# A Study of Lugeon Test Distribution and Uncertainty, with an Overview to the Test Advantage and Limitation

**Ghasem Deravi[1*], SasanTayyari[2], AmirHafezquran[3], Asad Mahrofi[4]**
1- Head of site supervision of drilling and grouting, Mahabghodss Consulting Engineering
2- Chief supervision engineer,Mahabghodss Consulting Engineering
3- Engineer site supervision of drilling and grouting, Mahabghodss Consulting Engineering
4- Site engineer of drilling and grouting, Omran-maroon Construction Company

*Email:Deravy@gmail.com

## Abstract

In 1933, Maurice Lugeon was first proposed the idea of "Lugeon test". Since that time, the test has been performed to estimating both permeability and groutabilityof dam foundation. The test being widely used for designing the dam curtain, despite that, there are some defects and limitations about the efficiency of test results.The result of lugeon test in three distinctive dams which located in north-west of Iran, in this article, has been discussed. distribution of Lugeon test values and behavior are investigated in this paper, also stated about use of real time monitoring by digital recorder advantage.

**Keywords: Lugeon test, Permeability, Dam, Grouting.**

## 1. INTRODUCTION

The Lugeon test introduced by MauriceLugeon in 1933, which is well- known in geotechnical engineering[1]. Test results are being widely used for estimating the permeability,groutability,seepage anderodibilityof rock mass in dam construction. It can be utilized for groutingnecessity and efficiency, selecting the most proper material and pressure for rock grouting, and predicting water seepage during tunnel excavationas well[2].

The Lugeon test is a type of constant head method in which a portion of the borehole is isolated with packer and water is injected into the isolatedstage in increasing and decreasing sequence pressure steps (usually 5 to 7 steps).The test interprets by plotting the pressure versus the rate of water absorption. Lugeon unit define as the rate of water absorption of 1 liter per minute and per meter borehole at 10-bar pressure.Figure 1 illustrates fivetypical behaviors of Lugeontest, presented by Houlsby(1976)[3]and revised by Quiñones-Rozo (2010)[4].
Despite its wide range of applications, this test has limitations and defects. Lugeon result has a poor correlation withhydraulic conductivity and grout take.It is impossible, by this test, to estimate long-term erodibility of dam foundation materials[5].Alist ofdefects related to the Lugeon testsuch as errors connected to test hypotheses, analysis of test results, implementation method and equipment are announced by Preene 2018. As an example, being 'small-scale' and short duration could be considered as a primary limitation [6].

Milanovic (2018) believe that hydraulic conductivitycannotbe evaluated by Lugeon test in karstifiedformations. In such cases,depend on karstified intensity, maximum planned pressure may not be reached.Therefore, satisfying results mainly can be gainedwithlower pressures (1 to 3bars). In his point of view, it is essential to divide the section into smaller stags for determiningkarstsifiedzones in highly cavernous rocks[7].

Purpose of the test play a significant role ontheaccepted accuracy of the Lugeonresults. The precision of the test depend onseveral factors namely assumptions, data measurement methods, test equipment and finally its execution factors.Holesby(1990)[8], Kutzner(1994)[9], and Quiñones-Rozo(2010)[4], have announced the sensitivity of the Logan test with respect to its values as in Table 1.In the sealing criteria ranges (less than fiveLugeon), the Lugeon test is the most accurate one. The accuracy of the test results decreases by increasing Lugeonvalues and it severely reduces in the range of more than 100 lugeons; that is why most researchers do not distinguish the values above 100 Lugeons.Tesema etal (2018)[11]have discussed the uncertainty of lugeon test in hydraulic conductivity estimation.

Holesby 1990 emphasizes that if the values of Lugeon are between 0 to 1, the trend should be roundedtoone,regardless the main criteria, its behavior considered as laminar[8]. On contrast, Sanchez 2002 argues that such a situation cannot always be modeled as laminarflow[11].Quiñones-Rozo(2010)stated that

Lugeon values of less than one,are related to the rock mass with a very tight discontinuous system and classified asvery low permeability [4].

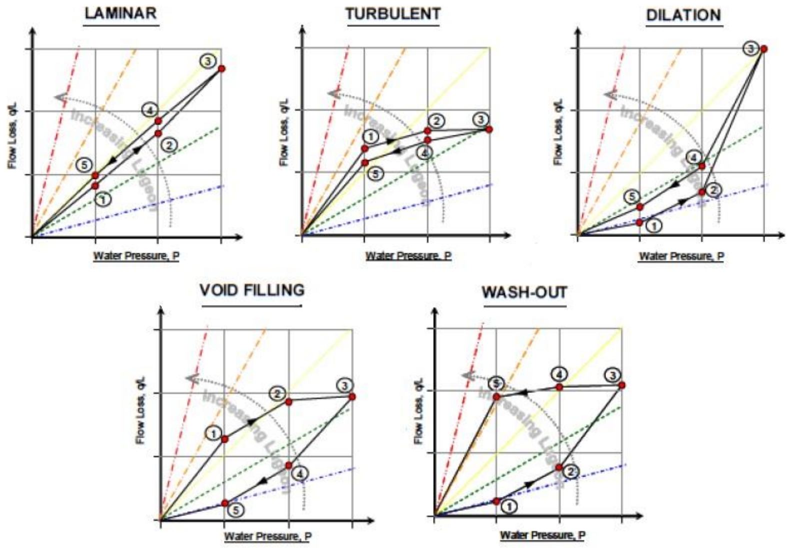

**Figure 1. Flow-pressure behavior in Lugeon test (Quiñones-Rozo, 2010)**[4].

**Table 1- Accepted accuracy for range of Lugeonvalues by different researchers**

| Houlsby, 1990, [8] | | Kutzner, 1996, [9] | | Quiñones-Rozo, 2010, [4] | |
|---|---|---|---|---|---|
| Lugeon Range | Accepted Accuracy | Lugeon Range | Accepted Accuracy | Lugeon Range | Accepted Accuracy |
| < 5 | 1 | 1-10 | 1 | < 1 | < 1 |
| 5-10 | 2 | 10-20 | 3 | 1-5 | 0 |
| 10-15 | 5 | 20-40 | 5 | 5-15 | ±2 |
| 15-50 | 10 | >40 | >40 | 15-50 | ±5 |
| 50-100 | 30 | | | 50-100 | ±10 |
| >100 | >100 | | | >100 | >100 |

In this paper,Lugeonvalues in which all steps are less than one, hasclassified as ” Impermeable” without defining the behavior.

## 2. LOCATION OF THE DAMS

Figure 2 shows the position of the three dams studied in this paper on the Iranian map. These dams has built or under construction to supply drinking water, power generation and water transferring.

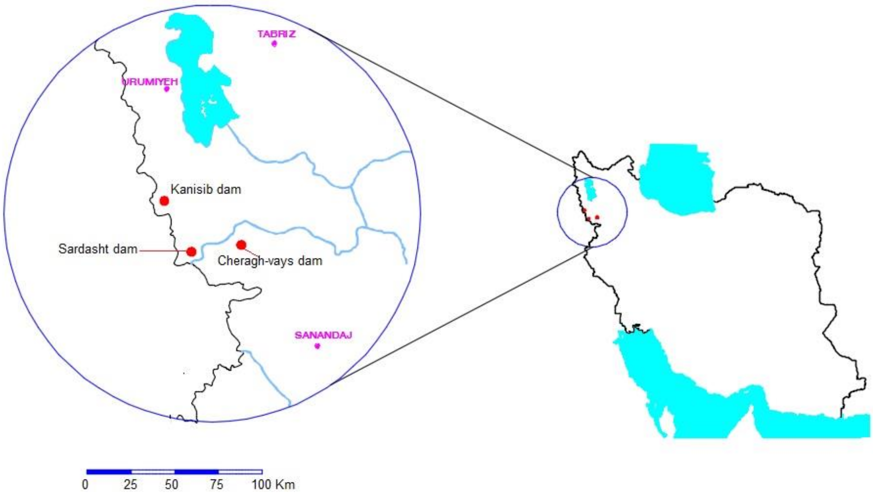

**Figure 2. Location of studded dam on IRAN map**

## 3. LUGEON INTERPRETATION

As mentioned, different factors such as geoengineering parameters, test purpose, the accuracy and efficiency of the test,should be considere in interpretation of the Lugeon test criteria.

In this article, theLugeon test results in three distinctive dams, located in northwest of Iran, have been interpreted and evaluated.Dam foundationsconsistof igneous and metamorphic rocks,and Lugeon valuesare generally in the range of moderate to low permeability.

### 3-1. KANISIB DAM

The Kanisib Dam is aclay core earth-filldam, and 60m in height.The dam foundation consists of granite-andesitic igneous rocks.The left bankis mainly light gray granites, the central foundationcomposed of granite to granodiorite and the right bank is diabase.On the left bank,there are couple of critical zones in different levels,characterized by close spacing joints(zone width of about 5 to 7 m).The most important complication in central foundation includes a high-altered granite due to hydrothermalphenomena,and four tectonic faults.A relatively large intrusive dyke,which extends to the middle part of the spillway, affects the right bank foundation[12].

About 200Lugeon tests has been done in curtain exploratory boreholes along dam axis.Fig. 3 shows the frequency of values and behaviorsagainst depth in the Kanisib dam. According to the figure, Lugeon value decreases with deepening (increasing depth).The representative values in wash-out behavior aregenerally more than 5Lu and it scattering at depths less than 35m,whilstin Laminar and dilation behaviors are broadly less than 5Lu, they are spread throughout borehole depth.Laminar and turbulent behaviors are the most frequent ones with 23% and 14% respectively.Impermeable(Lu<1) accounts for about 46% of the frequency of Lugeonresults.

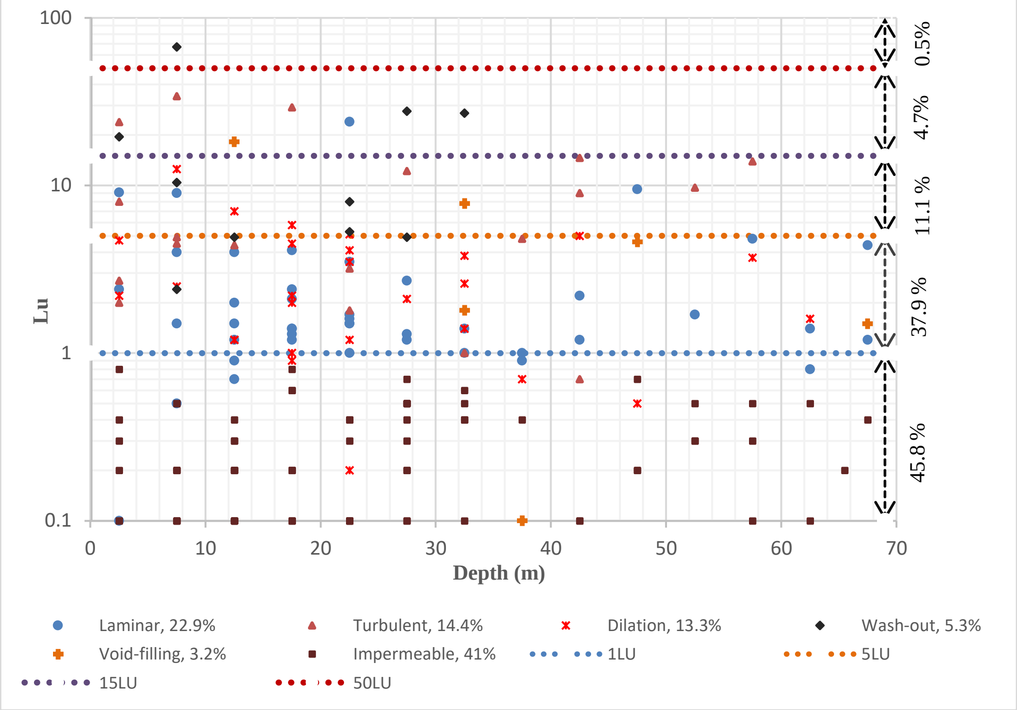

**Figure 3.Lugeon values and behaviorsdistribution versus depthin Kanisib dam**

Nowadays, continuous monitoring of test databy digital recording equipment can be considerably helpful in test result interpretation.The pressure andflow rate are two critical performance parameters.Becausethe sudden changes of these parameters real time monitoring is strongly recommended[13].

Figure 4shows an example of the Lugeon test data plotted with digital recorder in the Kanisib dam.In this graph, test pressure,cumulative and instantaneous rateof water absorptionare plotted continuously, and the lugeon value is shown as a column corresponding to each step.According to the diagram, the Lugeon values decreaseas the test proceeds, so it indicates void-filling behavior. Checking the cores of the test stage shows that the bedrock is partly altered hydrothermal graniteand discontinues plugging are taking place.Therefore, the test behavior is consistent with the geological conditions of the test stage.

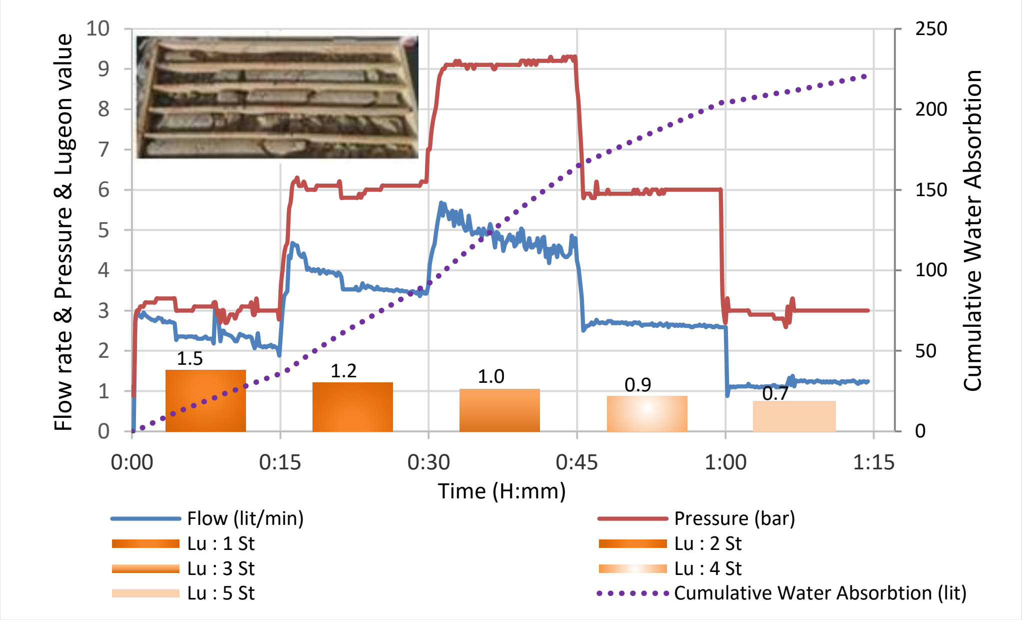

**Figure 4. Continuesdata recording by the digital recorder**

Figure 5 illustrates another example for digital recording ofhydraulic-fracturing test(30-35 meters stage) in which pressure against flow rateare plotted.According to the pressure diagram,approximately 11-bars is the turning point of the curve, after which the pressure diagram slope changes and this pressure is considered as the critical pressure.By this method, critical pressure determined precisely, therefor, this method has more advantages than thetraditional water pressure test.

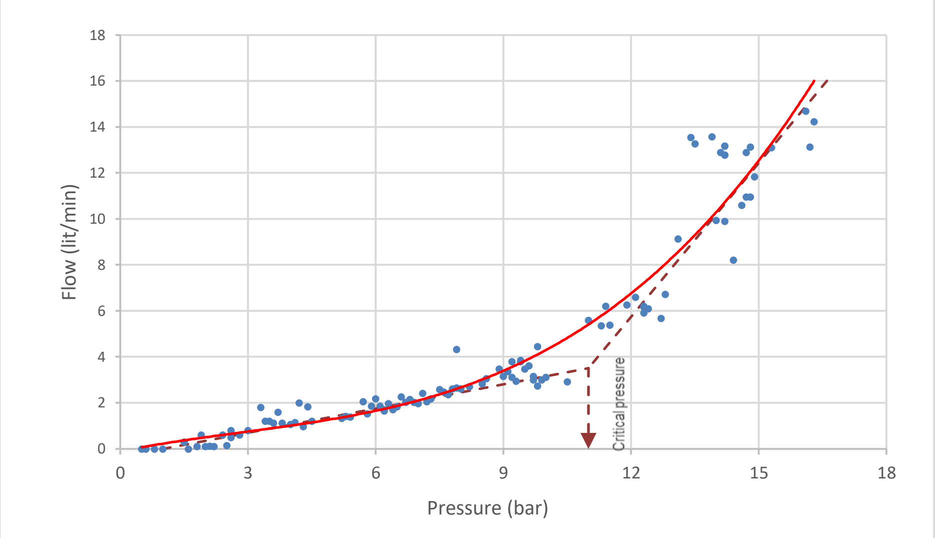

**Figure 5. Hydraulic-fracturing test by digital data recorder.**

## 3-2.Sardasht Dam

Sardashtdamisa clay core rock-fill dam with a height of 112 m.The dam site generally formed from Slate rocks, with locally meta-sandstoneand siliceous veins.Rock masses in the near-surface sections are highly weathered and generally are weak to very weak strength.However, often in depth of more than 10 to 15m, weathering and permeabilityare significantly reduced and rock mass strength increases [14].

Figure 6 shows the frequency distribution of the Lugeon test values and behaviorsagainst depth at the Sardasht Dam site.Wash-out behavior is seen at depths less than 25 m, andrepresentedLugeon is generally over 5 Lu.The dispersion of laminar behavior can be seen in almost all depths of the exploratory boreholes.Laminarflow in more than 10 Lugeon probably indicates a system of high frequencynarrow joints.According to the figure, about 60% of the Lugeon values are less than 5 and the highest frequency is related to laminar and turbulent behavior with 30% and 24%, respectively.Impermeable accounts for about 28% of the frequency of Lugeon results.

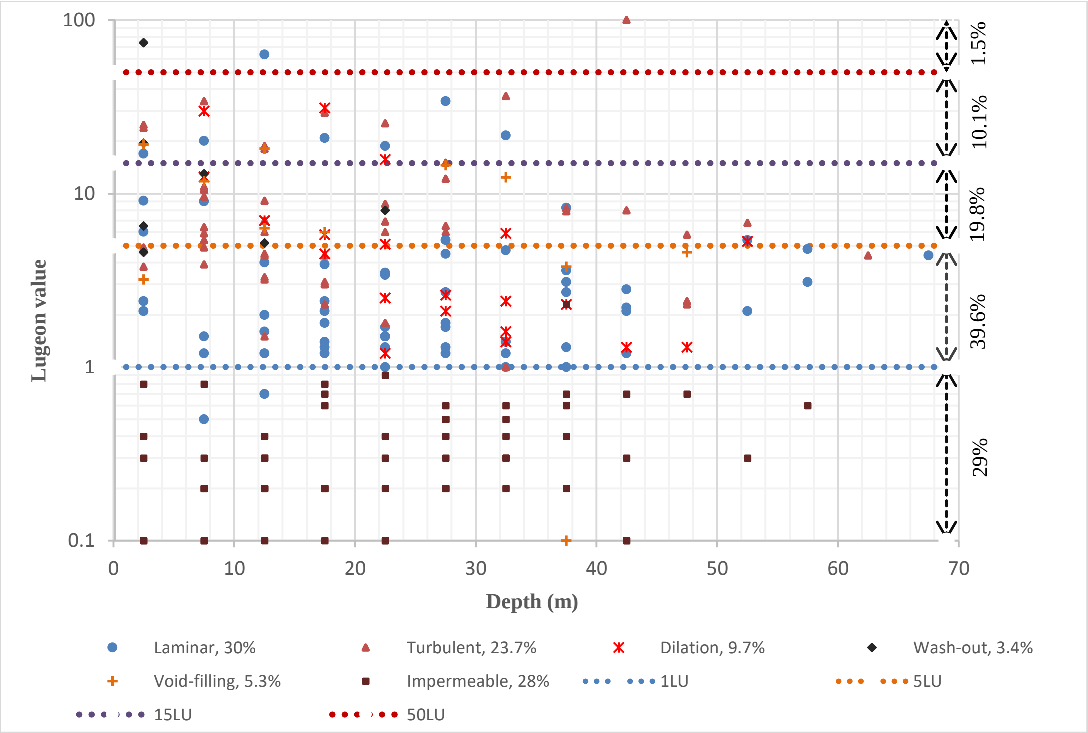

**Figure 6.Lugeon values and behaviors distribution versus depthin Sardasht dam**

### 3-3. Cheragh-vays dam

Cheragh-vays is a rock-fill dam with clay core type and 62m in height, located in the Sanandaj-Sirjan tectonic zone. The dam site consists of diorite to quartz-diorite rocks with sub-vertical rhyolite dikes, and alternative schistose schistdue to tectonic forces. Injection of hydrothermal quartz into the structural joints led to an alterationof surrounding rocks especially in schist formations. The extent of hydrothermal weathering ondam foundation is much less than reservoir area. Clay-filled joints have extended in the dam foundationup to 8 meters in depth[15].

About 50Lugeon tests have been performed in exploratory boreholesofCheragh-vays dam curtain.Final depth of curtain grout holes were 25-30 meters. The test behavior isdetermined by the Houlsby(1976) interpretation method.Figure 7 illustrates the distribution and behavior of the Lugeontest results with depth.As shown in the figure, the permeability is significantly reduced with deepening.According to this chart, the representative values for wash-out and turbulent behaviors are generally more than 5 Lugeon.Wash-out behavior is observed at depths less than 10 m, indicating the presence of erodible clay-filled joints.The percentage of behavior andquantitative classification of the Lugeon testsare also illustrated in this figure.According to the figure, the highest frequenciesare related to dilation, laminar and turbulent with 25%, 17% and 17%, respectively.Impermeable accounts for about 19% of the frequency of Lugeon results.

Wash-out behavior can be a perfect indicator of the erodability of joint filling. This behavior has been used to offer the special pressure washing in Cheragh-vays dam.

Pressure washing is a method for removal of loose joint-infilling by water (or air) pressure injecting into the boreholes (USACE 2017)[16].

For this purpose, a series of adjacent holes were drilled consecutively in a regular pattern, weak materials washed out from open holes while water was injected to other boreholes (figure 8). In order to gain better consequences, direction of pressure washing reversed after clearing up the muddy water. Pressure washing positively affected on groutability, follow that, average cement take increased from 16 kg/m to 26 kg/m.

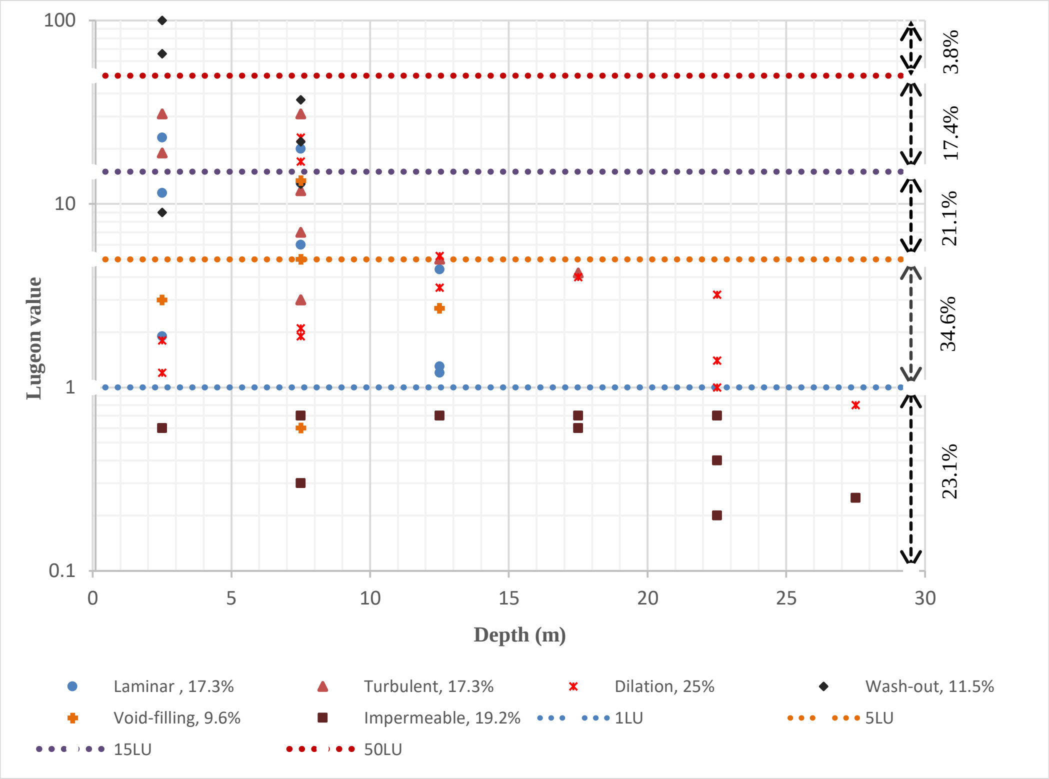

**Figure 7.Lugeon values and behaviors distribution versus depth in Cheraghvays dam**

**Figure 8. Left: quartz-clay filled joint, Right: pressure washing of clay filling**

## 4. UNCERTAINTY IN LUGEON INTERPRETATION AND ANALYSIS

In spite of its frequent usage and relative advantages, the Lugeon test has wide limitations and uncertainties, therefore, analyzing and interpreting of test results requires sufficient experienceand awareness of itslimitations. Main uncertainties of Lugeon test can be summarized as bellow:

- The lugeon test is a short duration and small-scale test; therefore, it does not have enoughvalidity as representative sample of rock mass permeability.
- Due to extremely poor relationship between Lugeon values with cement take,the estimation of groutability faces inevitable uncertainties.
- The correlationofLugeon values with hydraulic conductivity is strongly limited,thus,by this test, the prediction of leakage under dam foundation is of low accuracy.

- Finding out the behavior of the Lugeon test by pressure-flow diagrams, despite its profits, cannot meet the demands.Interpreting these graphs requires to be experienced enough and should be analyzed bysupplementary geological parameters.In some cases, this test exhibits an interstitials behavior and determination of the test behavior and representative value in such casesneeds technical expertise.Using these graphs is not adequate to determine the test behavior, especially at low Lugeon values.
- Test behaviors determinationdepend on the Lugeon accuracy. Geotechnical experts did not reach to an agreement about the accuracy of lugeon values. Therefore, determining the behavior and representative permeability,especially in low permeable rocks,would be in doubt.On the other hand, because ofvery low accuracy of the test in large amounts of absorptions,values of more than 100 Lugeonscannot bedistinguished.
- The representative value of the Lugeon test for turbulent, dilation, wash-out and void-filling behaviors directly depend on the test pressure and duration. Therefore, mentioned parameters have a significant impact on the test results, and should beselected in conformwith thein-situ geotechnical condition of the dam site.

## 5. CONCLUSIONS

- Representative values for wash-out behaviors in these dam sites are more than 5 Lugeon,generally, and its frequency decreases with deepening depth.The frequency distribution of values and behaviors of other groups have less order.Laminarflow was the main behavior of the Lugeontests in these dams.
- Real time monitoring of test data by digital recording equipment can be considerably helpful in interpretation and evaluation of Lugeon and hydraulic-fracturing test.
- In spite of widely usage and relative advantages, the Lugeon test has basic limitations and uncertainties, and interpretation of the test requires sufficient experience and awareness of its limitations.
- When the Lugeon testcited thatbehavior isWash-out result, itcan be a perfect indicator to assessingof the capability to special pressure washing, especially in near surface stages.

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