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Analysis of engineering properties of rock mass of Shah-wa-Arus dam site, Kabul, Afghanistan

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Abstract

The Shah-wa-Arus dam is currently being constructed on the Shakardara River, approximately 22 km to the north west of Kabul City, Afghanistan. The height and length of the dam are 77.5 m and 303 m, respectively, and the storage capacity of the dam is estimated around 9.38 million cubic meter. The type of the dam is roller-compacted concrete (RCC). It is a multi-purpose dam, designed to store water for irrigation, to mitigate flooding and generate electricity. The dam is located within a tectonically active zone, and the dam site has been strongly affected by tectonic activity. The paper presents results of comparison rock quality designation (RQD) and Lugeon parameters, based on a review and analysis of initial engineering-geological studies and additional field observations. The results of Lugeon and RQD were statistically evaluated in graphs and by using comparison of these graphs with all other conditions as of natural of this particular site. The obtained results show which state of the natural conditions is somehow a meaningful relationship between a Lugeon unit and RQD parameters. Finally, the rock mass of the dam foundation site is classified in accordance with the RMR classification.

Keywords: Shah-wa-Arus dam, RQD, Lugeon, Permeability, RMR.

Paper type: Research paper

1. Introduction

The quality of the rock mass is one of the most important geology characteristics influential in designing and building a dam. In general, geological structures, discontinuities and a degree of weathering are the most parameters that affect the rock mass engineering (Bell 2007).

The other important parameter, hydraulic conductivity of the rock mass, is having a close relation to the discontinuity and joints properties. Therefore, one of the major problems of the studies of a dam site foundation is correction of evaluation of the relationship between the discontinuity properties and the hydraulic behaviour of the rock mass. Water pressure test or Lugeon test which called “Packer test” is one of the common used tests in the evaluation of the rock mass permeability (Houlsby 1990). On the other hand, Deere (1990) reported that using the RQD index and its comparison with the obtained Lugeon test results is one of the

common methods for evaluating and explaining the hydraulic behaviour of a particular tested section. But there is not always a direct relationship between the two parameters - if in compliance or contradictory. Foyo et al. (2005) state that sometimes it has been observed that a region with a low degree of jointing (high RQD) shows high absorption, and on the contrary the opposite behaviour is possible. Some researchers like Houlsby (1990), Ewert (1997) and Palmstrom (2005) stated that reason behind this phenomenon could be some problems with the RQD parameter. Bell (2007) stated if the joint spacing is more than 10 cm, based on the RQD parameter, there would not be received any relevant information about the persistence and the filling of the joints. Palmstrom (2005) reported that this parameter is more affected rather by the borehole direction than by the joint spacing or frequency. On the other hand, the hydraulic conductivity of the rock mass has a strong and close connection with the discontinuities properties, such as opening, filling, fill material, orientation, persistence and the connections between the discontinuities. Bieniawski (1974) initially developed the rock mass rating (RMR) system on the basis of experiences in tunnel projects in South Africa. Since then, this classification system has undergone significant changes reflecting the local conditions.

This project is located within a tectonically active zone, and the dam site is strongly affected by tectonic activity - the riverbed itself is tectonically predisposed. The rocks in the area are highly fractured and they show brittle deformation. Therefore, it is possible that some further investigation would be needed as a result of this article if any problematic and unclear points will occur.

The engineering geological and geotechnical investigations were carried out by Tablieh-Parhoon Tarh (2011b) under the direct supervision of the Ministry of Energy and Water of Afghanistan. In general, 10 boreholes, totalling 420.32 m, were drilled on the dam site, of which 374.12 meters are drilled in the rock mass (Tablieh-Parhoon 2011b).

2. Geology and tectonic of the dam site

The Shah-wa-Arus dam site is located in the Shakardara River valley, approximately 22 km to the north west of Kabul city, Afghanistan. The type of the dam is roller-compacted concrete (RCC), according to the design the height and length of the dam are 77.5 m and 303 m, respectively, and the storage capacity of the dam is estimated around 9.38 million cubic meter. It is a multi-purpose dam, designed to store water for irrigation, to mitigate flooding and generate electricity. The rock of the dam site is thought to be a part of Kabul Block, which is intersected with the Herat-Bamian Fault in the north-west, Sorubi fault in the east, and the Chaman fault system in the south and west (Figure. 1). Therefore, the rock mass has been crushed along fractures and shears zones, drastically folded, and in some locations thrust including of creating of mylonite zones.

The Kabul Basin is a structural basin formed as a result of tectonic movements during the Late Paleocene (Tertiary). This basin is surrounded by metamorphic rocks. The foundation of the dam and srrounded areas are formed by various rocks of assumed Paleoproterozoic age

(including: two-mica, biotite, biotite-amphibole, granite-biotite and plagioclase gneiss; migmatite, quartzite, marble, amphibolite). The dominant lithologies of the dam area are tectonically fractured gneiss with interbeds of weathered biotite schist. Based on conducted field observation and studies, the area has been extensively influenced by tectonic activity and the rocks are highly fractured and jointed, with locally described intusions of granite leading on contact of forming just these metamorphic products as gneiss. Tectonic movement along the faults is recorded by lineations. Based on the saltellite images and some field observations there are two lateral faults in the upstream of the dam site in the right side of the resorvior.

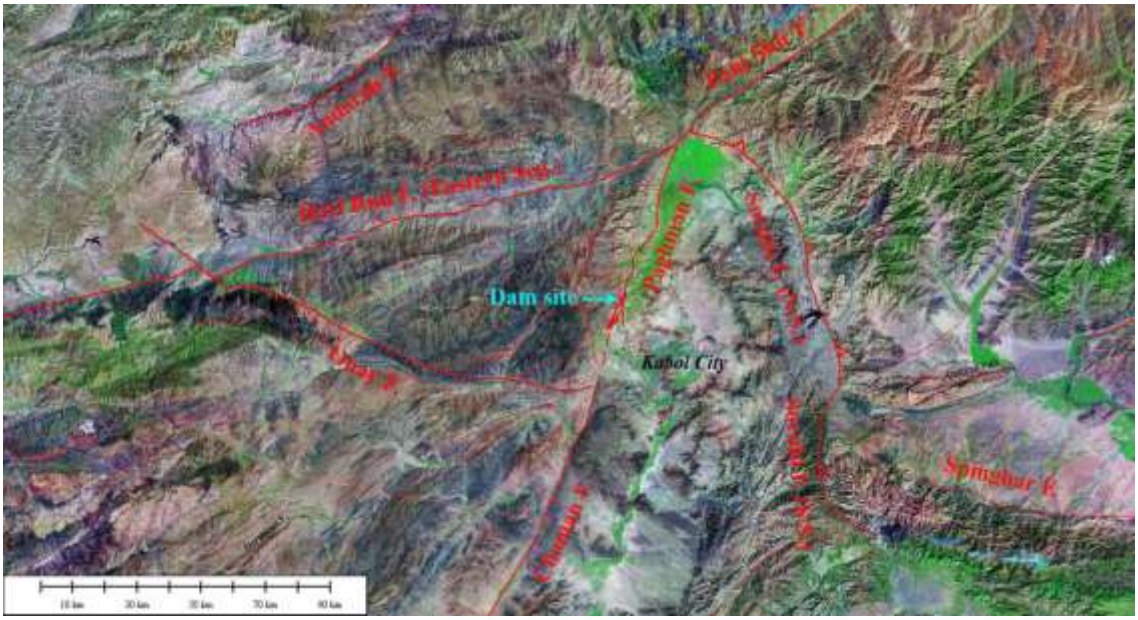

Figure 1. Satellite image of the Shah-wa-Arus project area, Quaternary and Major faults.

3. Engineering geology of the dam site

Engineering geological investigations, rock mechanics and hydrogeology studies included: discontinuity surveying, core drilling, and rock quality designation measurements and Lugeon test.

3.1. Drilling

In order to verify foundation conditions and to obtain rock samples for laboratory testing, borings were made at the Shah-wa-Arus dam site. 10 boreholes, totally 420.32 m, were drilled on the dam site, of which 46.20 meters were drilled in alluial deposits and 374.12 meters in the bedrock. The data of in-situ permeability and rock quality designation, RQD obtained from the field tests. Figure 2 shows borehole locations and a comprehesinve information about the boreholes are presented in Table I.

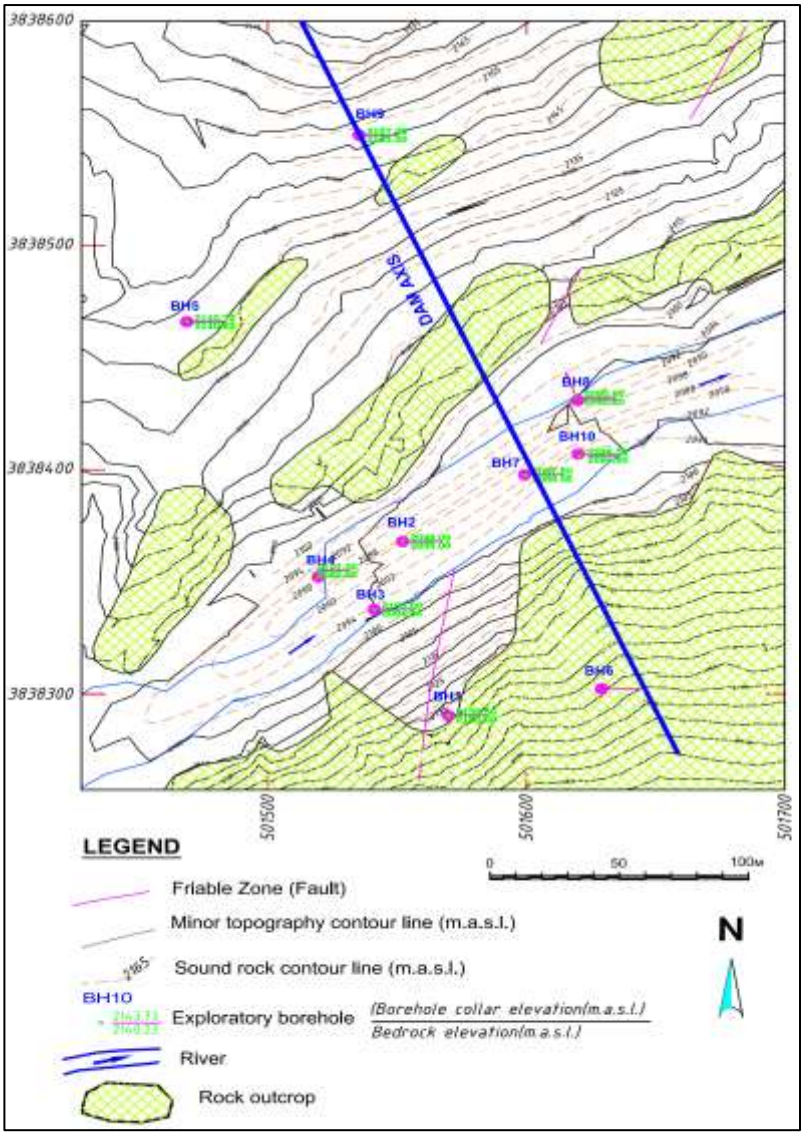

Figure 2. Borehole location.

Table I. Borehole descrption (Tablieh-Parhoon 2011a).

No.	Borehole	Borehole location	Depth of drilling (m)			Dip/D. Direction	Lugeon Value
			Total	Overburden	Rock mass		
1	BH1	Right. Ab	66.3	0.5	65.8	Vertical	53
2	BH2	Dam Axis/River	23.3	11	12.3	Vertical	4
3	BH3	Dam Axis/River	9.5	5.35	4.15	Vertical	-
4	BH4	River/Left bank	15.8	9	6.8	30/310	-
5	BH5	Left. Ab	60	3.5	56.5	Vertical	3
6	BH6	Right. Ab	65	0	65	Vertical	3
7	BH7	Dam Axis/River	60.17	8.15	52.02	Vertical	<1
8	BH8	PH/River	35	2.8	32.20	30/340	8
9	BH9	Left. Ab	65	4	61	Vertical	3
10	BH10	Dam Axis/River	20.25	1.9	18.35	30/140	-

3.2. Evaluation of RQD values with Lugeon test results

3.2.1. Rock Quality Designation (RQD)

RQD expresses the ratio of the cumulative length of fragments of the drill core of length more than 100 mm as a percentage of total length of a measured run of core (Bieniawski 1989). Reduced core recovery is indirectly dependent on the degree of weakness of the rock mass, the state of stress and fracturing, the abundance of joints and other factors affecting the coherence and isotropy of the rock environment. The data presented in Table II, only describes the average state of each boreholes, but it cannot describe the real state of run of boreholes. Because in some section of the boreholes the lugeon values are high, but in some other sections the Lugeon values are low. In general, the high and low values of Lugeon indicate that rock masses in the dam site are heterogeneous. In this study the Lugeon tests results are analzyed statistically and compared with RQD measurements.

3.2.2. Permeability

During core drilling, the packer permeability tests were carried out in the Shah-w-Arus Dam foundation directly in the vertical and inclined boreholes at descending sequence. The main objective of the tests was to determine the permeability of the each of rock masses of the dam foundation and its abutments, which allows for the determination of different sections that require a separate treatment. A total of 70 Lugeon tests were carried out during the geotechnical investigations.

The permeability of rock was measured in the Lugeon scale (0-3 Lugeon impervious, 3-10 Lugeon low permeability, 10-30 Lugeon medium permeability, 30-60 Lugeon high permeability, and >60 Lugeon very high permeability). The average Lugeon values are summarized and presented in Table I. The Lugeon values, determined from the Lugeon tests, indirectly expressed the status of the discontinuities in the dam foundation. The water pressure test indicated the necessity of providing a grout curtain the dam foundation. The results of water pressure tests and the degree of jointing also employed as a first aid to design the water to cement ratio and the injection pressure in the grouting process for foundation treatment.

According to the drilling results, the designation rock quality (RQD) was evaluated and provided in Table III. Respecting to the fact that this site is highly affected by tectonic and fault activities, the thickness of the weathered zone at this site is variable. In general, the results of Lugeon and RQD show that there is somehow a meaningful relationship between these two geotechncial parameters at the dam site. The results of Lugeon tests are presented in Table II.

Table II. Lugeon Test Results.

Borehole	Depth (m)	Average (Lu)	Description	Total	Lugeon value
BH1	2-35	100	Very high	53	High
	35-45	3	Impermeable		
	45-50	4	Low		
	50-65	<1	Impremeable		
BH2	13-23	4	Low	4	Low
BH4	11.8-15.8	16	Medium	16	Medium
BH5	5-10	12	Medium	5.5	Low
	10-15	7	Low		
	15-20	2	Impermeable		
	20-27.65	5	Low		
	27.65-60	1	Impermeable		
BH6	6-15	1	Impermeable	9	Low
	15-20	10	Low		
	20-25	25	Medium		
	25-65	<1	Impermeable		
BH7	10-60	<1	Impermeable	<1	Impermeable
BH8	5-15	0	Impermeable	9	Low
	15-20	41	Hgih		
	20-25	3	Impermeable		
	25-30	0	Impermeable		
	30-35	3	Impermeable		
BH9	5-10	9	Low	5	Low
	10-15	2	Impermeable		
	15-20	4	Low		
	20-25	3	Impermeable		
	25-30	6	Low		
	30-65	1	Impermeable		
BH10	10-19.95	1	Impermeable	1	Impermeable

3.2.3. Right abutment of the dam

In borehole No. 1, from surface to depth of 35 m, RQD is classified as very poor to poor, then RQD values gradually decreased and classified as fair to good. The permeability of rock in this borehole from surface to depth of 35m is classified as high permeability. Afterward, the permeability of rock steadily decreased to bottom of the borehole and classified as low to impermeable. Figure 2 is shown that borehole No.1 is located near to a fracture zone.

In borehole No. 6, from surface to depth of 16 m, RQD value gradually increased from 40 to 70 percent, then to depth of 27 m, RQD decreased to 40 percent. Afterward, RQD steadily increased to the bottom of the borehole. The Lugeon values increase to depth of 27 m. Subsequently the Lugeon values decrease by increasing depth.

3.2.4. Left abutment of the dam

In borehole No. 5, from surface to depth of 27 m, RQD is classified as poor, then RQD values gradually decreased and classified as good. The Lugeon values are increased by increasing of

depth in this borehole.

In borehole No. 9 in general, with the increasing of the depth, RQD values increases, in contrast the Lugeon values decreases. It means there is a direct relationship between Lugeon and RQD in this borehole.

3.2.5. Upstream of dam axis (riverbed)

Borehole No. 2 – Between the depths of 15 m and 23 m, the borehole consists of relatively very good quality rock mass, just one meter of the borehole is classified as very poor quality.

Borehole No. 3 – the RQD is evaluated as very poor to fair quality.

Borehole No. 4 – the RQD is evaluated as poor to excellent quality.

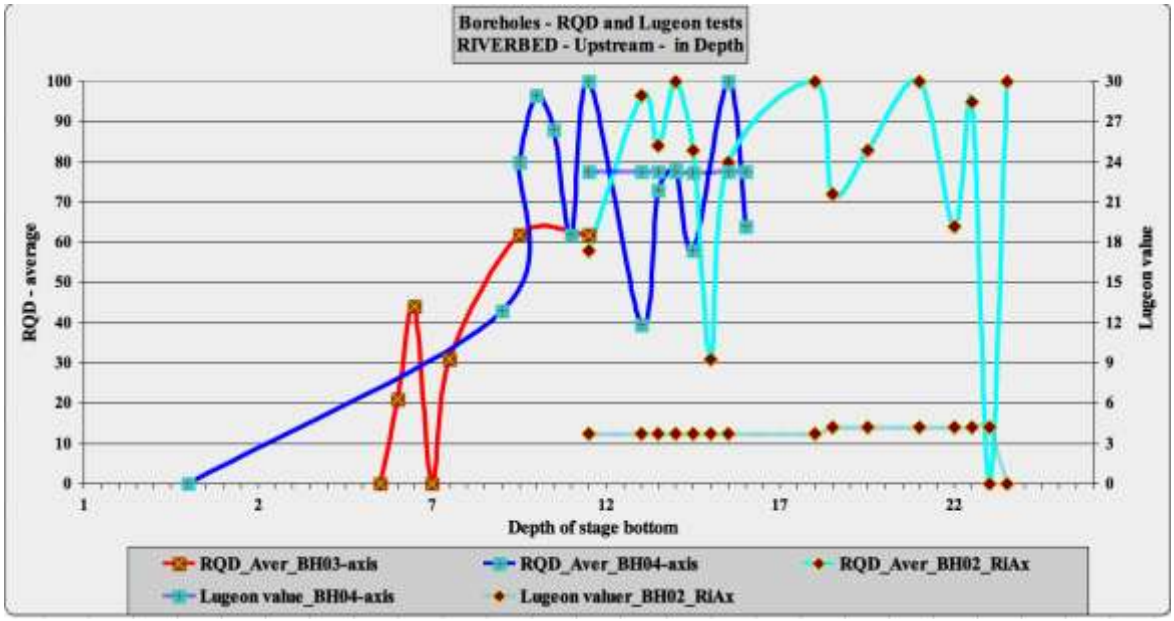

Figure 3. Comparing the results of RQD and Lugeon of boreholes in the riverbed (in the upstream of dam axis).

3.2.6. Downstream of dam axis (riverbed)

In borehole No. 7, from surface to depth of 14 m, RQD is classified as poor, then RQD values steadily decreased and classified as good to excellent. In addition, according to the Lugeon test results, the rock is classified as impermeable.

In borehole No. 8, which is located on downstream of dam body, RQD quality ranges good to excellent. In general, with increasing of depth the RQD values increase and Lugeon values decrease.

Borehole No. 10 – The RQD values from surface to depth 12 m are classified poor to fair. Afterward, from 12 to 19.5 m the RQD is classified as excellent. According to Lugeon test results the rock is classified as impermeable.

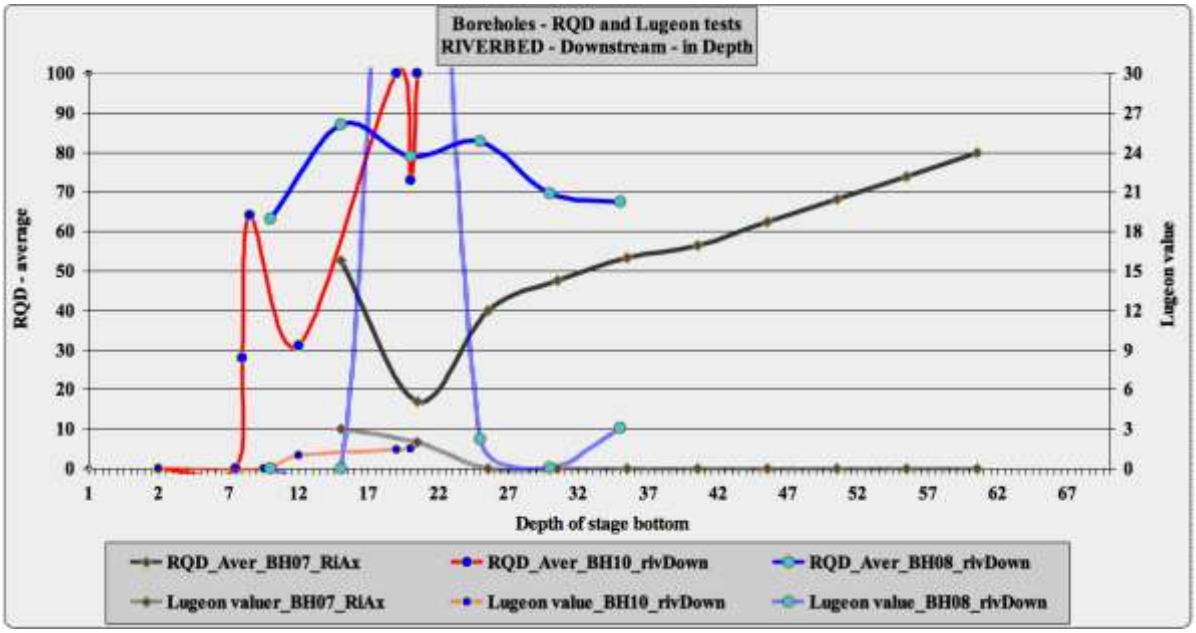

Figure 4. Comparing the results of RQD and Lugeon of boreholes in riverbed (in the downstream of the dam axis).

According to the Lugeon test results, there is a constant trend of decreasing in the Lugeon with increasing depth in the most boreholes.

Table III. Results of rock quality designation of drilling boreholes at SWA dam site (Tablieh-Parhoon 2011a).

No.	Borehole	Borehole Location	RQD		
			Average	Minimum	Maximum
1	BH1	Right Abutment	52.376	38.00	74.75
2	BH2	Dam Axis/River	76.548	73.43	79.67
3	BH3	Dam Axis/River	25.000	25.00	25.00
4	BH4	River/Left Ab.	81.875	74.75	89.00
5	BH5	Left Abutment	62.358	29.00	90.00
6	BH6	Right Abutment	65.794	38.40	97.25
7	BH7	Dam Axis/River	47.667	17.00	79.83
8	BH8	PH/River	74.854	63.17	87.00
9	BH9	Left Abutment	50.471	27.38	90.00
10	BH10	Dam Axis River	63.800	18.40	73.00

4. Laboratory test

Laboratory experiments were carried out according to the procedures recommended by ISRM (2007) and ASTM to determine physical and mechanical properties rocks including unit weight, density, absorption, porosity, uniaxial, compression and tensile strength, cohesion, internal friction angle, and deformation parameters (Poison's ratio and modulus elasticity). Test results are summarized and presented in Table V.

Table V. Laboratory test results of rocks at Shah-wa-Arus Dam site (Tablieh-Parhoon 2011b).

Durability Index (%)	Water Content (%)	Porosity (%)	Sat. density Gr/cm^3	Dry density Gr/cm^3	Rock Type
99.3	0.26	0.77	2.9	2.9	Granodioritic Gneiss

Unxial Compressive Strength and Elastic Modulus Test Results								
E-Sat (Gp)		E-Dry (Gp)		UCS–Sat (MPa)		UCS – Dry (MPa)		Rock Type
Ave	Range	Ave	Range	Ave	Range	Ave	Range	
35.0	24.9-48.1	43.0	29.6-62.1	108.5	51-146	142.6	111-177	Granodioritic Gneiss

Direct Shear Test Results			
Φ (Degree)	C (MPa)	Rock Type	
35	0.16	Natural	Granodioritic Gneiss
30	0.0	Saw cut	

Triaxial Compressive Strength Test Results				
Φ (Degree)	C (MPa)	Hoek – Brown Criterion		Rock Type
		m_i	S	Granodioritic Gneiss

5. Rock Mass Rating (RMR) classification

One empirical rock mass classification system have been used to summarize the geological and geotechnical data. The results of the classification are presented in Table VI.

Table VI. The scoring system of rock mass of Shah-wa-Arus dam site rock (Bieniawski 1989).

Parameters	**Value**
Uniaxial compressive strength [MPa]	108.5
Value	12
Index RQD%	60
Value	13
Discontinuity spacing (m)	0.2 – 2
Value	15
Condition of discontinuities:	
Persistence (m)	1 – 15
Aperture (mm)	0.2 - 20
Roughness	Very rough to smooth
Filling	Clean – Si and Plg crystal
Weathering	Slightly weathered
Value	2
Condition of groundwater	Dry
Value	15
Total score	**57**
RMR	**III**
Description	**Fair Rock Quality**

Table VII. Rock Mass Class (Bieniawski 1989).

RMR	Rock quality
0 – 20	Very Poor
21 – 40	Poor
41 – 60	Fair
61 – 80	Good
81 – 100	Very Good

Empirical rock mass classification system mostly depends on joint characterizations. The results of classifiation show that the rock mass on dam site is classified as fair rock quality (RMR=57).

6. Conclusion

The Shah-wa-Arus dam is located in the Shakardara river valley in an active tectonic zone. The rocks at the dam site are granitic-gneisses. Based on the field observations, there is possbility of rocksliding on the right side of the reservior. Based on availability of joints, altered zones and the rather steep slopes, the existing rocks in saturated conditions and under high water pressure are untirely unstable. Accoridng to results of Lugeon test, which are conducted in the nine boreholes at the dam site, the rocks are classifed as medium permeable to impermeable, just the rocks in borehole one (01) are classified as high permeable. The results of Lugeon show that the Lugeon value decreases by increasing depth at the dam site.

Genreally, the results of Lugeon and RQD show that there is somehow a meaningful relationship between these two geotechncail parameters at the dam site. The rock mass of the dam site is classified as fair rock quality in accordance with the RQD and RMR classifications.

7. Acknowledgments

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