Estimation of Rock Mass Deformability Based on Empirical Relations in GhezelOzan (Pirtaghi) Dam Site in Iran

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Abstract

Rock mass deformability is one of the most important parameters to design of underground structures and dam sites. The current methods to determine the rock mass deformability are measure by in situ tests and empirical relationships. In situ test are the best and accurate methods to determine deformability of rock mass, most notably contains of plate bearing, flat jack, dilatometer tests etc. Nevertheless, these in situ tests are difficult, time-consuming, expensive and sometimes even impossible. Many empirical methods have been developed to determine the rock mass deformability indirectly based on various parameters. This parameter presents by various researchers contains of strength and deformation modulus of intact rock (σ_c, E_r), rock mass rating (RMR), Q system, geological strength index (GSI) and longitudinal wave velocity (V_p) etc. This paper refers to some empirical methods were presented by some researchers. In this study, some of empirical methods for estimating rock mass deformability mentioned by some of researchers. In the following, according to the results of dilatometer in situ test carried out in GhezelOzan Dam site (Pirtaghi), the statistical correlation will be investigate between the modulus of rock mass deformability with basis of dilatometer in situ test results and the proposed empirical equation in the ghezelozan dam site. Finally, according to this study, the best empirical relationship will be propos to estimate the deformation modulus at the GhezelOzan Dam site.

Key words: Rock Mass, Deformability, Dilatometer, Empirical equation, Ghezelozan dam.

1. INTRODUCTION

Determination of geomechanical parameters is one of the important issues of engineering science in structures design. One of the most important geomechanical parameters is the deformation modulus of rock mass, which is used to design different structures like as rock foundations, underground spaces and dam foundation, bridges and high structures.The deformation modulus reflects the rock mass behavior under the influence of inductive stresses and since the rock mass contains various discontinuities such as joint surfaces, Bedding, Faults and shear zones; so accurate measurement of the rock mass deformation modulus is challengeable.The most important methods for determine the rock mass deformability include direct and indirect methods. The direct method involves performing laboratory tests on rock samples and performing in situ rock mass tests at the project site.Use of laboratory tests on rock samples to determine rock mass deformability is not sufficient, Therefore, in situ test should be performed in project site to determine the deformation modulus in the rock mass. There are various types of in situ tests including plate load test, pressure chamber, flat jack and dilatometer test. Estimation of deformation modulus by in-situ tests is time-consuming, expensive and often difficult be conducted.Indirect methods include the use of empirical equations based on empirical models and statistical methods such as regression which presented by different researchers. These models predict the rock mass deformation modulus at the least cost and time; therefore, an optimal model can forecast the deformation modulus with the least input parameter. The input parameters in the empirical models mainly include different parameters of rock mass classification systems such as rock quality designation (RQD), rock mass rating (RMR), Q-system, geological strength index (GSI) and etc. Rock mass parameter includes uniaxial compressive strength (σ_c) and its deformation modulus (E_t), seismic p-wave velocity of rock mass (V_p) and etc. Among the proposed classifications, the RMR method is a comprehensive classification and almost allproperties of discontinuities that affect the rock mass deformation modulus are contributed in this classification. Accordingly, several empirical models have been developed to determine the rock mass deformability based on the RMR classification parameter solely. However, since these models are developed based on case studies, the prediction of the deformation modulus using experimental models differs from its actual values. Therefore, depending on the geological and tectonic conditions, the nearest and most accurate model should be selected in each project.

In this paper, first, the relationship between deformation modulus values was performed by 31 dilatometer test in six exploratory boreholes with Rock mass classification such as rock mass rating (RMR) and Q-system and intact rock parameter contains of uniaxial compressive strength (σ_c) and its deformation modulus (E_t) values are investigated in the experimental sections. In the following, the relation between the definition and empirical models based on RMR and Q classification, uniaxial compressive strength (σ_c) and its deformation modulus (E_t)is investigated. The empirical models presented by different researchers, shown in Table 1. For evaluating the models and validating the developed model, Root Mean Square Error (RMSE), R-square (R^2) and Mean Absolute Percentage Error (MAPE) and MER were used. The GhezelOzen Dam is located about 50 kilometers to the east ofMiyane city and 45 kilometers to the southwest of Khalkhal city on the Ghezelozan River in Ardebil Province. The location of the dam site is shown in Figure 1.

Table 1- empirical equations used to determine the rock deformability (E_m) value in this study

Eq.No	Author	Used Parameters	Empirical Equation	Limitation
1	Barton(1980)	Q	$E_m = 25\log Q$	$Q > 1$
2	Serafim and Pereira(1983)	RMR	$E_m = 10^{(RMR-10)/40}$ (GPa)	$RMR > 50$
3	Bieniawski (1987)	RMR, E_t	$E_m = 2RMR - 100$ (GPa)	$RMR > 50$
4	Nicholson and Bieniawski (1990)	RMR, E_t	$\frac{E_m}{E_r} = \frac{0.0028RMR^2 + 0.9e^{RMR/22.82}}{100}$ (GPa)	
5	Mehrotra(1993)	RMR	$E_m = 10^{(RMR-20)/38}$(Gpa)	
6	Read et al(1999)	RMR	$E_m = 0.1(\frac{RMR}{10})^3$ (Gpa)	
7	Diederichs and Kaiser(1999)	RMR	$E_m = 7 + 3\sqrt{10}^{(RMR-44)/21}$ (Gpa)	
8	Hoek(2002)	RMR, σ_c	$E_m = \sqrt{\frac{\sigma_c}{100}} \times 10(\frac{RMR-10}{40})$ (Gpa)	
9	Barton(2002)	Q , σ_c	$E_m = 10(Q\frac{\sigma_c}{100})^{1/3}$	
10		Q	$E_m = 10^{(15\log Q+40)/40}$ (Gpa)	
11	Gokceglu et al(2003)	RMR	$E_m = 0.0736e^{0.0755RMR}$ (Gpa)	
12	Ramamurthy(2004)	RMR, E_t	$\frac{E_m}{E_r} = e^{(RMR-100)/17.4}$ (Gpa)	
13	Galera et al.(2005)	RMR	$E_m = 0.0876 + 1.056(RMR-50) + 0.015(RMR-50)^2$(Gpa)	$RMR > 50$
14			$E_m = \exp(RMR-10)/18$ (Gpa)	
15	Chun et al.(2009)	RMR	$E_m = 1.3326\exp(0.0364RMR)$ (Gpa)	
16	Mohammadi and Rahman nejad(2009)	RMR	$E_m = 0.0003RMR^3 - 0.0193RMR^2 + 0.3157RMR + 3.4064$ (Gpa)	
17	Shen et al(2012)	RMR	$E_m = 110e^{-(\frac{RMR-110}{37})^2}$ (Gpa)	
18		RMR, E_t	$E_m = 1.14E_ie^{-(\frac{RMR-116}{41})^2}$ (Gpa)	
19	Khabbazi et al.(2013)	RMR	$E_m = 9 \times 10^{-7}RMR^{3.868}$ (Gpa)	
20	Nejati et al(2014)	RMR	$E_m = 0.1627RMR - 5.17$ (Gpa)	$RMR > 30$
21	Kavur(2015)	RMR	$E_m = 4^{(RMR-20)/20}$ (Gpa)	
22	Alemdag et al.(2015)	RMR	$E_m = 0.058e^{0.0785RMR}$ (Gpa)	

2. THE GEOLOGY OF STUDY AREA

The study area is located in northwestern of Iran and with basis of geological classification of iran is mainly located in a part of the geological unit that nemedAzarbaijan zone. The rock mass is composed of Eocene and Oligocene volcanic rocks at the GhezelOzen Dam site. Geological map of dam siteis shown in figure 2.

These rocks include tuff, obsidian, andesitic tuff units, brecciated tuff with Eocene age and andesite, rhyolite, basalt and andesite-basalt with Oligocene age. The Eocene pyroclastic and tuff units Boundary on the dam axis investigated in approximately 30-40 meter deep in the dam foundation rock. The Eocene pyroclastic and tuffit units boundary with Oligocene rock unite are located in the dam axis is approximately 30-40 meter deep. The bedrock has less than 35 meter depth generated by andesitic and rhyolite rocks with Oligocene age and in the lower part of them contains of andesite, tuffit andesitic rocks, obsidian and tuff with Eocene age.

Figure 1. Location of GhezelOzen (Pirtaghi) Dam site in Northern Iran

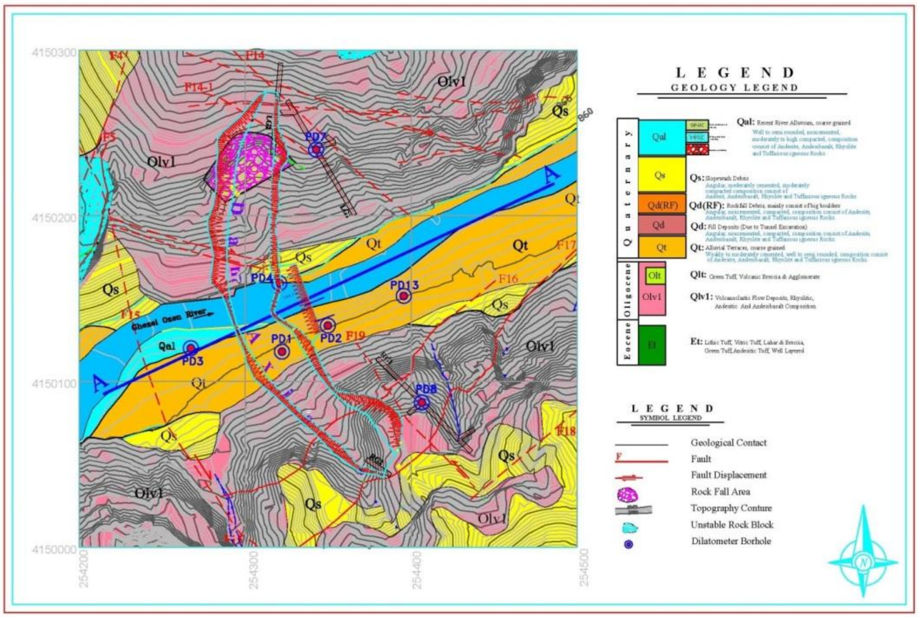

Figure 2. Geological map of the GhezelOzen(pirtaghi) Dam site and dilatometer boreholes location

3. INTACT ROCK PROPERTIES

After excavating exploratory boreholes and performing dilatometer tests, several rock samples were taken for laboratory tests. The most important laboratory test including uniaxial compressive strength (UCS) and intact rock deformability (E_t) have been carried out in dry and saturated conditions. The results are shown in table 2.

Table 2- Summary of test section intact rock properties

BH.No	Rock Unite	Parameters	Dry Condition			Saturated Condition		
			Min.	Max.	Av.	Min.	Max.	Av.
PD1	ANDESITE	UCS(Mpa)	219	219	219	197	197	197
		E(Gpa)	50	50	50	42	42	42
PD3	ANDESITE	UCS(Mpa)	183	183	183	176	176	176
		E(Gpa)	55	55	55	49	49	49
PD4	ANDESITE & Tuff	UCS(Mpa)	89	182	135	68	171	119
		E(Gpa)	25	41	33	20	39	29.5
PD7	ANDESITE & TUFFIT ANDESITE	UCS(Mpa)	97	243	233	76	238	194
		E(Gpa)	35	55	45	35	52	42
PD8	ANDESITE	UCS(Mpa)	158	247	198	149	179	164
		E(Gpa)	34	52	41	32	42	36
PD13	ANDESITE & TUFFIT ANDESITE & Tuff	UCS(Mpa)	197	45	93	126	126	126
		E(Gpa)	14	25	22	-	-	-

4. DILATOMETER TEST

The Dilatometer test is performed in exploratory boreholes under internal pressure to determine the deformation characteristics of rock mass. In this test, the surrounding rock mass borehole is affected by the flexible membrane via fluid force at the test section. The strain created in the rock mass in the borehole wall will be proportional to the amount of rock mass deformability. As noted, dilatometer tests were performed at the GhezelOzen Dam site in six exploratory boreholes in dam foundation and exploration galleries in abutment. The locations of these boreholes are shown in the geological map of the dam site in Figure 2. The dilatometer device that used for performing test was 96 mm in diameter and 1.77m in length and equipped with three deformation sensors. Figure 3 shows a dilatometer test in the PD1 borehole.

The rock mass deformation modulus(E_r) determined with ISRM standard according to following relation:

$$E_r = (1 + \vartheta) \times \frac{\Delta P}{\Delta D} \times D(1)$$

Where Er is the modulus of deformation (Gpa), ν is Poisson's ratio, ΔP is pressure changes applied to rock mass (bar), ΔD is borehole diameter changes and D is the borehole diameter. The dilatometer tests were performed on the boreholes is shown in the table 4.

Figure 3. Dilatometer test performance at PD1 borehole in river bed atGhezelOzen(Pirtaghi) Dam site

5. ROCK MASS CLASSIFICATION

Numerous rock mass classifications have been proposed for use in engineering design by various researchers. The most important of these include rock quality designation (RQD), rock mass rating (RMR), Q-system, geological strength index (GSI) and etc. In this study, since the results of dilatometer test in exploratory boreholes have been used, rock mass rating (RMR) and Q classification were performed in the test sections. The variation of the rock mass classification values and the deformation modulus measured in the exploratory boreholes are shows in table 3.

The changes between the RMR and Q classification are respect to the values of the rock mass deformation modulus measured in the test sections. The relationship between the mentioned classifications and the rock mass deformation is shown in Equations 2 and 3:

$$E = 35.16\mathrm{Ln}(RMR) - 13.594 \quad , \quad R^2 = 0.881(2)$$
$$E = -186.987\left(\frac{1}{Q}\right) + 3.563 \quad , \quad R^2 = 0.584(3)$$

Table 3- Variations of rock mass classification and deformation modulus values measured in exploratory boreholes

BH.No	Location	Rock Unite	Parameter	Min	Max	Av.
PD1	Dam Foundation	Andesite	RQD	100	-	100
			RMR-89	74	-	74
			Q	26.8	-	26.8
			E_r	20.70	-	20.70
PD3	Dam Foundation (Up Stream)	Andesite	RQD	96	100	98
			RMR-89	56	63	59
			Q	23.2	24.2	23.7
			E_r	21.6	28.2	44.8
PD4	Dam Foundation	Andesite & Tuff	RQD	95	100	99
			RMR-89	60	72	67
			Q	24.8	11.7	17.8
			E_r	8.90	22.30	16.04
PD7	LG1	Andesite & Tuffit Andesite	RQD	84	100	95
			RMR-89	62	83	71
			Q	13.4	25.2	18
			E_r	14.00	20.50	17.90
PD8	RG1	Andesite	RQD	77	100	92
			RMR-89	63	75	69
			Q	10.6	26.4	20.6
			E_r	18.10	25.70	21.10
PD13	Dam Foundation	Andesite & Tuffit Andesite & Tuff	RQD	97	100	99
			RMR-89	64	74	69
			Q	11.5	27.5	16.6
			E_r	6.94	17.90	11.68

According to the analysis performed, the relationship based on RMR classification has the highest regression coefficient compared to Q classification. The variations of the rock mass rating (RMR) and Q classification values and the rock deformability at the test sections are shown in figure 4.

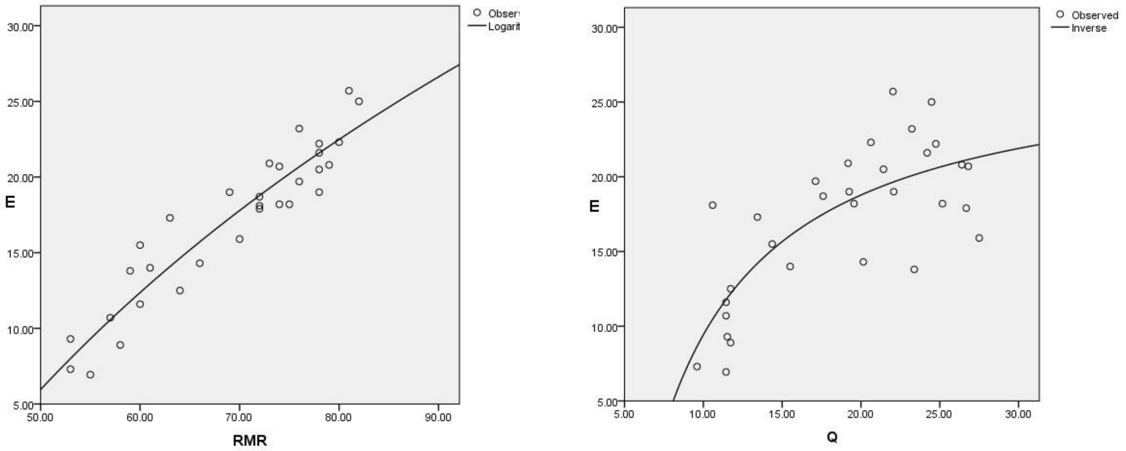

Figure 4. Relation between the measured deformation modulus (E_r) and the rock mass classification at the GhezelOzen dam site

6. PREDICTION OF ROCK MASS DEFORMABILITY BY EMPIRICAL METHODS.

According to the calculated RMR and Q values in the test sections, The empirical deformation modulus are represented by 22 equations of different researchers are shown in Figures 5 and 6. The study shows that the empirical relationships in basis the RMR classification have the highest correlation with the results of in situ test in the GhezelOzen dam site. Accordingly, the Chun et al (2009) and Hoek (2002) equations shows the highest correlation with the calculated deformation modulus values and Gokceglu et al (2003) and Alemdag et al (2015) equations also show good correlation with the results on the GhezelOzan dam site. Where there is a discrepancy between the deformation moduluscalculated with the empirical equations and in situ test values, with increase of RMR values the range of changes will be increase. This may be due to different tectonic, lithological and stratigraphic conditions. These factors may cause incompatibility of the presented empirical equation with different sites.

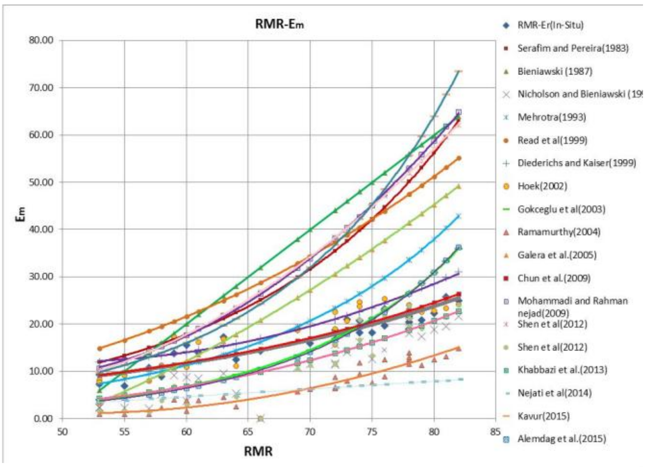

Figure 5. RelationbetweenEmpirical Equation Based on RMR Classification and Deformation Modulus Values Measured in Exploratory Boreholes by Dilatometer Test

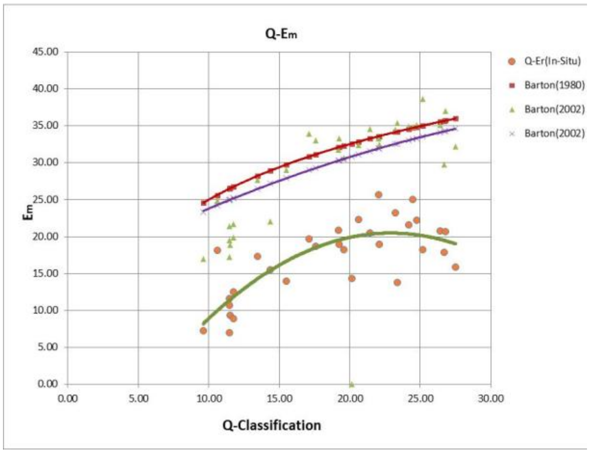

Figure 6. Relation between the empirical equations Based on Q classification and the deformation modulus values measured in the Test Sections

7. EVALUATION OF EMPIRICAL MODELS IN PREDICTION OF ROCK MASS DEFORMABILITY.

Statistical equations have been used to evaluate validating the developed model and to select the models that have the best accuracy in the rock mass deformability estimation.Statistical equation is used includes Root Mean Square Error R-square (R^2), (RMSE), Mean absolute percentage error (MARPE) and MER values which are mentioned in the equations 4 to 7.

$$R = \frac{n(\sum_{i=1}^{n} E_r.E_m)-(\sum_{i=1}^{n} E_r)(\sum_{i=1}^{n} E_m)}{\sqrt{[n\sum_{i=1}^{n} E_r{}^2-(\sum_{i=1}^{n} E_r)^2][n\sum_{i=1}^{n} E_m{}^2-(\sum_{i=1}^{n} E_m)^2]}} (4)$$

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(E_r - E_m)^2} (5)$$

$$\mathrm{MARPE} = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{E_r - E_m}{E_r}\right| (6) \mathrm{MER} = \frac{\sum_{i=1}^{n} E_m}{\sum_{i=1}^{n} E_r} (7)$$

In the above relations E_r is the deformation modulus measured by dilatometer test in expletory boreholes, E_m is the deformation modulus calculated by the empirical equations and n is the number of in situ test that in this study there were 31 tests.

Table 4: Correlation of Experimental Relationships with the Deformation Modulus Values Measured at GhezelOzen Dam Site.

Eq.No.	Empirical Equations	R	R^2	RMSE	MAPE	MER
1	Barton(1980)	0.745	0.554	14.63	2.69	1.83
2	Serafim and Pereira(1983)	0.918	0.842	20.24	3.21	2.00
3	Bieniawski (1987)	0.939	0.881	25.12	4.03	2.25
4	Nicholson and Bieniawski (1990)	0.898	0.806	5.86	0.94	0.71
5	Mehrotra(1993)	0.916	0.839	8.37	1.03	1.32
6	Read et al(1999)	0.931	0.867	19.39	3.34	2.04
7	Diederichs and Kaiser(1999)	0.919	0.845	3.98	0.61	1.19
8	Barton(2002)	0.704	0.496	12.80	2.15	1.66
9	Barton(2002)	0.733	0.537	13.09	2.39	1.74
10	Hoek(2002)	0.828	0.686	3.69	0.09	1.03
11	Gokceglu et al(2003)	0.906	0.820	5.38	0.07	0.98
12	Ramamurthy(2004)	0.902	0.814	10.19	1.88	0.42
13	Galera et al.(2005)	0.923	0.852	15.20	2.36	1.73
14	Galera et al.(2005)	0.935	0.874	13.88	1.89	1.59
15	Chun et al.(2009)	0.929	0.863	1.97	0.06	1.02
16	Mohammadi and Rahman nejad(2009)	0.924	0.853	22.19	3.50	2.08
17	Shen et al(2012)	0.927	0.860	21.60	3.43	2.06
18	Shen et al(2012)	0.694	0.482	8.35	1.13	0.65
19	Khabbazi et al.(2013)	0.926	0.857	4.74	0.80	0.75
20	Nejati et al(2014)	0.939	0.881	11.59	2.08	0.36
21	Kavur(2015)	0.910	0.828	23.81	3.56	2.10
22	Alemdag et al.(2015)	0.903	0.816	5.56	0.12	0.96

To evaluate empirical models with deformation modulus values obtained from in situ tests whatever the RMSE and MAPE values should be lower and closer to zero, and the MER value to closer one, the results will be more consistent. The correlation of the empirical correlation based on the changes of R^2, RMSE, MAPE and MER with the rock mass deformability values at the GhezelOzan dam site shows in table 4. According to the results, the maximum correlation coefficient (R^2) was 0.88, but it should be noted that in some models, despite the high correlation coefficient (R^2), no correlation could be seen. Therefore, other parameter should be used in selecting empirical equation. The correlation of the empirical equation based on R^2, RMSE, MAPE and MER parameter are shown table 4. According to the above parameter, the relationships of No. 10, 11, 15 and 22 are high correlation with the results of the tests carried out on the dam site. Among the equation mentioned, the Chun et al (2009) equation considering all parameters have most consistent with the results of dilatometer tests in exploratory boreholes.

8. CONCLUSION

Rock Mass Deformation modulus is one of the most important parameters for analysis and design of structures in rock foundations. Due to in-situ tests needs the high cost and time consuming, determine the amount of rock mass deformability modulus indirectly is an important issue. In this paper, the relationship between in situ rock mass deformation modulus and rock mass rating (RMR) and Q-system are studies in exploratory boreholes of GhezelOzen dam site. The correlation between these classifications and in situ rock deformability is shown in equations 1 and 2 and Figures 6 and 7. The results show a correlation coefficient (R^2) of 0.58 between the Q-system values and 0.88 between the rock mass rating (RMR) and the in situ rock mass deformation modulus (E_r) values obtained from the dilatometer tests in exploratory boreholes.

Then, different empirical equations based on rock mass rating (RMR) and Q-system classification and geomechanical parameters of intact rock (E_t,σ_c) were investigated to determine the rock mass deformation modulus (E_m). Adaptation and correlation between the deformation modulus (E_r) determined by in situ test are investigate by its value in different empirical equation (Table 1) based on R^2 and the RMSE, MAPE and ER parameter. Maximum correlation coefficient (R^2) for Q classification is 0.55 and for RMR classification is 0.88. According to the correlation coefficient (R^2) values and other statistical parameters presented in this study, the empirical deformation modulus (E_m) determined based on the empirical equation based on rock mass rating (RMR) have a higher accuracy with the deformation modulus values determined with the dilatometer test in exploratory boreholes. Based on research done and considering all statistical parameter (R^2, RMSE, MAPE, and ER), the equation 15 (Chun et al, 2009), equation 10 (Hoek, 2002) and equation 11 (Gokceglu et al. 2003) have a higher correlation and accuracy for determining the amount of rock mass deformability at the GhezelOzen dam site.

9. ACKNOWLEDGMENT

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