IOP Conf. Series: Earth and Environmental Science **95** (2017) 022019 doi:10.1088/1755-1315/95/2/022019

Modelling and Analysis of the Excavation Phase by the Theory of Blocks Method of Tunnel 4 Kherrata Gorge, Algeria

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Abstract. The aim of our work is to check the stability during excavation tunnel work in the rock mass of Kherrata, connecting the cities of Bejaia to Setif. The characterization methods through the Q system (method of Barton), RMR (Bieniawski classification) allowed us to conclude that the quality of rock mass is average in limestone, and poor in fractured limestone. Then modelling of excavation phase using the theory of blocks method (Software UNWEDGE) with the parameters from the recommendations of classification allowed us to check stability and to finally conclude that the use of geomechanical classification and the theory of blocks can be considered reliable in preliminary design.

1. Introduction

To ensure stability during the excavation of the tunnels, the quality of the support must be adapted to the conditions of the ground, where the importance of the support design. The latter this classification depends on the quality of the rock mass. Geomechanics rock masses classification allows us in the field of engineering to quantify this 'Quality' and get the most from this classification to estimate the dimensions of the structures that will ensure the stability of the structure. The aim of rock mass classification is to process information on rock material properties, characteristics and excavation geometry to obtain representative discontinuity values that provide a rational basis for rock engineering decisions (Priest 1993) [1]. There are several Geomechanics Classification methods: Terzaghi's Rock Load Theory (1946), the rock quality designation (1967), The Rock Mass Rating (1973), The Rock Mass Quality (1974), Rock Mass Index (1995) and the Geological Strength Index (1997) etc. Moreover, they have played an important role in underground constructions. However, these methods are based on semi-empirical principles and verification through a numerical model is needed.

Blocks theory is based on the identification of the geometry of all the blocks created by the intersection of the discontinuities and surface of excavation. The analysis of the system of joints is three-dimensional and permits to find the critical block representing a potential hazard. The application of this method in our case is through the UNWEDGE 3.0 software (Rocscience) [2], which allows calculating a safety factor to confirm whether the key block is stable, and allows modelling the support pressure requirements that acts on the underground excavation.

The objective of our work firstly is to classify our site by 02 methods of classifications namely the Rock Mass Rating (RMR) and The Rock Mass Quality (Q Barton), secondly to estimate the support pressure through recommendations and finally to verify this design by comparison with values obtained through the method of the theory of blocks (UNWEDGE).

2. Brief theoretical overview

The characterization of the rock mass and its classification allows us to estimate the type of possible support, the span and rock mass properties etc. In our case, it will focus on the RMR and Q Barton methods, which were developed specially for the design of the tunnels systems. The reader may consult "Engineering Rock Mass Classification" for details of other methods. [3]

2.1 Rock Mass Rating (RMR)

The Rock Mass Rating (RMR) was developed by Bieniawski (1973), [4]. It is also called Geomechanics Classification and has been modified several times.

RMR is the sum of six parameters:

$$RMR = A_1 + A_2 + A_3 + A_4 + A_5 + B \quad (1)$$

- Unconfined compressive strength of intact rock (A_1)
- RQD (A_2)
- Spacing of discontinuities (A_3)
- Condition of discontinuities (A_4)
- Ground water conditions (A_5)
- Orientation of discontinuities (B)

As mentioned by Bieniawski (1989): to apply the Geomechanics Classification, the rock mass is divided into a number of structural regions such that certain features are more or less uniform within each region [4]. The six rates values are obtained from the tables [4]. Based on the RMR value obtained, the rock mass is classified on into five classes named as very good, good, fair, poor and very poor (Table 1). These five classes give us the roof stand-up time, cohesion, internal friction angle and deformation modulus for the rock mass.

Table 1. Design parameters and engineering properties of rock mass

S. No	Parameter/ Properties of Rock mass	RMR (rock class)				
		100-81 ***(I)***	**80-61** ***(II)***	**60-41** ***(III)***	**40-21** ***(IV)***	**<20** ***(V)***
1	Classification of Rock mass	Very good	Good	Fair	Poor	Very poor
2	Average stand-up time	20 years for 15m span	1year for 10m span	1 week for 5m span	10 hours for 2.5m span	30 minutes for 1m span
3	Cohesion of rock mass (Mpa)*	>0.4	0.3 – 0.4	0.2 – 0.3	0.1 – 0.2	<0.1
4	Angle of internal Friction of rock mass	>45°	35 – 45°	25 – 35°	15 – 25°	<15°
5	Allowable bearing Pressure (T/m^2)	600 – 440	440 – 280	280 – 135	135 – 45	45 - 30
6	Safe cut slope (°) (Waltham,2002)	>70	65	55	45	<40

Estimate of support pressure:

Support load can be determined from the RMR system as proposed by Unal (1983) [5] based on his studies in coalmines and an opening with a flat roof [4]:

$$P_V = \left[\frac{100-RMR}{100}\right].\gamma.B \qquad (2)$$

, where P_V= support pressure, γ is the unit weight and B the tunnel width.

Goel and Jethwa (1991) [6] proposed a modified correlation of arched openings

$$P_V = \frac{7.5B^{0.1}.H^{0.5}-RMR}{20\,RMR} \qquad (3)$$

, where B is the span of opening in meters; H tunnel depth in meters (applicable for H = 50 to 600 m) and P_V the short term for support roof in MPa

2.2 Rock Mass Quality (Q-system)

The Q-system was proposed by Barton et al (1974) [7] and like RMR it is also specified for a tunnel support design. The expression of Q system is:

$$Q = \frac{RQD}{Jn}\frac{Jr}{Ja}\frac{Jw}{SRF} \qquad (4)$$

The six parameters are:

- RQD
- number of discontinuity sets (J_n)
- roughness of the most unfavourable discontinuity (J_r)
- degree of alteration or filling along the weakest discontinuity (J_a)
- water inflow (J_w)
- Stress Reduction Factor (SRF),

, where RQD is the Rock Quality Designation; Jn is the joint set number; Jr is the joint roughness number; Ja is the joint alteration number; J_w is the joint water reduction number; and SRF is the stress reduction factor.

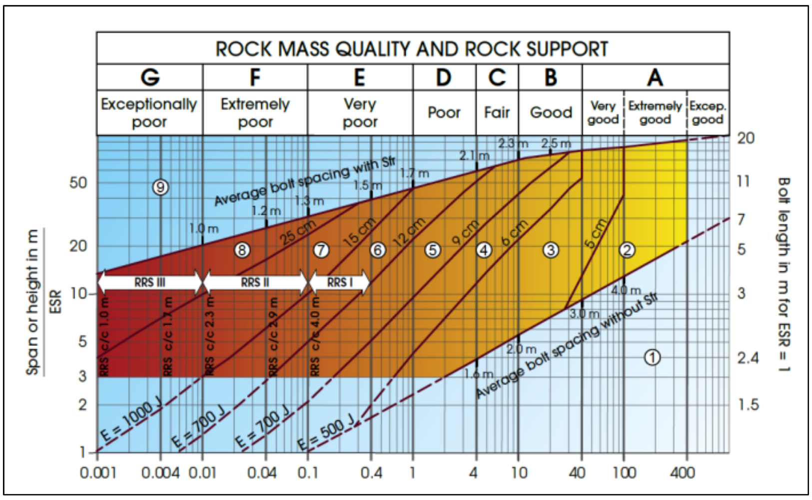

Figure 1. Classification and support recommendations based on Q-values

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Estimate of support pressure:
Barton et al (1974) [7] proposed the correlation for ultimate pressure support:

$$P_V = (0.2/J_r)Q^{-1/3} \quad (5)$$

$$P_h = (0.2/J_r){Q_w}^{-1/3} \quad (6)$$

, where P_V = the ultimate roof support pressure in MPa
P_h = the ultimate wall support pressure in MPa
Q_w = wall factor

The wall factor Q_w is obtained by multiplying Q by a factor that depends on the magnitude of Q as given below

Table 2. Determination of Q_w [7]

Range of Q	Wall Factor
>10	5.0 Q
0.1-10	2.5 Q
< 0.1	1.0 Q

Bhasin and Grimstad (1996) [8] suggested the following correlation for predicting support pressure in tunnels through poor rock masses (Q < 4):

$$P_V = (40B/J_r)Q^{-1/3} \quad (7)$$

, where B is diameter or span of the tunnel in meters. The equation shows that the support pressure increases with tunnel size B in poor rock masses.
Unsupported span:
Barton et al (1974) [7] suggested to estimate the maximum unsupported span by this correlation:

$$B_{MAX} = 2ESRQ^{0.4} \quad (8)$$

Barton et al. (1974) [7] defined an additional parameter which they called the *Equivalent Dimension, D_e,* of the excavation. This dimension is obtained by dividing the span, diameter or wall height of the excavation by a quantity called the *Excavation Support Ratio, ESR.*

$$D_e = \frac{span\ or\ hight\ in\ meter}{ESR} \quad (9)$$

The value of ESR is obtained from the Table 3.

Table 3. ESR-values.

Excavation category	ESR
Temporary mine openings, etc.	2-5
B Permanent mine openings, water tunnels for hydropower, pilot tunnels, drifts and headings for large openings, surge chambers	1.6-2.0
C Storage cavern, water treatment plants, minor road tunnels, access and railway tunnels	1.2-1.3
D Power stations, major road and railway tunnels, civil defense chamber, portals, intersections	0.9-1.1
E Underground nuclear power stations, railway stations, sports and public facilities, major gas pipeline tunnels	0.5-0.8

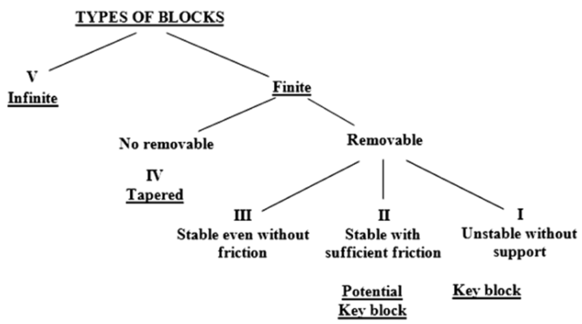
Barton et al (1974) [7] proposed also estimated length of bolts:

$$L_B = \frac{2 + 0.5B \ or \ H}{ESR} \tag{10}$$

L = length of bolt in meters,
B = span in meters,
H = excavation height in meters.

3. Block theory method

As demonstrated by Goodman and Shi (1985) the block theory method [8] is applicable for analysing the removability of blocks in underground chambers and tunnels. It permits the identification of the named key blocks for excavation geometry.
A key block is potentially critical to the stability for an excavation because, by definition, it is finite, removable and potentially unstable.



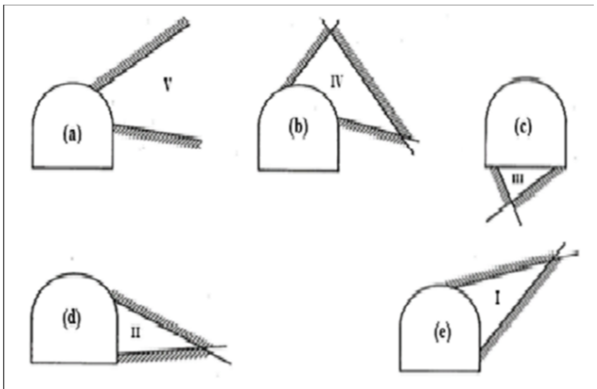


Figure 1 Types of blocks : (a) infinite; (b) tapered; (c) stable; (d) potential keyblock; (e) keyblock

Figure 2. a) Type of blocks (after Goodman and Shi [9]) b) Examples of types of Blocks (after Goodman and Shi, [9])

In this work, the software UNWEDGE (Rocscience) [10] is used for identification of potential blocks or wedges who can slide or fall from back or wall of tunnel. The calculation of safety factor of these wedges depending upon the mode of failure. Finally, calculation of the amount of reinforcement required permits to bring the factor of safety of individual wedges up to an acceptable level.

4. Case of study

The area where the project is located is at the Gorges between Bordj Mira and Kherrata the point of view of geology, the tunnel 4 PK 6+175 - PK6 + 570 m of a 395m length can be Divided into three sections:

North Portal Area

The zone of North Portal is characterised by the presence of calcareous rocks in layers of decimetric power and by the proximity of an anticlinal fold with an oriented axial plane EW and is bounded to the south by a fault at the Pk 6 + 280 of the project approximately. The N portal has been considered in the S-flank of this fold, and the layers have a strong dip (70º) towards S. The thickness of the layers varies between 60 cm and 1 m. The spacing between the joints varies between 30 cm and 1 m.

Figure 3. North Portal Zone

Central Area

This section is limited by two faults; in the north, it is bounded by a fault at Pk 6 + 280 approximately, and in the south by a second fault at Pk 6 + 500 approximately. On this section, calcareous marls with flint appear in centimetre to decimetre layers with intercalations of pelitic layers the rock has undergone a strong ductile deformation within very tight folds and with a hinge with a very small radius of curvature

South Portal Area

The section from Pk 6 + 500 approximately to the end of Tunnel 4, composed of grey limestone and marl-limestone with flint in centimetre-decimetre layers. The layers are close to the vertical. The rocks are cracked, the thickness of the layers varies from 10-40 cm.

Figure 4. South Portal Zone

Our classification will be devoted to the 02 zones namely the area of the north Portal P.K.6 + 175 P.K. 6 + 280 and that of the south Portal P.K 6 + 500 - P.K. 6 + 570. A geotechnical investigation campaign was carried out along the rock mass and in situ and laboratory tests gave the results of the table.

Table 4. Properties of rocks

Intact rock	Compression Strength (MPa)	RQD (%)	Unit Weight
Rock of the North Portal Zone	83	72	2.69
Rock of the South Portal Zone	43	< 25	2.7

The characterization was carried out on outcrops and determination of RMR and Q system values were done, the factor of orientation discontinuities B has been taken into account. A summary of the rock mass classification of the two sectors according to the RMR method, Q-system are given in Table 5.

Table 5. Values of classification after characterisation of rock mass

Tunnel section	Length (m)	RMR	Q
North portal zone	105	49	5.33
South portal zone	70	33	1.06

The two methods gave the same category of rock for the zones studied: fair rock class for the north portal zone and poor rock class for the south one.

Estimation of support pressure

The values of pressure support are estimated for each section mentioned in Table 6. The unsupported span, the pressure support or roof and wall, Shotcrete, wire mesh and the length of bolt were evaluated by using the recommendation’s and empirical correlation of RMR method and Q system as given in following table.

Table 6. Summary of empirical support type proposed by classification methods.

Tunnel section	RMR	Q
North portal zone	RMR Rating 49 Rock mass class III fair Rock Unsupported span 5 m Time 1 week Pressure support P_V=31.45 kpa (eq 3) Conventional Shotcrete: 100mm in crown and 30 mm in sides Systematic rock bolts 4 m	Q rating 5.33 Rock mass class Fair Span $B_{MAX} = 3.90$ m P_V= 57.21 kPa (eq. 5) P_h= 42.18 kPa (eq. 6) P_V= 44.65 kPa (eq. 7) L_B=3.40 m (eq. 10) $L_B = 3.72\ m$ (eq. 10) Systematic bolting and unreinforced Shotcrete 4 to 10 cm
South portal zone	RMR Rating 33 Rock mass class poor Rock Unsupported span 2.5 m Time 10 hours Pressure support $\boldsymbol{P_V}$=70.94 kPa (eq. 3) Conventional Shotcrete: 150mm in the crown and 100 mm in sides Systematic rock bolts 4-5 m Light to medium ribs	Q rating 1.06 Rock mass class Poor Span $\boldsymbol{B_{MAX} = 2.04}$ **m** $\boldsymbol{P_V}$= 98.07 kPa (eq. 5) $\boldsymbol{P_h}$= 72.26 kPa (eq. 6) $\boldsymbol{P_V}$= 44.65 kPa (eq. 7) $\boldsymbol{L_B}$=3.35 m (eq. 10) $\boldsymbol{L_B = 3.72\ m}$ (eq. 10) Systematic bolting and unreinforced Shotcrete 4 to 10 cm

5. Block stability of Kherrata tunnel

An analysis was performed by the software UNWEDGE to determine potential key blocks during the excavation of the tunnel. The axes of the tunnel have orientations N162/00 (trend/dip) for the North Portal zone and N180/00 for the south portal. A factor of safety Fs = 1.5 was used in this study for assessing the recommendations of the classification method. For strength parameter of joints, we consider the worst case and cohesion having a very low value, the friction angle is 30°

North portal zone:
In this section three main sets of discontinuities are considered, the mean vector of each is:
79/8, 56/244 and 69/43 (in format: dip/dip direction)

South portal zone:
From the structural point of view, this zone is characterised by the presence of 03 families of discontinuities whose families are represented by the following average values:
75/195, 63/124, 67/233.

The verification of the stability of the blocks and the proposed supports during the excavation carried out by the UNWEDGE gave the following results.

6. Results and discussions

Before application of supports
North portal zone
The results indicate instability on the roof of the tunnel with a factor of safety Fs = 0.288 and a pressure of 43.57 kPa, the rest of wedges are stable.
This value of pressure support calculated by UNWEDGE is closer to the estimate of Barton's method.

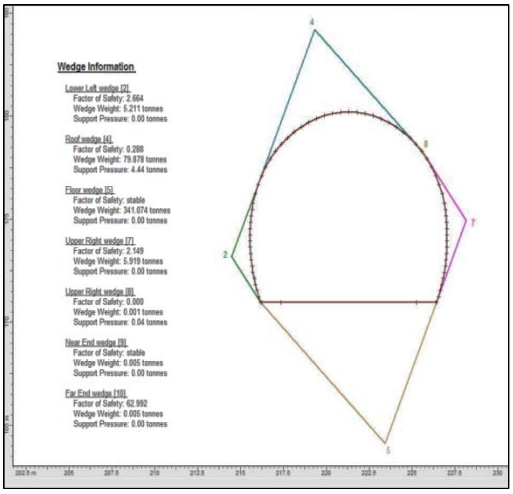


Figure 5. Perspective view of the North Portal Zone before the application of support

South portal

In this zone, the verification of the stability gave instability at the roof (roof wedge 4) a safety factor of 0.349 and a support pressure of 71.90 kPa.
Compared with the values obtained by the empirical correlations, we note that they are close: 70.90 kPa for RMR and 98.07 kPa for Q system.

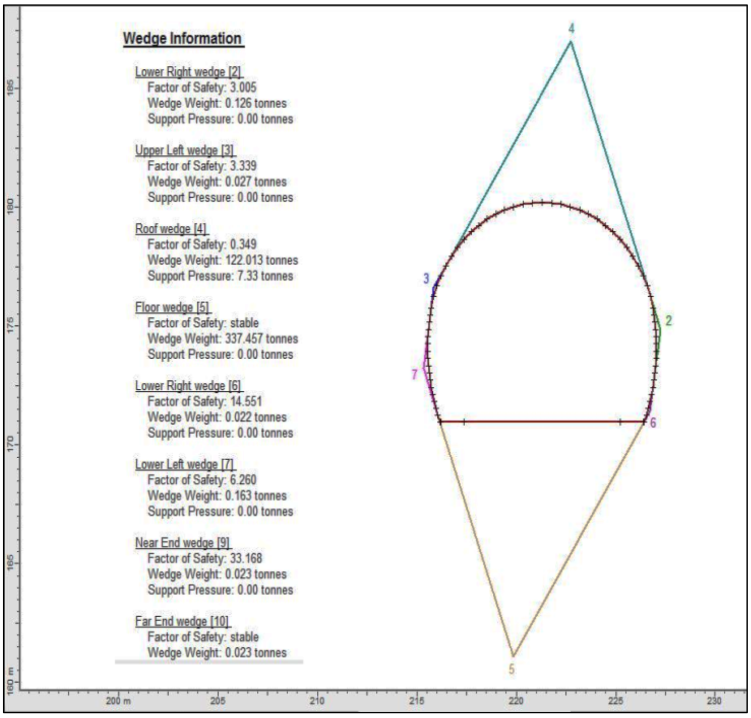


Figure 6. Perspective view of the South Portal Zone before the application of support

After application of support

The application of recommendation 'bolts + shotcrete' for both areas permits the stabilisation of the tunnel. The using of ribs is not necessary for the South Portal.

The values of parameter introduced in UNWEDGE are summarised in Table 7.

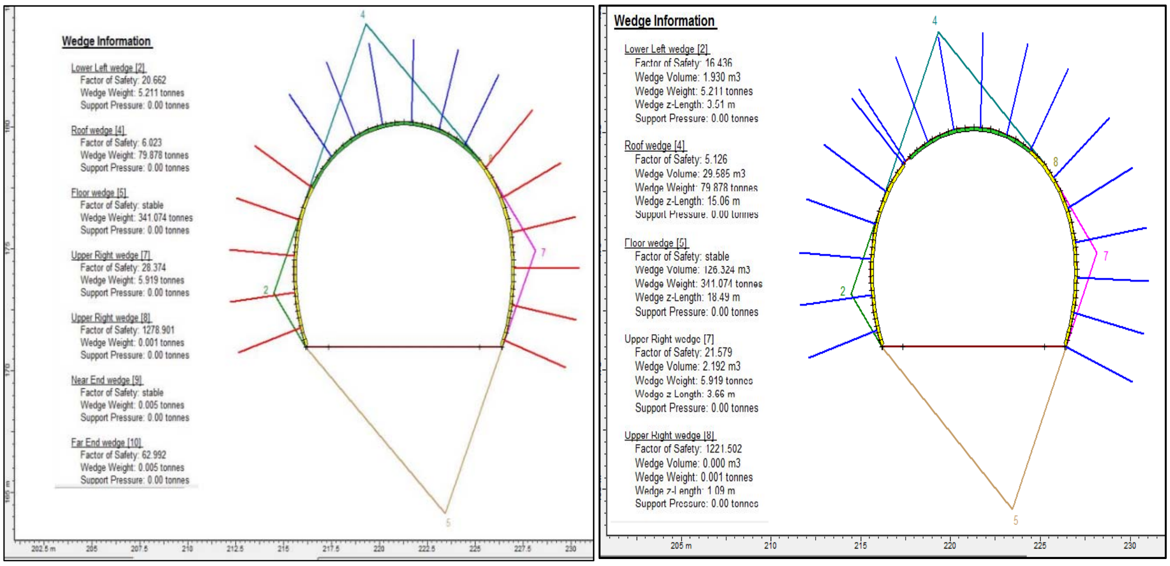


Figure 7. Perspective view after the application of support for North portal respectively RMR and Q system recommendations

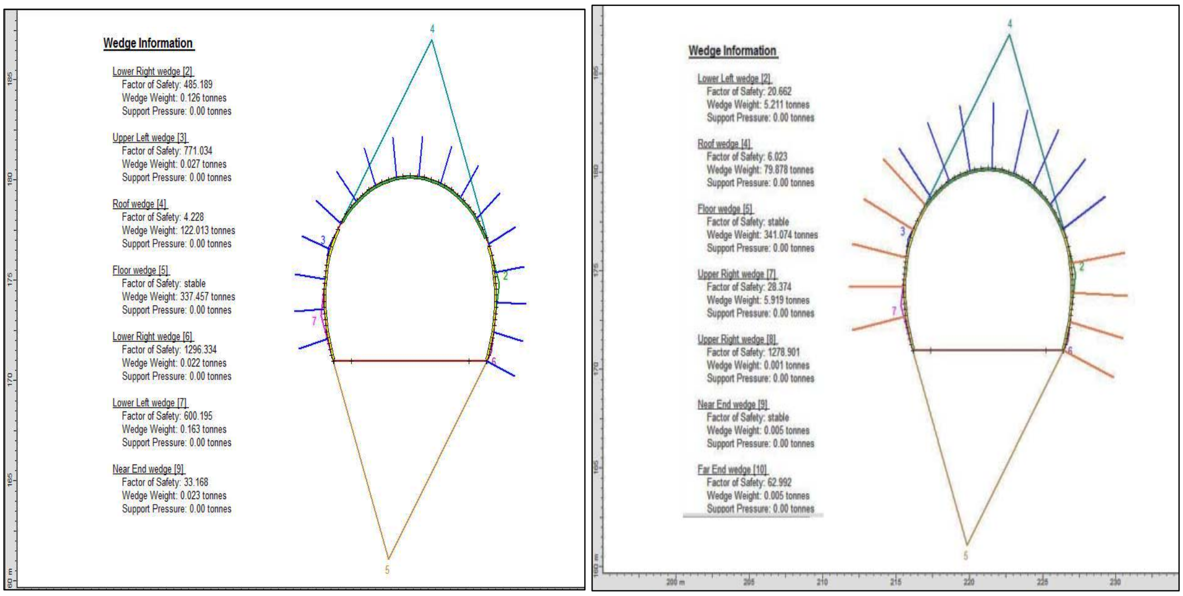


Figure 8. Perspective view after the application of support for North portal respectively RMR and Q system recommendations

Table 7. Summary of support parameters values used in UNWEDGE

Tunnel sections	RMR	Q
North portal zone	Span =5m Bolt length 4 m Shotcrete: 10 m in the crown 3 cm in sides	Span = 3.9 m Bolt length 3.4 m Shotcrete: 10 cm 4 cm
South portal zone	Span = 2.5m Bolt length 4 m Shotcrete: 10 m in the crown 3 cm in sides	Span = 2.04 m Bolt length 3.35 m in crown Bolt length 3.7 m in sides Shotcrete: 15m in crown 12 cm in sides

7. Conclusion

In this study, a characterization and classification of the rock mass were carried out using the RMR and Q system methods. This allowed us to conclude that the quality of the limestone rock in the sections studied is fair for the North Portal zone and poor in the South Portal zone. An estimate of the support pressure has been estimated through empirical relationships. Finally, the stability of the tunnel and the recommendations of the classification methods concerning the support were carried out by the method of the block theory through the software UNWEDGE which allows us to conclude that these methods are satisfactory.

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