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Professional paper

CONSIDERATIONS ON STABILITY OF OPEN STOPES IN "JAMA BOR" UNDERGROUND MINE

RAZMATRANJE STABILNOSTI OTVORENIH OTKOPA U JAMI RUDNIKA BAKRA BOR

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Abstract: Dominant ore bodies in "Jama Bor" underground mine in last few years, from the aspect of production and engaged resources, have a common characteristic that after being mined out, excavated areas remained open. These are following ore bodies: T, T1 and T2. Mining in ore body T had been ended two years ago and the stope was supposed to be backfilled after the end of excavation. However, process of backfilling did not start yet. Applied mining method in currently active ore bodies, T1 and T2, is pillar mining in horizontal slices, with leaving open voids after the end of extraction. Existence of voids in underground mines is always a challenge, regarding stability and safety. In considerations of stability of open stopes in "Jama Bor", there are several key factors: rock mass properties, stope geometry, support properties and interaction between installed support and surrounding rock. Contemporary approach applied in each phase of the process, including determination of rock properties, mine design, mining operations, support installation and monitoring of stope stability during and after the excavation, enables accurate and reliable defining of stope stability. Also, such approach enables early detection of possible endangerments in stope stability, thus providing possibility for prevention and securing of endangered zones. Since the future of underground mining in RTB Bor is related deep lying ore deposits, bellow current operations, importance of their stability is even bigger.

Key words: underground mining, open stopes, roof stability

Apstrakt: Rudna tela koja su u poslednjih nekoliko godina dominantna u Jami Rudnika Bakra Bor, sa aspekta proizvodnje i angažovanih resursa, imaju zajedničku karakteristiku da su, nakon završetka otkopavanja, otkopi ostali otvoreni. U pitanju su rudna tela: „T“, „T1“ i „T2“. U rudnom telu „T“, u kojem je otkopavanje završeno, predviđeno je zasipavanje otkopanog prostora suvim zasipom, ali ta aktivnost još uvek nije pokrenuta. U rudnim telima „T1“ i „T2“, koja su trenutno aktivna, primenjena je metoda otkopavanja pod nazivom

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„komorno stubna metoda etažnog otkopavanja“, gde je predviđeno da nakon otkopavanja komora ostane otvoreni prostor. Postojanje ovakvih otvorenih prostora većih dimenzija u podzemnim rudnicima uvek je izazov po pitanju stabilnosti i sigurnosti. Pri razmatranju stabilnosti pomenutih otkopa u borskoj Jami, treba uzeti u obzir karakteristike stenskog masiva, geometriju otkopa, karakteristike ugrađene podgrade kao i karakteristike sistema podgrada – stenska masa. Primena savremenih pristupa u svim fazama – od prikupljanja podataka o stenskom masivu i njihove analize, preko faze projektovanja, zatim primenjene tehnike i tehnologije otkopavanja i osiguranja otkopa, pa sve do monitoringa i praćenja ponašanja i procesa u stenskoj masi i podgradi za vreme izvođenja rudarskih radova i nakon njihovog završetka, omogućavaju da se stabilnost podzemnih otkopa velikih dimenzija utvrđuje sa većom preciznošću i poverenjem. Takođe, ovakav pristup omogućava i rano otkrivanje eventualnih ugrožavanja stabilnosti u pojedinim zonama, a samim tim i primenu preventivnih mera u cilju održanja stabilnosti. S obzirom da je budućnost podzemne eksploatacije rude bakra u RTB Bor vezana za ležišta koja zaležu na većim dubinama, značaj stabilnosti radne sredine je još veći.

Ključne reči: podzemna eksploatacija, otvoreni otkopi, stabilnost otkopa

1. INTRODUCTION

"Jama Bor" underground mine is specific by its numerous ore bodies, situated along the deposit, and various mining methods applied. Thus we had sublevel caving in ore bodies Tilva Ros and P_2A, room and pillar mining with backfilling in ore body Brezanik, mining in horizontal slices with NATM support system in ore body T, room and pillar mining with open stopes in ore bodies T1 and T2, etc. It is obvious that different mining methods require different treatment of excavated areas and different roof control.

Currently active ore bodies are T1, T2, Brezanik, Tilva Ros and P_2A. Ore body Brezanik is soon to be mined out, remaining parts of ore bodies Tilva Ros and P_2A are excavated with room and pillar mining and Borska Reka is in development, so the focus in this paper would be on ore bodies T, T1 and T2.

Ore body T was relatively small, isometric and elliptically shaped in horizontal cross section. In its thickest part, ore body was 60 m long, 40 m thick and 50 m high. It was a high-graded ore body, and the task of mine design was to provide maximal ore recovery. That is why designed mining method was downward mining in horizontal slices (RdS Grupa, 2010). As excavation advanced downwards, huge excavated area was opening. In order to provide roof stability, combination of cable bolts, steel meshes and shotcrete had been used, both in roof and sidewalls.

Ore bodies T1 and T2 are small, vein type ore bodies. Maximal length of ore body T1 is 185 m, maximal thickness 22 m and it is situated between K-100 m and K-250 m levels, with 65^o to 70^o dip towards north. Ore body T2 is a bit smaller, with maximal length reaching 150 m, maximal thickness 18 m and depth between K-130 m and K-180 m levels, with 40^o to 50^o dip towards north. Applied mining method in these ore bodies is room and pillar.

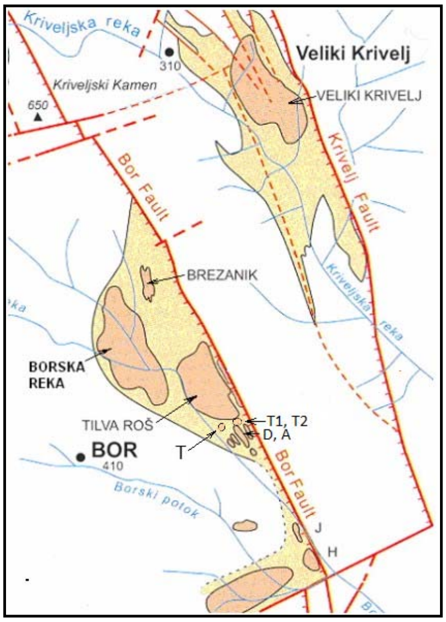

Figure 1 - Layout of ore bodies in Bor ore deposit

2. STABILITY OF UNDERGROUND OPENINGS

Any design of underground opening requires systematic and careful approach, in order to determine rock mass properties and behavior of rock around the opening. Rock mass quality, in combination with mechanical processes in the massif, especially stresses, are key factors in defining of stability. Main influential factors to stability of underground openings are shown on Figure 2.

Rock mass strength is a parameter which depends mainly on uniaxial compressive strength, but also on many other factors. Uniaxial compressive strength (UCS, σ_{ci}) is determined by laboratory testing on specimens of intact rock. However, beside UCS, there are many other factors influencing rock mass strength, such as the scale and anisotropy of specimens, effect of underground water, rock weathering and alternation.

As determination of rock mass strength depends on many factors and parameters, it is difficult to determine it accurately, and many authors have provided their models and empiric formulas for it, such as Bieniawski, based on Rock Mass Rating (RMR), Hoek et al., based on RMR and Geological Strength Index (GSI), Barton, based on normalized rock mass quality *Q*, etc.

While deformability of intact rock is referred to Young's modulus of elasticity, rock mass deformability, or modulus of deformation E_m, defined as a ratio of stress to corresponding strain during loading of rock mass, is commonly used in analysis of rock mass quality, because a jointed rock mass does not behave elastically. There are also several empiric formulas for determination of modulus of deformation, by various authors.

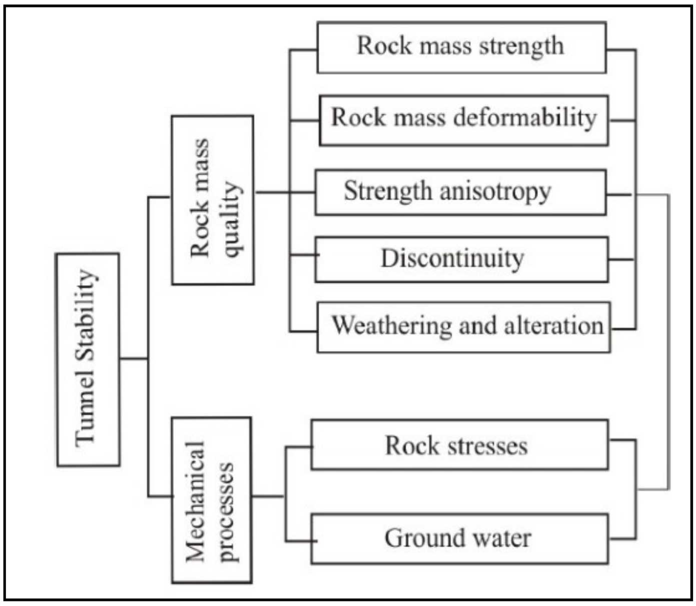

Figure 2 - Factors influencing the stope stability (Panthi, 2006)

The stress conditions existent in the rock mass before an excavation are referred to as the in-situ stresses, virgin stresses or initial stresses. Creating an underground excavation will change the stress conditions in the rock mass surrounding the opening. The final stress state will be a result of the initial stress conditions and the stresses induced by the excavation. The stability of an underground excavation will depend on the rock's ability to sustain failure induced by the stresses around the opening. (Larsen Vestad, 2014).

Since in-situ stress is the most dominant influential factor in estimating the risk of failure in underground openings, risk estimation should be expressed through the ratio of stresses to rock mass strength, or vice versa. For instance, C.D.Martin et al. (2003), proposed decision tree (Figure 3), based on relations provided by Muirwood and Adyan for soft rock and Hoek and Brown's stability index for hard rock. Muirwood (1972) and Adyan et al. (1995) claimed that ratio of uniaxial compressive strength σ_{ci} to vertical stress σ_v can be used for defining the stability in weak rock. Their conclusion was that squeezing in weak rock will appear if $\sigma_{ci} / \sigma_v > 2$. Hoek and Brown (1980) introduced a stress to strength ratio (σ_1 / σ_{ci}), or stability index for hard rock, where σ_1 is major principal stress. Their conclusion was that value of stability index ranges from 0.1 to 0.5. For values bellow 0.15, rock mass is stable, between 0.15 and 0.35 is referred to occurrence of minor instability and severe instability for values over 0.4, with heavy support required.

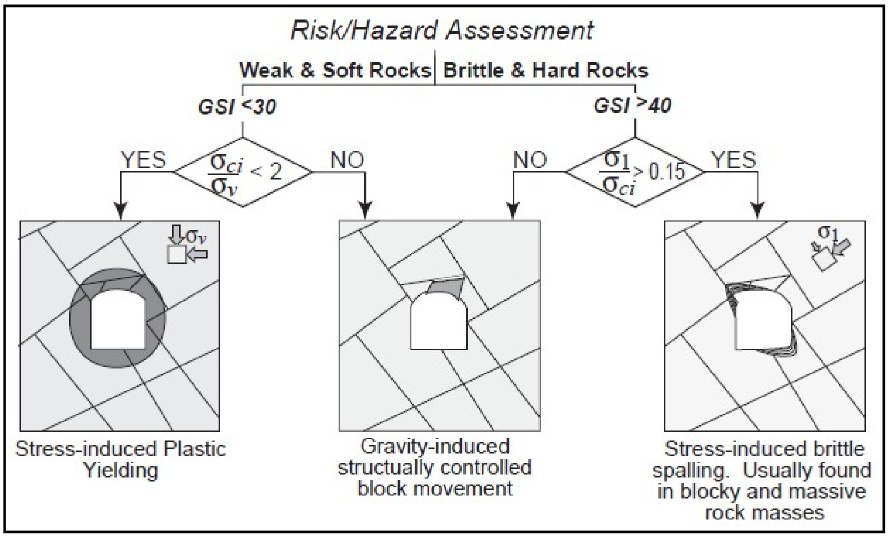

Figure 3 - Illustration of common modes of failure and decision tree (Martin et al. 2003)

Analytical and empiric approach are suitable for simpler excavation shapes and for highly simplified mechanical assumptions. Therefore, in order to provide more accurate models of rock mass behavior, various numerical models have been introduced. There are two major groups of numerical methods used in this purpose: continuum methods and discontinuum (or discrete) methods. First group of methods is based on continuum mechanics and it is used to simulate rock mass response to excavation process. However, the ability to consider discontinuities in rock mass is limited. That is why discrete methods may be more suitable for representation of discontinuous rock mass.

Most commonly used continuum methods are finite difference method (FDM), finite element method (FEM), and boundary element method (BEM).

Due to limitations in this group of methods, mentioned above, much enrichment have been added to original methods, thus forming improved methods such as generalized finite element method (GFEM), or extended finite element method (XFEM). (Lisjak et al, 2014)

Second group of methods is presented through discrete element method (DEM). This group of methods was developed based on laws of interaction. There are two main groups inside DEM. First one is referred to distinct element methods, such as universal distinct element code (UDEC), and the second is mainly represented through discontinuous deformation analysis (DDA) method. Further development of this group of methods led to introduction of hybrid finite-discrete element method (FDEM). (Lisjak et al, 2014)

Most of these methods are integrated into software, thus enabling quality and accurate modeling and prediction of behavior of rock mass around underground openings.

3. STABILITY OF UNDERGROUND OPENINGS IN "JAMA BOR"

3.1. Ore body T

As it was mentioned before, ore body T was a small, relatively isotropic, high graded ore body, situated in the central part of Bor ore deposit. Due to very valuable ore, the demand of investor to the mine designer was to enable maximal ore recovery, over 90%. Designed mining method was mining in horizontal slices downwards, with leaving empty space above excavations. When this ore body was mined out, dimensions of open stope were 60 m x 40 m x 50 m. In order to provide stability of such a large scale open stope during and after mining operations, roof and sidewalls were supported according to NATM. Combination of steel and cable bolts, 9 m to 25 m long, with several layers of wire mesh and shotcrete, additionally reinforced by steel ribs were installed as mining operations advanced downwards. Design of supporting works and analyses of stress and deformations were performed by Faculty of Mining and Geology, University of Belgrade. Finite element method (FEM) was used for analyses of stress and deformations, through software packages Phase2D and MIDAS-GTS. Figure 4 shows values of Strength Factor and yielding elements around the stope in the final stage of extraction, on specific vertical profile.

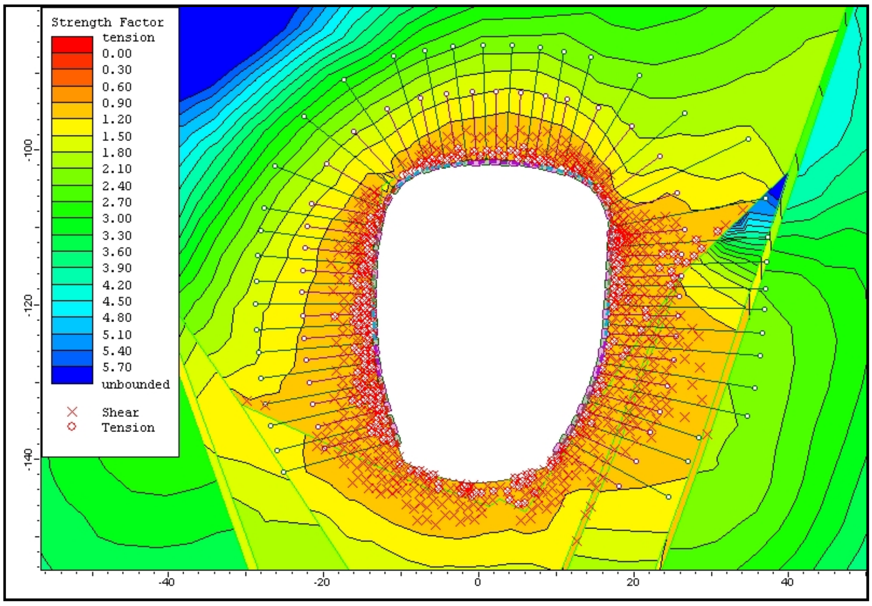

Figure 4 - Strength Factor and yielding elements in the final stage of extraction on vertical profile No. 28 (University of Belgrade - Faculty of Mining and Geology, 2010)

According to numerical analyses, roof and sidewalls are stable. Plastic deformations and displacements in the rock mass are inside permitted values. In order to provide constant monitoring of rock mass, installed support and newly established rock mass-support system, various techniques and instruments were engaged: geodetic survey of profile convergence; extensometers for measuring divergence of surrounding rock; pressure stress cells for monitoring of tangential stresses in shotcrete; electronic cells for measuring forces in the bolts and determination of bolt's bearing capacity.

Systematic survey, during entire process of mining operations, enabled constant insight into each influential factor related to stope stability. As a result, roof and sidewalls of the opening remained stable through the entire process of mining operations in the ore body. Furthermore, although mining operations ended in 2013, and the stope was supposed to be backfilled, backfilling hasn't started yet. Visual inspection of open stope in ore body T shows no visible damages and deformations. However, in order to accurately determine current situation in stope stability, it would be necessary to renew the monitoring process, which was aborted after the end of mining operations, due to lack of resources.

3.1. Ore bodies T1 and T2

Ore bodies T1 and T2 were already described in introduction, along with their dimensions. Mining operations in these ore bodies are currently active. Applied mining method is room and pillar mining, and basic stope geometry is given in Figure 5.

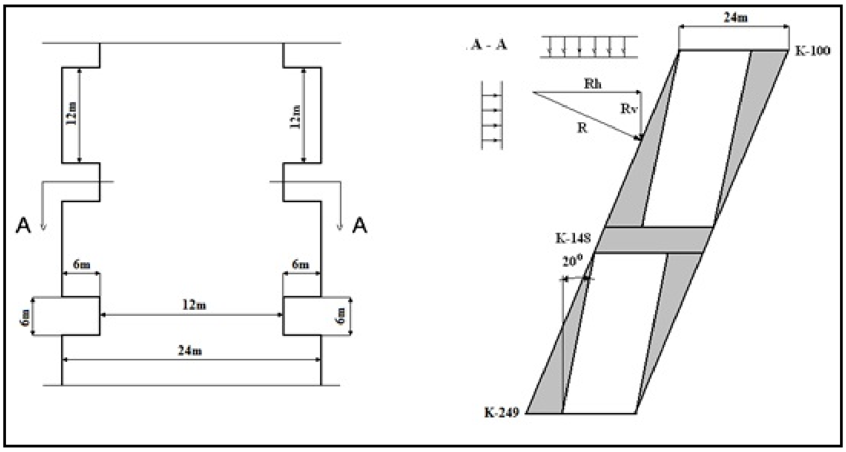

Figure 5 - Geometry ore body T1 (RdS Grupa, 2012)

Ore body T1 is divided into two sections vertically, separated by sill pillar. Each room is 12 m high, and there are a total of seven rooms in T1 and 2 rooms in T2. Adjacent rooms are also separated by sill pillars.

Rock bolting, in combination with wire mesh and shotcrete makes the support system. Stability of stopes was also analyzed on numerical models based on finite element method, using Phase2D software. The modeling and analyses were performed by Faculty of Mining and Geology, University of Belgrade. The results of analysis have shown that, with designed support, the rooms will remain stable during mining operations, but the re-composition of stresses inside surrounding rock will be significant, causing the occurrence of plastic deformations around the rooms, especially in sidewalls and footwall.

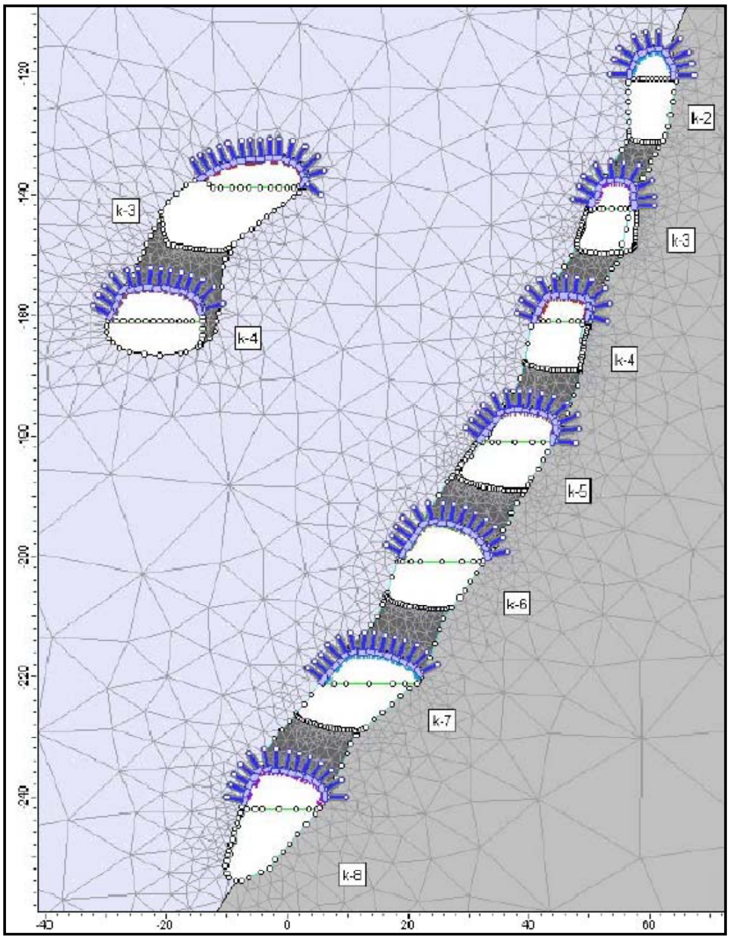

Figure 6 - Modeling in Phase2D software, rooms and pillars in ore bodies T2 (left) and T1 (right) and installed roof support
(University of Belgrade - Faculty of Mining and Geology, 2012)

Constant monitoring of most important parameters is also necessary in order to preserve stope stability. Monitoring of profile convergence, bearing capacity of installed bolts, compressive strength of shotcrete and seismic properties would provide a possibility to evaluate the stability of rooms and take actions in order to improve stability, if necessary. Some of possible actions for improvement of stability are installation of additional rock bolts and thicker shotcrete layer.

4. CONCLUSION

Providing a stability of underground openings, especially large-scale openings, is a very serious and complicated task. It requires specific actions in each part of mining process. It starts in the process of mine designing, were it is necessary to evaluate rock mass quality, analyze stress and deformations and predict behavior surrounding rock and installed support.

During mining operations, constant monitoring of most important stability parameters is required. Monitoring may include profile convergence, rock bolt's bearing capacity, strain in rock bolts, divergence of surrounding rock, seismic, etc. The importance of regular monitoring is very high, because it enables possibility to take actions in case of unexpected occurrences and prevent the endangerments on stability of underground openings.

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