ISSN: 0974-5823 Vol. 6 No. 3 December, 2021

International Journal of Mechanical Engineering

Design of a support system for underground mining excavations in serpentine rock massifs at the Bou Azzer mine, Morocco

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ABSTRACT

Geotechnical instability of underground excavations at the Bou Azzer mine at a depth of 500 m, in both types of very fractured and carbonate serpentine rock massifs. In order to recommend more reliable support systems for underground excavations, to minimize the potential economic and social impact, and to make the mining environment safe. This study presents a methodology based on empirical methods in order to carry out an evaluation of the stresses and strength factors by numerical geotechnical modeling using finite element software. The geomechanical classification results of rock mass rating and Q-system show that the very fractured serpentinite and the carbonate serpentinite, in a poor to very poor quality class. The major principal stress (Sigma 1) ranges from 21 to 49 MPa for excavations in very fractured serpentinite, and for excavations in carbonate serpentinite varies between 21 to 45 MPa. Therefore, the strength factors in underground excavations are very low in the range of 0.32 to 0.63. The suggested support for excavations in serpentine rock mass carbonated, metal arch or support by cement/resin bolting. Thus for excavations in very fractured serpentine rock mass, installation of a metal arch with reinforced concrete.

Keywords: Bou Azzer, Serpentinite, Mining Excavations, RMR, Q-system, Support.

1. INTRODUCTION

The Bou Azzer mine encounters geotechnical stability problems in the underground excavations at a depth of 500 m. Indeed, the serpentine, which is very fractured and carbonated, is a very friable metamorphic rock. Multiple support works of its excavations have encountered difficulties, so the depth of the excavations seems to aggravate the instability by the increase of the induced stress. The characterization of the rock mass is essential in geotechnical mining engineering, using different classification systems [1]–[4]. In order to evaluate the quality of the rock mass intended for underground works. Several more practical methodical research works for the support of deep underground excavations such as [5]–[8]. The development of a supporting system for these excavations is the focus of this research at a depth of 500 m, based on empirical methods with the rock mass rating classification of Bieniawski [2], and the Q-system of Barton and al. [1] are two internationally accepted systems for the design of supports that are widely used in the field of underground works. Thus an evaluation with the numerical method by geotechnical modelling with finite element software, in order to suggest a reliable support system.

2. GEOLOGICAL CONTEXT

The Bou Azzer El Graara inlier in Morocco (Figure 1), located along the major accident of the Anti-Atlas Morocco in its central part [9]. In this inlier the outcrop of the witnesses of the oldest formations, and the Paleozoic cover. The last stratigraphic subdivision, according to [10] reported that the ophiolitic complex of Bou Azzer presents all the ophiolitic terms. It consists of the following lithological units: serpentinized mantle peridotites, cut by a swarm of basic and ultrabasic veins, basic and ultrabasic cumulates, gabbros and microgabbros, spilitized basalts and diabases, and a volcano-sedimentary ensemble, considered to be Upper Cryogenian. Most of these ophiolite outcrops are in the Aït Ahmane area. The genetic model of serpentines in the Bou Azzer inlier in Morocco result from the total serpentinization of ultrabasic rocks [11], of the ophiolitic complex of lower Neoproterozoic age, and are distinguished by their yellow-green color and their shiny aspect.

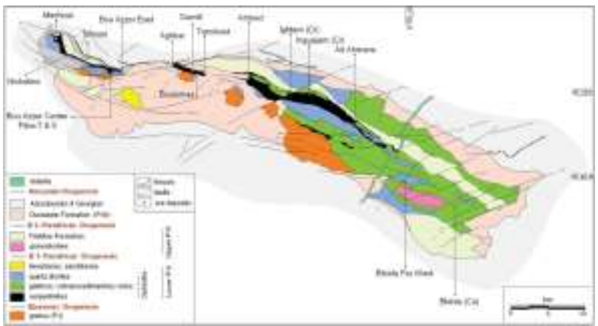

Figure 1. The Bou Azzer inlier in Morocco and location of mines redrawn by [11], [12]

3. CHARACTERIZATION OF UNDERGROUND FRACTURING

The structural characterization was based on in-situ surveys of the underground structures at the Bou Azzer mine. A total of 200 discontinuities were measured using the method suggested by the International Society for Rock Mechanics [13]. These measurements were processed using the Dips version 2.2 computer software [14] of stereographic projection on a Wolf-Smith canvas to represent the system of discontinuities by a set of directional families.

The serpentine massifs appear very smooth and are affected by an intense and anisotropic fracture network, which coincides with the contour and rosette plots. The results show at least three discontinuities families, the most dominant ones identified with tension and shear joints in the study area (Table 1). The massif is also characterized by a significant degree of fracturing, and schistosity is one of the structural elements most represented in the rock, with predominantly planar, smooth, slightly altered surfaces, with remarkable recrystallization of carbonates and asbestos. The whole terrains show intense deformation that can be related to two orogeneses [15]. The multidirectional fracturing results associated with the flow and fracture schistosity dated respectively to major phases B1 and B2, and a system of conjugate faults N60°E and N170°E corresponding to a maximum compressional direction N30°E [15].

Table 1. The major families of discontinuities at the Bou Azzer Mine

Jn	Type of discontinuity	Dip	Dip direction
J1	Schistosity	75	219
J2	Schistosity	88	91
J3	Schistosity	57	312
J4	Diaclase	40	220
J5	Joint	74	126

4. GEOTECHNICAL CHARACTERIZATION OF SERPENTINE ROCK MASSES

The quantitative assessment of the quality of rock masses in this study, using the most widely used geomechanical classification systems, RQD of Deere [3], Q-system of Barton and al. [1], RMR of Bieniawski [2], GSI of Hoek and al. [4]. In order to make a design of support system for these underground mining excavations.

4.1. The Classification of Deere and al. (1964)

This method proposed by Deere [3] to characterize the fracture density of rock masses based on the observation of core holes. The RQD is a percentage (%) of recovery of drill holes that includes only sound core pieces of 100 mm or greater in length, used as an index to quantitatively evaluate the quality of the rock [3]. Table 2 shows Deere's [3] classification for designation of rock quality.

Table 2. Classification of Deere for rock quality designation [3]

RQD (%)	Rock quality
< 25	Very poor
25 – 50	Poor
50 – 75	Fair
75 – 90	Good
90 – 100	Excellent

Table 3 presents the results, according to the classification of Deere [3]. The mean value for the very fractured serpentinite is 21 %, with a very poor quality of the rock mass, so the carbonate serpentinite is 30 % with poor quality.

Table 3. The results of the rock quality designation of serpentine rock massifs

The serpentine rock massifs	The mean value of RQD
very fractured serpentinite	21 %
carbonate serpentinite	30 %

4.2. The Tunneling Quality Index of Barton and al. (1974)

This empirical method called the Q-system, proposed by Barton and al. [1] and several revisions of the Q-system have been made by [16], [17]. The value of the Q- system is calculated by six parameters on a logarithmic scale,which varies from 0.001 to 1000 with the following equation 1 [1] :

$$Q = \frac{RQD}{Jn} \times \frac{Jr}{Ja} \times \frac{Jw}{SRF} \quad (1)$$

The parameters presented in the expression are as follows [1] :

RQD: Rock quality designation

Jn: Joint set number

Jr: Joint roughness number

Ja: Joint alteration number

Jw: Joint water reduction factor

SRF: Stress reduction factor

The results presented in Table 4 show that according to the Q-system classification of Barton and al. [1], the very fractured serpentinite with a value of 0.02 is in the extremely poor class and the carbonate serpentinite with a value of 0.48 of very poor quality.

Table 4. Q-system values of the two types of serpentinite at the Bou Azzer mine

Parameters	very fractured serpentinite	carbonate serpentinite
Q-system	0.02	0.48
Quality of the rock mass	extremely poor	very poor

4.3. The Rock Mass Rating of Bieniawski (1989)

The method of geomechanical classification is developed by Bieniawski [2]. It is a rock mass quality index based on the calculation by summing the scores for the first five parameters, after adjusting the RMR89 for the orientation of the discontinuity (R6). Rock mass quality obtained by the following equation (2) [2] :

$$RMR89 = R1 + R2 + R3 + R4 + R5 + R6 \quad (2)$$

The parameters presented in the equation are as follows [2] :

R1: Uniaxial compressive strength (UCS) of intact rock material

R2: Rock quality designation (RQD)

R3: Joint or discontinuity spacing

R4: Joint surface condition

R5: Groundwater condition

R6: Rating adjustment for discontinuity orientation

Table 5 presents the results according to the classification of Bieniawski [2], shows that the two serpentinite rock massifs very fractured and carbonated, located in the poor quality class. A correlation between Q-system and RMR in serpentinite massifs proposed by Driouch and al. [18], gives practically similar results for the RMR estimation of Bieniawski [2] for these two serpentinite rock massifs.

Table 5. RMR values of the two types of serpentinite at the Bou Azzer mine

Parameters	very fractured serpentinite	carbonate serpentinite
RMR	21	33
Quality of the rock mass	Poor rock mass	Poor rock mass

4.4. The Geological Strength Index of Hoek and al. (1995)

Hoek and al. [4] suggested a system of characterization of the rock mass, and extended by Marinos and Hoek [19] for weak heterogeneous rock masses. The geological strength index was estimated from in-situ examination of serpentinite excavations. The range of GSI in the carbonate serpentinite is between 40 to 45, and for the very fractured serpentinite, between 30 to 35 (Figure 2).

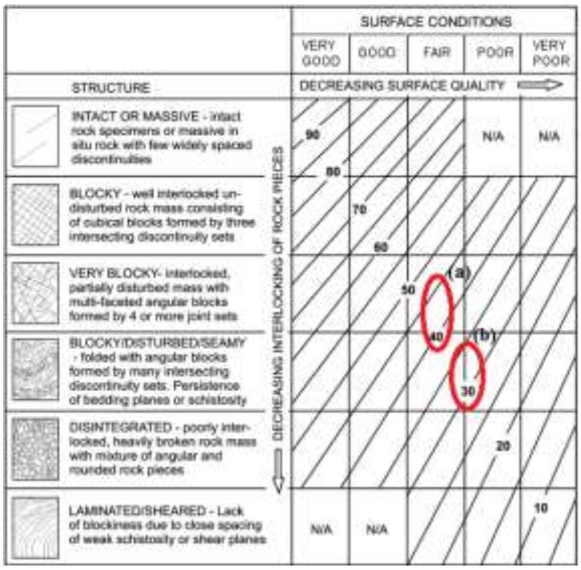

Figure 2. Schematic showing the location of the geological strength index, (a) carbonate serpentinite, (b) very fractured serpentinite

5. THE CHOICE OF SUPPORT SYSTEMS FOR SERPENTINE EXCAVATIONS

Empirical methods suggest support systems for serpentine excavations. According to the classification system of Barton and al. [1], the type of support for excavations with a span of 2.5 m, bolting and fibre-reinforced shotcrete (9 - 12 cm) for very fractured serpentine rock massifs. Thus for excavations in carbonate serpentinites, bolting with a spacing of 1 m.

In the same perspective, the suggested support method according to the geomechanical classification method of Bieniawski [2], for very fractured and carbonated serpentine rock masses, is in the same quality class, metal arch with a spacing of 0.7 - 1.5 m, or bolting with a spacing of 0.5 - 1 m and welded wire mesh, plus shotcrete (30 - 50 mm). According to the empirical approach of Potvin and Hadjigeorgiou [20], based on the Q-system and the many applications to underground mines. The suggested support for serpentine underground excavations with a Q-system < 1, bolts with mesh, or bolts with fibre-reinforced shotcrete.

6. GEOTECHNICAL MODELING OF SERPENTINE UNDERGROUND EXCAVATIONS

6.1. Preparation of Modeling Data

Estimation of modeling parameters for the Hoek - Brown failure criterion (Table 6), the most widely used in heterogeneous rock masses, using RocDataV.3.0 software [21]. The parameters required for numerical modeling are: (σci) uniaxial compressive strength, (mb) and (a, s) are values of the Hoek - Brown failure equation, (Ei) Young's modulus, and (v) Poisson's ratio.

Table 6. Geomechanical parameters of serpentine rock massifs

Parameters	very fractured serpentinite	carbonate serpentinite
mb	0.453	0.729
s	0.0002	0.0007
a	0.516	0.508
σcm (Mpa)	1.659	3.217
Em (Mpa)	1414.41	3028.73

6.2. The Results of the Numerical Simulations

The results of the numerical geotechnical simulations of serpentine excavations in the depth of 500 m are as follows :

6.2.1. Very Fractured Serpentinite

The major principal stress (Sigma 1) in the crown of the underground excavation ranges from 21 to 49 MPa, thus for the sidewall of the excavation varies from 10 to 21 MPa (Figure 3).

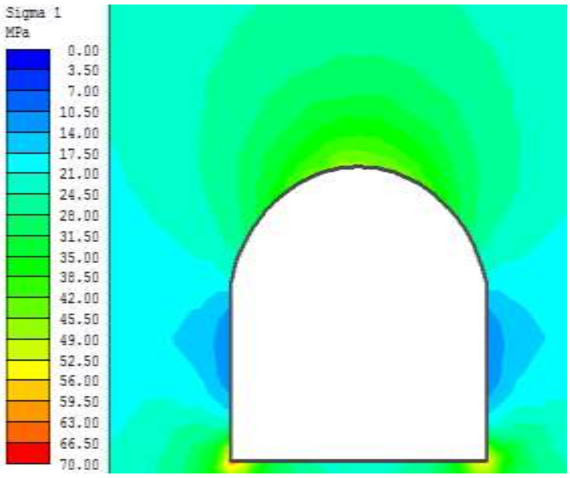

Figure 3. The results of the major principal stress (Sigma 1) of the underground excavation in the very fractured serpentinite at a depth of 500 m

The strength factors are very low is 0.32 in the crown and sidewall of the underground excavation (Figure 4). At the same time, the simulations showed a plastic zone (Broken ground) of 1.5 m length in the sidewall part of the excavation and a plastic zone exceeds 5 m length in the crown part of the excavation.

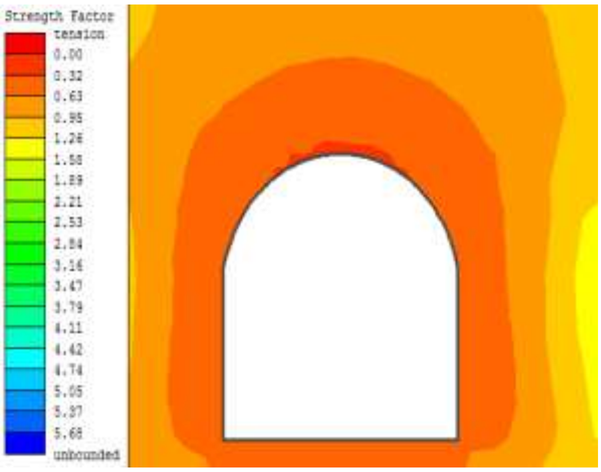

Figure 4. The results of the strength factors of the underground excavation in the very fractured serpentinite at a depth of 500 m

6.2.2. Carbonate Serpentinite

The major principal stress (Sigma 1) in the crown of the underground excavation ranges from 21 to 45 MPa, thus for the sidewall of the excavation varies from 10 to 21 MPa (Figure 5).

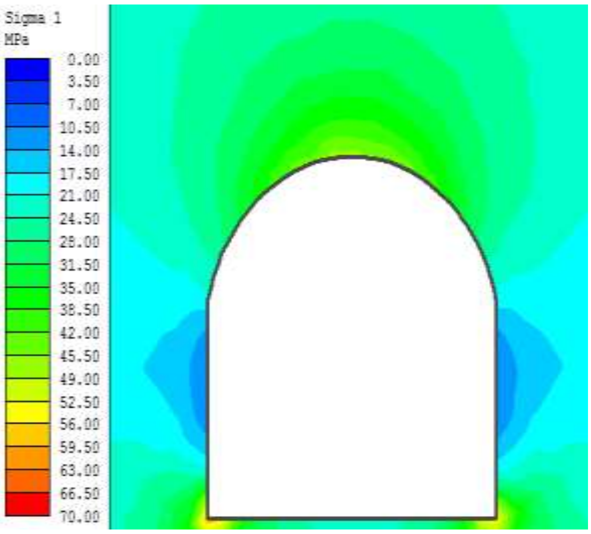

Figure 5. The results of the major principal stress (Sigma 1) of the underground excavation in the carbonate serpentinite at a depth of 500 m

The strength factors are very low is 0.32 in the crown and between 0.32 to 0.63 in the sidewall of the underground excavation (Figure 6). At the same time, the simulations showed a plastic zone (Broken ground) of 1.1 m lengths in the sidewall part of the excavation, and a plastic zone exceeds 2.6 m lengths in the crown part of the excavation.

Figure 6. The results of the strength factors of the underground excavation in the carbonate serpentinite at a depth of 500 m

The results of this geotechnical numerical simulation of these excavations, showed a severity of instability represented by the plastic zone at the crown in both types of serpentine rock mass, which exceeds the length of the bolts. Thus the difficulties of installation of bolt supports in these rock masses, which present a low resistance to abrasion by drilling tools. The field experiment in the LaRonde mine (Quebec, Canada) to design a series of numerical experiments to study the influence of different bolts and time of installation sequence, reported from the numerical results were in agreement with the field observations and demonstrated the practical implications of using elastic reinforcement elements that reduces the drift of convergence and rehabilitation [22].

According to Kai Guan and al. concluded that the problems involving large deformations, is the reduction of the excavation section, which requires a process of reprofiling work for the post-peak behavior of the rock (elasto-plastic) to obtain the desired profile [23].

7. CONCLUSION

The support of underground serpentine excavations is the subject of this study to find means for the stabilization of excavations, thus ensuring the safety of personnel and materials, with good progress of the underground mining. The numerical geotechnical modeling by finite element software shows the severity of the problem represented by the major principal stress (Sigma 1) very high at the level of the crown of the excavation, as well as low strength factors. Based on empirical methods and with coupling by returns of experience in the mine of Bou Azzer, we suggested the support by metal arch for the carbonated serpentinite or the support by bolting with cement/resin. Thus for the very fractured serpentinite, the installation of the metal arch to reinforce by reinforced concrete.

REFERENCES

[1] N. Barton, R. Lien, et J. Lunde, « Engineering classification of rock masses for the design of tunnel support », *Rock Mechanics*, vol. 6, nº 4, p. 189-236, déc. 1974, doi: 10.1007/BF01239496.

[2] Z. T. Bieniawski, *Engineering Rock Mass Classifications: A Complete Manual for Engineers and Geologists in Mining, Civil, and Petroleum Engineering*. John Wiley & Sons, 1989.

[3] D. U. DEERE, « Technical description of rock cores for engineering purpose », *Rock Mechanics and Enginee-ring Geology*, vol. 1, nº 1, p. 17-22, 1964.

[4] E. Hoek, P. K. Kaiser, et W. F. Bawden, « Support of underground excavation in hard rock: Rotterdam », *AA Balkema*, 1995.

[5] A. S. Luden, I. G. B. Indrawan, D. Karnawati, et D. F. Nadjamudin, « Engineering geological investigations for designs of excavation method and support system of diversion tunnel at Bulango Ulu Dam, Indonesia », p. 9, 2021.

[6] K. Peter *et al.*, « An Overview of the Use of Rockbolts as Support Tools in Mining Operations », *Geotech Geol Eng*, oct. 2021, doi: 10.1007/s10706-021-02005-5.

[7] B. Rahimi, M. Sharifzadeh, et X.-T. Feng, « Ground behaviour analysis, support system design and construction strategies in deep hard rock mining – Justified in Western Australian's mines », *Journal of Rock Mechanics and Geotechnical Engineering*, vol. 12, nº 1, p. 1-20, févr. 2020, doi: 10.1016/j.jrmge.2019.01.006.

[8] J. J. Ran, « Safe mining practices under wide spans in underground non-caving mines – Case studies », *International Journal of Mining Science and Technology*, vol. 29, nº 4, p. 535-540, juill. 2019, doi: 10.1016/j.ijmst.2019.06.006.

[9] M. Leblanc, « Chapter 17 The Late Proterozoic Ophiolites of Bou Azzer (Morocco): Evidence for Pan-African Plate Tectonics », in *Developments in Precambrian Geology*, vol. 4, A. Kröner, Éd. Elsevier, 1981, p. 435-451. doi: 10.1016/S0166-2635(08)70022-7.

[10] O. Blein *et al.*, « Geochronological constraints on the polycyclic magmatism in the Bou Azzer-El Graara inlier (Central Anti-Atlas Morocco) », *Journal of African Earth Sciences*, vol. 99, p. 287-306, nov. 2014, doi: 10.1016/j.jafrearsci.2014.04.021.

[11] M. LEBLANC, « Ophiolites precambriennes et gites arsenies de cobalt : Bou Azzer (Maroc) », *These Doctorat d'Etat, Faculte des Science Paris VI, Memoires Centre Geologique et Geophysique*, 1975, Consulté le: oct. 27, 2020. [En ligne]. Disponible sur: https://ci.nii.ac.jp/naid/10018419022/

[12] T. Oberthür *et al.*, « HERCYNIAN AGE OF THE COBALT-NICKEL-ARSENIDE-(GOLD) ORES, BOU AZZER, ANTI-ATLAS, MOROCCO: Re-Os, Sm-Nd, AND U-Pb AGE DETERMINATIONS », *Economic Geology*, vol. 104, nº 7, p. 1065-1079, nov. 2009, doi: 10.2113/econgeo.104.7.1065.

[13] ISRM (International Society for Rock Mechanics), « Suggested methods for the quantitative description of discontinuities in rock masses », *Rock characterisation, testing and monitoring–ISRM suggested methods*, p. 319-368, 1981.

[14] M. S. Diederichs et E. Hoek, « DIPS 2.2 », *Advanced version computer programme, Rock Engineering Group, Department of civil engineering, University of Toronto*, 1989.

[15] M. Leblanc, « Proterozoic oceanic crust at Bou Azzer », *Nature*, vol. 261, nº 5555, p. 34-35, 1976.

[16] N. Barton, « Some new Q-value correlations to assist in site characterisation and tunnel design », *International Journal of Rock Mechanics and Mining Sciences*, vol. 39, nº 2, p. 185-216, févr. 2002, doi: 10.1016/S1365-1609(02)00011-4.

[17] E. GRIMSTAD, « Updating the Q-System for NMT », *Proceedings of the International Symposium on Sprayed Concrete-Modern use of wet mix sprayed concrete for underground support, Fagemes, Oslo, Norwegian Concrete Association, 1993*, 1993, Consulté le: oct. 27, 2020. [En ligne]. Disponible sur: https://ci.nii.ac.jp/naid/10014902627/

[18] L. AnasDriouch, « Correlation between Q-System and Rock Mass Rating of the Serpentine Rock Mass at the Bou Azzer Mine in the Central Anti-Atlas of Morocco », *Annals of the Romanian Society for Cell Biology*, vol. 25, nº 6, Art. nº 6, juin 2021.

[19] P. Marinos et E. Hoek, « Estimating the geotechnical properties of heterogeneous rock masses such as flysch », *Bull Eng Geol Environ*, vol. 60, nº 2, p. 85-92, juill. 2001, doi: 10.1007/s100640000090.

[20] Y. Potvin et J. Hadjigeorgiou, « Selection of ground support for mining drives based on the Q-System », p. 16, 2016.

[21] « Rocscience Inc. », *Rocscience Inc.* https://www.rocscience.com/software/rocdata/program-updates (consulté le déc. 06, 2020).

[22] E. Karampinos, J. Hadjigeorgiou, et P. Turcotte, « Discrete Element Modelling of the Influence of Reinforcement in Structurally Controlled Squeezing Mechanisms in a Hard Rock Mine », *Rock Mech Rock Eng*, vol. 49, nº 12, p. 4869-4892, déc. 2016, doi: 10.1007/s00603-016-1080-3.

[23] K. Guan, W. Zhu, X. Liu, J. Wei, et L. Niu, « Re-profiling of a squeezing tunnel considering the post-peak behavior of rock mass », *International Journal of Rock Mechanics and Mining Sciences*, vol. 125, p. 104153, janv. 2020, doi: 10.1016/j.ijrmms.2019.104153.