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Geotechnical Assessment and Classification of Ultrabasic Rock Masses in the South of Mashhad based on GSI and RMi Classification Systems

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Abstract:
This paper presents the geotechnical assessment and classification of ultrabasic rock masses in the south of Mashhad. Both field and laboratory studies were carried out. The field study involved discontinuity surveying and jointing parameter and also calculation of block size measurements (weighted joint density and block size). Laboratory test were carried out to determine uniaxial compressive strength and point load values.

The block size measurement methods and also RMi and GSI classification systems were performed to determine the excavatability in the studied rock masses. Considering to obtained results, using ripper in the excavatability is the best method. According to RMi classification system, the ultrabasic rock masses are described as moderately strong to strong. Also according to the GSI system, these rock masses are described as very blocky.

Keywords: Ultrabasic, Joints, RMi, GSI, Excavatability

1. Introduction

The Engineering properties of rock masses heavily depend upon the properties of the discontinuities present within the rock mas. Therefore, the possibility to predict the common types of fractures in the rock masses can provide a proper definition of their general behavior. Assessing rock mass properties using direct experiments in the site is difficult and requires methods to determine the properties of rock mass using the properties of intact rock and discontinuities. Rock mass classification systems are mainly used in order to understand the geotechnical properties of rock mass. Many classification systems have been proposed by various researchers such as, RMR (Bieniawski, 1973), Q (Barton et al., 1974), GSI (Hoek, 1994), RMi (Palmstrom, 1995). RMi and GSI classification systems have been adopted in present study. The studied area is located in the north east of Iran and in the south of Mashhad (Fig.1). This area mainly consists of ultrabasic rocks. In recent years, due to increase in construction activities in the southern part of this city, numerous problems have been reported considering the instability of trenches and excavations.

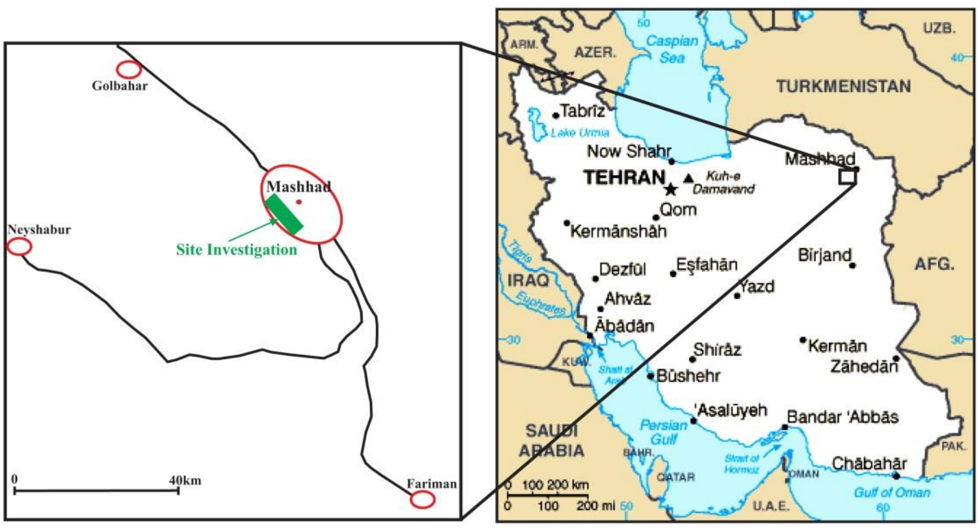


Figure 1. Image showing the location map of studied area

1.1 *RMi classification system*

The rock mass index, RMi, was first proposed by Palmstrom (1995). RMi is a volumetric parameter indicating the approximate uniaxial compressive strength of the rock mass. This index can be compared with the GSI system. The RMi value is recommended as an input data to specify the rock support. The input parameters of this system can be calculated by field observations and measurements. The RMi system requires more calculations compared to Q and RMR systems. The uniaxial compressive strength of intact rock (σc) and jointing parameter (JP) are used in order to calculate RMi in jointed rocks which is indicated by Eq.1.(Palmstrom,2000)

$$RMi = \sigma_c \times Jp = \sigma_c \times 0.2 \sqrt{jc} \times V_b^D \qquad (D = 0.37\, jc^{-0.2}) \qquad \text{Eq. (1)}$$

σc: the uniaxial compressive strength of intact rock
jC: the joint condition factor, which is a combination of the joint size (jL), the joint roughness (jR) and the joint altreration (jA) given as Eq.2.

$$jc = jL \times jR/jA \qquad \text{Eq.(2)}$$

Vb: the block volume, measured in m^3. In equation 3, β is the shape factor and Wjd is weighted joint density.

given as Eq.3.

$$Vb = \beta \times Wjd^{-3} \qquad \text{Eq. (3)}$$

JP: the jointing parameter, which fluctuates between 0 (for crushed rock masses) and 1 (for intact rock). given as Eq.4.

$$JP = 0.2 \sqrt{Jc} \times V_b^D \qquad \text{Eq. (4)}$$

Not only calculation of the block size is necessary and useful in analyzing the stability of rock structures, but also it is used in geomechanical classifications. For example, in the Q system (Barton et al., 1974), the size of the blocks is directly calculated using the ratio between RQD and the factor for the number of joint sets (Jn). In RMR classification system (Bieniawski, 1973), the rock mass quality index and the spacing are applied. The block volume in the RMi system (Palmstrom, 1995) has a wide range of application in assessing the rock support and excavatability. Most methods for numerical modeling and many analytical calculations apply input of the rock mass strength and/or the rock mass deformation modulus. By this, the block size is used indirectly (Palmstrom, 2005).
In order to calculate the values of RMi, three methods for measuring the block size have been used indirectly which include rock quality index (RQD) (Deere, 1964), volumetric joint count (Jv) (Palmstrom, 2005) and weighted joint density (Wjd) (Palmstrom, 2005). The most important method to measure the block size, i.e, the block volume (Vb) is directly used in the calculation considering the RMi classification system. The methods of measuring the block size have been fully described by Palmstrom (2005). In this study, weighted joint density (Wjd) and block volume (Vb) methods have been used to specify RMi values.

1.2 GSI classification system
Both the RMR and the Q classification systems are dependent upon the RQD classification (Deere, 1964). RQD is not an accurate index and is limited in several ways. Therefore, the GSI classification system was introduced. This system would not include RQD, would place greater emphasis on basic geological observations of rock mass characteristics, reflect the material, its structure and its geological history. Note that the GSI system was never intended as a replacement for RMR or Q as it has no rock mass reinforcement or support design capability, its only function is the estimation of rock mass properties (Marinos et al., 2005). The geological strength index (GSI) was introduced by Hoek (1994) in order to specify the rock mass strength in different geological conditions, the deformation modulus of jointed rock masses, and the application of Hoek and Brown failure criterion. This index has also been presented for weak rock masses by Hoek et al. (1998) and Marinos and Hoek (2000). Marinos and Hoek (2001) proposed the GSI chart for heterogeneous rock masses such as flysch which is frequently composed of tectonically disturbed alternations of strong and weak rocks. The chart

was modified by Marinos et al. (2007). Cai et al. (2004) proposed a chart for the quantitative classification of the GSI system in which the block volume (Vb) and joint conditions (jC) are used as quantitative indices. According to Palmstrom (2000), block size can be measured by means of block volume, Vb.

1.3 Determining excavatability using rock mass classification systems

Rock mass classification systems were used for the assessment of excavatability. Abdullatif and Cruden (1983) propsed a method for the assessment of excavatability on the basis of the RMR system. Kristen (1982) had proposed the excavatabiolity index (N) which is obtained on the basis of the Q system (Barton et al., 1974). Basarir and Karpuz (2004) proposed a ripability classification system. This classification is based on the seismic P-wave velocity, the point load index or uniaxial compressive strength, the average discontinuity spacing and the Schmidt hammer hardness. Khamehchiyan et al. (2003) have used the RMi system in order to assess the excavatability of the rock mass in open spaces and have eventually proposed a graphical chart for the assessment of excavatability. In this method a combination of several parameters (uniaxial compressive strength, block volume and join condition factor) has been used for the assessment of excavatability. In contrast to other methods in which parameters such as seismic velocity were used, in this method, inexpensive and simple parameters have been used. Tsiambaos and Saroglou (2010) have used the proposed GSI system by Marinos and Hoek (2000) for the assessment of excavatability. In this method, the intact rock strength and the properties of discontinuity sets and spacing (block size controller) have been carefully evaluated. This is an easy and quick method for the assessment of excavatability. In fact, the point load strength of intact rock and rock mass structure are used in this classification and two classification charts have been finally proposed for the following conditions:

1- GSI excavation chart with $Is_{50} < 3MPa$
2- GSI excavation chart with $Is_{50} \geq 3MPa$

2. Geology of the studied area

The Mashhad ophiolites were located in south of Mashhad city.This comlex is an indicative of the ancient Tethys ocean subduction to the north (Berberian and King, 1981). Alavi (1991, 1979) had studied the ophilite set of Mashhad and the relevant metamorphic rocks from the tectonic perspective and considers them as parts of the subduction set. In the area of Mashhad, ophiolites are in the form of large stretched lenses and are more or less associated with metamorphosed clay sediments in a layered mode. Most geologists believe that this set has oceanic origin and also indicates the ancient Tethys suture which separates Iran and Turan plates from each other. The ultrabasic rocks constitute the major part of ophiolites in Iran. The ultrabasic rocks in Mashhad mainly include Dunite and Wherlite. The age of the rocks is Permian and they have sometimes been metamorphosed into amphibolite facies due to Hercynian event. The geological map (1:20000) of the studied area is shown in Fig. 2.

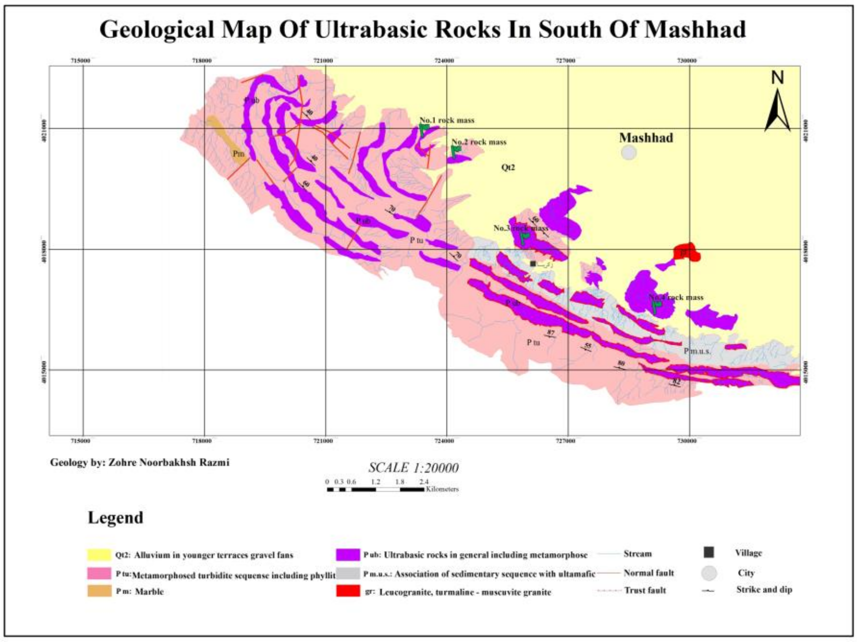


Figure2. Image showing the geological map of ultrabasic rocks in south of Mashhad

3. Methods and results

In the present study, the field investigation has been done in the south of Mashhad. Four locations have been selected for assessing the engineering properties of ultrabasic rock masses for the engineering classification of the rock mass and excavatability assessment. The selected locations consist of Hafte Tir 1(No.1), Hafte Tir2 (No.2), Delavaran (NO.3) and Abadgaran (No.4). Classifications used in this study include RMi and GSI classification systems.

3.1 RMi classification in ultrabasic rock masses

Palmstrom (1995) has proposed the classification for rock mass index. According to Fig.3, parameters used in RMi system include: block volume (Vb), uniaxial compressive strength of intact rock (σc) and joint condition factor (jC). The calculation method of each parameter is described as follows:

Figure 3. Image showing The input parameters to RMi (Palmstrom,2000)

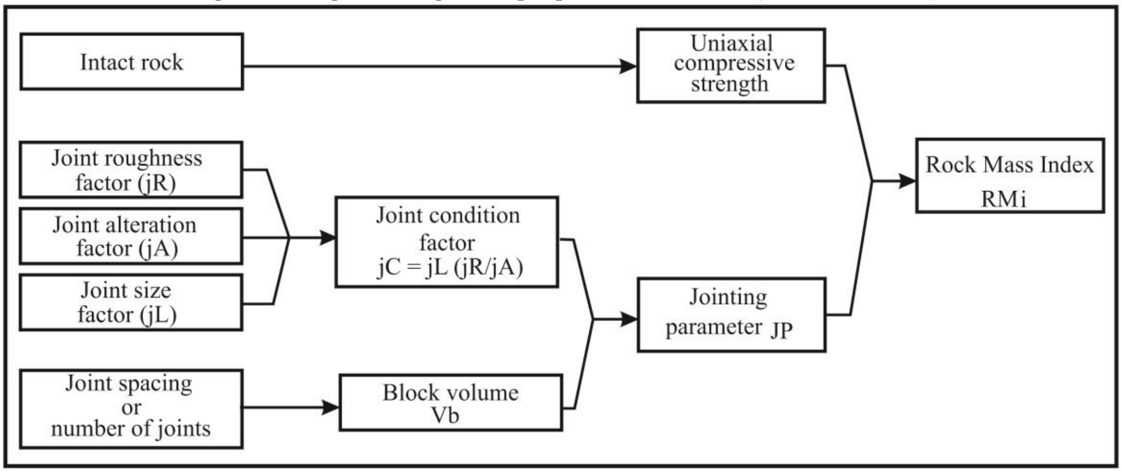


Table.1. Table showing the classification of the RMi (Palmstrom, 1995)

Characterization		Value RMi (MPa)
Term for RMi	**Term related to rock mass strength**	
Extremely low	Extremely weak	<0.001
Vey low	Very weak	0.001-0.01
low	Weak	0.01-0.1
Moderately high	Moderately strong	0.1-1
High	strong	1-10
Very high	Very strong	10-100
Extremely high	Extremely strong	>100

3.1.1 Calculation of the block volume in ultrabasic rock masses

The block volume is intimately related to the intensity or degree of jointing. The greater the block size the smaller will be the number of joints penetrating the rock masses. Hence, there is an inverse relationship between the block volume and the number of joints (Palmstrom, 1995). The only way for calculating block volumes (Vb) using Wjd is to use shape factor (β). In this study, weighted joint density and direct measurement methods have been used for calculating the block volume and the total volume of 417 blocks were measured. The results of weighted joint density have been used for calculating the block volume of No.1 and No.2 rock masses. In this regard, the one-dimensional measurement method was used for calculating Wjd. Three scanline have been taken into consideration in the rock mass in three different directions. In No.1 and No.2 rock masses, the intersection angles between joint and scanline were 216 and 136 respectively and the results are shown in table 2 and table 3.

Table 2. Table showing the results of Wjd (wieghted joint density) in No.1 rock mass

Angle of scanline	Scanline length (L)	Number of joints (n) Within each interval				Total number of joints	Number of weighted joints	WJd=(1/L)N w
		>60°	31-60°	16-31°	<16°			
degree	meter	(n)	(n)	(n)	(n)		$N_w=\sum n\times f_i$	
(0)Horizontal	10	67	61	12	4	144	224.5	22.45
45	3	22	15	1	4	42	72	24
90	2	17	8	5	0	30	46.5	23.25
Rating of f_i=		1	1.5	3.5	6			

Angle of scanline	Scanline length (L)	Number of joints (n) Within each interval				Total number of joints	Number of weighted joints	WJd=(1/L)N w
		>60°	31-60°	16-31°	<16°			
degree	meter	(n)	(n)	(n)	(n)		$N_w=\sum n\times f_i$	
(0)Horizontal	10.5	33	44	8	3	88	145	13.80
45	4	12	14	3	2	31	55.5	13.87
90	2.5	11	4	2	0	17	24	9.6
Rating of f_i=		1	1.5	3.5	6			

Table 3. Table showing the results of Wjd (wieghted joint density) in No.2 rock mass

Finally, the average values of Wjd in the three scanlines in each rock mass has been considered in calculations related to the block volume. The mean value of weighted joint density (Wjd) is 23 and 12 in No.1 and No.2 rock masses respectively. As mentioned above, the only way for calculating the block volume using Wjd is to use shape factor (β). According to field studies and calculations performed on 202 blocks, the value of shape factor (β) in No.1 and No.2 rock masses are 38 and 41. Using Eq.3, then, the mean value of the block volume in No.1 and No.2 rock masses are 0.0031 and 0.024 m^3 respectively. The direct measurement method of relevant dimensions of each block has been used for calculating block volume in No.3 and No.4 rock masses. According to the results of measurements on 215 individual blocks, the average block volume in No.3 and No.4 rock masses are 0.0119 and 0.0346 m^3 respectively.

3.1.2 uniaxial compressive strength

Uniaxial compressive strength test is the most common laboratory test for mechanical studies of intact rock. Despite its simple appearance, this test is extremely difficult to perform accurately. Intact rock strength has been taken into consideration as a main parameter in most rock mass classification systems. 19 samples of the ultrabasic rocks have been prepared to measure the uniaxial compressive strength from which UCS of 11 samples have been accurately carried out as per the ASTM, 2938 standard (Table 5). Table 8 indicates the average uniaxial compressive strength in each of the studied rock masses. Uniaxial compressive strength of ultrabasic rocks varies between 54 and 124 MPa and its mean value is about 78 MPa. The stress- strain diagram of the collected samples has been presented in this test by measuring the stress and strain values. Final results of uniaxial compressive strength are shown in table 4. The behavior of the sample ultrabasic intact rock is elastic-plastic-elastic in the uniaxial compressive strength test (Fig.4).

Table4. Table showing the final results of uniaxial compressive

Number of rock mass	Tangent modulus	Poissons ratio	Shear modulus	Lama coefficient	Compressibility coefficient	Compression modulus
No.2	6.33	0.13	3.58	0.67	1.56	5.34
No.3	2.50	0.14	1.42	0.12	0.60	1.97
No.4	6.95	0.19	4.13	1.19	1.43	5.36

Table5. Uniaxial compressive strength (UCS) values of 11 sample

No.	Location of sampling (Number of rock mass)	uniaxial compressive strength (MPa)
1	No.3	54.06
2	No.1	54.87
3	No.1	55.1
4	No.2	60.53
5	No.4	99.49
6	No.1	55.25
7	No.2	63.86
8	No.4	118.87
9	No.3	66.36
10	No.2	67.72
11	No.4	123.97

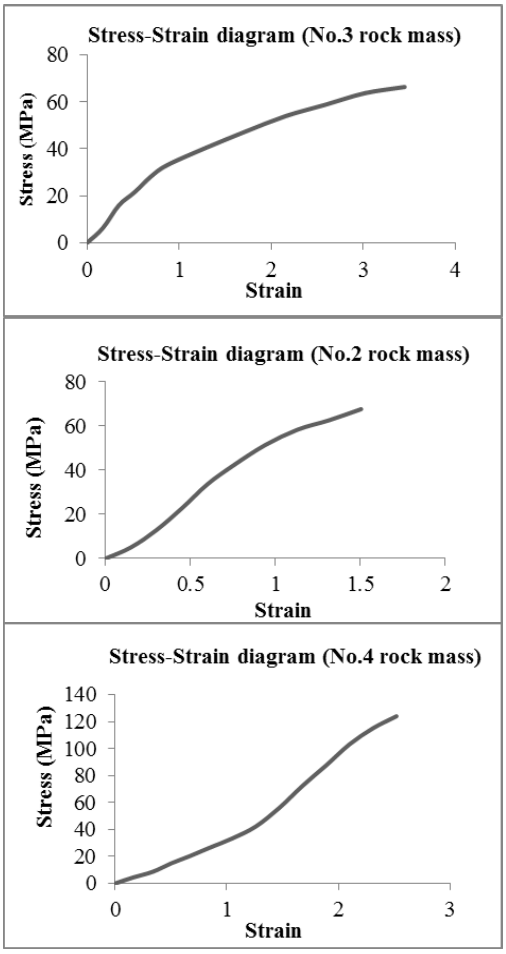


Figure4. Image showing Stress-Strain diagrams

3.1.3 Joint condition factor

200 joints have been examined in this area through field studies in order to measure the joint condition factor. In this regard, the standard table offered by Palmstrom (2000) was used in order to calculate jointing parameter (JP), joint roughness factor (jR), joint alteration factor (jA), and the joint size factor (jL) for each joint. Finally jC and JP values were calculated respectively for each joint using Eq. 2 and 4, then statistical properties (mean, median, standard deviation, minimum data, maximum data) of JP and jC have been calculated for each rock mass by SPSS (table 6 and 7). Figure 5 showing the joint sets of No.4 rock mass.

Figure5. Image showing the joint sets of No.4 rock mass.

Table 6. Table showing the statistical properties of joint condition factor (jC)

statistical properties of jC	No.1 rock mass	No.2 rock mass	No.3 rock mass	No.4 rock mass
Total number of joints	50	50	50	50
average	0.850	1.45	1.36	1.26
median	0.66	1.50	1.00	1.00
standard deviation	0.59	0.71	1.10	0.96
minimum	**0.38**	**0.25**	**0.17**	**0.33**
maximum	3.00	3.00	4.00	4.00

Table 7. Table showing the statistical properties of jointing parameter (JP)

Statistical properties of JP	No.1 rock mass	No.2 rock mass	No.3 rock mass	No.4 rock mass
Total number of joints	50	50	50	50
average	0.019	0.065	0.046	0.064
median	0.016	0.068	0.038	0.057
standard deviation	0.012	0.025	0.031	0.036
minimum	**0.009**	**0.016**	**0.007**	**0.024**
maximum	0.062	0.114	0.115	0.155

Table 8. Table showing the values of input parameters RMi for ultrabasic rock masses

The name of rock mass	jC	D	Vb (m^3)	JP	σc (MPa)	RMi	Term related to rock mass strength
No.1 rock mass	0.38	0.450	0.0031	0.009	55	0.49	Moderately strong
No.2 rock mass	0.25	0.488	0.024	0.016	64	1.02	strong
No.3 rock mass	0.17	0.529	0.011	0.008	60.1	0.47	Moderately strong
No.4 rock mass	0.33	0.488	0.034	0.024	114	2.79	strong

Since the joints have been selected randomly, JP and jC have the minimum values in the calculations which are the best and the most conservative values for these parameters.

Table 8 indicates the value of the input parameters of the RMi system in addition to the values of rock mass index in each studied rock mass. With respect to the RMi classification (Palmstrom, 1995), the studied rock masses are considered as relatively strong to strong rock masses.

3.2 GSI classification system of ultrabasic rock masses

Outcrops, excavated slopes tunnel faces and borehole cores are the most common sources of information for the estimation of the GSI value of a rock mass. Outcrops are an extremely valuable source of data in the initial stage of project but they suffer from the disadvantage that surface relaxation, weathering and/or alteration may have significantly influenced the appearance of the rock mass components (Marinos et al., 2005).

To determine the geological strength index (GSI) in each rock mass, the average block volume and joint condition factor (jC), explained in sections 3.1.1 and 3.1.3, have been applied. The minimum value of jC was selected as joint condition factor in each rock mass (Table 6). Figure 6 indicates the GSI chart for each of the studied rock masses.

According to the classification of geological strength index, the GSI values of ultrabasic rocks in the south of Mashhad vary between 26 and 36. The ultrabasic rock masses are described as very blocky and joint conditions are described as poor to very poor.

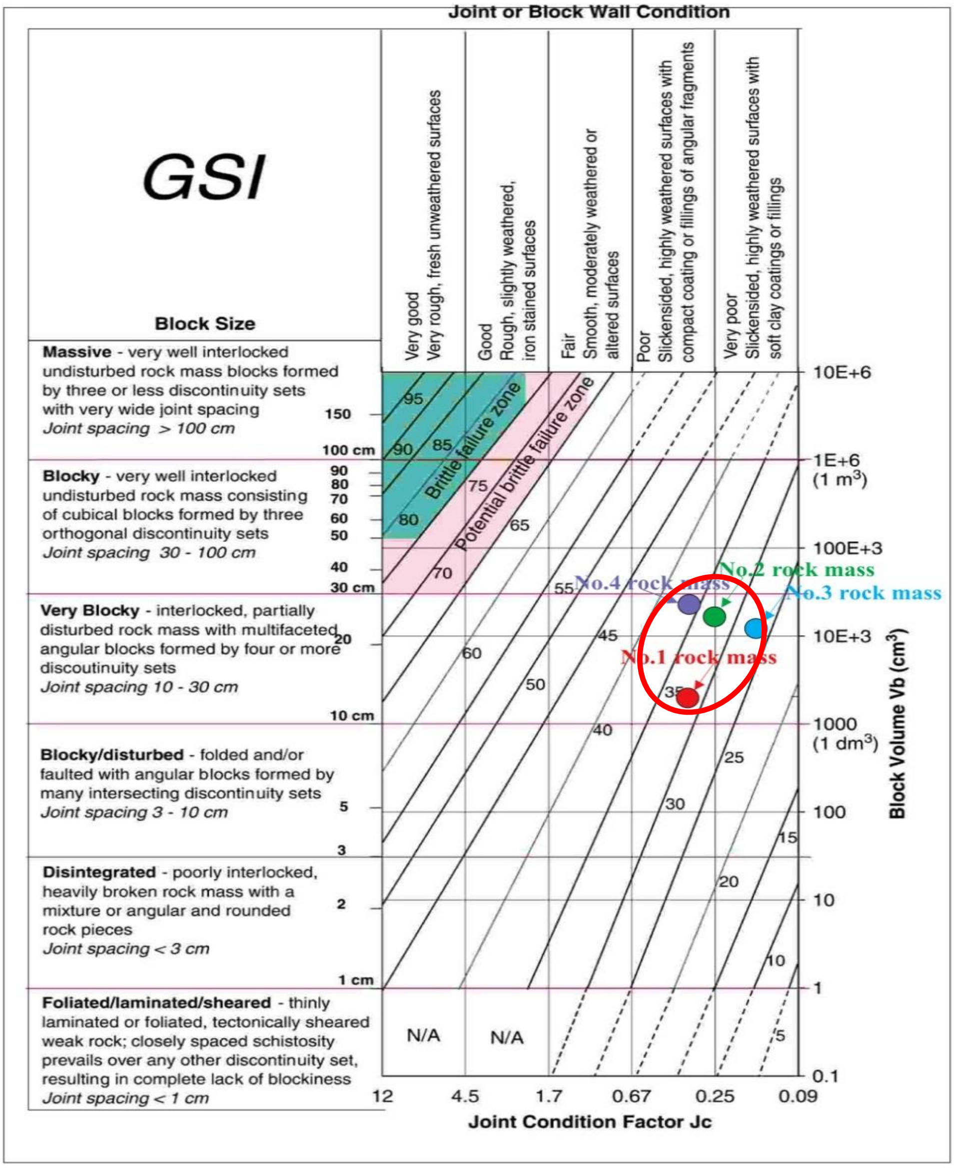


Figure 6. Figure showing the values of GSI in studied rock masses

3.3 Excavatability assessment

The most common excavation methods are based on two main mechanisms: mechanical and blasting. In a broader sense, mechanical excavation can be divided into two types with regard to the case of excavation in rock and rock masses: digging and ripping. Digging is defined as the process of cutting and displacement by blade or bucket, usually done by an excavator in softer ground. On the other hand, ripping is a process of breaking the harder ground by digging tines attached to a bulldozer. The blasting method has recently found a widespread application because the ripping method is very expensive and there are some physical limitation with this method (Khamehchiyan et al., 2013).

For the excavatability assessment of ultrabasic rock masses in the south of Mashhad, The RMi and GSI systems have been used and the type of excavatability has been specified in each studied rock mass.

3.3.1 Excavatability assessment of ultrabasic rock masses using the RMi classification system

To assess the excavatability using the RMi classification system, the chart in Fig.7 has been used after calculating the values of rock mass index and the average of block volume in each rock mass (Table 8) and the position of each rock mass has been marked on the chart. According to this diagram, the ultrabasic rock masses in this area can be easily excavated using ripper.

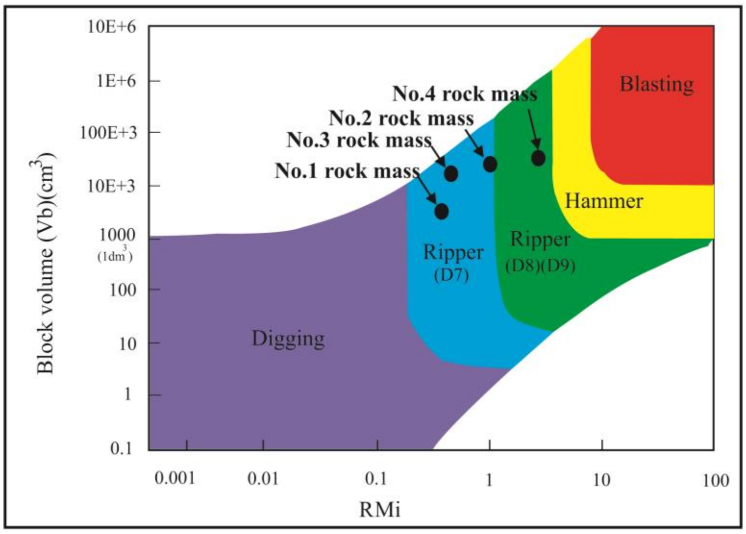


Figure 7. Image showing excavatability chart of studied ultrabasic rock masses (Khamehchiyan, 2013)

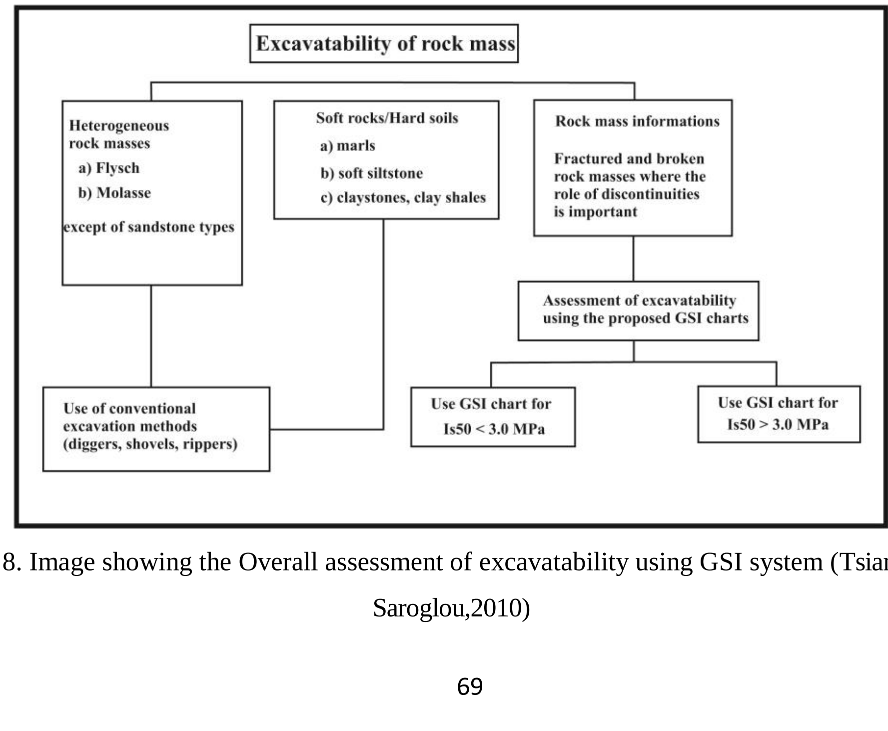


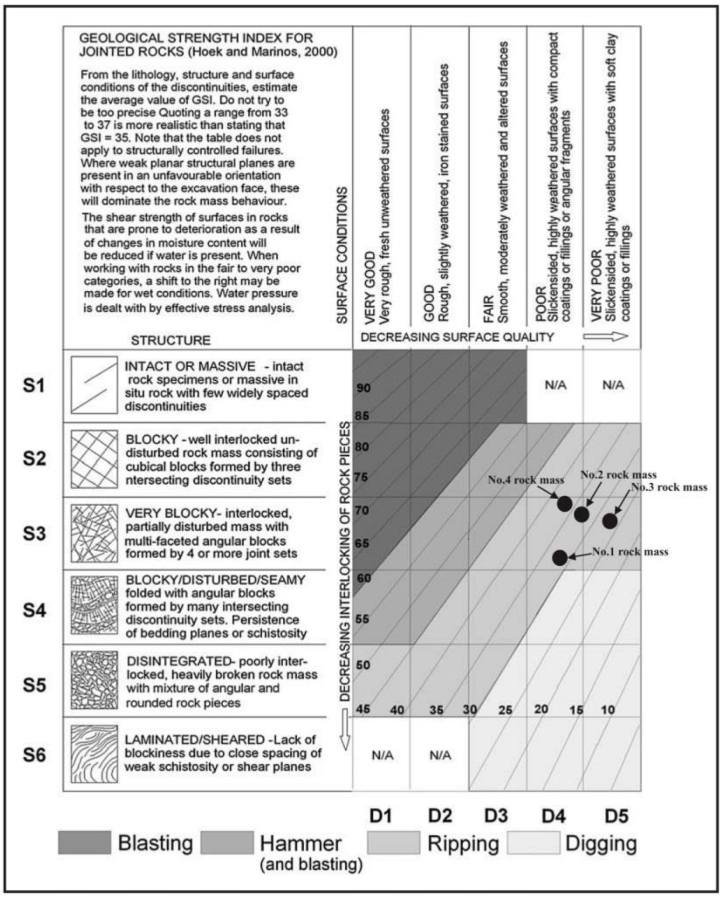
Figure 8. Image showing the Overall assessment of excavatability using GSI system (Tsiambaos & Saroglou,2010)

3.3.2 Excavatability assessment of ultrabasic rock masses using GSI classification system

In addition to the rock mass index classification system, the GSI system has been used for excavatability assessment. Fig.8 shows the assessment of excavatability of rock masses. Considering to the results of point load index (Is_{50}) test on the collected samples, the chart in Fig.9 has been used. Because the point load index for all samples is more than 3 MPa,. The position of each rock mass is shown on this chart.

Generally, the excavatability of ultrabasic rock masses in both GSI and RMi charts is within the ripper range. Considering the assessment of excavatability using the RMi system for No.4 rock mass which is stronger than other rock masses, D8 and D9 rippers and for No.1, 2 and 3 rock masses D7 ripper is recommended.

Figure 9. Image showing excavatability assessment of studied rock masses based on GSI classification system



4. Conclusion

This study is aimed at assessing the geotechnical properties and classification of ultrabasic rock masses based on GSI and RMi classification systems in south of Mashhad. Due to the rising prices of land in Mashhad, there is more construction in areas in which there was no construction previously due to geological problems. In recent years, with development of city and construction on ultrabasic rocks in the south of Mashhad there is a growing concern considering instability of slopes and trenches.

Based on the information collected in the field and laboratory, the excavatability and classification of ultrabasic rocks were investigated. The result of uniaxial compressive strength test for these rocks varies between 54 and 124 MPa and its mean value is about 78MPa. During the uniaxial test, the rock behavior is plastic-elastic-plastic. In this study, the weighted joint density method has been used as a relatively simple and easy method to measure the joint density and block volume. This method will lead to a decrease in the number of boreholes required for researches. According to the site investigation and classification of Jv (Palmstrom,2005), the degree of jointing of No.1 and No.2 rock masses is high (Jv = 10-30). It can be difficult to specify the block size, esp. the bock volume and the real shape of each individual blocks, using experimental and field methods in rock masses with irregular and discontinuous joints. Therefore, we can easily get better and more practical results using the weighted joint density method in a shorter time and with lower expenses, especially when individual blocks are not accessible in the surface of the ground and the only available parameters for specifying the block size are the joints.

With respect to the results of the two methods i.e. weighted joint density and direct measurement of the block size on 417 blocks in the area, it was found that the blocks in this area are relatively slightly long and flat. The mean of block volume in No.1, No. 2, No. 3 and No. 4 rock masses, is 0.0031, 0.024, 0.011, 0.034 m^3 respectively. The field investigation for determining RMi and GSI values indicated that The RMi values of ultrabasic rock masses vary between 0.47 and 2.79 and the GSI values are between 26 to 36. According to RMi classification system, the ultrabasic rock masses are considered as relatively strong to strong. Also, with respect to the classification of geological strength index, GSI, these rock masses are considered as very blocky and joint condition is described as poor to very poor.

The excavatability assessment charts proposed by Tsiambaos and Saroglon (2010) and Khamehchiyan (2013) were used for determining the excavatability of ultrabasic rocks. According to excavatability chart based on RMi, ripping is easy in No.1, No.2 and No.3 rock masses, due to weathering and surface condition. However the type of ripper in No.4 rock mass should be D8 or D9, because ripping is difficult in this rock mass. As a result of this, The excavatability assessment investigations based on GSI and RMi systems reveal that using ripper is the most appropriate excavation method.

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