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The analysis of engineering properties of the rock mass of Ghordanloo dam site, NE Iran

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***Abstract* - Ghordanloo dam on the Atrak river, is located about 36 km of northwest of Bojnord city, in the northeast of Iran. This dam currently is at the final stage of the study phase and has been designed as an earth dam with clay core. In this study, engineering geological properties of the rock mass at the dam were investigated in order to evaluate engineering geology properties of the rock masses. The lithology of the rock masses consist of Tirgan formation limestone with lower Cretaceous age that outcrops on both abutments. The thickness of alluvial deposit at the dam axis is 61 meters and it consists of river bend of fine grained and coarse grained materials.**

The rock mass investigation of the site is performed in both filed geology and laboratory studies. Field study includes the analysis of discontinuity system, boreholes exploration, performing permeability test and sample extraction for laboratory studies. The laboratory study consists of performing uniaxial compression test, Young's modulus, unit weight, water content and porosity. Based on the obtained results, the permeability of the rock mass is high in the both abutments. According to the results of Lugeon test and borehole log, the relation between Lugeon and RQD were performed. The obtained results showed that there is no meaningful relationship between Lugeon unit and the RQD parameter. Finally, the rock mass of the dam site was classified in accordance with RMR classification.

***Keywords* - RQD, Lugeon, dam site investigation, rock mass.**

I. Introduction

Engineering geology studies plays a key role in dam site studies. In recent years, the evaluation of the dam site properties was the main attention for many researchers (e.g. Lashkaripour and Ghafoori, 2002; Romanov et al., 2003; Ghobadi et al., 2005; Kocbay and Kilic, 2006; Unal et al., 2007; Ghafoori et al., 2011; Uromeihy and Farrokhi, 2012). The quality of the rock mass is one of the most important geology characteristics influential in designing and building a dam. In general, the geological structures, discontinuities and degree of weathering are the most parameters that affect the rock mass engineering (Bell, 2007).

On the other hand, hydraulic conductivity of the rock mass is highly in relation with the discontinuity properties. Thus, one of the major problems in dam site studies is the correct evaluation of the relationship between the discontinuity properties and the hydrogeological behavior of the rock mass.

Water pressure test or Lugeon (Lugeon, 1933) is one of most common tests in the evaluation of the rock mass permeability (Nonveiller, 1989; Houlsby, 1990; Ewert, 1997). On the other hand, using the RQD index (Deere, 1963) and a comparison of that with the Lugeon test results is one of common methods for evaluating the hydrogeological behavior of test section behaviour under Lugeon test. But not always there is a direct relationship between the two parameters. Sometimes, it has been observed that a region with a low degree of jointing (high RQD) shows high absorption, and sometimes the opposed situation is possible (Foyo et al., 2005). The reason behind this phenomenon can be some problems with the RQD parameter and some researchers pointed this out (Hudson and Priest, 1983; Houlsby, 1990; Ewert, 1997; Choi and Park, 2004; Palmstrom, 2005; Bell, 2007). Bell, 2007 stated if the joint spacing is more than 10 cm, based on RQD parameter there would be no information about the persistence and the filling of the joints. Palmstrom reported that this parameter is more affected by the borehole direction rather than the joint spacing or frequency (Palmstrom, 2005). On the other hand, the hydro-geological conductivity of the rock mass has a strong connection with the discontinuities properties, such as opening, filling, orientation, persistence and the connections between the discontinuities (Sahimi, 1995; Ewert, 1997; Hamm et al., 2007). Therefore, in this study, the engineering geological analyses are performed on the rock mass of the dam site, in order to attain a righteous evaluation of the engineering properties of the rock mass of this site.

The Ghordanloo dam is located in the northwest heights of Bojnurd in northeast of Iran in the geographical coordinate of N 37° 37′ and E 57° 19′.

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The dam will be implemented on the Atrack River as an earth dam with clay core. The dam height is 46 meters and the crest length is 236 meters with a reservoir of 220 million cubic meters.

This dam is going to be at the level of 850 masl and is supposed to provide the drinking water of Bojnourd city and also the required water for the industrial and agricultural use in downstream (Toossab Co, 2009).

II. Geology of Study Area

Among the parameters influential in the dam design, the geological parameters play a major role in designing and constructing a dam. Not only do they control the character of formations, but they also govern the material available for construction. There are several projects that faced troubles due to the lack of thorough knowledge of the foundation properties and caused an increase in the cost of construction and treatment (Ichikawa, 1999).

The studies on the geology of the region are done by Afshar-Harb (1984) and the Toossab Engineering Company (2009). From the stratigraphy point of view, Tirgan Formation, Sarchashmah Formation and Quaternary Deposits can be named among the existing formations in the construction site (Fig. 1).

A. Tirgan Formation (KTr):

This formation is composed of oolitic limestone with fine layers of marly limestone and marl. Because of the high roughness of the layers and especially the density and hardness, the limestone can be easily identified from the shale deposits and Sarcheshmah marly. This formation has an age between Barremian and Aptian and covers the most of the abutments, the initial part of the reservoir and the bed rock of this dam site.

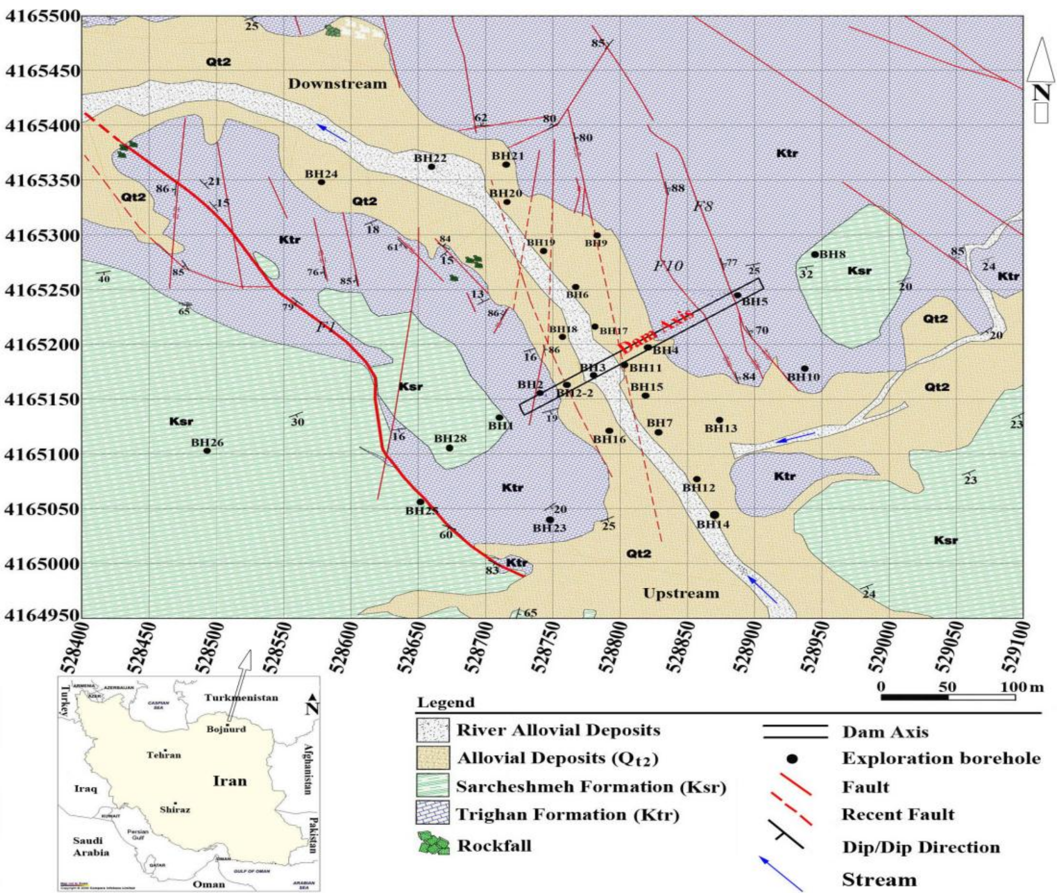

Fig. 1 The geological map of the dam site

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, Volume 2, Issue 9, September 2012)

B. Sarcheshmah Formation (KSr):

This formation from the age of Aptian is composed of gray-dark gray marly and shale with lime layers, which are highly weathered and fragmented. This formation covers the upper part of the left abutment (higher than the dam crest) and has outcrops up to the middle part of the reservoir and also the bed rock up to the middle of the reservoir. This formation is lies on the Tirgan Formation in a conformable strata form.

C. Quaternary Deposits (Qt):

These sediments are in the location of the abutment, and consist of riverbed alluvial deposit, alluvial terrace and the talus material. Riverbed alluvial deposits are extended at the river bed. These sediments are usually fine grained and coarse grained up to cobble is hardly observed. The sediments of alluvial terrace are extended around the dam site at the river bank along the valley. These materials are usually fine grained in the central part of the strait and gradually become coarser closer to the abutments.

The dam site is located at an asymmetric U-shape valley with the ration of 4.61 between the width and height (W/H). The right abutment dip is between 27° and 40° and the left abutment dip is between 50° and 70° (54° in average). From the tectonics point of view, the studied region is located in an active tectonic. At the construction site, the tectonic force highly affects the region under study and cause the appearance of a joint and some fractures at the site. Due to the performance of theses tectonic forces, a collection of faults with various dips and strikes are made. Among these faults, faults F_1, F_8, and F_{10} are more important (Fig. 1). These faults have caused the rock mass to be crushed at the dam site. On the other hand, since the strike of these faults is almost vertically set on the dam axis, they can cause seepage from the dam abutment and foundation.

III. ENGINEERING GEOLOGY OF DAM SITE

A. Discontinuities

The mechanical behavior of the rock is highly affected by the discontinuities systems properties. Discontinuities can cause the strength to be lessened, and cause permeability and plasticity to increase (Bell, 2007; Goodman, 1989). Therefore, the field study and the precise analysis of the conditions and properties of discontinuities and fractures are among the most important issues in geotechnical studies of the dam construction. In this study, based on the method suggested by ISRM 1981 for the field studies of the joint and fractures in the region, 652 discontinuities were analyzed according to scanline method.

In table 2 the results of discontinuity systems properties are given. And then the discontinuity systems were statistically analyzed (Fig. 2). Based on the results, there are 2 joint sets with high dip were identified with a low dipped bedding at the abutments (Table 1). In addition to the major discontinuity systems, a few minor discontinuities were identified at the dam site. The strike of joint set 1 in both abutments is almost completely vertical at the dam axis (N057). The strike of joint set 2 is almost in parallel with the dam site. The bedding dip of both abutments is upstream.

Table I
The discontinuity systems properties at the dam site

Location	Discontinuity	Dip	Dip Direction
Left Abutment	Joint Set 1 (J1L)	82	242
	Joint Set 2 (J2L)	77	316
	Bedding (bL)	15	150
Right Abutment	Joint set 1 (J1R)	84	246
	Joint set 2 (J2R)	80	314
	Bedding (bR)	18	153

B. Rock Mass Quality Evaluation

In order to evaluate the engineering geological properties of the dam site, 27 the borehole was drilled at the maximum depth of 120 meters and in sum, 349 in-situ permeability tests were performed. In Fig. 3 the locations of the drilled boreholes are shown at the dam axis. The sum of all the boreholes is 1720.70 meters, from which 679.30 meters are drilled in alluvial deposits and 104.40 meters at the rock mass (Table 3).

The Lugeon, Lofran, CPT, SPT and vane shear test were performed at the rock mass and alluvial deposits.

According to the drilling results, the designation rock quality (RQD) was evaluated for the riverbed, right and left abutments and the results were provided in table 4. Regarding the fact that this site is highly affected by tectonic and fault activities, the thickness of the weathered zone at this site is variable. The least thickness of weathered zone was less than 1 meter and was for the right abutment and the most thickness was around 80 meters for the left abutment. The reason behind the thickness of the weathered zone of the left abutment is the faults activities at this abutment.

According to the Lugeon test results, there is not a constant trend of decreasing in the Lugeon with increasing depth. The relationship between RQD and Lugeon parameters were performed.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, Volume 2, Issue 9, September 2012)

In Fig. 4 the Lugeon charts and RQD parameters are given for some of the boreholes. Borehole BH-1 has a high permeability and 72% of the sections had a Lugeon number more than 30. At the depth of 3 to 24 meters, Lugeon unit is high. The reason of the increase of Lugeon unit at this depth is in relation with dilation behavior at the joints due to the pressure of the test. From 65 meters deep to the end of the borehole, it is observed that despite the increase of RQD, the Lugeon unit does not fall and even four times it was impossible to perform the test due to high absorbance.

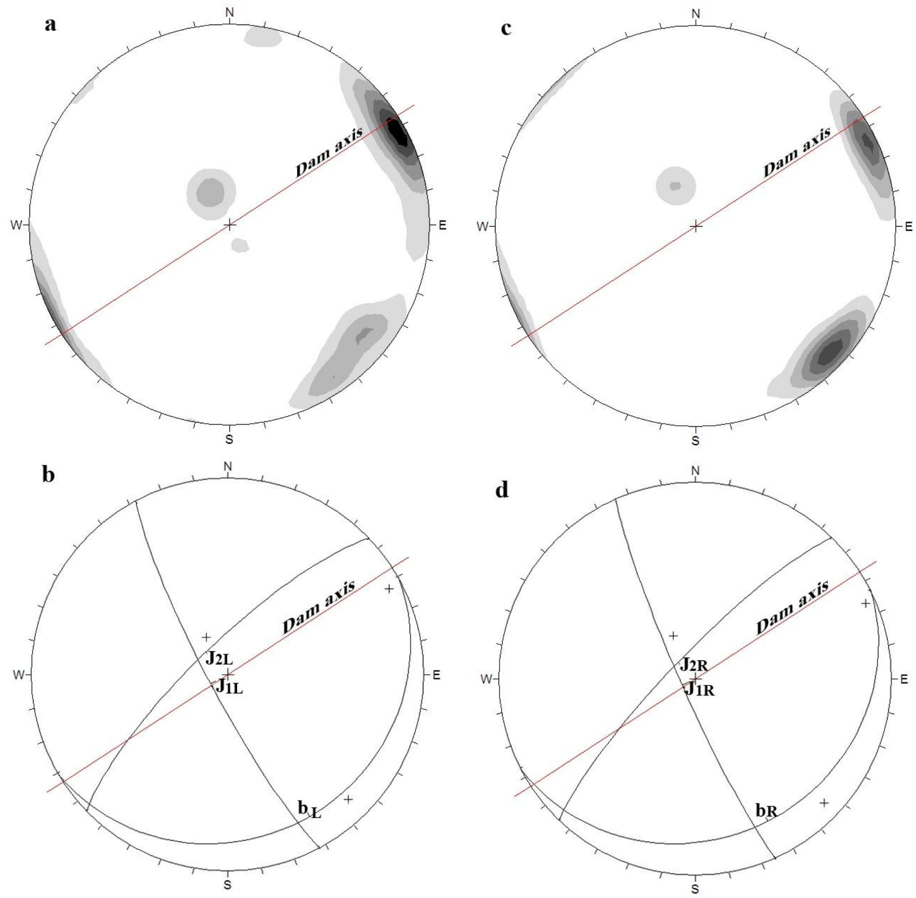

Fig. 2 The stereographic images from the studies of the discontinuities at left abutment (a, b) and right abutment (c, d)

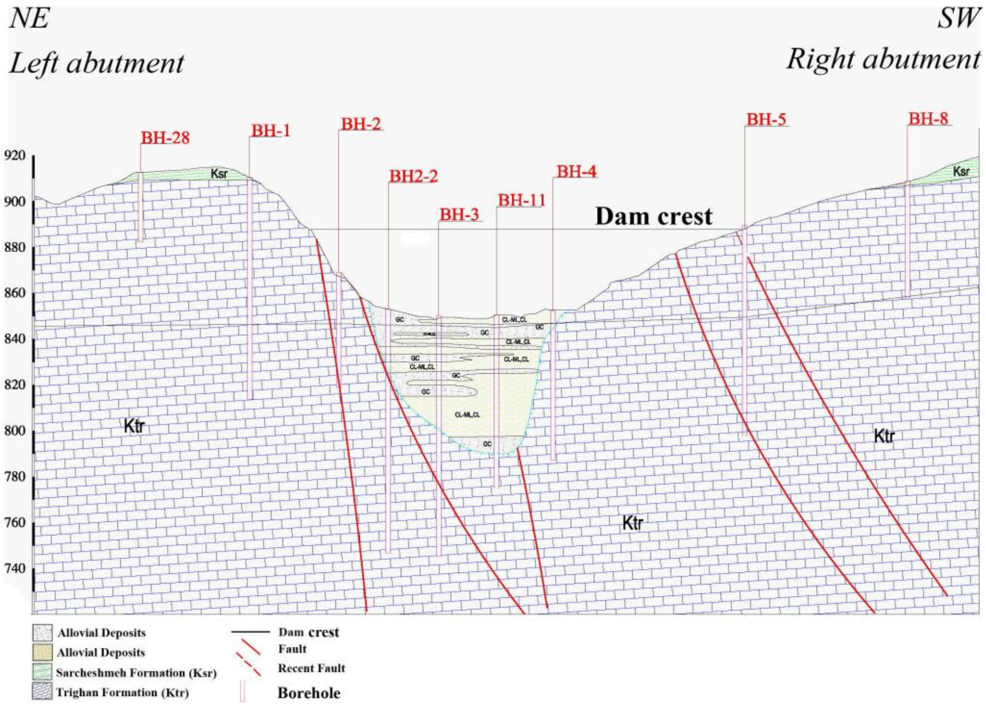

Fig. 3. Cross section of the dam axis

International Journal of Emerging Technology and Advanced Engineering
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Table II
The engineering properties of the discontinuities at the dam site

	Location		Right Abutment		Left Abutment	
	joint Systems		J1 R	J2 R	J1L	J2L
Property of Discontinuity	Spacing (m) %	2.00>	-	-	3.08	1.54
		0.60-2	30.18	24.80	36.44	37.38
		0.20-0.60	42.72	31.01	42.07	39.84
		0.06-0.20	23.26	33.87	18.41	15.91
		0.060<	3.84	10.32	-	5.33
	Persistence (m) %	20>	0.83	-	3.67	2.01
		10-20	18.00	5.96	12.92	6.58
		3-10	30.68	22.18	40.26	21.05
		1-3	29.33	39.08	29.48	49.31
		1<	21.16	32.78	13.67	21.05
	Filling %	Clay	28.81	36.85	31.91	32.82
		Calcite	25.84	19.16	21.32	28.12
		Goge	34.70	29.21	35.46	25.31
		Clean	10.65	14.78	11.40	13.75
	Aperture (mm) %	0.10>	4.38	6.29	1.02	-
		0.10-0.50	11.26	5.35	13.34	15.15
		0.50-2.50	15.60	20.94	17.05	22.42
		2.50-10	32.57	37.58	28.41	36.66
		10>	36.19	29.57	40.18	25.77
	Weathering	Slightly Weathered	23.80	36.97	38.88	30.02
		Moderately Weathered	54.40	49.70	34.64	43.90
		Highly Weathered	17.00	9.10	12.96	15.45
		Fresh	4.80	4.23	13.52	10.63
	JRC	8-10	3.45	3.40	-	4.22
		10-12	21.55	25.58	24.00	18.17
		12-14	35.69	40.69	39.42	32.25
		14-16	32.40	26.13	30.32	39.73
		16-18	6.06	4.20	6.26	5.63
		18-20	0.86	-	-	-

International Journal of Emerging Technology and Advanced Engineering
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Table III
Borehole Description

Boreholes	Depth of Drilling (m)			In-situ Permeability Test		Borehole Location
	Total	*Alluvial*	*Rock mass*	*Lofran*	*Lugeon*	
BH 1	96.80	0	96.80	-	18	Left Abutment
BH 2	50	-	50	-	9	Left Abutment
BH 2-2	106.20	28	78.20	-	14	Left Abutment
BH 3	104.6	49.20	55.40	14	10	Riverbed
BH 4	65.15	8	57.15	3	11	Riverbed
BH 5	91.40	-	91.40	-	17	Right Abutment
BH 6	70.20	56.50	13.70	16	3	Riverbed (Downstream)
BH 7	73.90	50	23.90	16	4	Riverbed (Upstream)
BH 8	50.80	-	50.80	-	10	Right Abutment
BH 9	47.75	37.1	10.65	12	2	Riverbed (Downstream)
BH 10	31.10	-	31.10	-	6	Right Abutment
BH 11	75.4	60.50	14.90	19	1	Riverbed
BH 15	72.50	55	17.50	16	2	Riverbed (Upstream)
BH 16	67	39	28	11	5	Riverbed (Upstream)
BH 20	85	63	22	19	4	Riverbed (Downstream)
BH 21	40	9	31	2	6	Riverbed (Downstream)
BH 22	85	59	26	18	5	Riverbed (Downstream)
BH 23	55	-	55	0	10	Left abutment (Diversion tunnel)
BH 24	50	22	28	4	5	Left abutment (Diversion tunnel)
BH 24a	75	-	75	-	14	Right abutment (Grouting Site)
BH 24b	65	-	65	-	13	Right abutment (Grouting Site)
BH 25	60	-	60	-	10	Left abutment (Over fall tunnel)
BH 26	120	-	120	-	13	Left abutment (Over fall tunnel)
BH 27	53	43	10	16	1	Left abutment (Over fall tunnel)
BH 28	30	-	30	-	4	Left Abutment

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International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, Volume 2, Issue 9, September 2012)

Table IV
Results of the Rock Quality Designation and Lugeon test for the dug boreholes at the dam site

Location	Boreholes	Parameter Geotechnical					
		Lugeon			RQD		
		Average	Minimum	Maximum	Average	Minimum	Maximum
Right Abutment	BH5	34	4	112	56	0	93
	BH8	71	5	266	64	0	100
	BH10	165	63	392	65	26	100
Riverbed	BH3	42	1<	306	51	0	100
	BH4	44	0	131	55	0	100
	BH6	27	11	38	44	0	95
	BH7	32	23	49	31	0	100
	BH9	16	11	22	30	10	51
	BH11	33	33	33	61	0	86
	BH15	26	12	40	85	81	89
	BH16	10	1	23	74	0	100
	BH20	21	10	39	67	0	100
	BH21	28.75	21	42	60.33	40	80.4
	BH22	17.4	1	57	76.06	27	98.80
Left Abutment	BH1	56	10	135	49	0	93
	BH2	65	27	111	32	0	88
	BH2-2	17	4	28	15	0	77
	BH23	56	1	169	30	0	100
	BH24	5.50	4	7	30	0	75
	BH25	23.25	7	46	41.64	18	59.4
	BH26	18.8	1	82	42.09	4	90
	BH27	4	4	4	0	0	0

In borehole BH-2 in general, with the increase of the depth, RQD unit becomes smaller. Despite the fact that the smaller RQD unit reports the lower quality of the rock mass, it is observed that as the depth increases, the Lugeon unit decreases. In borehole BH-2-2, 85% of the sections had a Lugeon unit between 10 and 30. Also 77% of the borehole length had an RQD unit less than 25%. The reason behind the crush of the rock mass in this borehole can be the faults activities. The reason of high Lugeon unit in this borehole is related to the wide opening of joints and the rock mass crush.

In borehole BH-3 from the depth of 82 meters on, in average with the increase of the depth, the RQD unit increases and Lugeon unit decreases. In this borehole, it is observed that from 82 to 97 meters deep, Lugeon unit increases, despite an RQD bigger than 72% and that stands for the rock mass quality.

In borehole BH-4, 55% of the examined sections had a Lugeon unit higher than 30 Lugeons. In this borehole, it was observed that from 20 to 60 meters deep the Lugeon unit and RQD decrease as the depth increases.

In Borehole BH-5, around 76% of the borehole length had an RQD higher than 50%, in this borehole, the Lugeon unit decreases as the depth increases. From 12 to 27 meters deep, despite the increase in RQD unit, Lugeon unit increases, as well at two sections (sections of 12 to 17 meters deep and 22 to 27 meters deep). The reason behind the increase in Lugeon unit is dilation behavior at these two sections. From 72 meters deep to the end of the borehole the Lugeon unit increases, which is because of the effect of fault F8 activity on this section of the borehole. In borehole BH-8 from 16 to 31 meters deep, the Lugeon unit increases dramatically. It is observed that at the depth of 16 to 21 meters, despite the fact that RQD unit is big (RQD 78%), absorb is higher than 10 Lugeons. The reason of high Lugeon unit is related to the void filling of the soft filling materials of the joints.

In borehole BH-16 there is a direct relationship between Lugeon and RQD. As the depth increases RQD unit increases and the absorbance of the borehole decreases. This fact represents the increase in the rock mass quality.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, Volume 2, Issue 9, September 2012)

In borehole BH-20 there is no direct relationship between the Lugeon and RQD units. In borehole BH-23 as the depth increases, the Lugeon unit decreases.

In this borehole there is no direct and meaningful relationship between the Lugeon and RQD, either.

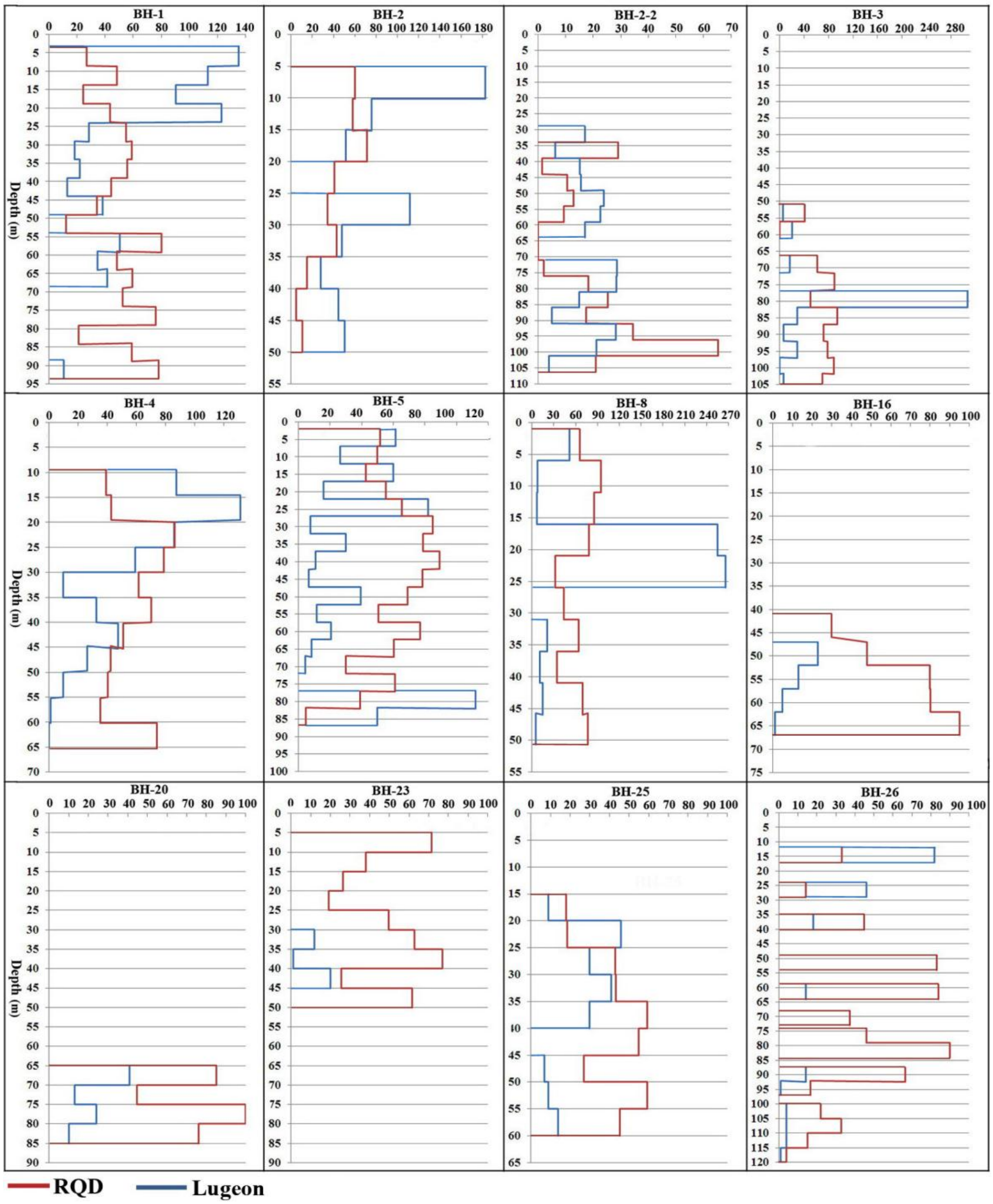

Fig. 4 The chart of Lugeon units and RQD of the boreholes

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International Journal of Emerging Technology and Advanced Engineering
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IV. Physical And Geo-Mechanical Characteristics Of The Rock Mass

To evaluate the physical and geo-mechanical characteristics of the rock mass, tests of porosity content determining, water content, unit weight, uniaxial compressive strength, and statically young's modulus were performed on rock samples both in dry and saturated conditions. The results of these tests are given in table 5.

V. Rock Mass Categorization Based On RMR

The rock mass of the dam site is categorized based upon RMR classification (Bieniawski, 1989). The results of the categorization are given in table 6. According to this categorization, the rock mass of the right abutment is categorized very poor to fair, and the rock mass of the left abutment is categorized poor to good.

Table V
The results of the physical and geo-mechanical characteristics of the rock mass

Location	Rock Mass	Poisson's Ratio		Young's Modulus (GPa)		Unit Weight (gr/cm^3)		Uniaxial Compressive Strength (MPa)		Water Absorption	Porosity %
		Saturated	Dry	Saturated	Dry	Saturated	Dry	Saturated	Dry		
Right Abutment	Tirgan limestone	0.11	0.21	59.90	70.83	2.79	2.76	69	81.80	1.12	18.33
Riverbed	Tirgan limestone	-	-	62.49	36.52	2.82	2.80	77.35	82	0.81	22
Left Abutment	Tirgan limestone	0.13	0.21	43.71	99.64	2.83	2.81	83.78	96.03	0.72	19

Table VI
RMR categorization of the rock mass

RMR Parameters	Tirgan limestone, Left Abutment						Tirgan limestone, Right Abutment					
	Maximum		Average		Minimum		Maximum		Average		Minimum	
	Ratings	Value	Ratings	Value	Ratings	Value	Ratings	Value	Ratings	Value	Ratings	Value
Strength of Intact rock	12	142	7	96.03	7	69	7	97.19	7	81.80	4	49.64
RQD Index (%)	17	86	8	26.75	3	0	20	96.30	13	59.69	3	9.68
Discontinuities Spacing (cm)	20	200>	10	20-60	8	6-20	15	60-200	10	20-60	5	6<
Condition of Discontinuities	17	-	14	-	13	-	17	-	15	-	13	-
Condition of Groundwater	0	Dry	0	Dry	0	Dry	0	Dry	0	Dry	0	Dry
Orientation of Discontinuities	0	Very Favorable	-2	Favorable	-5	Fair	0	Very Favorable	-2	Favorable	-5	Fair
Total	66		37		26		59		43		20	
Class/Description	II/ Good		IV/ Poor		IV/ Poor		III/Fair		III/Fair		V/Very poor	

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VI. CONCLUSIONS

The results from the permeability tests at the dam site show that the permeability of the right abutment does not follow a pattern to 60 meters deep from the foundation. The permeability to this depth varies from low to very high and the very high permeability sections are among the low permeability sections. This can be because of the existence of crusty pores and shear zones. Regarding permeability, the rock masses from lower than this depth are categorized in the category of low permeable rock masses.

In the left abutment, the depth of permeable zone is more (120 m); however, the permeability decreases as the depth increases. The reason of high permeability depth can be associated to the activities of series of faults and the high thickness of the weathered zone.

At the riverbed, too, as the depth increases permeability decreases and at the depth of 50 m. we reach low permeability. Thus, regarding the achieved results about the permeability of this dam site, the injection operation seems essential, in order to reduce the permeability and water proofing of the dam site.

The results of Lugeon and RQD show that there is no meaningful relationship between the two parameters at the dam site.

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