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Evaluate the permeability Damsite Jamishan with Emphasis on engineering geology

Vajiha Habibi*

Department of Geology, Science & Research Branch, Islamic Azad University, Tehran, Iran.

* *Corresponding Author, e-mail: vajihahabibi@ymail.com*

Rassoul Ajalloeian
Department of Geology, The Isfahan University, Isfahan, Iran.
e-mail: rasajl@sci.ui.ac.ir

Abstract:

The dam body and foundation seepage is one of the important points in design parameters. This index is related to the permeability. Therefore permeability is one of the basic parameter in design grout curtain, prevent water escape from foundation and avoid negative seepage pressure in borrow materials, so grouting is used. Jamishan rockfill dam with clay core is located in northeast of Kermanshah on the Jamishan River that is one of the branches Karkheh river. The dam foundation located on the schist conglomerate and schist limestone. The main aim of this study is determination of permeability damsite based on calculation hydraulic aperture of joint, secondary permeability index (SPI) and lugeon value. The permeability of damsite cannot estimate alone with Rock Quality Designation (RQD) and lugeon values because in the zones with similar lugeon value may frequency and aperture of joint is deferent. So, frequency and aperture of joint was calculated and analysed in damsite. Type of cement for grouting operation, grouting pressure and grouting curtain was designed and recommended with considering data this.

Key Words: *Jamishan rockfill dam, hydraulic aperture, Secondary Permeability Index (SPI), Lugeon.*

Introduction

The sealing of dam foundations and abutments is required due to the geological conditions of rock masses (their lithology, the strength of the rock, their hydrothermal veins as primary discontinuities, their main joint sets as secondary discontinuities, the distribution of the discontinuities, the quality and strength of the joint-filling material) and their permeability conditions (Sadeghiyeh et al 2012). The decision to install a grout curtain depends largely on the results of water pressure tests (WPTs), as introduced by Lugeon (Ewert 1997c). Turkmen (2003) evaluated the seepage problem at Kalecik Dam in Turkey and similar studies were carried out at the Chapar-Abad Dam, Iran by Uromeihy and Barzegari (2007); Ghobadi et al. (2005) investigated the water leakage through the Karoon-1 Dam in Iran; Nusier et al. (2002) studied remedial measures to control seepage problems at the Kafrein Dam in Jordan; Gurocak & Alemdag (2011) studied permeability and injection depth at the Atasu dam site (Turkey) based on experimental and numerical analyse, Uromeihy & Farrokhi (2011) investigated groutability at the Kamal-Saleh Dam based on Lugeon tests, Ajalloeian et al (2011) investigated hydrojacking and hydrofracturing behavior in Aghajari formation (Gotvand dam site foundation), Iran and Zeidabadi et al (2012) investigated engineering geological properties of Cheshmeh-Asheq dam site. The geological and permeability conditions of a rock mass may be evaluated based on laboratory, field and office studies. This paper discusses the Jamishan Dam which is under construction in the Kermanshah province, west of Iran. The under construction Jamishan dam with a crest length of about 277.6 m, a maximum height above the river bed level of 53 m, and total storage capacity of about 62.8 million m^3 will be built on the Shirinrood river, about 30 km west of Kermanshah city in southwest of Iran with a geographical coordinate 34 N and 47 E (Fig. 1). The Jamishan dam has been designed as a Rockfill dam with clay core. The purpose of the dam is flood control, providing facilities for fishing, recreational and touring facilities, water supply and distribution for domestic and irrigation of agriculture land. The dam and its associated structures are mainly founded on schist conglomerate and schist limestone. This paper explains permeability and groutability assessment of dam foundation based on secondary permeability index (SPI), hydraulic aperture and Lugeon test and ability to control seepage water from foundation and abutments.

Geology Setting

Geological factors play a major role in designing and constructing a dam. Of the various natural factors that influence the design of dams, none are more important than the geological ones. Not only do they control the character of formations, but they also govern the material available for construction. There exist numerous examples of projects where the conditions of the foundation were not sufficiently known and the cost of construction and treatment greatly exceeded the original budget (Ichikawa, 1999). According to the classification of Iran tectonics aspects of structural-sedimentary by different researchers, the studying region is placed Sanandaj-Sirjan plain. The dam and its associated structures are mainly founded on schist conglomerate and schist limestone (Fig. 2). This rocks consisting chertly conglomerate with interbeding schist-limestone layers. This rocks unit has limestone cement and rubble of its components mainly consist orbitolina limestone Paleocene age, sandstone, volcanic rocks and slate. The rubble has weak roughness and sorting. This conglomerate unit is impermeable. The discontinuity data were interpreted statistically to define the rock-mass conditions of the dam site and reservoir area. The discontinuity surveying was undertaken according to the suggested method of the International Society of Rock Mechanics (ISRM 1978) at dam site in order to provide basic parameters for classification of the rock mass and to determine engineering characteristics of the rock mass. Generally, three representative joints sets are identified in damsite: J1:71/101; J2: 32/297, J3: 61/009 (Bedding plane). The quantitative descriptions and statistical distributions of discontinuities of rock units derived from boreholes and those obtained from the geomechanical mapping through scan lines at the dam site according to ISRM (1981) are summarized in Table 1.

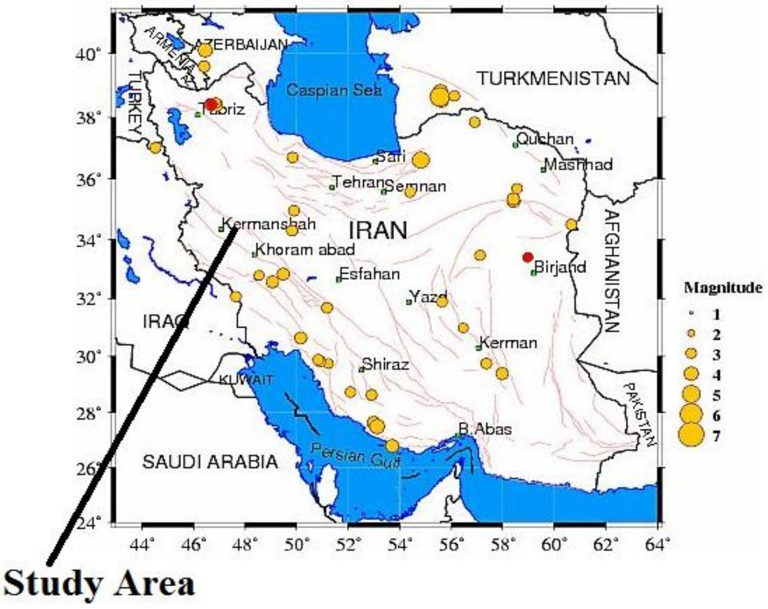

Figure 1: location of Jamishan damsite

Table 1: characteristics of joint set and bedding plain in damsite.

Joint Set	Dip/Dip direction	Spacing (m)	Persistence (m)	Roughness (JRC)	Aperture (mm)	Infilling
J1	71/101	0.2-0.6	1-3	2.3	<1mm	Calcite
J2	32/297	0.2-0.6	1-3	2.3	<1mm	Calcite
J3 (Bedding plane)	61/009	0.2-0.6	1-3	2.3	<1mm	Calcite

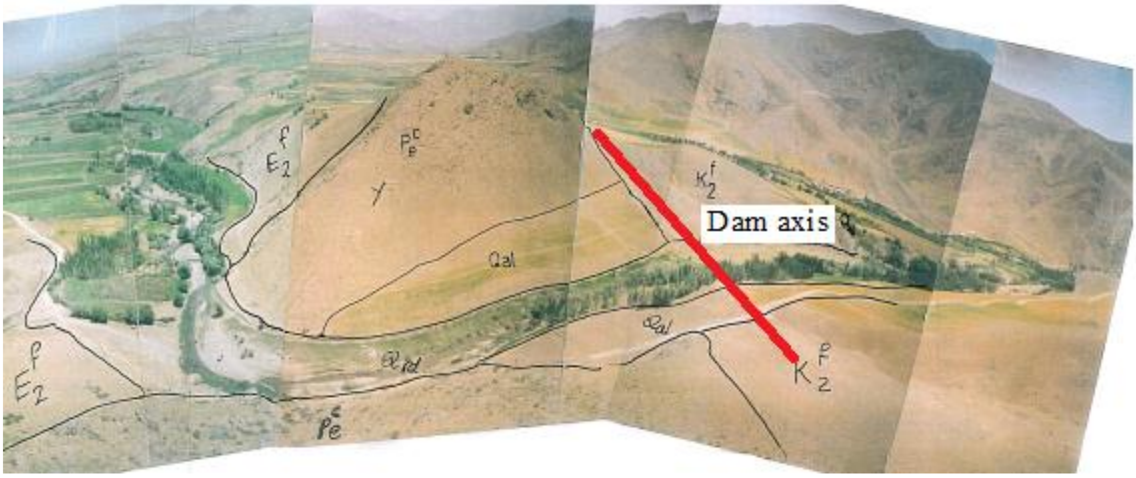

Figure 2: abutments and damsite axis (see NE-SE).

Permeability

Water pressure test is the most common and appropriate method in order to determine rock mass permeability due to the presence of weak planes. The results of rock mass permeability test are strongly related to the geometric characteristics and weathering degree of the water paths (Ewert 1997a , b, c and d; Karagüzel and Kilic¸ 2000). The results of the water pressure tests can be used to delimit the zones of the dam foundation that show different rock mass quality (Foyo et al. 2005). At present, it is broadly accepted that the water pressure test can induce modifications in the joints characteristics (Shibata et al. 1981; Kutzner 1996; Foyo and Sánchez 2002). The rock mass quality of the test section obtained from water pressure test completed with the degree of jointing of the drill core acts as a useful reference for ground treatment design (Foyo et al. 2005). The underlying foundation with unknown discontinuities needs to be improved to raise its engineering properties and ensure a watertight reservoir. Using cement grouting to improve bedrock has been quite common (Verfel 1989; Deere 1982; Houlsby 1992), and there are numerous examples of its application to the engineering of dam foundation improvement (Ewert 1985; Weaver 1991; Warner 2004). In this paper permeability and groutability of based on Secondary Permeability Index (SPI), hydraulic aperture of joint and Lugeon test were investigated.

Water Pressure Test (WPT)

The hydraulic conductivity of the rock mass at the damsite was evaluated by conducting a number of Lugeon tests. One of the main objectives of these tests is to determine the ‘Lugeon Coefficient’, i.e., water absorption measured in liters per meter of test per minute at a pressure of 10 kg/cm^2 ($1 Mn/m^2$). Eq. (1) is the definition of the Lugeon value expressed as:

$$\mathrm{Lu} = \frac{VP_s}{TP_iL} \qquad (1)$$

Where V is the water take (lit), P_s is the standard injection pressure (981 kPa), T is the injection time (min), P_i is the injection pressure used (kPa) and L is the length of grout section (m). The Lugeon value is the best physical parameter to express the status of discontinuities in a dam foundation. The pressure of the test is usually adjusted to take account of the depth and the type of rock mass. The information obtained from the water pressure tests can also be used to determine water/cement ratio and grout injection pressure used in the grouting operation. Houlsby (1990) suggested that when the Lugeon values are below three, no grouting is necessary, when they are between 3 and 10; a single row of grouting holes is required while with values of over 10, a grout curtain should include three rows of grouting holes. The result of this test, aided with a diagram, introduced 5 behaviors: linear, tabulated, joint filling, wash out and dilation. Kutzner (1996) found 5 behaviors based on P-Q diagram, but it was different from the viewpoint of Houlsby. However, Ewert did a geology interpretation on Lugeon test, using P-Q diagrams. In addition to the 5 behaviors, he interpreted the WPT results, so that, saturation and tight rock mass, for the first time, is used to analyze hydraulic fractures. For the first time, Lugeon described water pressure test and then other researchers did many interpretations on these tests. However, Houlsby (1990) interpreted this and the hydro-jacking phenomenon.

Secondary Permeability Index (SPI)

To describe and estimate the permeability of jointed rock, the result of water pressure test should be transferred to k-value instead of lugeon value. Much more effort had been done to find correlation between the result of water pressure test and k-value. This problem was solved by using Secondary Permeability Index method (SPI). The Secondary Permeability Index (SPI) usually, expressed from the conversion of the take of water pressure test into a permeability coefficient analogous to porous mass (Foyo et al 2005). Usually, the grouting of the dam foundation requires that the rock mass be previously divided in zones with different ground treatment. The Secondary Permeability Index (SPI), based on water flow trough fissures, allows zoning the dam foundation regarding different quality classes. The importance of the SPI method is possibility of distinguishing difference between dilation and hydraulic fracturing. The dilation is occurred at elastic manner, but the hydraulic fracturing is occurred at plastic manner (Ajalloeian and Moein 2009). Therefore, the Secondary Permeability Index (SPI) is defined as follows:

$$\mathrm{SPI} = C\frac{\mathrm{Ln}\left(\frac{2le}{r}+1\right)}{2\pi le}\frac{Q}{Ht} \qquad (2)$$

Where SPI Secondary Permeability Index, l/s per m^2 of borehole test surface. C constant depending upon viscosity for an assumed temperature of rock at 10 ºC, 1.49×10^{-10} (Snow, 1968). le length of the test section (m), r borehole radius (m), Q water flow absorbed by fissured rock mass (l), T duration of each pressure level (s) and H total pressure expressed as water column (m).

The SPI establishes a new permeability based rock mass classification (Table 2). Based on this classification, different considerations regarding ground treatment are proposed (Foyo et al. 2005). The proposed classification differs from classical geomechanical classifications. Most critically, it does not reflect the strength of the intact rock. Instead, the classification defines the quality of the rock mass based on the permeability of the discontinuities (Foyo et al. 2005).

Table 2 Rock mass classification based on the SPI and ground treatment considerations (Foyo et al. 2005)

	Secondary Permeability Index, SPI ($1/s\ m^2$)			
	$< 2.16\times10^{-14}$	2.16×10^{-14}	1.72×10^{-13}	1.72×10^{-12}
Rock mass	Class A	Class B	Class C	Class D
Classification	Excellent	Good–Fair	Poor	Very poor
Ground Treatment	Needless	Local	Required	Extensive

Hydraulic Aperture of Discontinuities

In order to understand and quantify the influence that discontinuities have on rock mass behavior, it is necessary to measure and represent the relevant characteristics of the discontinuities quantitatively. Characteristics of joints greatly influence permeability and cement take. As mentioned earlier, the characteristics include aperture, roughness, frequency, persistence, filling, orientation and dip (Bell, G. 2000). The mechanical aperture, or opening, e_m of a discontinuity is here defined as the distance between the opposing interfaces measured along the mean normal to the discontinuity surface. Mechanical aperture is usually generated as a result of geological shear displacement along an irregular discontinuity surface. Discontinuity apertures in rock immediately adjacent to a free surface are also particularly susceptible to opening as a result of blast induced vibrations, erosion and washing out of infill (Priest, P. 1993). The permeability of most of igneous and metamorphic rock materials, and many of sedimentary rock materials, is negligibly small. This low permeability for material means that the flow of fluids through the material and hence the permeability of rock mass of this type are dependent on the geometry of the fracture network. Since the flow of fluid along a single fracture is dependent on its aperture, any measure of permeability of a mass provides indirectly a measure of the effective hydraulic aperture of the conducting discontinuities as (Priest, P. 1993):

$$e_h = \left[\frac{42 Q_t \nu}{\lambda g \pi h H_o}\right]^{1/3} \qquad (3)$$

Where Q_t is total flow (m^3/s), λ is the discontinuity frequency, h is length of section, v is viscosity of water and H_o is effective pressure in section. All of the parameters in Eq. (3) can be measured directly, except discontinuity frequency, λ, which may be obtained from Eq. (7). Barton et al. (1985) concluded that the theoretical smooth wall effective hydraulic aperture e_h is generally less than the mechanical aperture e_m determined by the physical measurement techniques outlined above. They found that flow test results reported for a range of rock types indicate that the ratio e_m/e_h was close to unity for smooth-walled discontinuities of relatively large aperture, but this ratio is increased to values exceeding 7 as the roughness and the aperture were increased. Barton et al. (1985) also found that the following Eq. is valid for em ≥ eh and provides the best model for the observed flow test data trends (Barton et al. 1985 & Barton 2008).

$$e_h = \frac{{e_m}^2}{(JRC)^{2.5}} \quad em \geq eh \qquad (4)$$

Discontinuity frequency λ is one of the fundamental measures of the degree of fracturing in a rock mass. Frequency can be expressed in terms of the frequency discontinuities that are observed or predicted to occur in a unit volume, a unit area or a unit length of a sample from a given rock mass (Snow 1970). Also RQD (rock quality designation) proposed by Deer 1964 as a measure of the quality of borehole core, is defined as the percentage of a given length of core (or length of borehole) that consists of sound, intact pieces which are 0.1 m (4 inch) or longer (Deer 1964 and 1989). Figure 3 shows variation of theoretical TRQD given by Eq. (5), plotted against discontinuity frequency λ (Priest and Hudson 1976), for a general threshold value of t=0.1as:

$$TRQD = 100e^{-\lambda t}(1 + \lambda t) \qquad (5)$$

Priest and Hudson 1976 showed that a linear approximation to Eq. 3 for t = 0.1 m is given by the tangent to the curve at the inflection point where The Eq. (6), for this tangent is given by:

$$TRQD_{0.1} = 110.4 - 3.68\lambda \qquad (6)$$

To estimate the discontinuity frequency λ for the borehole core, Eq. 3 cannot be inverted to yield λ explicitly in terms of RQD. Therefore, it is necessary to adopt an iterative method for determination of λ. A good starting point for this iteration can be found by inverting the linear approximation in Eq. (6), hence

$$\lambda = \frac{110.4 - \mathrm{TRQD}}{3.68} \qquad (7)$$

Also flow transmitted of each joint calculated with Eq. (8) is expressed as:

$$\mathrm{F_j} = \frac{10\mathrm{Q}}{\mathrm{P_e.N_j}} \qquad (8)$$

Where F_J is flow transmitted of each joint, N_j is the discontinuity frequency, P_e is effective pressure in section, Q is total discharge (m^3/s).

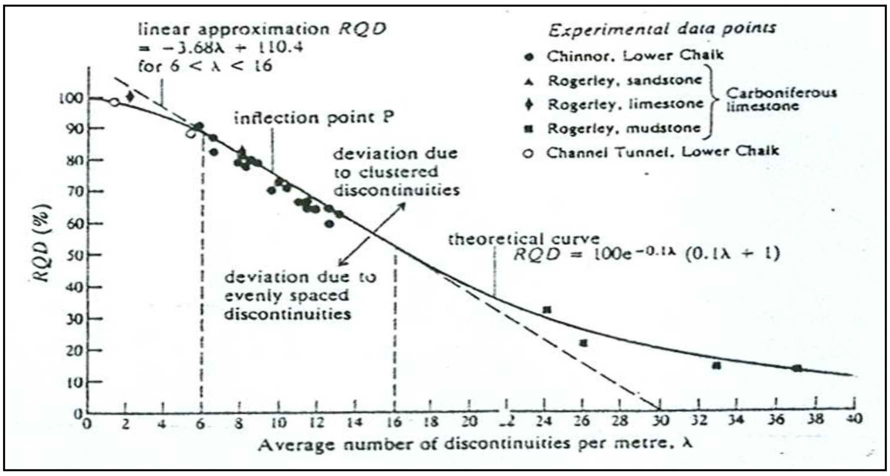

Figure 3: Relation between TRQD and mean discontinuity frequency (after Priest and Hudson 1976).

Investigation permeability based on Lugeon

The results of the water pressure tests (WPT) conducted at the damsite are plotted in Fig 4. based on Ewert 1997 classifications about 80% of sections are impermeable. Generally, in damsite about 84% has permeability less than 3 lugeon and 16% other has permeability more than 3 lugeon (Fig.4). High permeability values exist until 15 m of the ground surface and correlation between permeability and depth for the rock units in the dam site shows a reduction in permeability with increasing depth. In addition, analysis of drilling data shows that permeability rises in low quality rock masses.

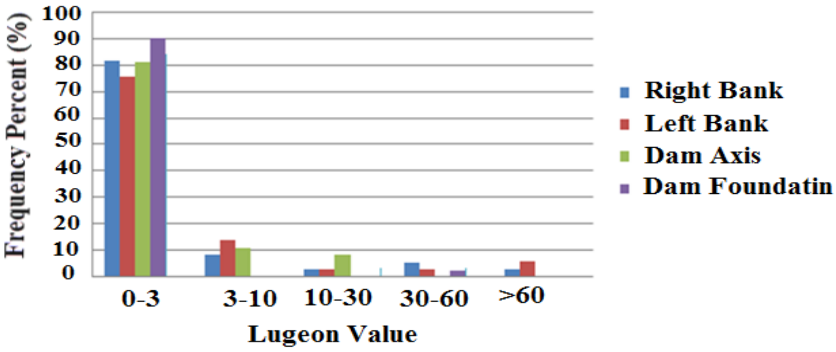

Figure 4: graph of varing permeability in damsite rock mass

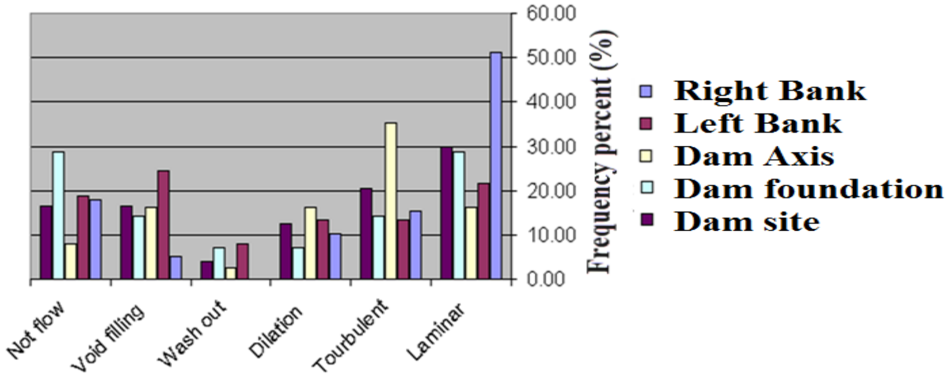

Figure 5: Type of water flow in various parts.

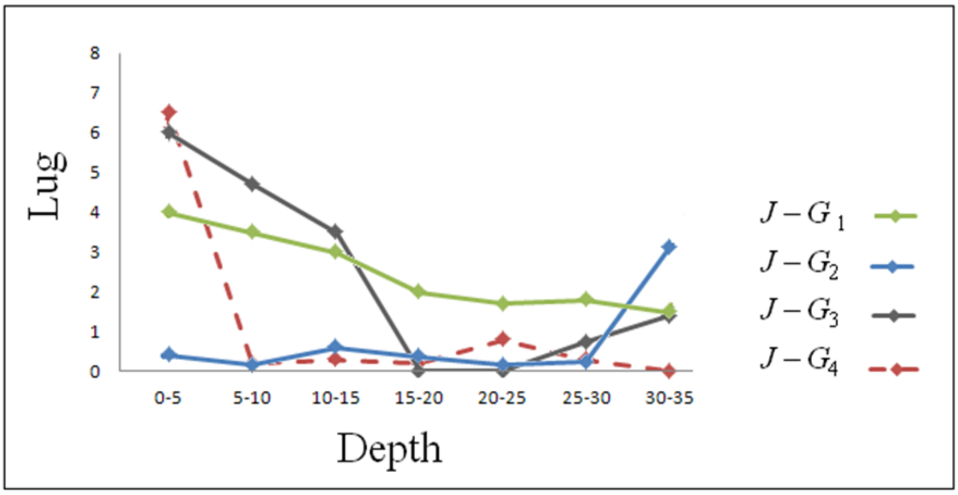

Figure 6: Relation between permeability and Depth in right borehole

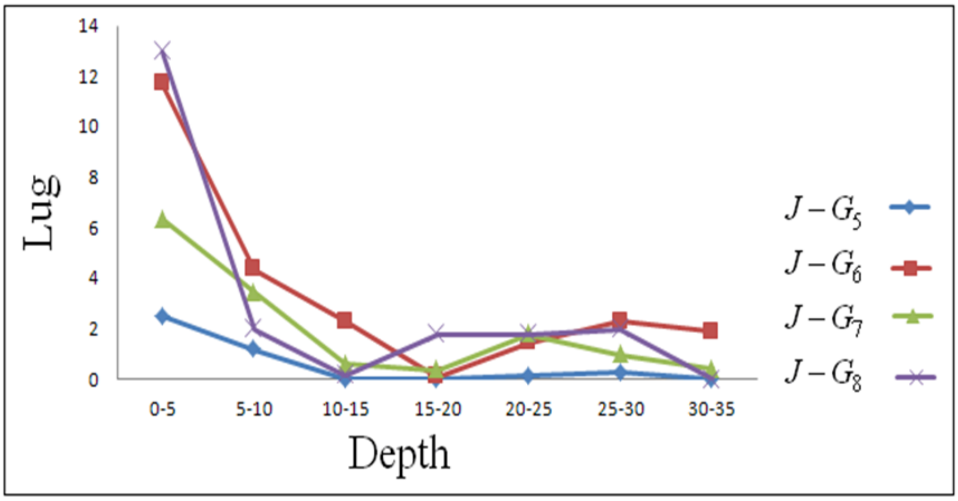

Figure 7: Relation between permeability and Depth in dam axis

It can be seen that laminar flow has most frequency in right abutment that indicate an increasing pressure of water take in with increasing depth (Fig. 5). In left abutment, void filling is dominant flow that shows filling of joints. Turbulent flow is dominant in dam axis that indicate high opening of joint and high groutability potential. Generally, laminar flow has more frequency and wash out flow has minimum frequency in damsite. The correlation between permeability and depth for the rock units in the dam site shows a reduction in permeability with increasing depth (Figures 6 & 7).

Investigation and Analysis Permeability Based on Hydraulic Aperture

In this paper analysis of joints hydraulic aperture carried out only in experimental grouting borehole. Experimental grouting drilled in right abutment and dam axis. In right abutment, three trial grouting borehole (J-G1, J-G2 and J-G3) was drilled to depths of up to 35 m at 2 m spacing with angle 25 degree versus vertical. A trial grouting layout triangular form was designed and grouting operation was checked by J-G4. Also, in dam axis three trial grouting borehole (J-G5, J-G6, J-G7) drilled to depths of up to 35 m at 2 m spacing with vertical angle. A trial grouting layout triangular form was designed and grouting operation was checked by J-G8. It is known that intact rock may not conduct fluid whereas in rock mass, discontinuities conduct fluid. To investigate effect of discontinuities on permeability and groutability of rock mass in Jamishan dam foundation, joint frequency, hydraulic apertures and flow transmitted of each joint were initially calculated from Eqs. (7), (3) and (8) for each section of all the boreholes, respectively. According fig.8 in the right abutment most joints has high aperture and only J-G2 borehole has joints with 0.2 mm opening. Also, there is no meaningful relation between joint frequency and joint aperture. Also, according fig.9 in dam axis most joints has frequency about 0.4 mm that is similar right bank. In fig.9 is no meaningful relation between joint frequency and joint aperture.

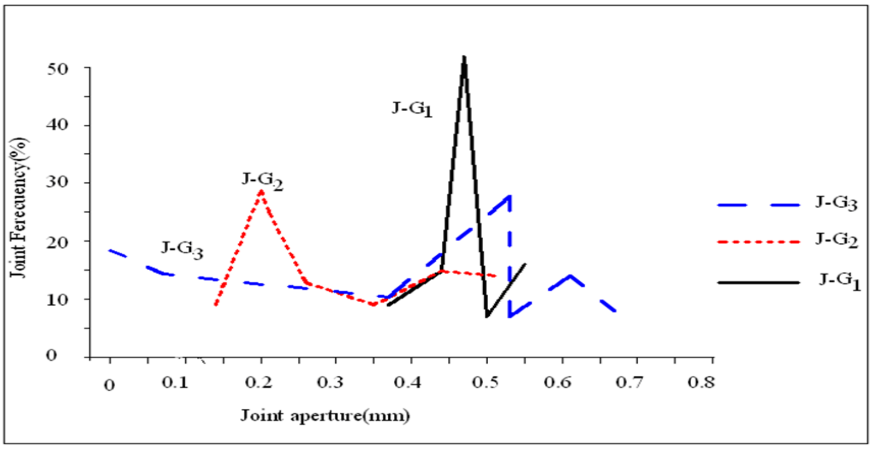

Figure 8: relation between joint aperture and joint frequency in right abutment

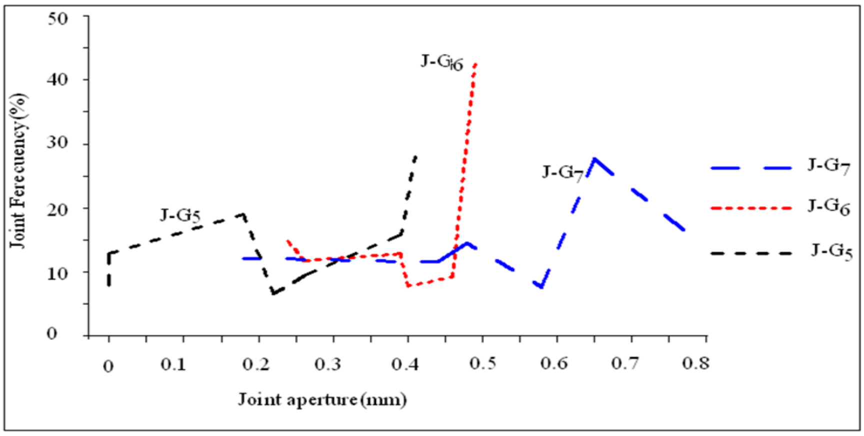

Figure 9: relation between joint aperture and joint frequency in dam axis

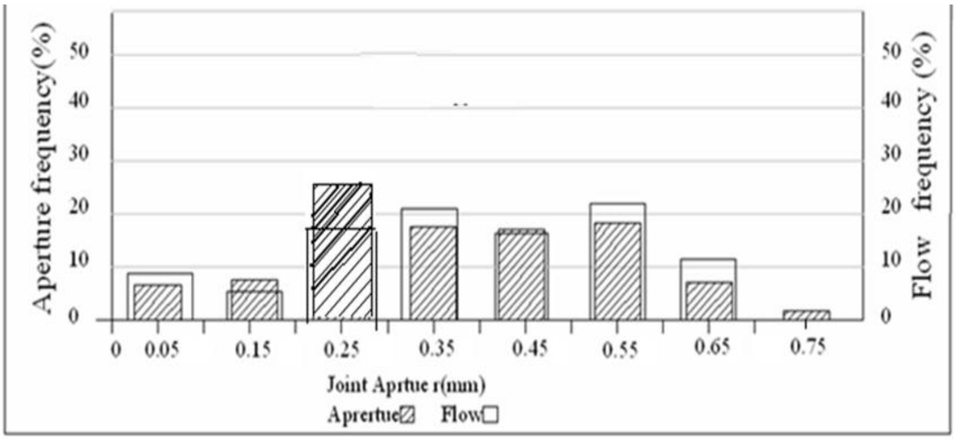

Figure 10: joints frequency and flow transmitted of joints in damsite.

According fig.10 most joints has opening about 0.25 mm. Generally, hydraulic joint aperture has fluctuated between 0.2 – 0.6 mm. The joints with aperture 0.5 mm about 9% total flow in damsite transmitted of itself that indicate capillary crack and fracture with high hydraulic activity. There is also a good correlation between flow frequency and joint frequency.

Evaluations of Permeability and Groutability Based on the SPI

Pressures carried out in tests are differ that main reason it's due of high varing RQD value and varing permeability in different depths. The correlation between permeability and depth for the rock units in the dam site shows a reduction in permeability with increasing depth and in addition, analysis of drilling data shows that permeability rises in low quality rock masses except in 30-35 m depth with increasing permeability and RQD and rock unit similar that shows effect joint orientation versus drilling direction. In dam axis, about 75% section situated in A class based on SPI values that ground treatment is needless (Fig. 11). The 25 % of sections situated on the B class based SPI values that need to be improved locally. In right abutment, about 57.2 % section situated in A class based on SPI values that ground treatment is needless (Fig. 12). The 42.8 % of sections situated on the B class based SPI values that need to be improved locally (Fig.12). In trial grouting borehole C and D class based on SPI classification are not observed that shows low groutability potential.

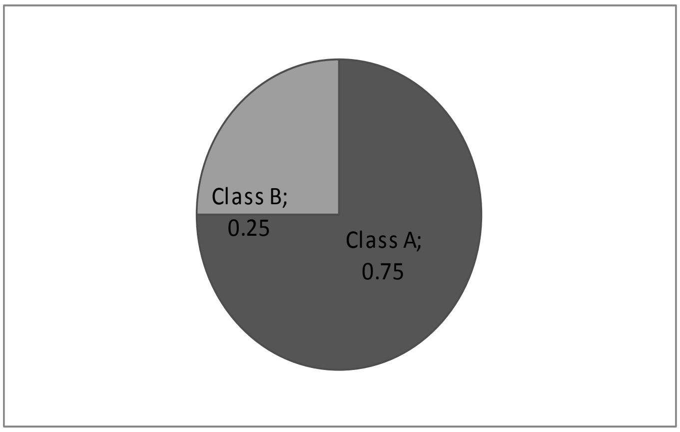

Figure 11: Rock classification based SPI value in dam axis.

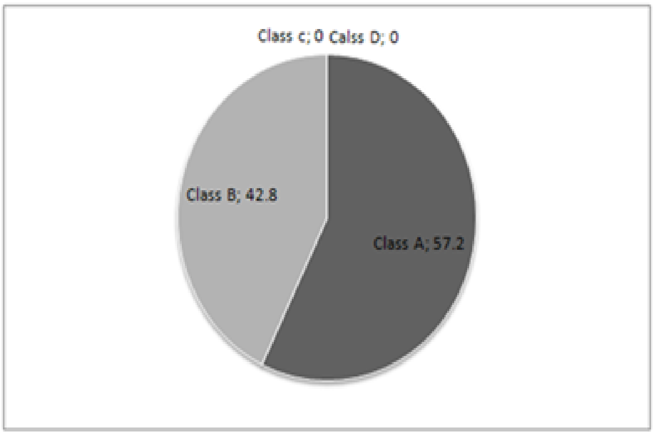

Figure 12: Rock classification based SPI value in right bank.

Sealing plan in damsite

One of the methods for prevent of escape water is using grout curtain. The appropriate depth for grouting is 25-40m with considering result obtained of studies and calculations of hydraulic joint aperture, lugeon value and SPI. The spacing borehole is variable between 0.3 to 3 m that this distance associated to joint area, joint orientation, strength of rock mass and length borehole. In Jamishan dam based on results of trial grouting borehole, borehole spacing is 1 m recommended. According Bruce et al 2007 Groutability Ratio (G.R) determined for open joints, followed as:

$$\mathrm{G.R} = \frac{\text{Crack width}}{\text{D95 of Grout}} \qquad (9)$$

For joints less than 0.2 mm can be use of cement Portland III type and for joints more than 0.2 mm must be use of cement Portland I type. With considering joints distribution in damsite cement Portland I type recommended for grouting operation. Dip proper for borehole grouting is between 20^{o}-55^{o} according calculation and draw polar of joints and bedding dip (Fig. 13).

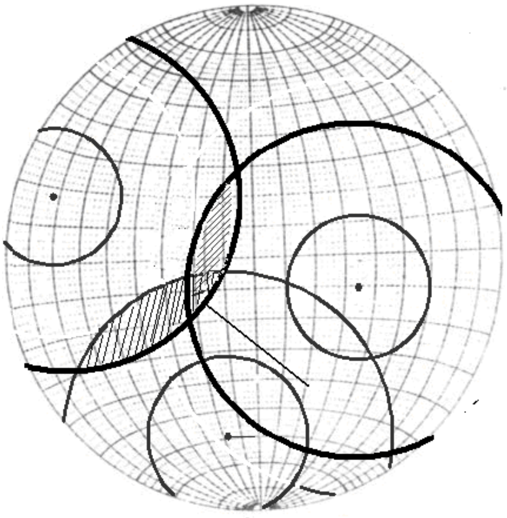

Figure 13: Dip and Dip Direction for drilling borehole grouting in damsite by stereonet.

Conclusion:

Due to rock mass permeability and groutability because of complexity of rock mass, it is not possible to evaluate by using only WPT. In this regard, in present study using SPI method, hydraulic joint aperture and degree of jointing to overcome this weakness. The following results and conclusions can be deduced from the present study:

1- Bedding plane is parallel with dam axis and its dip is toward upstream and this condition provides prevent escape water of dam foundation.
2- Generally, in damsite about 84% has permeability less than 3 lugeon and 16% other has permeability more than 3 lugeon.
3- laminar flow has most frequency in right abutment that indicate an increasing pressure of water take in with increasing depth but in left abutment, void filling is dominant flow that shows filling of joints. Turbulent flow is dominant in dam axis that indicate high opening of joint and high groutability potential. Generally, laminar flow has more frequency and wash out flow has minimum frequency in damsite.
4- The correlation between permeability and depth for the rock units in the dam site shows a reduction in permeability with increasing depth.
5- There is no meaningful relation between joint frequency and joint aperture.
6- Generally, hydraulic joint aperture has fluctuated between 0.2 – 0.6 mm. The joints with aperture 0.5 mm about 9% total flow in damsite transmitted of itself that indicate capillary crack and fracture with high hydraulic activity.
7- There is also a good correlation between flow frequency and joint frequency.
8- In right abutment, about 57.2 % section situated in A class based on SPI values that ground treatment is needless. The 42.8 % of sections situated on the B class based SPI values that need to be improved locally.
9- In dam axis, about 75% section situated in A class based on SPI values that ground treatment is needless. The 25 % of sections situated on the B class based SPI values that need to be improved locally.
10- In trial grouting borehole C and D class based on SPI classification are not observed that shows low groutability potential.
11- Cement Portland I type recommended for grouting operation with considering joints distribution in damsite.
12- Dip proper for borehole grouting is between 20^o-55^0 according calculation and draw polar of joints and bedding dip.

Akcnolngment

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