

Stability of a rock mass using the key block theory: a case study

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Abstract : In underground mines, excavating disturb the initial equilibrium state of the rock mass, and therefore require selection of a support in order to control the movement of rocks, avoid landslide and work safely. Thus, the progress of mining operations in the ST2 mineralization, in the eastern zone of the Bouazzar mine, is disrupted because of stability problems. On the basis of field observations and analyzes of core drill, the geological and structural study, carried out in this area, has shown the existence of three types of facies: altered and cracked diorite, cobaltiferous mineralization which is in contact with serpentinites. In fact, the empirical methods such as Barton, Bieniawski and the recommendations of the AFTES have qualified the rock mass as poor, furthermore they proposed as kind of supports: steel arches, shotcrete and rock-bolts. Numerical simulation by the finite element method proved to be very complex due to existence of several types of discontinuities (faults, shistositities and joints). These discontinuities are natural fractures that delimit various shapes and sizes of wedges, which can become detached from the roof or siding of the excavation and collapse under their own weight. Although the empirical methods cited above provide supports for each facies, however, this support is expensive and difficult to implement in practice because it must cover the entire surface of the excavation and thus not allowing to detect stable blocks that do not require a support. For this it was essential to carry out an analysis of wedges to better locate unstable blocks. The treatment of fracturing data has highlighted the presence of five sets of discontinuities of which three sets are principals and the other two are minor joints. Then, while taking into account the geometrical, mechanical data of the discontinuities as well as the geometrical data of the excavation, we were able to detect the shape and the size of the unstable blocks and the sets of discontinuities delimiting them and which favor their sliding and tilting. Thus, we calculated the number of anchor bolts needed to stabilize these blocks in order to ensure an acceptable safety factor. This study shows clearly how a wedge analysis of the rock mass can guide and optimize the support work.

Key words: rock mass, wedge stability, discontinuities, support

Introduction:

To exploit the depth-seated mineralization of cobalt at Bou-Azzer mine, underground excavations are executed. Indeed, the mineralization exploited is in the form of vein, with a subvertical dip and variable thickness, collected between the serpentines and the quartz diorites of the Precambrian II Inferior. The progress of the mining operations is often disturbed because of stability problems of the rock mass, that may harm safety of mine workers, materials, and negatively impacts the production in the working sites.

In the present study, we will firstly present the characterization results of a rock mass by empirical methods (Deere, Barton, Beniaowski, Aftes, Hoek and Brown) and the modes of support recommended ensuring the stability of the rock mass. We will then complete the study with a structural analysis in order to evaluate the risks of tilting and sliding of the blocks and to determine the sets of discontinuities that are responsible.

Finally, by using the Unwedge program, based on Goodman-Shi key block theory [3], we will study the instable blocks and thus design an appropriate and optimized support for these blocks. A methodology of selection of this support will be presented.

1. Geotechnical study :

1.1 Description of the study area:

Bouazzer mine is located in the central Anti-Atlas, at 140 Km south of Ouarzazate in Morocco. It's the largest cobalt deposit in Morocco with a production of 2000t/year. The nickel Ore is contained in serpentinite and quartz diorites. The main orebody called ST2, of Bouazzer East deposit (BAE), has a direction NE-SW, a subvertical dip, an average extent of 160m, a thickness that vary from 0.5 cm to 2.7m and depth of -560m. This orebody is exploited by

To classify the rock mass, Barton calculates the note Q [7][8]. On the basis of the value of this note and also the equivalent diameter of the excavation, we can determine which kind of support is recommended. In fact, for quartz diorites and mineralization of ST2, steel arches or shotcrete and anchoring bolts with a length of

using cut and fills mining method and subdivided to levels.

In the mining level -560m, the main orebody is oriented NW-SE and has a dip 60° toward the NE. Figure 3 shows that serpentinite and quartz diorites are respectively the hanging wall and the foot wall. According to the geological study, the dip direction of serpentinite changes between levels (-510m and -560m) and the shistosity, affecting them, is characterized by a strong dip to the SE. This fracturing system is one of the main causes of block falling problems that occurred during the mining phases in the level -560m.

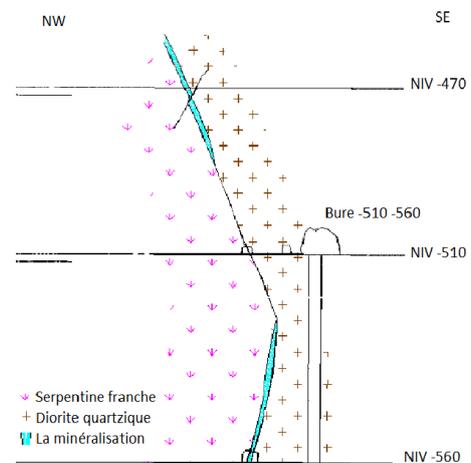


Figure 3: Cross-section of the vein in ST2 [4]

1.2 Empirical classification of the rock mass in ST2 :

In order to classify and describe the rock masses quality of ST2, different classification systems were used [4]:

Deere's classification is based on the evaluation of the Rock Quality Designation index (RQD) [1]. This index gives an idea about the degree of fracturing in the rock mass. After calculating the RQD average for each facies, the rock masses of ST2 could be described as low according to Deere.

1.6m and a spacing of 1.35m should be used as support. Whereas for the serpentinite, it is necessary to use steel arches, rock-bolts (with a length of 1 m and a spacing of 1m) as a well as the shotcrete with a thickness between 50-90mm.

Proposed by Beniaowski in 1976 [11][12]. This classification is based on the evaluation of six qualitative and quantitative parameters of the rock mass. At each value of these six parameters, a score is assigned. The sum of these scores enables the classification and also selection of the support. According to this classification, mineralization and quartz diorites are described as a fair rock need to be supported by systematic bolts (4 m long, spaced 1.5 - 2 m in crown and walls with wire mesh in crown) or by shotcrete (50-100 mm in crown and 30 mm in sides). For the serpentinite, it is qualified as very poor rock. Systematic bolts (5-6 m long, spaced 1-1.5 m in crown and walls with wire mesh. Bolt invert), shotcrete (150-200 mm in crown, 150mm in sides, and 50 mm on face) or Medium to heavy ribs spaced 0.75 m must be used to avoid rock-falling.

The French association of underground works (AFTES) provides a useful description of the rock mass to the study of stability of underground excavations [6]. This classification does not give a note like the other classification methods but a description of the rock masses. It is based on the evaluation of several parameters taken separately from each other. To switch from values of each parameter to the selection of the support, tables are used. According to the AFTES recommendations, we should use rock-bolts, shotcrete or steel arches in order to ensure stability of ST2 rock mass.

Although the empirical methods cited above provide supports for each rock, however, this support is expensive and difficult to implement in practice because it must cover the entire surface of the excavation and thus not allow detecting stable blocks that do not require a support.

2. Structural Analysis of discontinuities:

Since the ST2 rock mass contains several types of natural fracturing (faults, schistosity and joints) Numerical simulation was not possible to use. These discontinuities are surface planes that may intersect each other if their extent is large enough and becomes discrete, in other words, the discrete rock masses become one kind of spatial structural shape, or called blocks. The main failure mode of rock masses in an underground excavation is the movement of the unstable rock

blocks that consist of soft structure planes and critical excavation plane. Thus, it's necessary to carried out a structural analysis in order to determine which sets of discontinuities may cause rock movements.

Le traitement des levés de fracturation par le logiciel Dips de Rocscience a permis de réaliser des projections stéréographiques sur le canevas de Wulff-Schmidt (figure 4). Ainsi, on note que les pôles se concentrent surtout vers l'Est.

After collecting and processing the discontinuities data using Dips program, it was possible to represent projection of pole discontinuities on the Wulff net. Thus, we note that the poles are mainly situated in the East (figure 4).

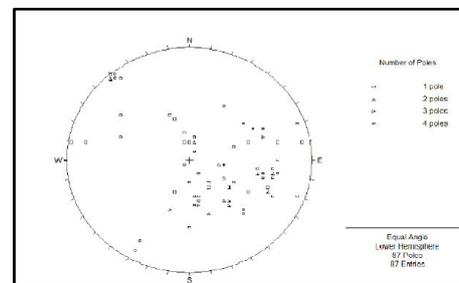


Figure 4: stereographic diagram of joints in the level -560m

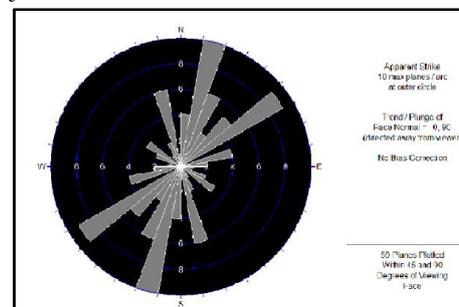


Figure 5: Rose diagram of dip directions

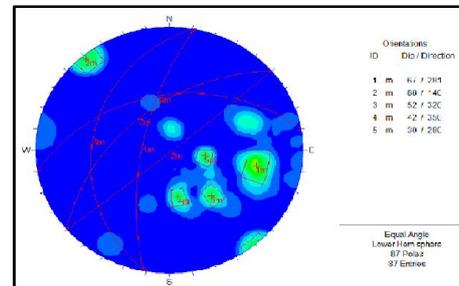


Fig 6: Stereonet of main joint sets

The figure 5 shows that the discontinuities, represented on the rose diagram, can be grouped into three main sets with a direction respectively

ENE-SSW, NNW-SSE and NE-SW, and a secondary sets oriented NW-SE.

By grouping discontinuities belonging to the same family, it was revealed three main sets and two minor joints (figure 6). These sets have variable dip directions as well as a dip that vary from inclined to steeply inclined (Table 6).

The analysis of natural fractures shows that the rock masses is very cracked and requires assessing the risk that may cause this state of fracturing on the progress of mining operations. For that, Goodman's Kinematics analyzes were

used, taking in consideration the standard variables (1 and 2), foot and hanging wall surface planes.

Table 6: Dip and dip direction of main joint sets

sets	Dip	Dip direction	Description
1	67	283	Principal set
2	88	140	Principal set
3	52	320	Principal set
4	42	350	Minor Joint
5	30	280	Minor joint

Risk of toppling :

The projection of the hanging and foot wall planes on the stereonet diagram, that contains the main joint sets (fig 6), allowed to visualize potential risk areas of rock toppling and which set is responsible. Thus, it was revealed that there is a risk in the zone located between the hanging wall of serpentinites and the mineralization and it is caused by the second joint set (88/140) (Fig 7).

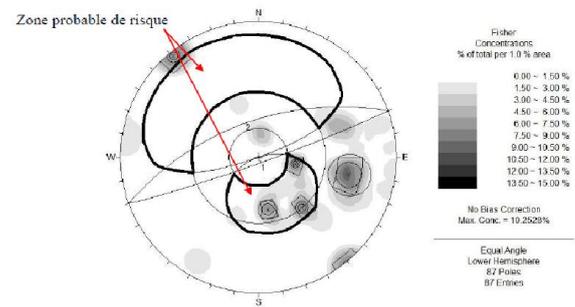


Figure 8: Sliding risk zones [5]

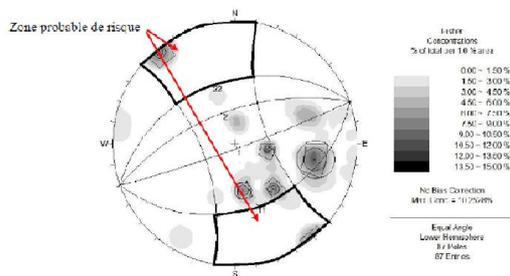


Figure 7: Toppling risk zones [4]

Risk of sliding

The analysis of sliding risks generated by intersections between joints and excavation surfaces was determined by projecting on contour diagram main joint sets and excavation sides planes and by adding by adding vertical N00 direction of angle equal to $90-\phi$ (ϕ : internal friction angle of the rock). This analysis allowed it possible to visualize potential risk areas of sliding as well as the responsible sets. Indeed, it was revealed that there is a risk in the zone located between the hanging wall of serpentinite and the mineralization and it is mainly caused by the joint set (52/320) (Fig 8), and also by 42/350 and 30/280 main joint sets.

3. Wedge stability analysis :

As mentioned above in section 2, the rock mass consist of a juxtaposition of heterogeneous rocks affected by several natural fractures. The intersection between at least three different of these discontinuities defines blocks. Depending on orientation and properties of joints, tunnel orientation and rock properties, blocks can slide or topple into the excavation. Hence, an analysis of the stability of these blocks is important.

In order to carry out this study, the Unwedge program, based on key block theory of Goodman-Shy, was used to analyze the geometry, shape and stability of underground wedges defined by intersecting structural discontinuities in ST2 rock masses surrounding an underground excavation.

3.1 Key blocks principle :

According to Goodman, the unstable blocks or key blocks have a finite dimension, a critical orientation and located at the periphery of the

excavation. These blocks are potentially dangerous and it is essential to implement a support in order to avoid their movement. Once, they are supported thanks to a support or a friction between the joints, the blocks which are behind them finally will be also stabilized (Fig 6).

If we want to use Goodman and Shy theory, some hypothesis should be done:

1. Each discontinuity can be described as perfectly planar.
2. All the rock blocks intersected by discontinuities are rigid, ignoring the failure of rock block itself.
3. The failure of blocks is due to the shear displacement along discontinuity under various loads.

3.2 Methodology :

To study the block stability of excavations in ST2, Unwedge was used to describe and identify the most critical rock blocks formed by the intersection of the joints in a specific underground excavation $2.5 \times 2.5 \text{ m}^2$. Indeed, the tunnel orientation, orientation and properties of main joint sets, and rock properties as well as the state of stress in the field are introduced in Unwedge, After this, we could detect and visualize the key blocks on Unwedge, Once they are located, we check the value of the safety factor if it is satisfy the condition ($F_s > 1.5$), if yes we will not need a support as the blocks ensure their own stability thanks to the friction between them joints. Otherwise, we change the excavation form, recalculate F_s , if the security factor is not verified we design a support in order to increase the safety factor (Fig10).

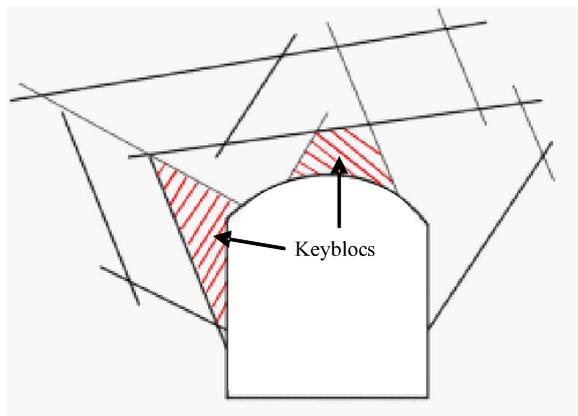


Fig 9: Examples of key blocks

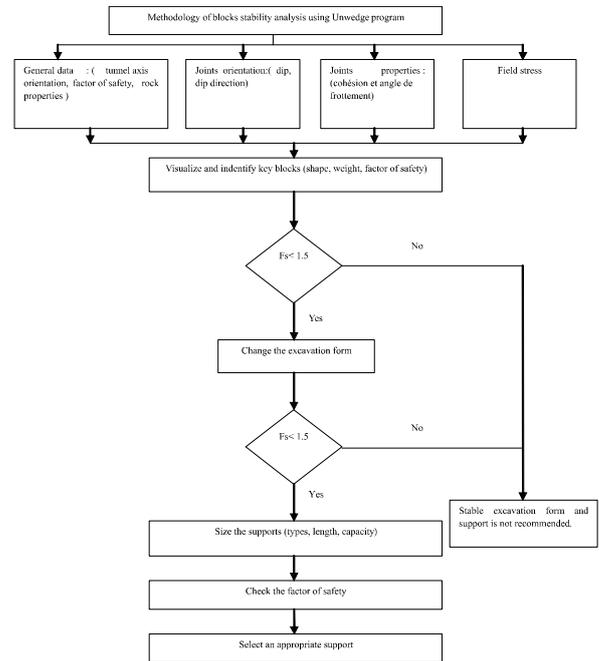


Figure 10: Selection method of support

Results and interpretations:

Since at the ST2 level, the main orebody is in contact with quartz diorites and fractured serpentinite having poor geomechanical properties. So, it would be necessary to consider these two types of rocks when designing and sizing the support.

In addition, it should be noted that:

- the ore density exceeds that of the other facies (2.8 for ore versus 2.75 for diorite and 2.55 for serpentinite)
- the contact between the ore and the serpentines is slippery

- For the quartz diorites :

For the quartz diorites, we first studied stability of wedges located in the periphery of a rectangular excavation (2.5×2.5) in the serpentinite, and we found that the upper right and roof wedges are instable since the safety factor is less than 1.5 (fig 11). Then, to stabilize these wedges, we have chosen a new form represented in figure 12. In this case, we do not need a support system.

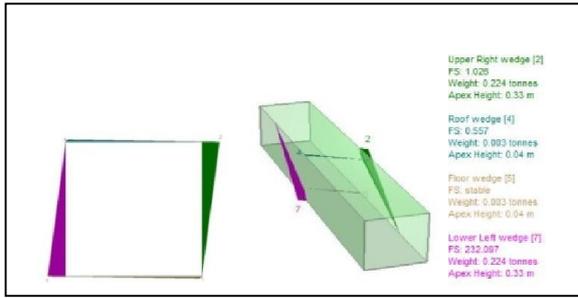


Figure 11: results by using Unwedge program for a rectangular excavation

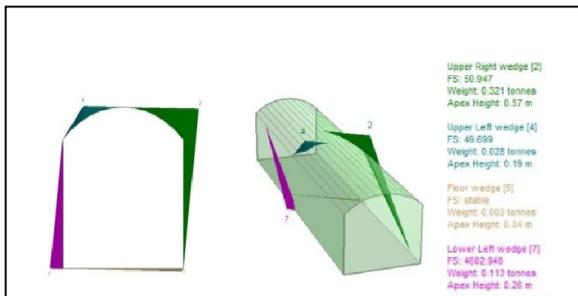


Figure 12: results by using Unwedge program for a new excavation form

- **For the serpentinite :**

For the serpentinite, we first analyzed blocks stability located in the same rectangular excavation, but now excavated in the serpentinite, and we found that the upper right, lower left and roof wedges are instable since the safety factor is less than 1.5 (fig 13). Then, to improve this factor, we tried to adopt a new form but the problem of blocks stability is still present (Fig 14). Then, to ensure the stability of these blocks, we choose as a support the swellex rock-bolts (with a tensile capacity of 12 tons and a spacing pattern of 1.5*2.5 m*m) (Figure 15).

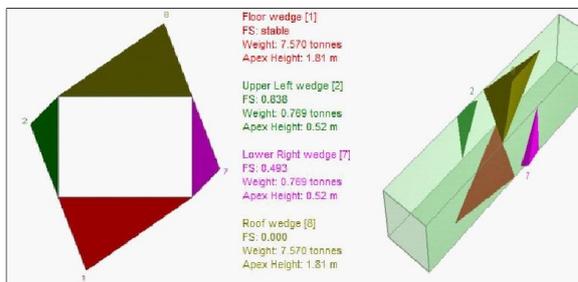


Figure 13: Results by using Unwedge program for a rectangular excavation

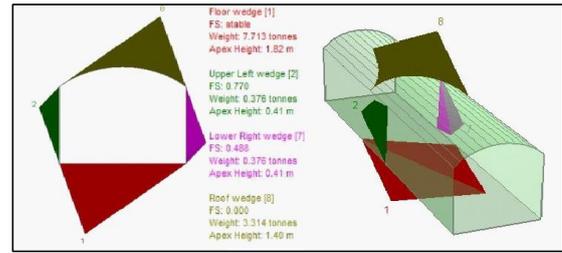


Figure 14: results by using Unwedge program for a new form of excavation

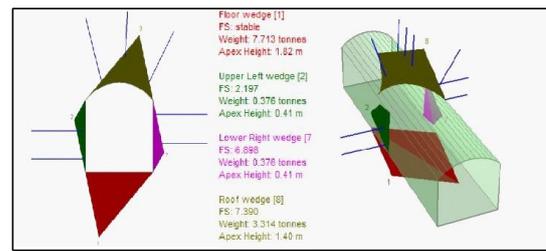


Figure 15: results after reinforcement of instable blocks

Conclusions

At Bouazzer mine, the cobaltiferous mineralization is a vein contained in the serpentines and quartz diorites of the lower Precambrian II. Empirical classification methods (Deere, Barton, Beniaowski and AFTES) applied to the rock mass of ST2, have described the terrain as poor. These methods propose as supports anchoring bolts, shotcrete and steel arches in the three types of rocks, with a special mesh of rock-bolting for the serpentines. Structural analysis of discontinuities in ST2 have highlight the existence of three main sets oriented NNESSW, NNW-SSE, NE-SW and two minor joints, as well as the localization of the zones at risk of toppling and sliding due to the intersection between discontinuities. These joint sets were the inputs of Unwedge program.

Unwedge's analysis of key blocks has made it possible to identify the shape and size of the unstable blocks, defined by the intersection of main joint sets, around the excavation. Once we have located them, we can either try to adopt a new stable excavation shape or size the support by anchor bolts if necessary to ensure their stability. In our case study, we recommend to use swellex rock-bolts of 2 m in length and with a pattern spacing of 1.5*2.5 m² between bolts. This

method has shown the advantage of identifying precisely the location and therefore the optimization the establishment of the support.

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