Journal of Geology and Mining Research Vol. 4(2), pp. 23-34, March 2012
Available online at http://www.academicjournals.org/JGMR
DOI: 10.5897/JGMR11.041
ISSN 2006 – 9766 ©2012 Academic Journals

Full Length Research Paper

Study of fractured rock masses deformation in Boukhadra (Tebessa) underground mine empirical and numerical approach (N-E Algeria)

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Accepted 15 February, 2012

The purpose of this paper is to assess the engineering geological characteristics of Boukhadra's iron mine rock mass. Several problems of deformation and stability were frequently encountered during the progress of the exploitation. This phenomenon affects seriously the safety of the miners and the progress of the work. In this research project, we try to estimate the behavior of the host rock mass, its deformability and stability. Field studies consisted of geological mapping, discontinuity surveying, core drilling and sampling for laboratory studies. Physical properties, uniaxial compressive strength and shear strength tests were conducted in the laboratory. Rock mass classes and rock mass strength and deformability parameters were determined based on the AFTES guidelines, rock quality designation (RQD), rock mass rating (RMR) and *Q* rock mass classification systems. The deformations were then numerically determined using Plaxis Software. The modeling results were in good agreements with the rock mass qualities as assessed by RMR, Q-system, AFTES guidelines.

Key words: Engineering geology, finite element method, rock mass classification, iron mine, Boukhadra, Algeria.

INTRODUCTION

Rock mass classification systems such as Q and rock mass rating (RMR) have been successfully applied to estimate stability conditions and support systems for many underground constructions. In addition to their use as empirical design parameters, they are used to estimate rock mass strength parameters (Bieniawski et al 2007). Reliable estimates of the strength and deformation characteristics of the rock masses are required for numerical approaches. These parameters are easily obtained via rock mass classification systems RMR, Q and geological strength index (GSI). Today's trend is mainly directed towards the use of numerical analysis techniques in order to model and estimate the stresses and strains around galleries. Moreover, they are used either to specify the support system or to check the appropriateness of the support system empirically chosen (Gadde et al., 2007). They are also used to model the interaction between rock and the support system.

In this study, the materials encountered along the gallery alignment were limestone, mineralized marl, conglomerate, sandstone, multicolored marl, yellow marl and iron ore. The ground conditions along the gallery alignment including bedding planes, joint sets and joint conditions, rock quality, water flow, and rock strength were evaluated based on the drilled boreholes and rock

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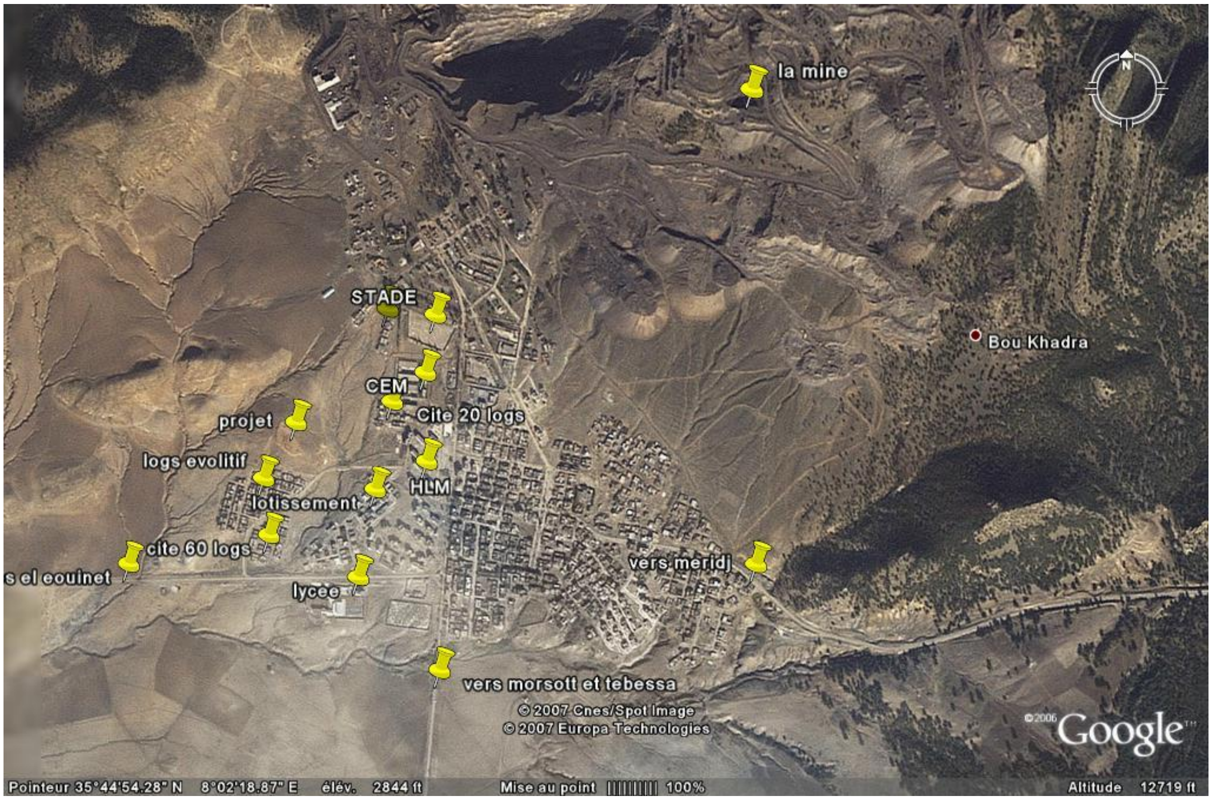

Figure 1. Boukhadra's iron mine (google earth).

exposures.

The geological and hydrogeological conditions are determining factors of the degree of difficulty and cost of realization of any underground work and they have a great influence on the choice of the methods of excavation and supporting system. The more informative data when dealing with rock mass are discontinuities. These later represent a wide variety of surfaces whose geological identification conveys important information on some of their geometrical and mechanical parameters. Other parameters such as degree of weathering, strength of intact rock and water flow are also important in the process of rock support system design. The knowledge of the former conditions has been of a great help in the identification of potential problems and the suggestion of appropriate solutions that is special supporting system, drainage system, and/or treatments of the encountered problems.

In order to confirm the empirical results obtained and hence the decision taken as a solution for a particular problem, the widely used finite element analysis method was used. The Plaxis Software was used to calculate the stress conditions and the resulting deformations around the studied underground mine gallery. The calculation results showed a great reduction in the total displacement around the excavation after the installation of the support system according to the empirical approach.

GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

The Djebel Boukhadra is located in eastern Algeria, 45 Km North of Tébessa City, 13 Km from the Algerian-Tunisian border. The ferruginous deposit of Boukhadra, belonging to the Atlas Saharan domain, is located in the mountainous Jebel Boukhadra, characterized by a simple anticline structure of NE-SW direction with a periclinal termination NE. Jebel Boukhadra extends over a length of 7 to 8 km and a width varying from 3 to 5 km along a NE-SW (Figure 1).

The iron mine is located between 8° 01' and 8° 04' east and between 35° 40' and 35° 50' North. Djebel Boukhadra is an anticline structure composed mainly by Mesozoic and Tertiary sediments with a quaternary thin cover.

The Triassic deposits encountered in Boukhadra region are represented by variegated marls, gypsum, dolomite, limestone and sandstone (Dubordieu, 1956). They are found in the West as well as in the South and South East parts of the anticline. The Triassic formation is unconformably in contact with the cretaceous limestones. The lower part of the Aptian is mainly constituted by marl and reef limestone (rudist); this latter is the main ore bearing formation; while the upper part of the Aptian which is mainly sandstone and limestone are unproductive. Tertiary formations (Miocene) are observed

Table 1. Gallery dimensions.

Average height (m)	Average width (m)	Section (m²)	Length (m)
3.5	4	12-13	225

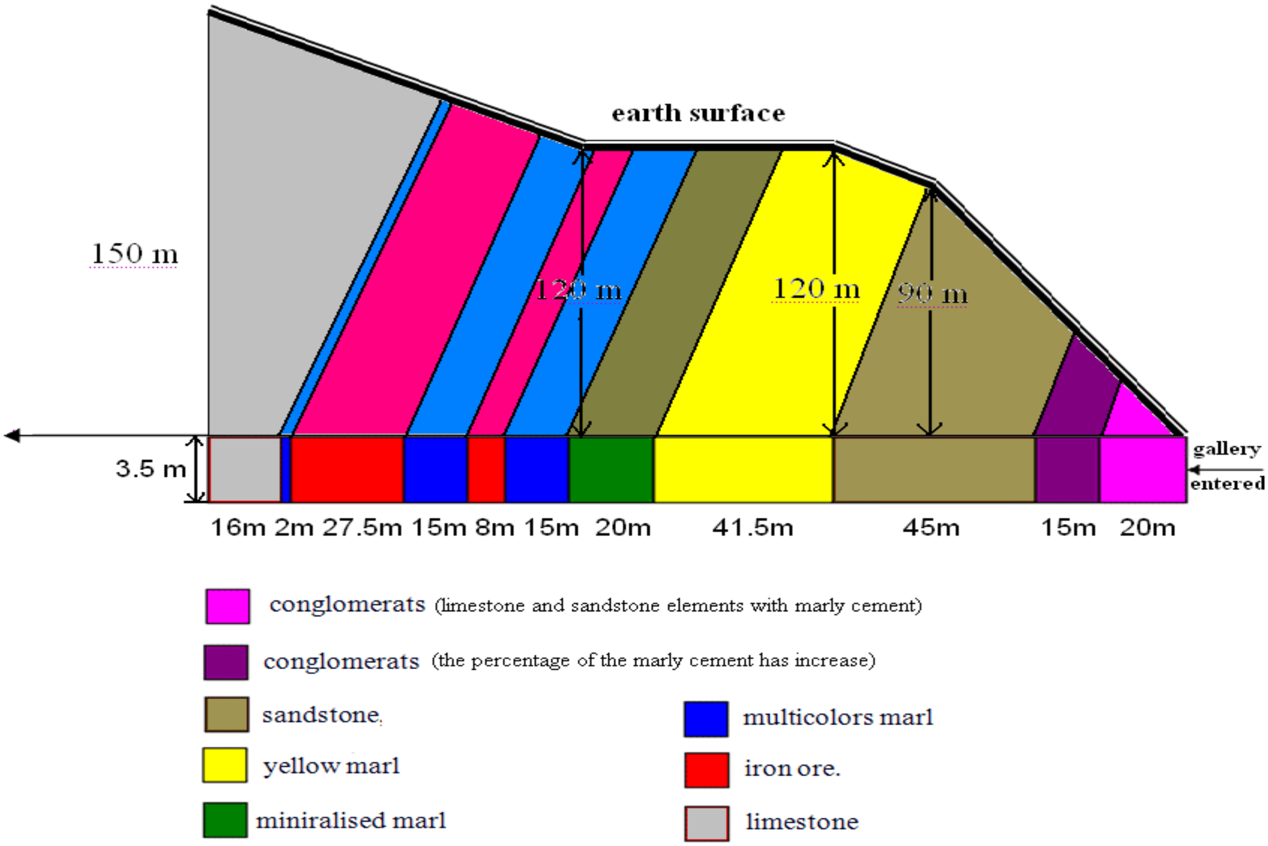

Figure 2. Geological cross-section through Boukhadra Massif.

only in the western part of the study area and are represented by polygenic conglomerates, cemented by a matrix of carbonate and interbedded sandstone rocks.

The recent quaternary deposits are formed by a stony material, blocks of limestone, sandstone, debris and conglomerates. Usually, they are encountered as a cover on the mountain sides and all along its foot.

The hydrogeological studies carried out by the Agence Nationale des Resources Hydrauliques (ANRH) show that there is no aquifer in the level of the mining area of Boukhadra. The only aquifer in the area is located at a level well below the mine. The level of the mine is at 1463 m while the aquifer is at 818 m.

The exploitation gallery oriented N-E passes through several rock lithologies for 225 m (Table 1). It starts at a 20 and 15 m thick conglomeratic formations and passes through sandstone, yellow marl, mineralized marls interbeded with iron ore and limestone (Figure 2).

ROCK MASS CLASSIFICATION OF BOUKHADRA IRON MINE

Rock mass property is governed by the properties of intact rock materials and of the discontinuities in the rock. The behavior of rock mass is also influenced by the conditions the rock mass is subjected to, primarily the *in situ* stress and groundwater. The rock mass quality can be quantified by means of rock mass classifications. It is believed that, one or more rock mass classification schemes should be used to build up a picture of the composition and characteristics of a rock mass and in order to provide initial estimates of support requirements using estimates of the strength and deformation properties of the rock mass (Basarir et al., 2005).

Although, the concept of rock mass classification still carries some ambiguities despite the world wide debate it, from day to day, continue to prove its usefulness and

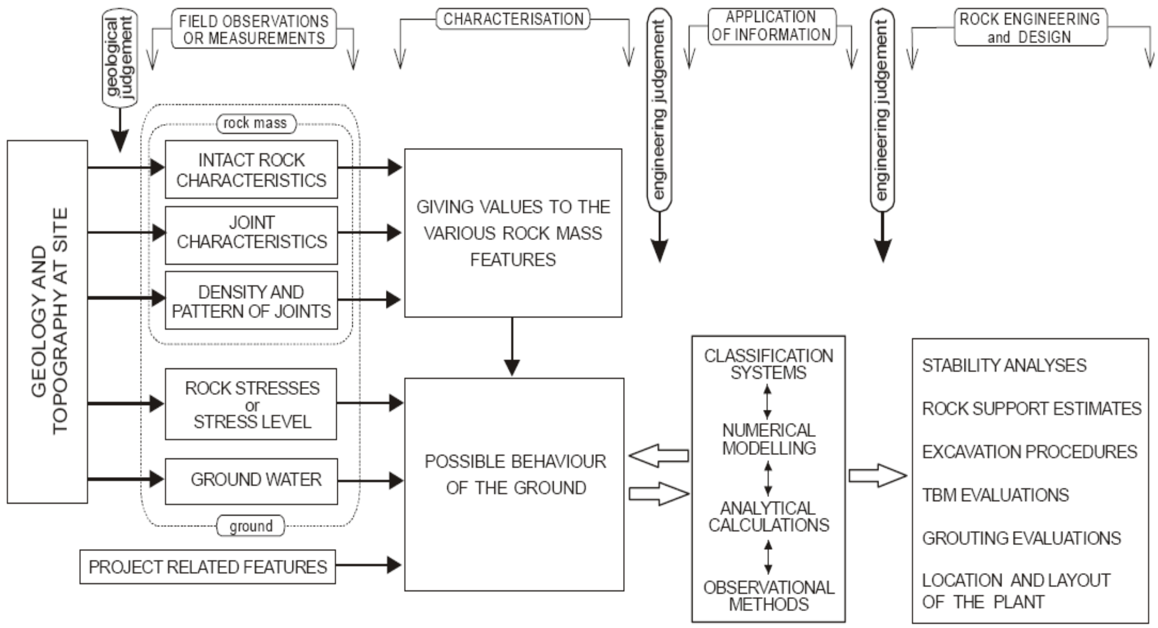

Figure. 3. Observation, measurement and characterization applied in rock engineering (Håkan and Arild, 2003).

ease of use. What a rock mass classification system characterization with good engineering judgment and knowledge of the system limits (Figure 3) (Still et al., 2003).

This section addresses rock mass properties and rock mass classifications, where RMR, Q-system and AFTES guidelines were used without application of correlation equations as it is strongly not recommended (Arild and Einar, 2006).

RMR classification system

RMR system has been applied in more than 268 case histories such as tunnels, chambers, mines, slopes, foundations and rock caverns. The reasons for using RMR are, according to Bieniawski (1989), the ease of use and the versatility in engineering practice. When applying this classification system, one divides the rock mass into a number of structural regions and classifies each region separately. The RMR system uses the following six parameters, whose ratings are added to obtain a total RMR-value.

1. Uniaxial compressive strength of intact rock material;
2. RQD;
3. Joint or discontinuity spacing;
4. Joint condition;
5. Ground water condition; and
6. Joint orientation.

The first five parameters (1 to 5) represent the basic parameters ($RMR_{\mathbf{basic}}$) in the classification system. Each of these parameters is given a value. All the values are algebraically summed for the five first given parameters and then adjusted by the sixth parameter depending on the joint and tunnel orientation as shown in the following equations

$$RMR_{basic} = \Sigma parameters\ (1 + 2 + 3 + 4 + 5)$$

$$RMR = RMR_{basic} + \text{adjustment for joint orientation}$$

The obtained results are given in Table 2.

Rock mass quality system (Q –system)

The original *Q*-system (Barton et al., 1974) uses the following six parameters

i) *RQD*,
ii) Number of joint sets,
iii) Joint roughness,
iv) Joint alteration,
v) Joint water conditions,
vi) Stress factor.

The fundamental geotechnical parameters are, according to Bieniawski (1988), block size, minimum inter-block shear strength and active stress. These fundamental geotechnical parameters are represented by the following ratios (Barton, 2002)

i) Relative block size = RQD / Jn

Table 2. Classification of the rock mass of Boukhadra (RMR-system).

Classification	Uniaxial compressive strength	Rock quality designation	Joint spacing	Joint condition	Ground water condition	Joint orientation	RMR	Classification	GSI	E_M (GPa)
Yellow marl	2	13	20	10	15	-5	55	Fair	50	4.47
Mineralized marl	2	13	20	10	15	-5	55	Fair	50	4.47
Conglomerate	2	13	20	10	15	-5	55	Fair	50	4.47
Sandstone	2	13	20	10	15	-5	55	Fair	50	4.47
Limestone	7	13	20	20	15	-5	70	Good	65	19.84
Multicolored marl	2	13	20	0	15	-5	45	Fair	40	3.35
Iron ore	7	13	20	20	15	-5	70	Good	65	21

GSI: Geological strength index; GSI = RMR_{89}-5 (Hoek and Brown 1994, 1995); $E_M = 1000*[\sigma_c/100]^{0,5} * 10^{(GSI-10)/40}$ (σ_c<100 MPa) (Hoek and Brown, 1997).

Table 3. Classification of the rock mass of Boukhadra (Q-system).

Rock mass	Conglomerate	Sandstone	Yellow marl	Mineralized marl	Multicolored marl	Iron ore	Limestone
RQD	75	70	60	65	70	90	50
Joint set number (*Jn*)	3	3	3	3	3	3	3
Joint roughness number (*Jr*)	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Joint alteration number (*Ja*)	1	1	1	1	1	1	1
Joint water and pressure reduction factor (*Jw*)	1	1	1	1	1	1	1
Stress reduction factor (*SRF*)	7.5	7.5	7.5	7.5	7.5	7.5	5
Q	5	4.66	4	4.33	4.66	6	5
Rock class	Faire	Faire	Faire	Faire	Faire	Faire	Faire

ii) Relative frictional strength (of the least favorable joint set or filled discontinuity) = *Jr / Ja*
iii) Active stress = *Jw / SRF*

The rock mass quality is defined as (Barton et al., 1974):

$$Q = RQD/Jn \times Jr/Ja \times Jw/SRF$$

Where, RQD, Deere's rock quality designation ≥ 10 (Deere et al., 1968); J_n, joint set number; J_r, joint roughness number (of least favorable discontinuity or joint set); J_a, joint alteration number (of least favorable discontinuity or joint set); J_w, joint water and pressure reduction factor; SRF, stress reduction factor-rating for faulting, strength/stress ratios in hard massive rocks, and squeezing and swelling rock. The obtained results are given in Table 3.

The excavation of the underground mine of Boukhadra is realized with blasting method. The considered rock mass is cut by several sets of discontinuities, those cracks in addition with very short joints (fissures) are not considered by the *Jn* parameter in Q-system method. In this case, Löset (1997) recommends that cracks formed by tunnel blasting and very short joints are included in the *Jn* as random joints.

iv) RMR and AFTES guidelines have recommended support systems for all rock mass but Q-system method has end at unsupported rock mass who leads us to conclude that this method is inadequate in this case (Figure 4).

AFTES guidelines

The AFTES guidelines are rarely used in mining engineering, generally it is RMR, Q-system and GSI which are the most used systems in this field.

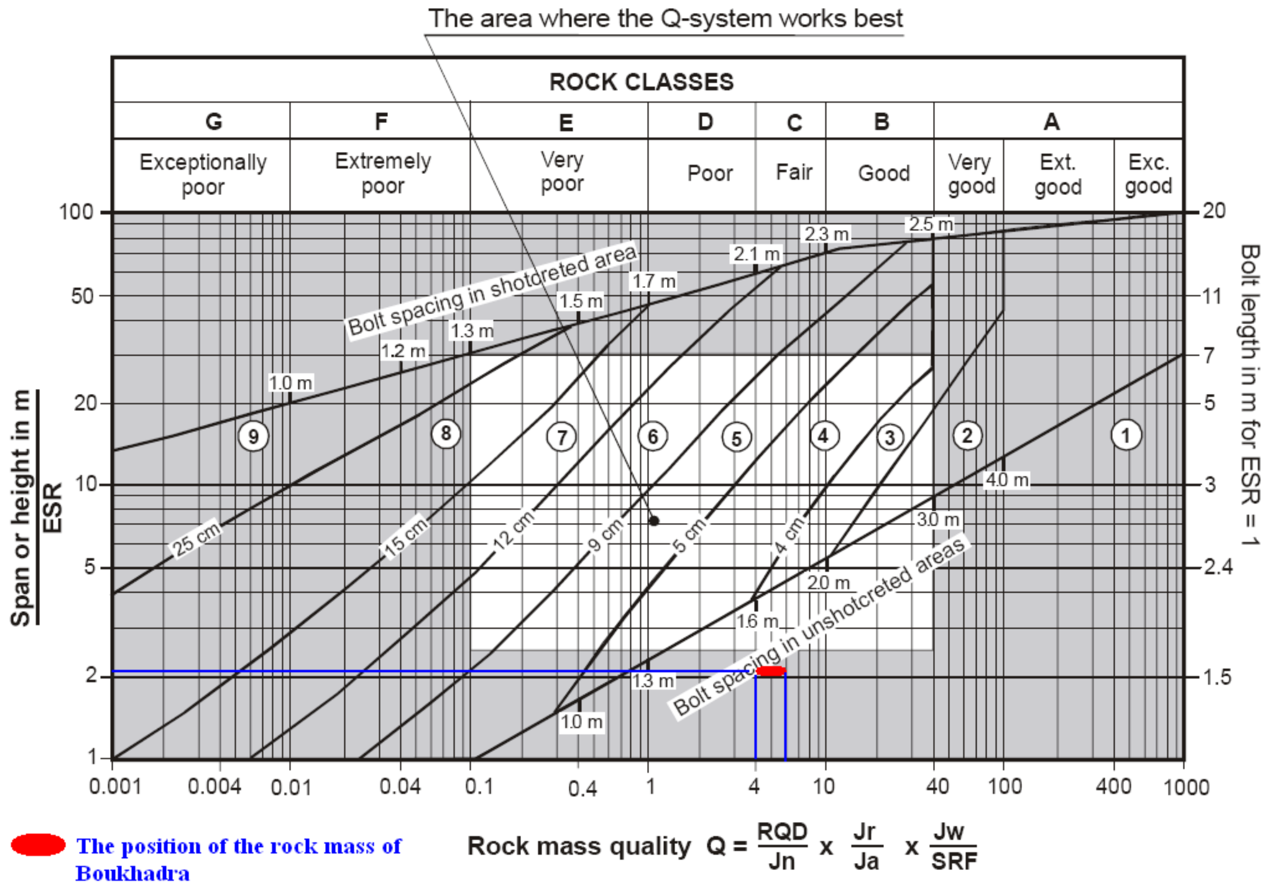

Figure 4. Limitations in the Q rock support diagram (Palmstrom et al., 2002).

These guidelines aim at defining quantifiable parameters from which the quality of the rock mass can be estimated. The nature of the parameter's guideline can be classified in three groups, geological, hydrogeological and Geotechnical. Out of these three groups, eleven (11) parameters are used in these guidelines: ultrasound wave velocity (Ic), unconfined compressive strength (σc), joint set orientation, joint set numbers, joint spacing in each joint set, interval between discontinuity sets (ID index), degree of alteration, rock mass deformation modulus (E_{Mas}), hydraulic head, permeability, stress states.

AFTES guidelines give much more importance to discontinuities in the process of stability evaluation. Therefore, the system of discontinuities in the rock mass must be investigated in detail.

It is the first time that these guidelines are going to be used in mining engineering. It is going to be compared to the well known RMR and Q systems. The obtained results are given in Table 4.

Following the application of these guidelines, it appears that some parameters are common among the different formations of Boukhadra's ore mine. These common parameters are

i) Joint set orientation (Angle δ between direction of dip vector αp and axis of heading (0 to 30°) and Dip β [(20 to 90°) (OR 2b)].
ii) Joint set numbers [one main set plus random discontinuities (N 2b)].
iii) Joint spacing in each joint set (very widely spaced discontinuities (> 200 cm) (ES 1)).
iv) Interval between discontinuities [very low density (ID INDEX > 200 cm) (ID 1)].
v) Hydraulic head [zero head (Lower than invert) (H 0)].
vi) Stress states [weak (σc/σ0> 4, rock matrix satisfactorily strong but support may be needed because of jointing) (CN 1)].

The remaining five parameters which are not common between the different formations of Boukhadra's rock mass are shown in Table 5.

EMPIRICAL SUPPORT DESIGN

Empirical design methods based on Q, RMR and AFTES guidelines formed the basis of the design of the underground mines support during planning and construction phases of the project. The application of

Table 4. Classification of the rock mass of Boukhadra (AFTES guidelines).

Classification	Conglomerate	Sandstone	Yellow marl	Mineralized marl	Multicolored marl	Iron ore	Limestone
Ultrasound wave velocity (Ic)	IC4 low continuity	IC3 moderate continuity	IC4 low continuity	IC3 moderate continuity	IC4 low continuity	IC2 high continuity	IC4 low continuity
Unconfined compressive strength σc	RC 5 low strong matrix	RC 5 low strong matrix	RC 5 low strong matrix	RC 5 low strong matrix	RC 5 low strong matrix	RC 3 strong matrix	RC 3 strong matrix
Joint set orientation	OR 2b 20° to 90° against dip	OR 2b 20° to 90° against dip	OR 2b 20° to 90° against dip h	OR 2b 20° to 90° against dip	OR 2b 20° to 90° against dip	OR 2b 20° to 90° against dip	OR 2b 20° to 90° against dip
Joint set numbers	N 2b one main set plus random discontinuities	N 2b one main set plus random discontinuities	N 2b one main set plus random discontinuities	N 2b one main set plus random discontinuities	N 2b one main set plus random discontinuities	N 2b one main set plus random discontinuities	N 2b one main set plus random discontinuities
Joint spacing in each joint set	ES 1 very widely spaced discontinuities > 200 (cm)	ES 1 very widely spaced discontinuities > 200 (cm)	ES 1 very widely spaced discontinuities > 200 (cm)	ES 1 very widely spaced discontinuities > 200 (cm)	ES 1 very widely spaced discontinuities > 200 (cm)	ES 1 very widely spaced discontinuities > 200 (cm)	ES 1 very widely spaced discontinuities > 200 (cm)
Interval between discontinuities (ID index)	ID 1 very low density > 200 (cm)	ID 1 very low density > 200 (cm)	ID 1 very low density > 200 (cm)	ID 1 very low density > 200 (cm)	ID 1 very low density > 200 (cm)	ID 1 very low density > 200 (cm)	ID 1 very low density > 200 (cm)
Degree of alteration	AM 5 texture and large fractures still visible	AM 2 little weathering of rock in the mass but well developed in discontinuities	AM 3 weathering clearly visible in whole rock mass but material not friable	AM 2 little weathering of rock in the mass but well developed in discontinuities	AM 4 severe weathering in the mass	AM 1 weathering confined to surfaces of main discontinuities; rock sound in the mass	AM 1 weathering confined to surfaces of main discontinuities; rock sound in the mass
Rock mass deformation modulus E_{Mas}	D_M3 moderate deformability	D_M3 moderate deformability	D_M3 moderate deformability	D_M3 moderate deformability	D_M3 moderate deformability	D_M2 low deformability	D_M2 low deformability
Hydraulic head	H 0 zero head	H 0 zero head	H 0 zero head	H 0 zero head	H 0 zero head	H 0 zero head	H 0 zero head
Permeability	K 3 high permeability	K 2 moderate permeability	K 1 low permeability	K 1 low permeability	K 1 low permeability	K 2 Moderate permeability	K 4 very high permeability
Stress states	CN 1 σc /σ0 > 4	CN 1 σc /σ0 > 4	CN 1 σc /σ0 > 4	CN 1 σc /σ0 > 4	CN 1 σc /σ0 > 4	CN 1 σc /σ0 > 4	CN 1 σc /σ0 > 4

these three methods in the case of Boukhadra's iron ore mine gave comparable results. The recommended support systems for the different rock types crossed by the mine gallery did not differ much among the three applied methods. It is clearly seen (Table 6) that Q and AFTES support system recommendations are very close to each other. The RMR which is more flexible in the choice of the support system than the former two but did not, in reality, disagree with them. For the same rock quality the RMR based support system gave three support alternatives (Table 6). Though the three methods gave relatively similar recommendations for the support system, in our opinion, the engineer should, on the basis of a technical and economical study, decide which system is the best for a given case.

In the case of Boukhadra's mine though the

Table 5. Description of the rock mass of Boukhadra.

Description	Ultrasound wave velocity (Ic)	Unconfined compressive strength (σc)	Degree of alteration	Rock mass deformation modulus (E_{Mas})	Permeability
Conglomerate	Low continuity (IC 4)	Low strong matrix (5 MPa < σc < 25 MPa) (RC 5)	Completely weathered rock; texture and large fractures still visible (AM 5)	Moderate deformability (E_{Mas} = 3 to 10 GPa) (D_M 3)	High permeability (10^{-6} à 10^{-4} m/s) (K 3)
Sandstone	Moderate continuity (IC 3)	Low strong matrix (5 MPa < σc < 25 MPa) (RC 5)	Slightly weathered rock; little weathering of rock in the mass but well developed in discontinuities (AM 2)	Moderate deformability (E_{Mas} = 3 to 10 GPa) (D_M 3)	Moderate permeability (10^{-8} à 10^{-6} m/s) (K 2)
Yellow marl	Low continuity (IC 4)	Low strong matrix (5 MPa < σc < 25 MPa) (RC 5)	Moderately weathered rock; weathering clearly visible in whole rock mass but material not friable (AM 3)	Moderate deformability (E_{Mas} = 3 to 10 GPa) (D_M 3)	Low permeability (< 10^{-8} m/s) (K 1)
Mineralized marl	Moderate continuity (IC 3)	Low strong matrix (5 MPa < σc < 25 MPa) (RC 5)	Slightly weathered rock; little weathering of rock in the mass but well developed in discontinuities (AM 2)	Moderate deformability (E_{Mas} = 3 to 10 GPa) (D_M 3)	Low permeability (< 10^{-8} m/s) (K 1)
Multicolored marl	Low continuity (IC 4)	Low strong matrix (5 MPa < σc < 25 MPa) (RC 5)	Well weathered rock; severe weathering in the mass (AM 4)	Moderate deformability (E_{Mas} = 3 to 10 GPa) (D_M 3)	Low permeability (< 10^{-8} m/s) (K 1)
Iron ore	High continuity (IC 2)	Strong matrix (50 MPa < σc < 100 MPa) (RC 3)	Sound rock (AM 1)	Low deformability (E_{Mas} = 10 to 30 GPa) (D_M 2)	Moderate permeability (10^{-8} à 10^{-6} m/s) (K 2)
Limestone	Low continuity (IC 4)	Strong matrix (50 MPa < σc < 100 MPa) (RC 3)	Sound rock (AM 1)	Low deformability (E_{Mas} = 10 to 30 GPa) (D_M 2)	High permeability (10^{-6} à 10^{-4} m/s) (K 3)

overall gallery is stable, we have noticed that failures occur from time to time as the gallery is not supported. For the safety of the miners it is recommended to apply the proposed RMR based support system shown in (Table 6). The improvement of the stability of the overall gallery after applying the proposed support system should be, subsequently, reassessed by numerical methods.

NUMERICAL METHOD

Although, empirical design methods have proved to be very efficient in the process of the support system design, the use of numerical techniques has become a routine work. Moreover, some researchers recommend this practice as it strengthens the value of the obtained results (Figure 5). It also helps to check the performances of the proposed support system (Stille and Palmström, 2003). In carrying out numerical analysis one should be aware not to forget reality for ideal model. Then the rock mass model should be as close as possible to the conceptual model of the geological site. All the physical, mechanical and geometrical parameters of the discontinuous rock mass of Boukhadra were carefully assessed (Table 7). How to assess these parameters is not

Table 6. Support systems proposed by RMR, Q-systems and AFTES guidelines.

Ormation	Rock mass class		Proposed support types by different classifications			
			Rock bolts	**Shotcrete**	**Steel sets**	**Mesh reinforced**
Yellow marl	RMR = 55 fair rock	1	1.0 to 1.5 m	30 mm in crown	none	None
		2	Systematic bolts 4 m long, spaced 1.5 to 2 m in crown and walls with wire mesh in crown	50 to 100 mm in crown and 30 mm in sides	none	Occasional wire mesh
		3	None	None	Light support 1.5 to 2.0 m	None
	Q = 4		None			
	AFTES		None	None	Heavy or light support	None
Mineralized marl	RMR = 55 fair rock	1	1.0 to 1.5 m	30 mm in crown where required	None	None
		2	Systematic bolts 4 m long, spaced 1.5 to 2 m in crown and walls with wire mesh in crown	50 to 100 mm in crown and 30 mm in sides	none	Occasional wire mesh
		3	None	None	Light support 1.5 to 2.0 m	None
	Q = 4.33		Unsupported			
	AFTES		None	None	Heavy or light support	None
Conglomerate	RMR = 55 fair rock	1	1.0 to 1.5 m	30 mm in crown where required	None	None
		2	Systematic bolts 4 m long, spaced 1.5 to 2 m in crown and walls with wire mesh in crown	50 to 100 mm in crown and 30 mm in sides	None	Occasional wire mesh
		3	None	None	Light support 1.5 to 2.0 m	None
	Q = **5**		Unsupported			
	AFTES		None	None	Heavy or light support	None
Sandstone	RMR = 55 fair rock	1	1.0 to 1.5 m	30 mm in crown where required	None	None
		2	Systematic bolts 4 m long, spaced 1.5 to 2 m in crown and walls with wire mesh in crown	50 to 100 mm in crown and 30 mm in sides	None	Occasional wire mesh
		3	None	None	Light support 1.5 to 2.0 m	None
	Q = 4.66		Unsupported			
	AFTES		None	None	Heavy or light support	None

Table 6. Contd.

Limestone	RMR =70 good rock	1	1.5 to 2.0 m	None	None	Locally, bolts in crown 3 m long, spaced 2.5 m with occasional wire mesh
		2	None	50 mm in crown where required	None	None
		3	None	None	None	None
	Q = 5		Unsupported			
	AFTES		None	None	Heavy or light support with forepoling	None
Multicolored marl	RMR = 45 Fair rock	1	1.0 - 1.5 m	30 mm in crown where required	None	None
		2	Systematic bolts 4 m long, spaced 1.5 to 2 m in crown and walls with wire mesh in crown	50 to 100 mm in crown and 30mm in sides	None	Occasional wire mesh
		3	None	None	Light yielding 1.5 to 2.0 m	None
	Q = 4.66		Unsupported			
	AFTES		None	None	Heavy or light yielding	None
Iron ore	RMR = 70 Good rock	1	1.5 to 2.0 m	None	None	Locally, bolts in crown 3 m long, spaced 2.5 m with occasional wire mesh
		2	None	50 mm in crown where required	None	None
		3	None	None	None	None
	Q = 6		Unsupported			
	AFTES		None	None	Heavy or light yielding with forepoling	None

in the scope of this paper. These parameters were used to carry out numerical analysis with the two dimensional finite elements code *PLAXIS* V8.2. In this code, a plane strain calculation was carried out by mean of a numerical model characterized by:

1. The material model used is Mohr–Coulomb.
2. The type of material behavior is drained.
3. Element type: 15 nodded triangles.
4. 1238 elements and 10065 nodes.
5. The model dimensions are 40 m length and 28 m height (Figure 6).

Using this code the deformations of the rock mass around the gallery were computed before and after applying the support system (Table 8). The results show that the deformations of weak rock masses such as marls, conglomerates and sandstones improve greatly after applying the support. The improvements are very remarkable and vary from 100 to 1000 times. Limestones and mineralized marls are stronger and consequently they show no difference in deformation before and after applying the support.

When we compared the numerical results obtained with the empirical methods, we found that good quality rock displayed high RMR values while rocks of low RMR gave relatively values (Table. 8). Knowing that the fields of deformation

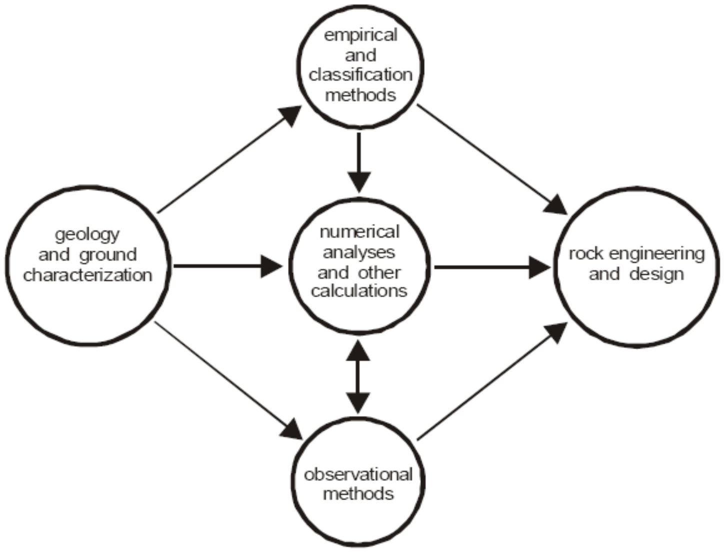

Figure 5. The place of numerical analyses in rock engineering and design (Håkan and Arild, 2003).

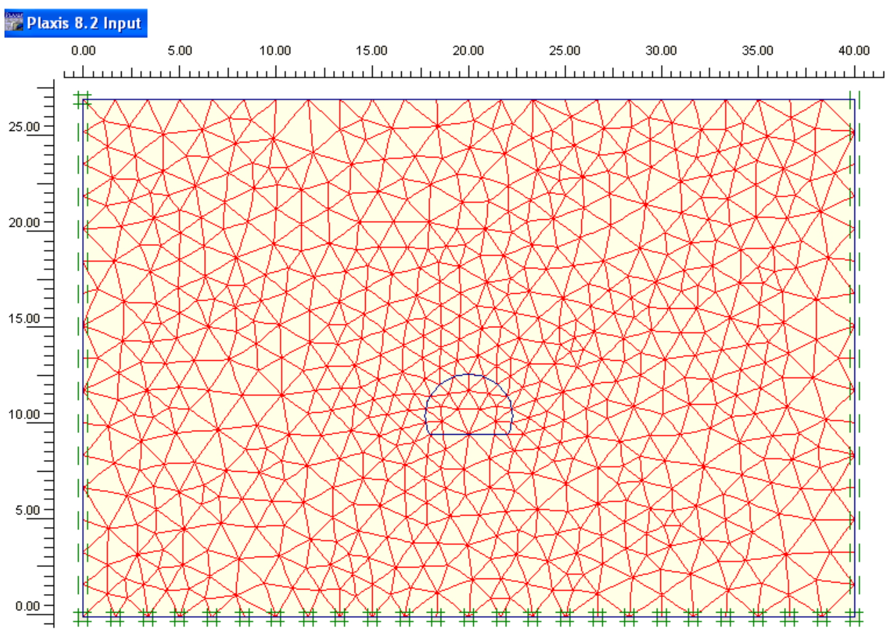

Figure 6. Diagram showing the model dimensions and the partitioning into finite elements.

Table 7. Physics and mechanics characteristics of rock mass of Boukhadra.

Characteristics	E [GPa]	ν	γ_h [g/ cm^3]	γ_{sat} [g/ cm^3]	C [Bars]	φ [°]	Hardness	R_c [Mpa]
Yellow marl	4.47	0.33	2.2	2.6	0.33	23	3	20
Mineralized marl	4.47	0.3	2.4	2.5	2.6	40	-	20
Conglomerate	4.47	0.35	2.2	2.4	0.33	26	4	20
Sandstone	4.47	0.35	2.3	2.7	2.7	35	4	20
Limestone	19.84	0.22	2.6	2.65	3.5	50	7	70
Multicolored marl	3.35	0.38	1.95	2.2	0.3	19	-	20
Iron ore	21	0.25	2.7	2.9	3.2	45	**5**	78.4

Table 8. Results of numerical analysis with finite elements method.

Analysis	Conglomerate	Sandstone	Yellow marl	Mineralized marl	Multicolored marl	Iron ore	Limestone
Field of deformations	Great deformations	Average deformations	Average deformations	Average deformations	Great deformations	Average deformations	Average deformations
Total displacement Utot(m) unsupported	$1.09*10^{-3}$	$1.50*10^{-4}$	$3.16*10^{-4}$	$84.74*10^{-6}$	$1.42*10^{-3}$	$84.26*10^{-6}$	$87.34*10^{-6}$
Total displacement Utot(m) supported by steel sets	$351*10^{-6}$	$316.73*10^{-6}$	$332.2\ 1*10^{-6}$	$85.13*10^{-6}$	$447.34*10^{-6}$	$84.26*10^{-6}$	$85.80*10^{-6}$
Total displacement Utot(m) supported by bolts	$389.32*10^{-6}$	$334.99*10^{-6}$	$358.41*10^{-6}$	$88.02*10^{-6}$	$339.11*10^{-6}$	$86.34*10^{-6}$	$88.21*10^{-6}$
RMR	55	55	55	55	45	70	70
Q	5	4.66	4	4.33	4.66	6	5
GSI	50	50	50	50	40	65	65

are classified as follows:

(1) Field of the very small deformations ($0<\varepsilon<10^{-5}$)
(2) Field of the small deformations ($10^{-5}<\varepsilon<10^{-4}$)
(3) Field of the average deformations ($10^{-4}<\varepsilon<10^{-3}$)
(4) Field of the great deformations ($\varepsilon>10^{-3}$)

DISCUSSION

Boukhadra iron ore mine gallery has been opened for twenty years now. It passes almost perpendicularly through several layered sedimentary rock types. It crosses limestone, yellow marl, multicolored marl iron ore and conglomerates each with different strength and deformability characteristics. Several rock falls mainly from the roof occur from time to time. The main challenge of the work is how to arrive to preview the sections of rock masses concerned with the fall problem.

In this study, the problem is being handled by two different approaches. The first consists of a comprehensive rock mass characterization by means of three rock mass classification methods which are Q and RMR. According to their obtained values; it has been clearly shown that sections of strong rock masses with good RMR and Q values require light to none support while those of marginal quality rock masses require support that varies from shotcrete, steel ribs to rock bolt systems. AFTES support system recommendations are in a good agreement with those provided by Q and RMR. The variety of support systems recommended by the previous three methods for each rock type along the gallery raises the question of which among the proposed (recommended) support system is the best?

The numerical study on a well elaborated geological conceptual model using Plaxis code show that low deformations coincide well with high strength, good quality rock mass while relatively great deformations are obtained on low strength lower quality rock masses. When recalculating deformations after the application of the recommended support systems, improvements in deformations are obtained for rocks of lower quality while those of good quality show practically no change.

The numerical method can therefore be used as an efficient decision making tool in choosing which among the primarily recommended support system is the best.

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