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Determination strength parameters rock masses jajarm tunnel based on geotechnical study

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Key words: Jajarm tunnel, Geotechnical survey, RMR, Q, GSI, Rock mass strength.

Abstract

The Jajarm tunnel will be built in Alumina mine area, located in 20 km of north of Jajarm city in north east of Iran. This tunnel is 4.8 m in height and 800 m in length and is mainly excavated on sedimentary rocks of the Carboniferous age, Triassic age and Jurassic age. This paper discusses the results of geotechnical survey carry out at the propose Jajarm tunnel. Geotechnical information obtains from field study and the field study includes engineering geological and surface discontinuity mapping. The rock units were classified by RMR, Q-system and GSI. According to results from RMR and the Q-system are shown Mobarak unit and Elika unit are classified as good rock masses and Shemshak unit is classified as poor rock masses. In this study, rock mass strength parameters were estimated by using the Hoek-Brown equation and rock classification. Results of rock mass classifications RMR and Q produces a higher Rock mass modulus compared with the results of the Hoek-Brown equation.

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Introduction

The assessment of rock mass strength is a key element in any rock excavation for both, open pit and underground excavations. When numerical models are used as a tool of analysis, this strength is defined in terms of a strength envelope. The envelope may be linear, like Mohr – Coulomb or non linear like that suggested by Hoek *et. al.* (1995). There are empirical methods that relate rock mass classifications with design parameters like slope angles, open-spans and support, Bieniawski (1989), Barton (1974). The classification methods do not however directly provide the strength characteristics. The non-linear Hoek – Brown criterion relates the strength envelope to the rock mass classification through the GSI index. This method allows strength assessment based on actual data collected on site, mainly discontinuity density, discontinuity condition, plus laboratory information like unconfined compressive strength. One drawback of this method is that different characteristics of the rock mass, like joint condition and discontinuity density, are combined in a single number, GSI, and this number is used to assess the rock mass strength. Two different rock massescan have the same GSI but if the joint condition and discontinuity density are different, it is unlikely that both rock masses would have the same strength. If the joint condition and discontinuity density are considered separately it is possible to estimate the rock mass strength for each one.

Over the last few decades in order to shorten the route, as well as access to minerals, performing underground excavations have taken an increasing rate. Exploration, design and safety during the construction of tunnels and underground spaces in general, and if necessary, long term sustainability, including issues that should be considered by designers. In this regard, it is necessary to pre-drill information about the geology, structural geology (tectonics) and Geological Engineering Executive range is obtained.

In this study, rock mass strength parameters were estimated by using the Hoek-Brown equation and rock classification. Results of rock mass classifications RMR and Q produces a higher Rock mass modulus compared with the results of the Hoek-Brown equation.

The purposes of this study are show relationship between Geological factor roles in designing and constructing a tunnel.

The Jajarm tunnel will be situated in Alumina mine area, 20 km north of Jajarm in the north-east of Iran (Fig. 1). The rock mass strength and deformation behaviors play a major role in design of many engineering structures in or on rock, such as foundations, slopes, tunnels, underground caverns and drifts. When rocks and rock masses are classified for geotechnical purposes, they need to be classified on the basis of strength and modulus to give an indication of their stability and deformability (Ramamurthy, 2003). The empirical rock-mass classification systems commonly used to design excavations in rock have long been recognized as useful tools for the prediction of rock masses and choice of support requirements on the basis of experience in similar geologic conditions (Grimstad and Barton, 1993; Barton *et. al.*, 1980).

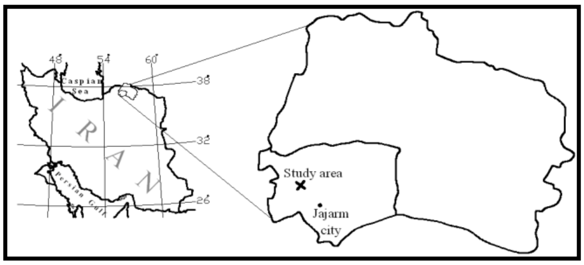


Fig. 1. Location map of the Jajarm tunnel site.

The purpose of this study is to investigate the engineering geological characteristics of the rock material and rock mass a Jajarm tunnel. This paper explains engineering geological assessment for safe design of the proposed Jajarm tunnel.

These geotechnical Investigations have been carried out at the project site. In this study, rock mass properties were classified using RMR (Bieniawski, 1989), Q (Barton *et. al.*, 1980) and GSI system (Marinos *Et. al.*, 2005) was used to obtain rock mass strength parameters.

Geological factors play a major role in designing and constructing a tunnel. Not only do they control the character of formations, but they also govern the material available for construction. There exist numerous examples of projects where the conditions of the foundation were not sufficiently known and the cost of construction and treatment greatly exceeded the original budget (Lashkaripour and Ghafoori, 2002). The tunnel was built in a sedimentary rock formation as shown in Fig. 2. Rocks surrounding the tunnel mainly include limestone and Shale. The Geological cross-section of the tunnel is shown in Fig. 3.

The main aim of this study is determination Strength Parameters Rock Masses Based on Geotechnical Study in the Jajarm Tunnel.

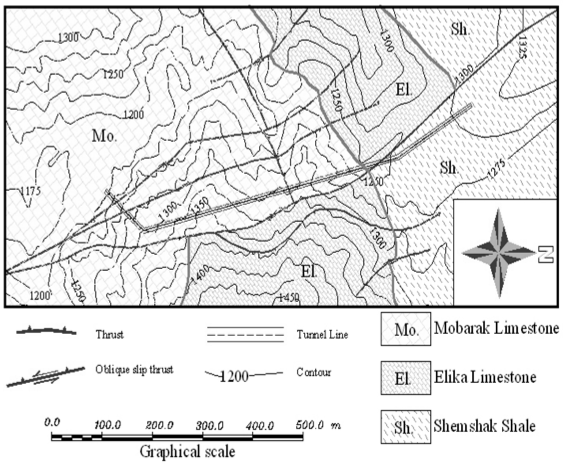


Fig. 2. Engineering geological map of the site.

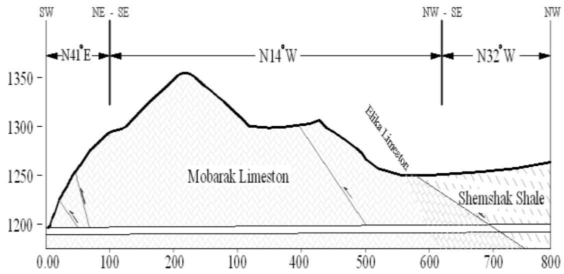


Fig. 3. Geological section of the Jajarm tunnel.

Materials and methods

The area under study

The Jajarm tunnel will be situated in Alumina mine area, 20 km north of Jajarm in the north-east of Iran. The entrance of the tunnel is composed of a Mobarak limestone formation (0 + 600 km). From 0 + 600 km to 0 + 750 km Elika limestone formation are placed on the Mobarak limestone. From 0 + 750 km to 0 + 800 km, the tunnel crosses a Shemshak formation consisting of black, grey and green shale.

Research Method

Engineering geological investigations include discontinuity surveying. Discontinuity analysis in underground spaces is very important, Because of it occurs individually displacement around the underground space (Goodman, 1989). Discontinuities surveys consisted of orientation, aperture, roughness, persistence, infilling and spacing was determined at the site by exposure mapping in accordance to ISRM (1981). Orientations and characteristics of the discontinuities have been defined based on the field measurements. Shear strength parameters of the discontinuities are obtained based on the conditions of the joint surfaces and type of rock materials (Hassani *et. al.*, 2008).

Research Hypotheses

In this study, a total of 445 discontinuities, 190 on the Mobarak formation, 95 on the Elika formation and 160 on the Shemshak formation, have been measured (Table 1).

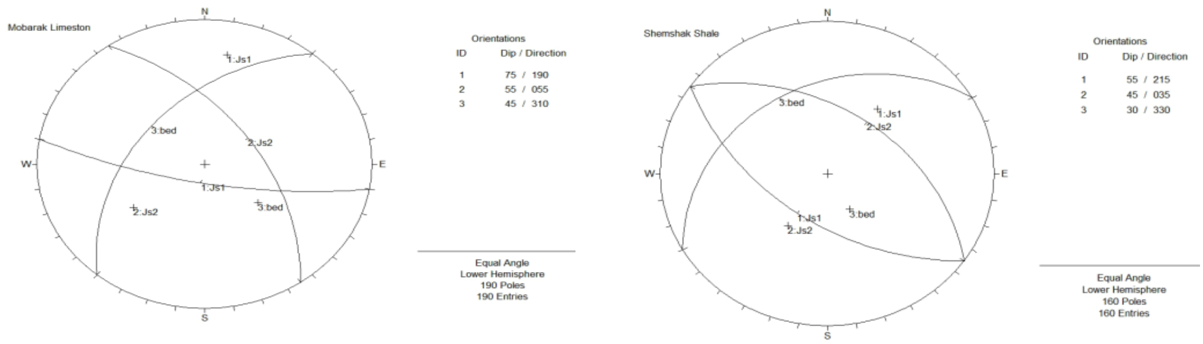
Table 1. Orientation discontinuity in this area.

Rock formation	Discontinuity	Dip	Dip Direction
Mobarak limestone	Js1	75 – 80	180 – 200
	Js2	50 – 60	50 - 60
	Bedding	45	310
Elika limestone	Js1	50 – 60	190 - 210
	Js2	40 – 60	40 – 60
	Bedding	60	320
Shemshak shale	Js1	50 – 60	210 – 220
	Js2	40 – 50	20 – 50
	Bedding	30	330

Quantitative descriptions and statistical distributions discontinuity in the Jajarm tunnel route are shown in Table 2; the water level is lower than the tunnel axis. The dip of joints in Mobarak and Elika formation generally varies from 40° to 80° and the dip of joints in Shemshak formation generally varies from 40° to 60°. The joint apertures are mostly less than 0.1 mm. The surfaces discontinuities in limestone rocks are planar and rough and in shale rocks are planar and smooth. In the Fig. 4 shows the Stereonets of joint sets (Dip and Dip Direction) in rock units.

Table 2. Quantitative descriptions and statistical distributions of discontinuities of Jajarm tunnel site.

	Parameters	Mobarak unite		Elika unite		Shemshak unite	
		Js1	Js2	Js1	Js2	Js1	Js2
Condition of discontinuities	Spacing (m)	2.0-3.0	3.0-3.5	1.0-1.5	0.7-1.0	0.1-0.15	0.08-0.1
	Aperture (mm)	0.1 >	0.1 >	0.1 >	0.1 >	0.1 >	0.1 >
	Persistence (m)	5.0-7.0	8.0-10.0	4.0-5.0	6.0-7.0	1.0-1.5	1.0-1.5
	Filling	Calcite	Calcite	Calcite	Calcite	Clay	Clay
	Water Condition	Dry	Dry	Dry	Dry	Damp	Damp
	Roughness	Rough	Rough	Rough	Rough	Smooth	Smooth
	Weathering	Slightly weathered	Slightly weathered	Slightly weathered	Slightly to Moderately weathered	Moderately weathered	Moderately weathered



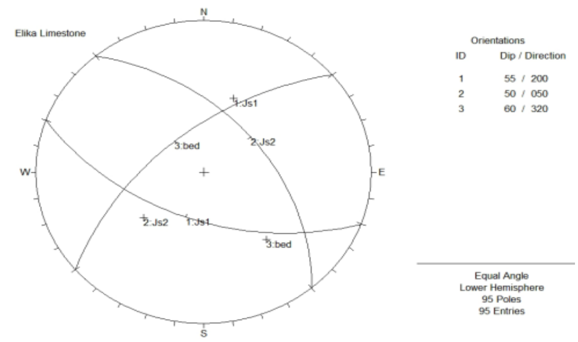


Fig. 4. Dominant joint sets on rock units of the Jajarm tunnel site.

Results and discussion

Rock mass classifications

In recent decades, rock mass classifications have been used for the construction and design of foundations, slopes, tunnels, underground caverns and drifts using geological and geotechnical data (e.g. Pells and Bertuzzi, 2007, Hassani *et. al.*, 2008, Pantelidis, 2009). The rock mass classification the Jajarm tunnel approaches using the Q-system (Barton *et. al.*, 1980), RMR (Bieniawski, 1989) and GSI (Marinos *et. al.*, 2005) have been applied to predict rock mass behavior and strength parameters.

The RMR classification of the tunnel site rock units is shown in Table 3, the Mobarak unit is classified as good rock masses (RMR=80). The Elika unit is classified as good rock (RMR=71) and Shemshak unite is classified as poor rock (RMR=40).

The summary of the results for all sections and rock mass classifications of the Jajarm tunnel, according to the Q-system is presented in Table 4. As shown in this table, Mobarak (Q=11.87) and Elika (Q=8.13) units are classified as good and medium rock quality. The Shemshak unit is classified as poor rock masses (Q=1.67). In the study, Rock mass properties observed in the site Jajarm tunnel were classified using the geological strength index (GSI) system (Marinos *et. al.*, 2005). The Mobarak unit is classified as blocky with good surface quality (GSI=70-80). The Elika unit is classified blocky with good-fair surface quality (GSI=60-70) and Shemshak unite is classified as very blocky with poor surface quality (GSI=37-47).

Table 3. The RMR classification of the tunnel site rock units.

	Parameters	Mobarak limestone		Elika limestone		Shemshak shale	
		Value	**Rating**	**Value**	**Rating**	**Value**	**Rating**
	Uniaxial compression strength (MPa)[1]	100-150	12	100-130	12	20-30	4
	RQD	90-100	17	60-70	13	25-35	8
	Spacing (m)	> 2	20	0.6-2	15	0.06-0.2	8
Condition of discontinuities	Persistence (m)	3-10	2	3-10	2	1-3	4
Condition of discontinuities	Aperture (mm)	0.1 >	5	0.1 >	5	0.1>	5
Condition of discontinuities	Roughness	Rough	5	Rough	5	Smooth	1
Condition of discontinuities	Filling	Hard < 5 mm	4	Hard < 5 mm	4	Soft < 5	2
Condition of discontinuities	Weathering	Slightly weathered	5	Slightly weathered	5	Moderately weathered	3
	Groundwater	Dry	15	Dry	15	Damp	10
	Discontinuity orientation	Drive against dip, joint dip 45– 90^o	-5	Drive against dip, joint dip 45– 90^o	-5	Drive against dip, joint dip 45– 90^o	-5
	RMR	80		71		40	

[1]determined from table of Bieniawski (1989)

Table 4. The Q classification of the tunnel site rock units.

Parameters	Mobarak limestone		Elika limestone		Shemshak shale	
	Value	**Rating**	**Value**	**Rating**	**Value**	**Rating**
RQD	95	95	65	65	30	30
Joint set number (Jn)	2 + Random	6	2 + Random	6	2 + Random	6
Joint roughness number (Jr)	Rough and irregular, undulating	1.5	Rough and irregular, undulating	1.5	Smooth and plan	1
Joint alteration number (Ja)	Slightly altered joint	2	Slightly altered joint	2	Coatings, small clay fraction	3
Joint water reduction factor (Jw)	Dry excavation or minor inflow	1	Dry excavation or minor inflow	1	Dry excavation or minor inflow	1
Stress reduction factor (SRF)	Medium stress	1	Medium stress	1	Medium stress	1
Q	11.87		8.13		1.67	

Rock mass modulus

In recent decades, rock mass classifications have been used for estimate the modulus and strength of jointed Rock (e.g. Justo *et. al.*, 2010; Cai *et. al.*, 2007). Rock mass modulus can be estimated from two rock mass classifications RMR and Q. Bieniawski (1978) has suggested the following equation to determine this parameters based on the for RMR values less than 50.

E_m (GPa) = 2 RMR – 100 RMR>50 (1)

The following equation from Serafim and Pereira (1983) was used to determine in situ deformation modulus of rock mass for RMR values higher than 50.

$$E_m(GPa) = 10^{(RMR-10)/40} \quad \text{RMR<50} \quad (2)$$

In order to estimate in situ deformation modulus of rock masses from the Q system the equation of Barton (2002) was used.

$$E_m(GPa) = 10\left(Q\left(\frac{\sigma_{ci}(MPa)}{100}\right)^{\frac{1}{3}}\right) \quad (3)$$

In situ deformation modulus of rock units Jajarm tunnel are presented in Table 5.

Table 5. Modulus of rock masses.

Rock units	Em (GPa)	
	According to RMR	According to Q
Mobarak	60	127.86
Elika	42	83.92
Shemshak	5.62	10.52

Rock mass strength estimation

All the strength parameters of rock mass such as, rock mass constants, uniaxial compression strength and the in situ deformation modulus are essential for the design and performance tunnel. The most important parameter in the design tunnel is to estimate Hoek–Brown criterion. So, in this study strength of rock masses at Jajarm tunnel site was expressed by using Hoek–Brown empirical failure criteria. The generalized empirical failure criterion is as follows (Hoek *et. al.*, 2002)

$$\sigma_1' = \sigma_3' + \sigma_{ci}\left(m_b \frac{\sigma_3'}{\sigma_{ci}} + s\right)^a \quad (4)$$

Where σ'1 and σ'3 are the major and minor effective principal stresses at failure σci is the uniaxial compressive strength of the intact rock material and mb is a reduced value of the material constant mi and is given by (Hoek *et. al.*, 2002)

$$m_b = m_i \exp\left(\frac{GSI-100}{28-14D}\right) \quad (5)$$

Intact rock constant (mi) was found from Table 8.3 of Hoek *et. al.* (1995). S and a are constants for the rock mass given by the following relationships:

$$s = \exp\left(\frac{GSI-100}{9-3D}\right) \quad (6)$$

$$a = \frac{1}{2} + \frac{1}{6}\left(e^{-GSI/15} - e^{-20/3}\right) \quad (7)$$

Also the rock mass deformation modulus can be obtained by using the GSI value in the formula below (Hoek and Diederichs, 2006).

$$E_{rm}(MPa) = E_i\left(0.02 + \frac{1-D/2}{1+e^{((60+15D-GSI)/11)}}\right) \quad (8)$$

$$E_i = MR.\sigma_{ci} \quad (9)$$

D is a factor which depends upon the degree of disturbance to which the rock mass has been subjected by blast damage and stress relaxation. It varies from 0 for undisturbed in situ rock masses to 1 for very disturbed rock masses (Hoek and Diederichs, 2006). Intact rock modulus (Ei) from the intact rock strength σ_{ci} is given, based on a modulus reduction factor MR. This factor (MR) was found from Table 3 of Hoek and Diederichs, 2006. The rock mass constants, GSI values, Uniaxial compression strength and the modulus of each rock mass Jajarm tunnel are presented in Table 6. These parameters were estimated using the Hoek–Brown strength criterion.

Table 6. Geotechnical parameter of the Jajarm tunnel site rock units.

Parameter		Location		
		Mobarak limestone	Elika limes-tone	Shems-hak shale
Intact Uniaxial Compressive Strength (MPa)		125	110	25
mi		12	12	6
material constants	mb	4.914	3.438	0.756
	s	0.0622	0.0205	0.0016
	a	0.501	0.502	0.510
Modulus ratio		500	500	200
Intact modulus (MPa)		62500	62500	5000
Modulus of Deformation(GPa)		51.02	34.75	0.915
GSI		75	65	42

Conclusions

Rocks surrounding the Jajarm tunnel include Mobarak limestone formation, Elika limestone formation and Shemshak formation consisting of black, grey and green shale. Based on the information collected at site carried out, showed two joint set and bedding exist. According to results from RMR classification and the Q-system are shown Mobarak unit and Elika unit are classified as good rock masses and Shemshak unit is classified as poor rock masses (Fig. 5). The regional and local engineering geology have played a major role in the planning, design, construction and preference of the Jajarm tunnel. So, in this study, Hoek–Brown strength criterion was used for determined the strength parameters of rock mass. Among the rock units in the tunnel site, strength parameters of the Mobarak limestone are much higher than for other rock units. Engineering geological investigations and results indicate that Jajarm tunnel can be safely constructed on the limestone. Hoek–Brown parameters recommenda-tions from the empirical results were used input in the numerical analysis.

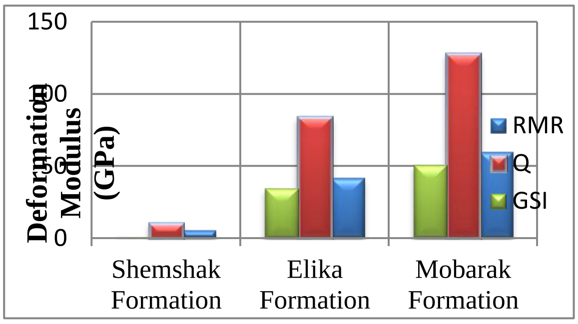


Fig. 5. Dominant joint sets on rock units of the Jajarm tunnel site.

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