens or dike from a herder rock. It is necessary that the released energy from blasting the middle part of designed slope to be increased. In the mine such cases, although very rare, can happen at the borders between shists and quartzmonodiorite porphyrite. This can be corrected by increasing the charge or narrowing the spacing of the stab row;
- Example 10. The actual slope in its middle part is behind the designed slop – this is due to the presence of tectonic faults or when there is a lens or dike body from a weaker rock. It is necessary that the energy released during blasting in the middle parts of the slope to be reduced. This can be corrected by reducing the charge or increasing the spacing in the stab row;
- Example 11. When achieving the designed location of the toe and the designed slope angle of the bench, the actual slope, in its lower part, is behind the designed one – this can happen when there is a more cracked and broken area in the lower part of the slope. This happens when there is some damage from blasting level 3 and 4, which means high to very high. This usually happens with granodiorites. It is necessary that the energy released during blasting in the lower parts of the area of the designed slope to be reduced. With this type of damage on the wall the charge in the buffer row should be reduced or the spacing in it to be increased;
- Example 12. The real slope of the lower bench in its upper part is in front of the actual slope of the upper slope leaving a small berm between them – this happens with double benching, mostly because of the drilling specifics for the pre-split row. It is necessary that the energy released when blasting in the upper part of the designed slope of the lower bench to be reduced. This can be corrected through increasing the charge or narrowing the spacing of the stab row in the lower bench.

Conclusion

The way the blasting is performed, especially the last bench blasting that forms its final configuration, respectively – its final slope angle, can be crucial for the final stability of the pit wall. The correct application of the controlled blasting technique allows to lower to the minimum the explosive seismic impact on the slopes and the precise contouring of the benches' crests and toes. This is how optimization of the slope angles and maximum width of the final berm are achieved. For example, by increasing the slope angle in hard rocks from 65° to 70° ÷ 75° allows berm widths to be increased by 1 m to 3 m or to increase the angles between the ramps and the general board angles that, respectively, reduces the waste coefficient.

The timely provision of detailed and precise information about the geotechnical properties of the rock body has a huge impact on the optimization and improvement of the drilling and blasting activities in the mine.

The results of the recommendations described in the 12 examples need to be carefully investigated. The follow up blasting designs need to be changed singularly and in random combinations between changing the burden to the pre-split holes, the spacing in different rows and the burden between the rows, the quantity of explosive and the timing in the holes, the amount of stemming and the number of holes left without stemming. This should be done until achieving the optimal designed slopes of the mine benches in the examined area.

Using a pre-split row with preliminary blasting, as well as the positioning and charging of the inside and outside buffer rows reduces the explosive seismic impact on the wall behind, by restricting the influence of the typical geology. Using stab row of holes (to improve material movement in the upper part of the slope) is especially needed in cases of blasting harder rocks. When there are deviations from the designed walls, in the toe and lower part of the ore bench, some improvement can be achieved by changes in the holes of the buffer row.

The faults are having a destructive impact on the surrounding rock body and the rocks in the hanging wing of the fault are considerably more damaged. This is the main reason for extremely damaged surfaces in the upper part of the wall.

It is noteworthy that you can participate with a more intense contact change, near magmatic rocks, a larger gravitational case with the nature of wedge-shaped landslides and sliding surfaces is formed. This is due to the loss of flow properties of these metamorph rocks and formation of cracks in them. There is a narrow protruding berm formed in the middle of the slope at some of the double 30m benches.

Something that is characteristic for the quartzmonodiorite porphyrite and the hornfels is the development of some gravity processes in it that look like wedge slides in cases when the top of the pyramid, formed by the prismatic cracking, points at the airy part of the bench slope. Such slides with different scale often occur in these rocks. Sometimes they cover the wall surface from crest to toe.

In the granodiorite slopes there can be seen almost everywhere the traces of the presplit holes which shows that the design and the actual wall surface match. In some areas these rocks, however, form slopes that are steeper than the designed ones. This is due to some subvertical cracks with direction that is parallel or sub-parallel to the slope. In these rocks, the main gravitation processes have the characteristics of flat slide

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