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Engineering geological assessment of the Shahid dam site (Semirom, Iran)

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Abstract

This paper discusses the results of the site investigations and rock mechanics studies carried out at the proposed Shahid dam site. Engineering geological properties of rock masses, such as permeability along the dam axis, discontinuities, strength, and stability of abutments, were investigated in order to determine probable problems prior to constructions. Shahid Dam is an earth fill dam with the clay core. The dam on the Marbor river, is located about 110 km of south of Semirom city in the Isfahan Province, Iran. The dam and its associated earth structures are mainly founded on alluvium and limestone in the High Zagros zone. Quaternary alluvium at the dam site has a thickness of about 20 m and overlies the Surmeh, Gadvan and breccia formations, comprises the Jurassic, Cretaceous and Post-Cretaceous rocks of the Zagros Mountains. Studies were carried out both at the field and the laboratory. Field studies include engineering geological mapping, intensive discontinuity surveying, kinematical analyses, drilling, Lugeon and Lofran permeability tests, and sampling for laboratory testing. Rock mass classifications, strength characteristics, and constants of rock masses were expressed by using Hoek-Brown empirical failure criteria, RMR, GSI, and Q values. The results of the investigations indicate that the foundation rocks are suitable for designing the proposed Shahid dam, and the rocks exposed in the right bank are of higher quality rock masses when compared to those in the left bank.

Keywords: Shahid dam, RMR, GSI, Q, Lugen, Lofran, Rock mass classification, Surmeh formation, Semirom, Iran.

1. Introduction

The principal factors that constrain the geomechanical properties of rocks are geological structure, mineralogical composition, discontinuities, and degree of weathering. Accordingly, the geological and geotechnical properties of rocks that comprise the basement to major engineering structures (such as dams) should be determined in the field and in the laboratory prior to construction. Engineering geological investigations and rock mechanics studies mainly include discontinuity surveying, core drilling in-situ testing (özsan & Akn 2002).

In the present study, the sedimentary rocks that represent the basement to the Shahid dam constructed on the Marbor River approximately 110 km of south of Semirom city in the Isfahan Province were investigated from an engineering geological perspective (Fig. 1). This dam is an earth-fill type and intended for drinking water, irrigation and industrial for urban and regional towns and cities in the Fars Province. The Shahid dam is designed by Mahab Qods Engineering Company and under the direction of Fars Regional Water Authority.

The dam's reservoir will have a normal capacity of 154,000,000 m^3. At a normal elevation of 2315 m above sea level, maximum width of 305m, with a height of 95 m from base to top.

The dam site is included in the 1/100,000 scale geological map of the Yasuj, and engineering geological section along Marbor river with 1:1000 scale (Js, Kgv, PKBr, Jn, layouts, respectively). The 1/25,000, 1/5,000, and 1/1,000 scale topographic map, engineering geological maps and sections were prepared by Mahab Qods Engineering Company. There are some publications in the literature concerning dam investigations (e.g., Ozsan & Karpuz 1996; Abderahman & Darwish 2001; Ozsan & Akin 2002; Glawe & Linard 2003; Lee et al. 2004; Fengshou et al. 2006; Kocbay & Kilic 2006; Ozsan et al. 2007; Lambropoulos 2010; Gurbuz 2011; Liu et al. 2012; Ghanbari et al. 2013; Rahimi Shahid 2015, Arbabi, et al.2015, Ansarifar et al. 2015, Ostadmahmoodi-do et al. 2015 andUmoren et al. 2016. This paper describes engineering geological assessment for the safe design of the proposed Shahid dam. Geological and geotechnical investigations have been carried out both in

Figure 1. Location of the study area

the field and the laboratory. Field studies include engineering geological mapping, intensive discontinuity surveying, kinematical analyses, drilling, Lugeon permeability tests, and sampling for laboratory testing. Various laboratory tests were performed for rock mass characterization studies. Rock mass classifications were performed according to uniaxial compression strength, rock quality designation (RQD), rock mass rating (RMR), geological strength index (GSI) and rock mass quality (Q) systems.

In order to study vertical and lateral variations in the lithology and take core samples thereof, do Lugeon tests in order to determine the coefficient of hydraulic conductivities, and to determine the ground-water level, we benefited from 34 basement investigation drill holes that were drilled at construction sites for the dam project (Fig. 2). These 34 drillholes had depths between 12 and 190 m and a total depth of 2730 m. Furthermore, the predominant strike and dipdirections of joints in the rocks were determined, and representative block samples were taken from outcrops. Using these data, an engineering geological map and sections for the traces of the axis location for the Shahid dam. On the basis of all of these characteristics, the rock mass was classified.

2. Geology of the dam site

Geological factors play a major role in designing and constructing a dam. They control the formations characters of and govern the material properties available for construction. The dam and reservoir sites are located on Surmeh, Gadvan, Fahlian, Najmeh and Breccia formations of the Jurassic to Pliostocene Age overlaid by Quaternary deposits (Fig. 3 and 4). The formations are consists of mainly limestone and marl. Limestones are thin to thick stratified, and it contains shale and marl intercalated. At the top is a Quaternary deposit, represented by alluvium (Qat). The Qal is composed of gravel, sand, silt and clay, poorly cemented, coarse-grained materials. The maximum thickness of the Qal under the dam axis is 20 m as indicated by drilling. The Surmeh Formation comprises the Jurassic rocks, and is composed of thick-bedded carbonate rocks. The Gadvan formation consists of Cretaceous shale, clay limestone and bioclast. The Fahlian Formation is a carbonate sequence of Lower Cretaceous age and Najmeh formation consists of Jurassic carbonate rocks. The effects of tectonism and the development of joints are obvious. The study area located near to Zagros main fault, one of the most important tectonic features of Iran, therefore the dam site affected by several faults. Some faults observed during the site exploration, as well as an anticline by NNE-SSW-trending. The dam site is located within a moderate damage risk zone (Rahimi Shahid et al. 2017).

3. Engineering geological investigations

Engineering geological investigations and rock mechanics studies mainly include discontinuity surveying, in situ drilling, laboratory tests, and kinematic analyses.

3.1 Discontinuity surveying

The orientation, degree of openness (aperture), roughness, filling, persistence, and spacing (frequency) characteristics of the joints are parameters that directly influence the characteristics of the rock

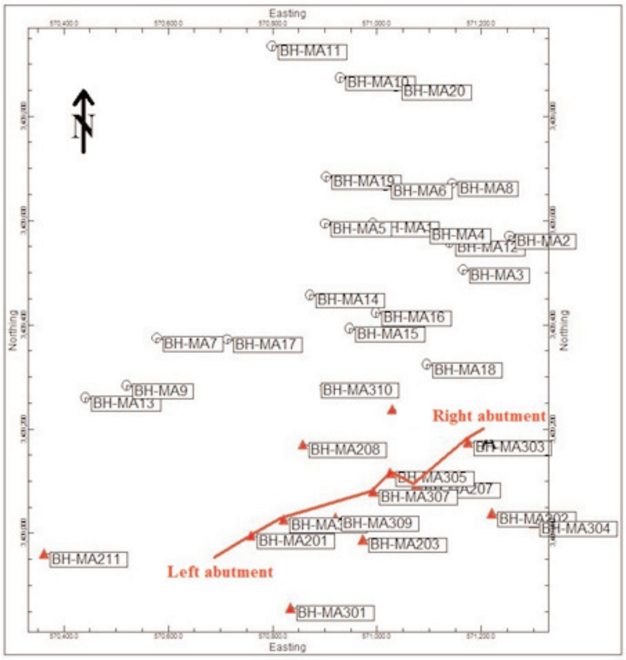


Figure 2. Location of the boreholes in the study area.

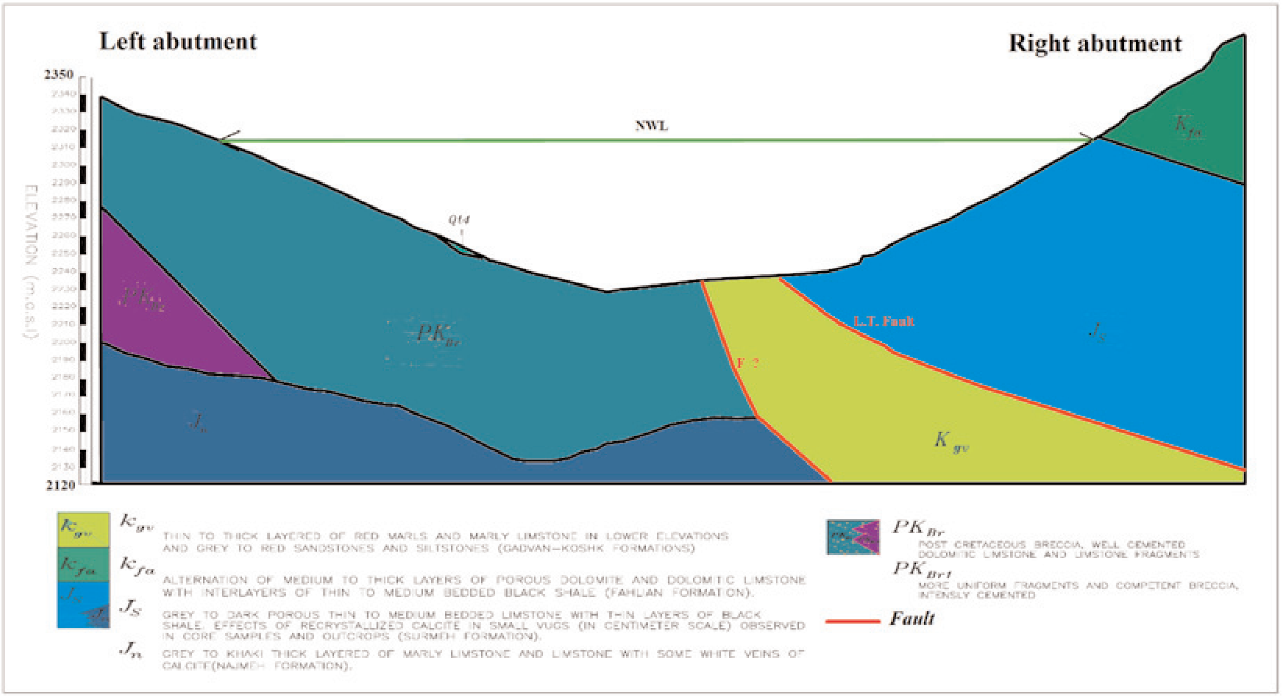


Figure 3. Geological cross-section of Shahid dam site

Figure 4. Dam axis (View to the south)

mass. In the study area, many fissures and fractures with varying orientations developed in response to tectonism. The orientations of the fissures, their degree of openness, frequency, filling or lack thereof and its characteristics (where present), directly influence the characteristics of the rock mass. The strikes and dips of 1723 joints, 483 on the right shore of the dam, and 1240 on the left shore, in outcrops were measured. These measurements were evaluated using the "DIPS" program, which is based on the stereographic projection technique, of Diederichs and Hoek (1989). On the right abutment, the predominant strikes and dips of the joint sets in the Surmeh formation are 20/288, 75/102, 77/186, in the Fahlian formation 87/182, 49/161, 66/133,while on the left abutment in the Surmeh formation 76/307, 62/188, 56/248, 78/293, in the Fahlian formation 71/189, 62/175, 69/45, 51/116 (Figs. 5 and 6) (Tables. 1 and 2).

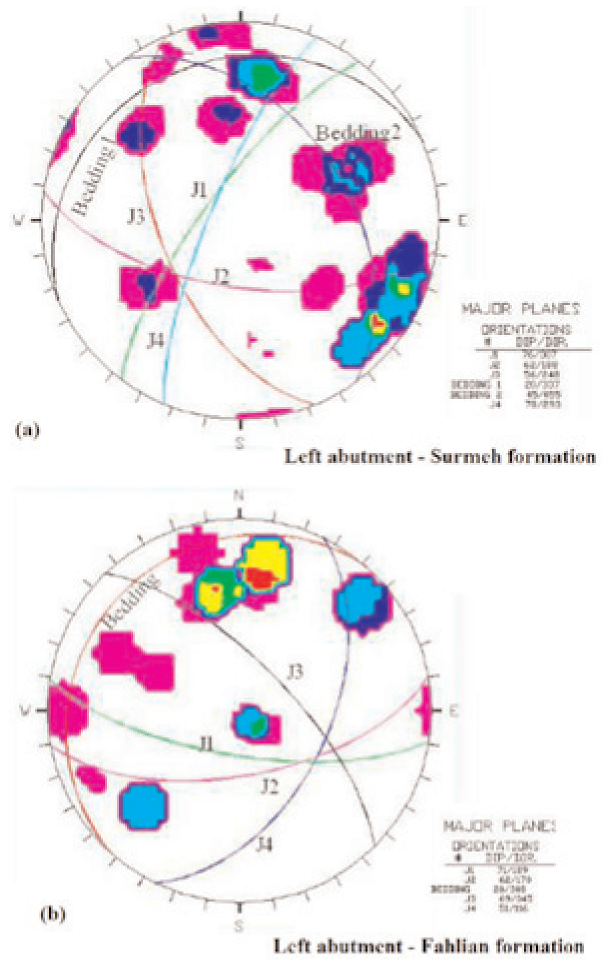


Figure 5. Dominant joint sets on the left abutment of the (a) Surmeh formation, (b) Fahlian formatiom

On the right abutment, the predominant strike and dip of the thin to thick layered limestone in the Surmeh formation is 25/264, in the Fahlian formation 38/36, as on the left abutment in the Surmeh formation 20/377, 45/55, in the Fahlian formation 20/308 (Figs. 5 and 6) (Tables. 1 and 2). According to the failure criteria of kinematic analyses (Hoek & Bray 1981), no wedge failure risks were determined.

3.2. Drilling

In order to determine the lithology, to verify the foundation conditions, to measure the groundwater level, to perform Lofran and Lugeon tests in order to determine the coefficient of hydraulic conductivities, and to obtain rock samples for laboratory testing, a total of 34 boreholes, with 2730 m in length were drilled on the dam axis, riverbed, left and right abutments for the dam project (Figure. 2). Surmeh, Fahlian, Gadvan, Najmeh formations were crossed along the boreholes. The formations and rock-quality designation (RQD) values of geologic units have been determined for each borehole.

Table 1. Descriptions discontinuities (Left abutment)

Fahlian Formation		Surmeh Formation	
Discontinuities	Dip/ Dip direction	Discontinuities	Dip/ Dip direction
layout	20/308	Layout 1	20/337
Joint Set 1	71/189	Layout 2	45/055
Joint Set 2	62/170	Joint Set 1	76/307
Joint Set 3	69/045	Joint Set 2	62/188
Joint Set 4	51/116	Joint Set 3	56/248
-	-	Joint Set 4	78/293

Table 2. Descriptions discontinuities (Right abutment)

Fahlian Formation		Surmeh Formation	
Discontinuities	Dip/ Dip direction	Discontinuities	Dip/ Dip direction
layout	38/036	Layout	25/264
Joint Set 1	87/182	Layout 1	20/288
Joint Set 2	49/161	Joint Set 2	75/102
Joint Set 3	66/133	Joint Set 3	77/186

3.2.1. Permeability tests

Permeability is one of the most important parameter in designing of a dam project. A total of 274 pressured water pumping tests were carried out during the drilling, and the permeability of the units is expressed in terms of Lofran and Lugeon values (Tables 3 and 4). Evaluation of the data shows that permeability rises with low rock quality. The correlation between permeability and depth for rock units shows a reduction in permeability with increasing depth, and after 50m permeability decreased significantly. According to the permeability of the rock units measured in Lugeon scale, the left abutments' rock mass is classified as permeable to highly permeable. The right abutments rock mass is interpreted as permeable. The foundation rock mass is classified as moderately permeable. The result of Lugeon test, aided with a diagram, introduced linear, tabulated, wash out, joint filling, dilation, total loss and impervious behaviors (Figure. 7). Since the Qat (Table. 3) are interpreted as low permeable, however it is proposed to remove the Qat units before construction of the dam.

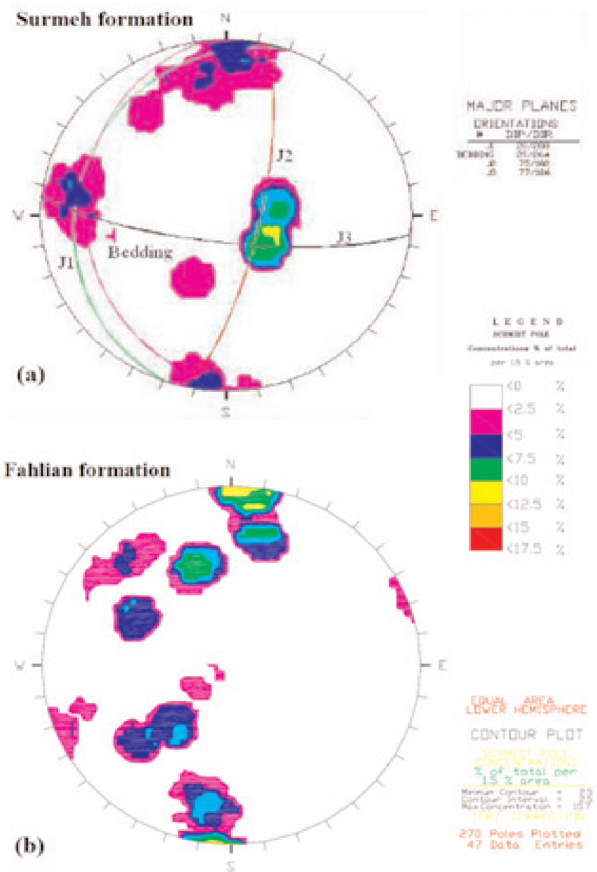


Figure 6. Dominant joint sets on the right abutment of the (a) Surmeh formation, (b) Fahlian formatiom

3.2.2. Rock Quality Designation (RQD)

Rock-mass quality index is a modified core recovery percentage in which the lengths of all sound rock core pieces over 100 mm in length are summed and divided by the length of the core run. The purpose of the soundness requirement is to downgrade rock quality where the rock has been altered and/or weakened by weathering. RQD can be measured through direct core drilling or indirect, in cases where there is no possibility of the core, such as seismic methods or

Table 3. Results of the Lofran test in Shahid dam

Boreholes	Kc (cm/s)	Kf (cm/s)	Depth (m)
MA-205	1.10E-04	1.97E-04	2-3
	4.08E-05	1.77E-04	5-6
	6.86E-05	4.78E-05	8-9
MA-207	1.52E-05	1.52E-04	2-3
	5.15E-06	5.22E-05	5-6
	2.28E-05	9.60E-05	8-9
	4.86E-05	1.07E-04	11-12
MA-301	1.72E-03	1.16E-03	2-3
	1.10E-03	5.96E-04	5-6
	5.71E-04	5.72E-04	9-10
	6.27E-04	3.62E-04	11-12
	4.68E-04	5.27E-04	14-15
MA-302	1.40E-03	2.14E-03	2-3
MA-15	4.04E-03	4.04E-04	2-3
	5.98E-03	2.06E-03	5-6
	3.28E-06	3.01E-06	8-9
	1.14E-03	6.63E-04	12-13
	1.74E-04	1.22E-04	15-16
	4.48E-06	2.62E-06	18-19
MA-01	3.45E-03	3.58E-04	2-3
	1.66E-03	5.71E-04	5-6
	4.39E-05	6.63E-04	9-10
MA-16	2.16E-03	9.95E-04	3-4
	6.41E-04	9.88E-04	5-6
MA-09	4.77E-03	2.24E-03	2-3
	6.30E-03	3.12E-03	5-6

Table 4. Results of the Lugeon test in Shahid dam

Boreholes	Lugeon Value	Conductivity classification	Boreholes	Lugeon Value	Conductivity classification
MA-1	31.2	High	MA-18	19.43	Medium
MA-2	18.9	Medium	MA-19	44	High
MA-3	45.5	High	MA-20	68.4	Very high
MA-4	28.85	Medium	MA-201	22.3	Medium
MA-5	24.83	Medium	MA-202	24.2	Medium
MA-6	72.5	Very high	MA-203	33.7	High
MA-7	39.3	High	MA-207	8.7	Low
MA-8	64.6	Very high	MA-208	83.8	Very high
MA-9	48.1	High	MA-211	8.3	Low
MA-10	61.4	Very high	MA-301	29.5	Medium
MA-11	31.6	High	MA-302	63.1	Very high
MA-12	30	Medium	MA-303	85.7	Very high
MA-13	39.6	High	MA-304	18.4	Medium
MA-14	29.7	Medium	MA-305	27.4	Medium
MA-15	94	Very high	MA-307	29.2	Medium
MA-16	86	Very high	MA-309	17.1	Medium
MA-17	38.7	High	MA-310	84	Very high

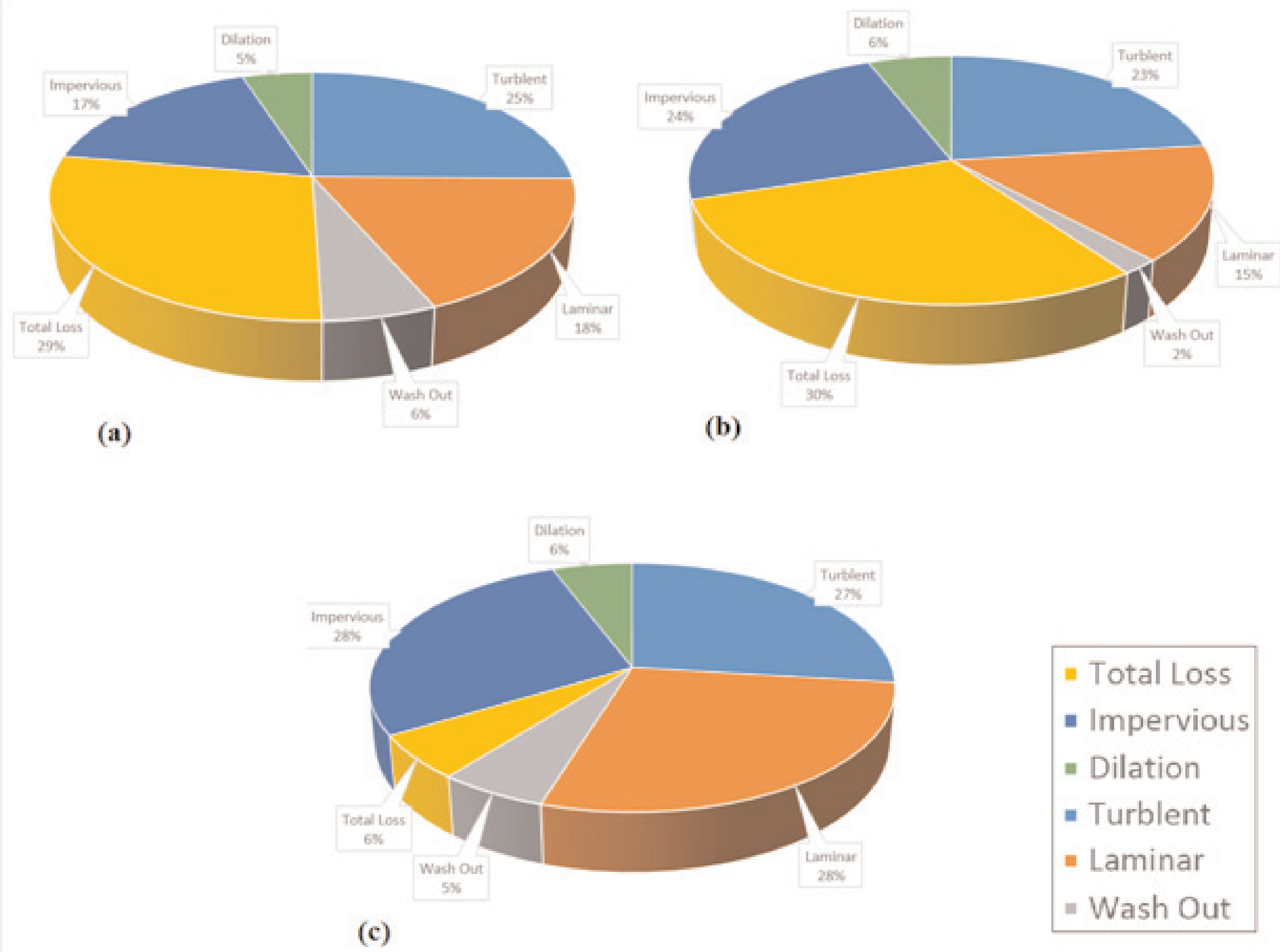


Figure 7. Dominant water flow type during pressure tests conducted at Shahid dam site and reservoir(a) Surmeh formation, (b) Breccia, (c) Gadvan formation

Table 5. Results of RQD in dam axis

Formation	Location	Boreholes	RQD (%)	RQD (avg)	Rock Quality
Surmeh & Gadvan	Right abutment	MA-303	71.6	54.32	Fair
		MA-202	74.4		
		MA-304	2.1		
		MA-18	69.2		
Gadvan, Fault Breccia & Bakhtiari	The middle section (Foundation)	MA-207	12.4	29.97	Poor
		MA-305	30.6		
		MA-307	20.2		
		MA-203	65.5		
		MA-309	61.6		
		MA-310	44.5		
Bakhtiari, Fault Breccia & Najmeh	Left abutment	MA-302	73.1	48.45	Poor
		MA-201	68.5		
		MA-301	20.5		
		MA-208	19.9		
		MA-15	74.6		
		MA-211	34.1		

Table 6. Results of RQD in the downstream site

Formation	Location	Boreholes	RQD (%)	RQD (avg)	Rock Quality
Surmeh	Right	MA-02	57.9	71.16	Fair
		MA-08	75.8		
		MA-12	80		
		MA-03	84.2		
		MA-20	57.9		
	Middle	MA-04	82.8	65.3	Fair
		MA-16	85.1		
		MA-06	56.2		
		MA-10	46		
		MA-11	51.2		
		MA-19	70.5		
	Left	MA-01	63.7	71.23	Fair
		MA-05	85.9		
Surmeh&Fahlian	Karst valley	MA-07	60	56.88	Fair
		MA-09	52.1		
		MA-13	32.6		
		MA-14	84.3		
		MA-17	55.4		

volumetric counting joints. In the project area, geological structures such as faults, the anticline-axis zone, the joint sets, and in some cases the lithological bedding planes have a remarkable effect on the RQD value.

According to this method, the numerical quality-index values corresponding to each part of the rock masses of the Shahid dam site has been done. Based on RQD values five definite rock-mass classes are described. The RQD values were determined by examining drill cores and joint frequency (Tables 5 and 6). The Table shows that the right abutment RQD value was fair, left abutment and foundation were poor to fair for the projected dam construction (Table 5). In the downstream site increased levels of RQD to good and fair, because in this part the rocks are carbonate (Table 6). The major problem of the downstream is Karst distribution due to Surmeh formation.

3.3. Engineering classification of the rock mass

Rock mass classification methods are commonly used at the preliminary design stages of a construction project when there is very little information. It forms the bases for design and estimation of the required amount and type of rock support and groundwater control measures. Many researchers to the present day (see Ulusay & Sonmez 2002) have developed a number of rock mass classification systems. Nevertheless, the most widely known of these methods are RQD (Deere 1968), RMR (Bieniawski 1973), and GSI (Hoek & Brown 1997), which employed for rock mass characterization studies in both left and right abutments. The modified version of RMR (Bieniawski 1989) and the modified versions of GSI (Hoek et al. 1998; Sonmez & Ulusay, 1999, 2002) were considered. Summaries of the engineering classification of the rock mass estimation in the Shahid dam site are presented in Tables (7-11).

Table 7. Rock mass classification of the Breccia

RMR & GSI		Q	
Parameters	Score	Parameters	Score
Strength of intact rock material (M pa)	2	RQD	62
RQD (%)	12	Jn	9
Spacing of discontinuities (mm)	8	Jr	2.5
Condition of discontinuity	17	Ja	5
Ground water	15	Jw	0.66
RMR = 54		SRF	2.5
GSI = 49		Q = 0.909	

Table 8. Rock mass classification of the Weak Breccia (with Clay Cement)

RMR & GSI		Q	
Parameters	Score	Parameters	Score
Strength of intact rock material (M pa)	1	RQD	50
RQD (%)	5	Jn	15
Spacing of discontinuities (mm)	5	Jr	3
Condition of discontinuity	5	Ja	4
Ground water	15	Jw	0.66
RMR = 31		SRF	2.5
GSI = 26		Q = 0.66	

4. Discussion and results

Shahid dam, Earth-fill dam with clay core, will be situated in an area underlain by Carbonate, shale and

Table 9. Rock mass classification of the Limestone (Surmeh formation)

RMR & GSI		Q	
Parameters	Score	Parameters	Score
Strength of intact rock material (M pa)	4	RQD	75
RQD (%)	15	Jn	12
Spacing of discontinuities (mm)	8	Jr	2.5
Condition of discontinuity	12	Ja	3
Ground water	15	Jw	1
RMR = 54		SRF	1
GSI = 49		Q = 5.208	

Table 10. Rock mass classification of the Gadvan formation

RMR & GSI		Q	
Parameters	Score	Parameters	Score
Strength of intact rock material (M pa)	2	RQD	50
RQD (%)	8	Jn	15
Spacing of discontinuities (mm)	8	Jr	3
Condition of discontinuity	11	Ja	4
Ground water	15	Jw	0.66
RMR = 44		SRF	2.5
GSI = 39		Q = 0.66	

Table 11. Rock mass classification of the Breccia zone

RMR & GSI		Q	
Parameters	Score	Parameters	Score
Strength of intact rock material (M pa)	1	RQD	20
RQD (%)	5	Jn	15
Spacing of discontinuities (mm)	4	Jr	2
Condition of discontinuity	4	Ja	6
Ground water	15	Jw	1
RMR = 29		SRF	5
GSI = 24		Q = 0.089	

Table 12. Total results of rock mass classification

	Right abutment	Left abutment		Foundation	Breccia zone
Rock→ Classification ↓	Surmeh formation (Limestone)	Weak Breccia (with Clay Cement)	Breccia (with Clay Cement)	Gadvan formation	Breccia zone
Q	5.20	0.66	0.9	0.66	0.08
	Fair rock	Very poor rock	Very poor rock	Very poor rock	Extremely poor rock
RMR	54	31	54	44	44
	Fair rock	poor rock	Fair rock	Fair rock	Fair rock
GSI	49	26	49	39	24
	Fair rock	Very poor rock	Fair rock	poor rock	Very poor rock

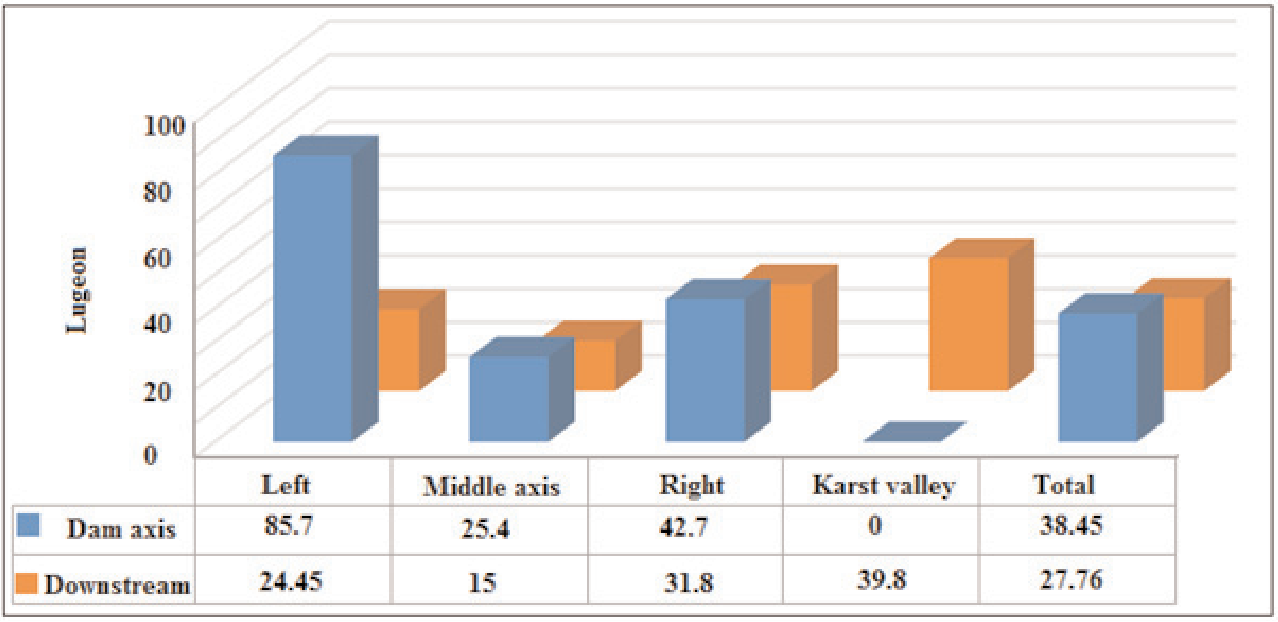
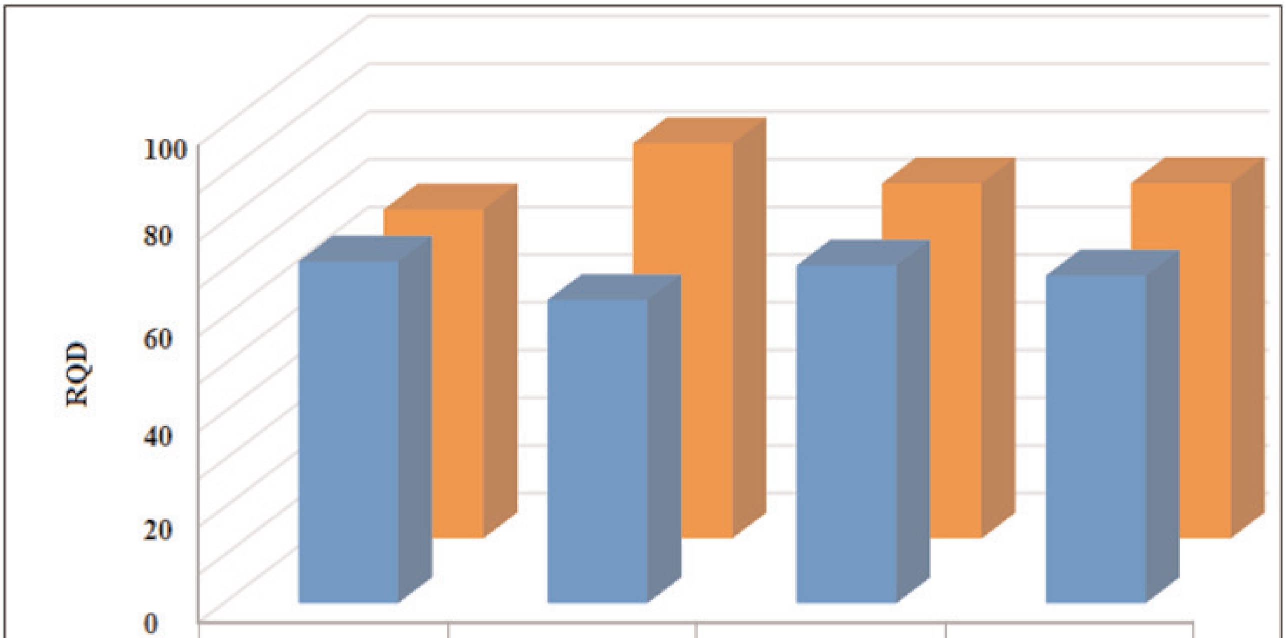


Figure 8. Results of the Lugeon tests in Shahid dam site

breccia rocks of Jurassic to Pleistocene age. The dam axis intersects a fairly shallow valley of limestone slopes and alluvial bottom. These limestone rocks indicate fair to good rock mass quality. In situ investigations, laboratory tests, kinematical analyses, and computations indicate that Shahid dam can be safely constructed on the proposed site. For the final design purposes, additional geotechnical investigations and toppling failure analysis will be required for the other dam structures. The characterization of the rock mass was studied by the RQD, RMR, GSI and Q. The rocks were classified according to the RMR (Bieniawski 1989), GSI (Sonmez & Ulusay 2002) and Q (Barton et al. 1974; Barton 2002) systems in order to determine quality rock masses. A summary of the all estimations are presented in Table 12.

All of the shaded GSI values are intersecting in the area of 24-49. In the GSI rock-mass classification, the right abutment falls into the "fair rock" and the left abutment falls into the "fair" and "very poor rock" groups. The foundation falls into the "poor rock" group and breccia zone falls into "very poor rock" group. Based on the Q values calculated for the worst conditions, the obtained Q value is 0.08; thus, the breccia zone falls into the "extremely poor rock" group. The Q value obtained for right abutment is 5.2 and, thus, the rocks falls into the "fair" group and for foundation and left abutment are 0.66 to 0.90; then, the rocks falls into the "very poor" group. In the RMR rock-mass classification, the right abutment falls into the "fair rock" and the left abutment falls into the "fair" and "poor rock" groups, while in the Q rock-mass classification, it falls into the "very poor" group. Foundation and breccia zone fall into the "fair



	Left	Middle axis	Right	Total
Dam axis	71.6	63.55	70.8	68.65
Downstream	68.95	82.8	74.45	74.5

Figure 9. Results of the RQD in Shahid dam site

rock" while in the Q rock-mass classification, foundation falls into the "very poor" group and breccia zone falls into "extremely poor rock" group. According to the results of all the rock mass characterization studies (RQD, RMR, and GSI, respectively), the rocks exposed in the right bank are of higher quality rock masses when compared to those in the left bank. During drilling along the dam axis and downstream, Lofran and Lugeon tests were performed, in order to determine hydraulic conductivities and it was ascertained that most of the rocks are permeable (Fig. 7 and 8). Evaluation of the data shows that Quaternary alluvium at the foundation is "slightly permeable to permeable" except to MA-301 and MA-302 boreholes. Nevertheless, it is proposed to remove these units by using cutoff method. The Lugeon results in the rocks at the left abutment are permeable to highly permeable (Fig. 8). In all sections on downstream and in the karst valley are interpreted as "highly permeable", despite to low value of the Lugeon test (Fig. 8). According to the rock-quality designation (RQD), the rocks in the right abutment are of "fair quality", and in the left abutment and dam axis are of "poor to fair quality" (Fig. 9). In the left abutment of the downstream reduced RQD compared to foundation, the reason is high porosity of the upper part of the Surmeh formation. All these results have led to the conclusion that the foundation rocks are suitable for designing the proposed Shahid dam. However, the rocks exposed in the downstream are of higher quality rock masses when compared to dam axis. It is thought that the existing of faulting and crashing in the dam axis causes this status.

5. Conclusions

The Shahid dam is an earth fill dam with a clay core. The dam and its associated earth structures are mainly founded on alluvium and limestone in the High Zagros zone. Quaternary alluvium at the dam site has a thickness of about 20 m and overlies the Surmeh, Gadvan and breccia formations, comprises the Jurassic, Cretaceous and Post-Cretaceous rocks of the Zagros Mountains. In situ investigations, laboratory tests, kinematical analyses, and computations indicate that the Shahid dam can be safely constructed on the proposed site. Since the limestone are slightly permeable to highly permeable, grouting treatment design in the foundation and the abutments, especially in the left abutment is highly recommended to prevent leakage from permeable zones.

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