**IRAQI BULLETIN OF GEOLOGY AND MINING (IBGM)\
IRAQ GEOLOGICAL SURVEY (GEOSURV-IRAQ)**

Vol.19, No.2, 2023 ***p 141 – 150***

EFFECT OF SITE GEOLOGY ON THE GROUTABILITY OF CHERAGH-VEIS DAM, KURDISTAN, IRAN

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Received: 08/ 09/ 2022, Accepted: 19/ 02/ 2023
Keywords: Cheragh-Veis Dam; grouting; Saqez River; Zarrineh-rood watershed.

ABSTRACT

Geological investigations are among many essential studies that should be carried out before deciding the location, type, and size of a dam. Without proper geological investigation, the sitting of the dam will cause serious hazards during construction and the commissioning of the dam. In this paper, the effect of site geology on the profitability of Cheragh-Veis Dam is evaluated. The dam is an embankment (rock-fill) type with crest length and height of 274 and 67 meters, respectively. The reservoir's volume is 88 M^3 meters which is mainly used for supplying drinking water and agriculture irrigation. The dam is located to the southwest of Saqez City in Kurdistan Province, Iran.

The geological setting of the dam site includes a sequence of igneous rock of diorite and metamorphic rocks of schist type. The intrusion of hydrothermal solutions through the joint system of the rock mass has a great effect on the disintegration of the schists rock especially on the left abutment. The disintegration of the rock mass is expanded up to 10 m from the surface with a permeability of more than 10 lugeon. Therefore, the strength of the rock mass beneath the dam's core was improved by establishing 4400 m consolidation grouting.

Permeability of rock mass below 10 meters was less than 3 Lugeon, and 1400 meters' grout curtains were installed to ensure the water leakage stoppage from the dam foundation and abutments.

INTRODUCTION

Complex geological conditions at a dam site require extensive reconnaissance activities prior to construction phases. By conducting advanced site investigations, geomechanical properties of rock, and hydrogeological features. and seismic risk of the site can be evaluated and analyzed. Effective dam engineering requires respect for the destructive potential of uncontrolled water. To ensure this force is subdued, it must be confined to safe passages. Otherwise, water leakage can cause water loss from the reservoir or foundation instability. Each dam site has its individual characteristic, which requires special consideration (Adamo *et al*., 2019).

Many papers and articles have been published concerning the role of geological investigation in dam construction. For example, the geological features regarding the solution of evaporate rocks of Mosul Dam were investigated by Sissakian *et al.*, 2019. Adamo *et al.*, 2019, considered the geological specifications of the Mosul Dam with emphasis on safety issues. The engineering geological of the Ayvali Dam site in Turkey based on rock mass

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classification was investigated by Kanil and Erosy 2019. The relationships between RQD and Lugeon values of schist rocks at Kamal-Saleh Dam (Iran) were evaluated for designing curtain grouting (Uromeihy and Farrokhi, 2012). The seepage e problem through alluvial deposits with special reference to groutability was the main concern at the Chapar-abad Dam site (Uromeihy and Barzegari, 2007)

The paper reports the engineering geological investigations undertaken at the Cheragh-Veis Dam site, including mapping, discontinuity surveys, core drilling, water pressure testing, and sampling for laboratory tests. This investigation aims to evaluate the rock mass quality and predict the water leakage through the dam foundation and abutments. Advanced field investigations were performed taking into account the geological features of the site and precise measurement of the joint system. Several boreholes were driven up to 30m depth from the surface to determine the RQD and take rock samples for laboratory tests. The permeability of the rock mass was evaluated by measuring the Lugeon values. The results were used to design the consolidation and curtain grout of the site according to the quality and leakage potential of the rock.

DAM SITE LOCATION

Cheragh-Veis dam is located 17 Km to the south of Saqez City of Kurdistan Province. The climate of the region is considered a semi-arid zone with mean annual precipitation of about 450 mm and temperature of about 11 ºC which varies between – 20 ºC and 39 ºC in winter and summer respectively (Khazaei *et al*., 2019). The highest rain season occurs during winter and early spring from March to May.

The dam is constructed on the Saqez-Chay River which is one of the main streams of the upper Zarrineh-rood watershed. Zarrineh-rood is the main drainage system of the area and has a maximum length of 240 Km which discharges into Urmia Lake in the North West of Iran (Daraine *et al*., 2019). Almost 40% of Urmia Lake is supplied by the Zarrineh-rood watershed. Figure 1A shows the location of the Cheragh-Veis Dam and Urmia Watershed area. The altitude of the region varies between 3751 m to 1202 m above sea level. The topographic map of the Urmia Lake watershed is illustrated in Figure 1B.

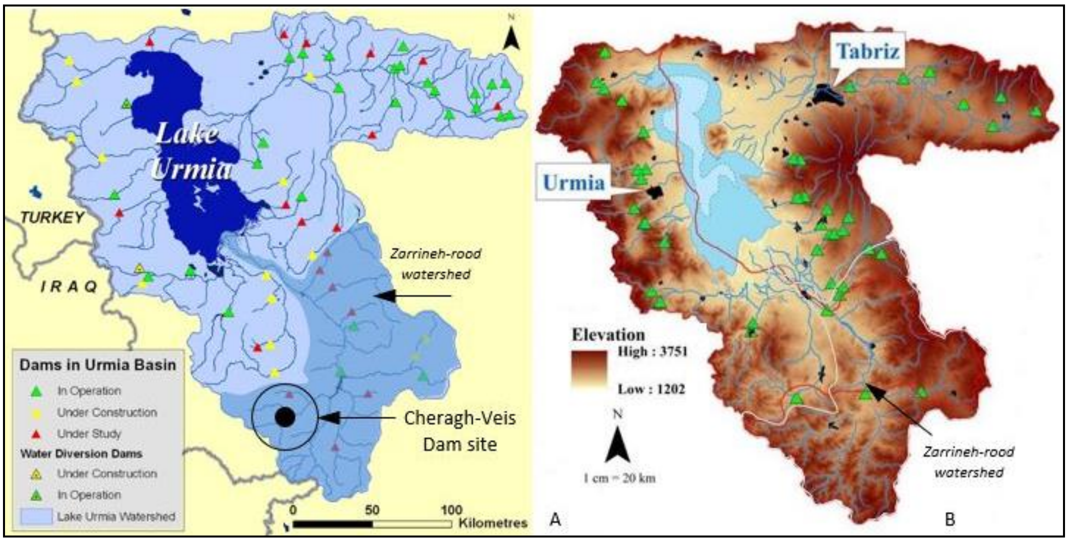

Figure 1: Cheragh-Veis Dam site location, **A)** Zarrineh-rood watershed (modified from Rahimi and Breuste, 2021), **B)** Urmia watershed topography (modified from Zarghami and Rahmani, 2017).

DAM SPECIFICATIONS

Cheragh-Veis dam is an embankment (rock-fill) type with central and symmetrical impervious core clay. The crest length is 274 m, the maximum height is 67 m, and the reservoir capacity of 88 × 10^6 m^3. The volume of the dam is about 970 × 10^3 m^3. A general view of the dam is presented in Figure 2A and the layout of the dam and auxiliaries are shown in Figure 2B. The primary purpose of the dam construction is to store water for irrigation usage of over 5575 hectares of agricultural land downstream, supply drinking water to Saqez City with over 170.000 populations, and mitigate flash flood risks. Also to develop the tourism industry and recreational facilities in the region.

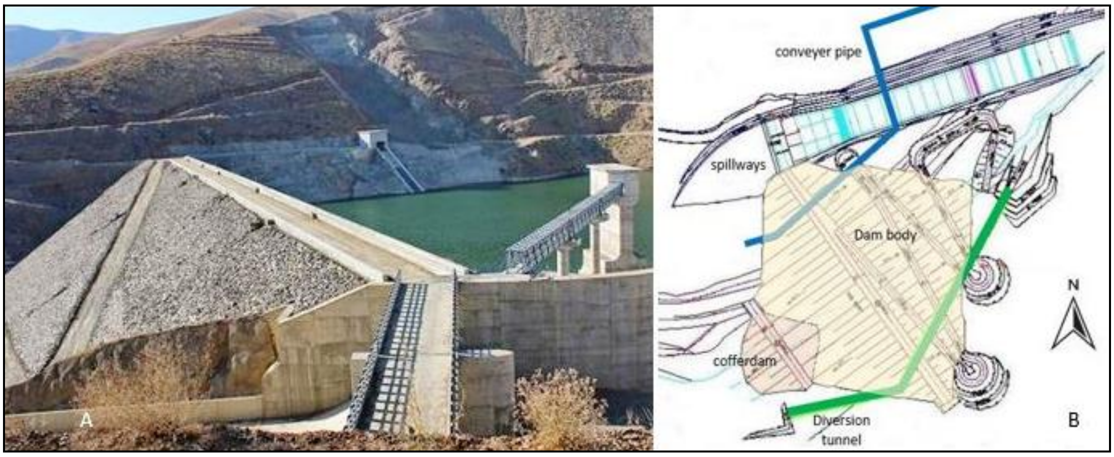

Figure 2: General View of Cheragh-Veis Dam. **A)** Downstream of the dam and spillways, **B)** Dam layout.

SITE GEOLOGY

The dam site predominantly consists of Precambrian and Cretaceous volcano-sedimentary sequences of diorite and quartz-diorite with interlayer of schistose rocks (Niroomand *et al*., 2021). The region is located in the northern part of the Sannadaj-Sirjan metamorphic Zone (Babakhani *et al*., 2003). The Sannadaj-Sirjan zone is a northwest-trending orogenic belt immediately north of the Zagros suture, which represents the former position of the Neotethys Ocean. The zone contains the most extensive, best-preserved record of key events in the formation and evolution of the Neotethys, from its birth in Late Paleozoic time through its demise during the mid-Tertiary collision of Arabia with Eurasia Tectonically (Hassanzadeh and Wernick, 2016). Tectonically, the site is affected by the presence of many thrust and transverse faults with the general trend of North-west South-east orientation.

The main geological feature of the site is the intrusion of hydrothermal solutions which diversely affect the quality of the rock mass and causes disintegration of the rock components especially along the joints and cracks. Due to the presence of fractured rocks on the left abutment where the spillways are located, the weathering and alteration of rock mass is more advanced in this part of the site. The quality of rock on the right abutment is in better condition and the hydrothermal intrusion caused the deposition of quartz minerals along the joints and veins. In addition, many rhyolite dyke with different dimensions from 0.2 to 2 m wide were intruded in both left and right abutments.

The geological setting of the dam site in both plane view and cross-section is shown in Figure 3.

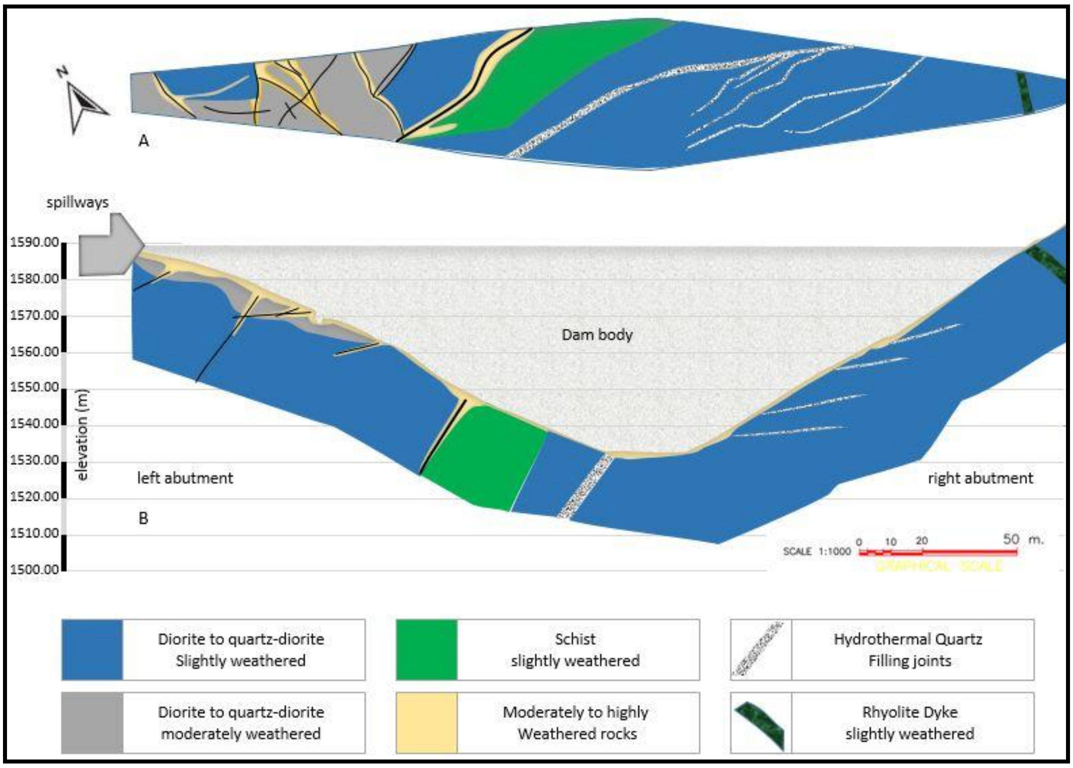

Figure 3: Geological setting of the dam site. **A)** Plan view of the dam body, **B)** Cross-section of the dam site (modified from Mohab Ghods Consultant Engineers, 2017).

JOINT SETTING

The stability of a discontinuous rock mass at dam abutments is controlled by the orientation, geometry, and strength of the rock mass. If these discontinuities are sufficiently large and frequent, they can combine to form separate blocks that could fall and unstable the free face of the slope (Priest, 1985). Joints are always to be considered as a source of weakness of the rocks and as pathways for the leakage of water through the rock. Both these properties of joints destroy the inherent soundness of the rock to a great extent. If a rock forming the foundation of a dam or reservoir happens to be heavily jointed and the region is one of the low water tables, the risk of leakage of water from under the dam or from the reservoir may be of substantial magnitude demanding very heavy cost for treatment of the rocks (Brown, 2017).

To evaluate the geometry of the blocks in the rock mass, systematic joint information regarding their physical conditions and orientation was recorded. The results of these measurements are shown in Table 1.

Table 1: Joint sets orientation records.

Location	Measures	Joint sets				
		Set 1	Set 2	Set 3	Set 4	Set 5
left abutment	dip	41	74	32	78	
	dip direction	237	032	035	155	
right abutment	dip	31	79	37	75	18
	dip direction	247	267	348	152	142

The lower hemisphere stereographic projection of the joints regarding their alignment to the dam axis is presented in Figure 4. According to Phillips (1971), and Ragan (1973), hemispherical projection is a graphical method whereby data on the three-dimensional orientation of planar and linear features can be presented and analyzed in a two-dimensional sheet of paper which is known as a Stereonet. Effects of joint set on the possibility of water leakage and slope stability are described as follows:

- Joint set 1: the alignment of this set of joints on both abutments is almost parallel to the direction dam axis. the joint is mostly filled with hydrothermal quartz minerals.
- Joint set 2: this set of joints represents the schist discontinuity layers and has neither a great effect on water leakage nor stability.
- Joint set 3: this joint set on the left abutment is almost parallel to the alignment of the dam axis but the right abutment is aligned right angle to the dam axis but dips 37º to the upstream direction therefore has a minor effect on water leakage.
- Joint set 4: both abutments This set of joints is oriented perpendicular to the dam axis has a dip of 75 – 78 degrees and has the potential of water leakage through the dam foundation. However, according to the field investigation, the joint opening is tight which reduces possible water leakage.
- Joint set 5: the joint set has an outcrop on the right abutment. Although its alignment is perpendicular to the dam axis these joints are few and have a gentle slope angle (about 18º) oriented into the right abutment, so the water leakage through them can be neglected

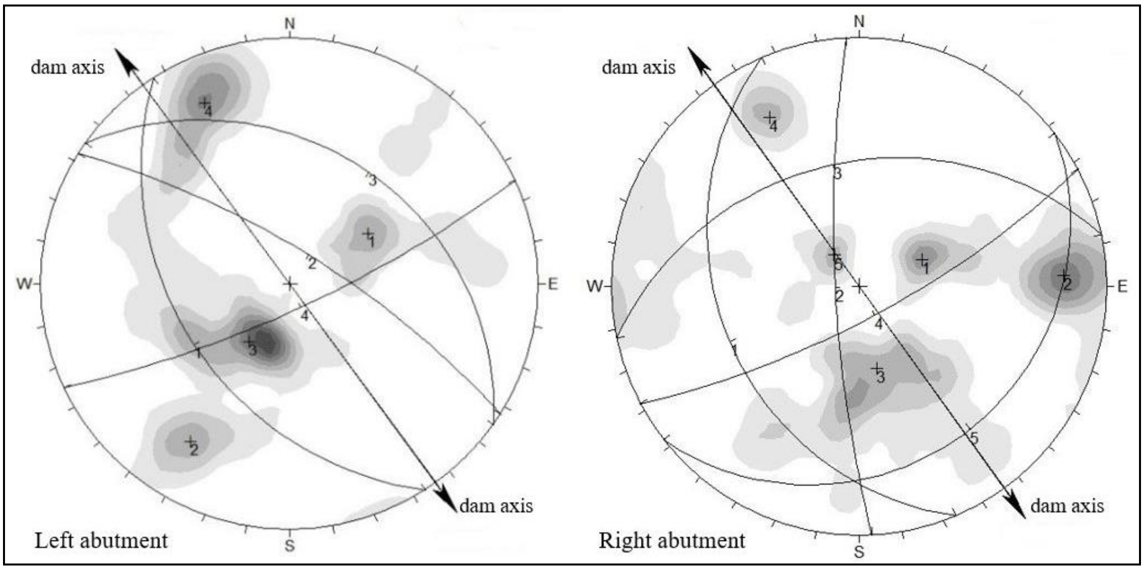

Figure 4: Lowe hemisphere projection of joint sets at Cheragh-Veis Dam.

PRIMARILY EXPLORATION

To evaluate the rock mass quality of the dam site, three primary exploration boreholes were driven at different locations along the dam axis. The location of the boreholes with information regarding the variation of RQD values with depth is illustrated in Figure 5. The RQD (Rock Quality Designation) is a widely used index to evaluate the fractures and discontinuities of rock masses. According to the derived information from the coring of rock samples, it can be noted that the rock mass on the right abutment benefits of higher quality in comparison to the left abutment and foundation. The depth of weathering and alteration on the left abutment expands to over 10 meters. While the depth of alteration on the right abutment is limited to less than 5 meters from the surface. Below these depths, the RQD was in the range of 100% which indicates the presence of high-quality rock mass. Usually, there is a direct relationship between the values of RQD and the permeability of strong igneous rock such as diorite which is predominant at this site. Therefore, on these bases, the groutability of the site can be predicted and the layout of the grouting curtain is designed.

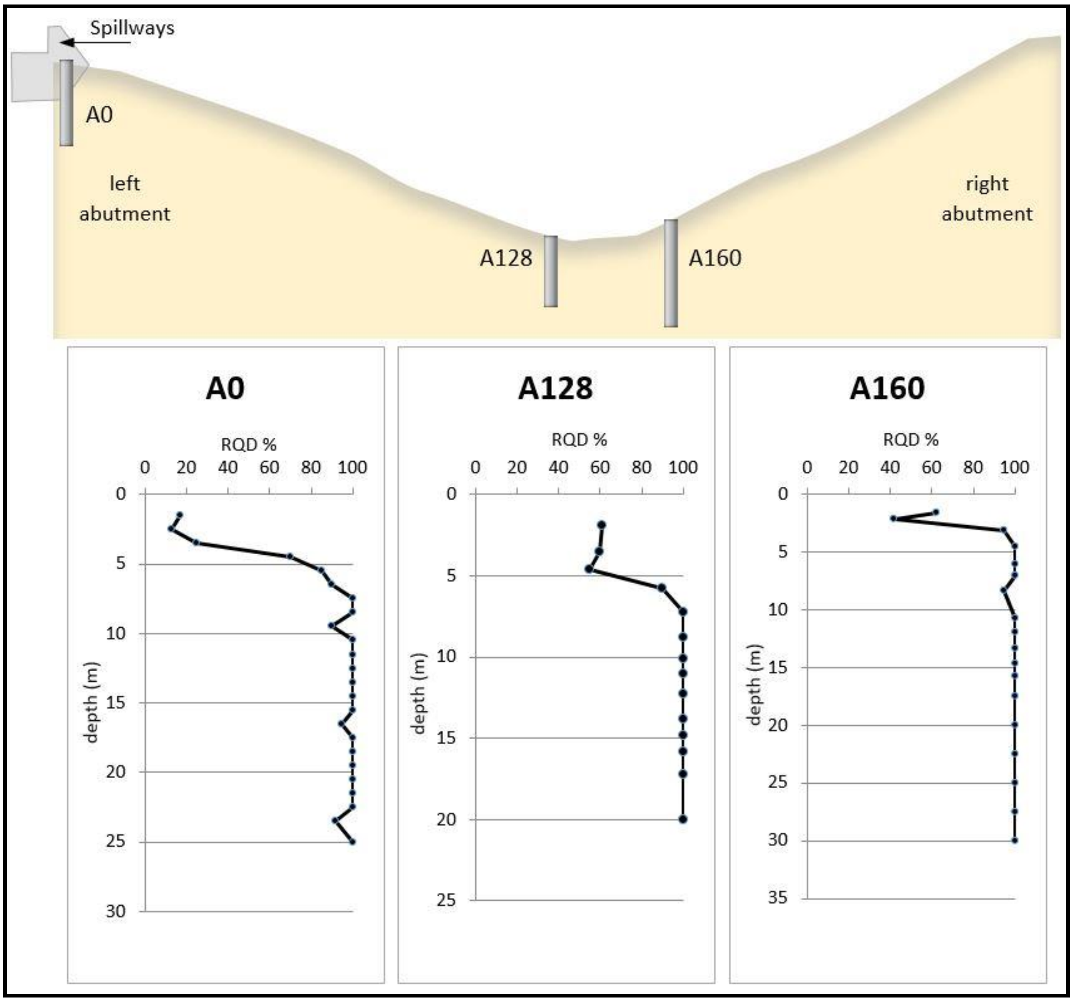

Figure 5: Location of primary drilling boreholes along the dam axis.

PERMEABILITY TEST

In-situ evaluation of rock mass permeability can be done by conducting a water pressure test which is known as the Lugeon test. The test is used to measure the amount of water injected into a segment of the bored hole under a steady pressure; the value (Lugeon value) is defined as the loss of water in litters per minute and per meter borehole at an over-pressure of 1 MPa. A Lugeon is a unit devised to quantify the water permeability of rock mass and the hydraulic conductivity of the bedrock resulting from water flow through the rock joints and fractures. The hydraulic conductivity of rock mass depends on many parameters, such as the connection of the joint system, joint aperture, joint filling, filling type, joint orientation, and joint erosion resistance during water flow (Oge, 2017).

A series of Lugeon tests were performed in exploratory boreholes at different depths and locations to assess the hydraulic conductivity of the bedrock both of consolidation and curtain grouting. The results of these tests are illustrated in Figure 6. Consolidation grouting aims to improve rock mass strength and reduce its deformability by injecting the cement grout into joints and fractured rock. Over 1400 m^3 of cement grout were injected for this purpose. The curtain grouting is aimed at reducing water leakage and increasing the water tightness of the bedrock to resist water pressure after the reservoir filling. About 4400 m^3 of cement grout was injected into the rock to establish the impervious curtain up to a depth of 30 m.

Evaluating the consolidation grouting for depths less than 10 meters shows that over 80% of Lugeon values were in the range of 0 to 10, less than 20% were in the range of 10 to 30, and less than 5% represented over 30 Lugeon. On the other hand, for depths 10 – 30 m, the curtain grouting shows that 75% were less than 1, 20% between 1 – 3, and only 4% over 10 – 30 Lugeon.

Plots of Lugeon values versus depth for both consolidation and curtain grouting are presented in Figure 7. The results indicate permeability for consolidation grouting of less than 40 and 20 Lugeon are predominant at depths less than 5 m and 10 m respectively. In case of curtain grouting, the Lugeon values decrease dramatically with depth.

The relationship between grout intake and Lugeon

There are many ways to analyze the Lugeon test results using the pressure diagram or Lugeon diagram. In both cases flow loss vs. pressure space is considered. According to Houlsby (1976), five types of flow behaviors and corresponding diagnostics can be interoperated. The five types of flow behaviors are known as laminar, turbulent, dilatation, void filling, and wash-out. Each represents the geological conditions of the joint system and the hydraulic specification of the rock mass. The groutability of rock mass at the dam site can be outlined regarding the type of flow.

The plots of Lugeon values vs rate of intake (groutability) for different types of flow are shown in Figure 8. Intake represents the amount of grout (kg) per unit length of injection. Only for laminar and void-filling types of flow, there are direction relationships that can be derived between Lugeon and the intake values. For other types of flow, the plots are scattered.

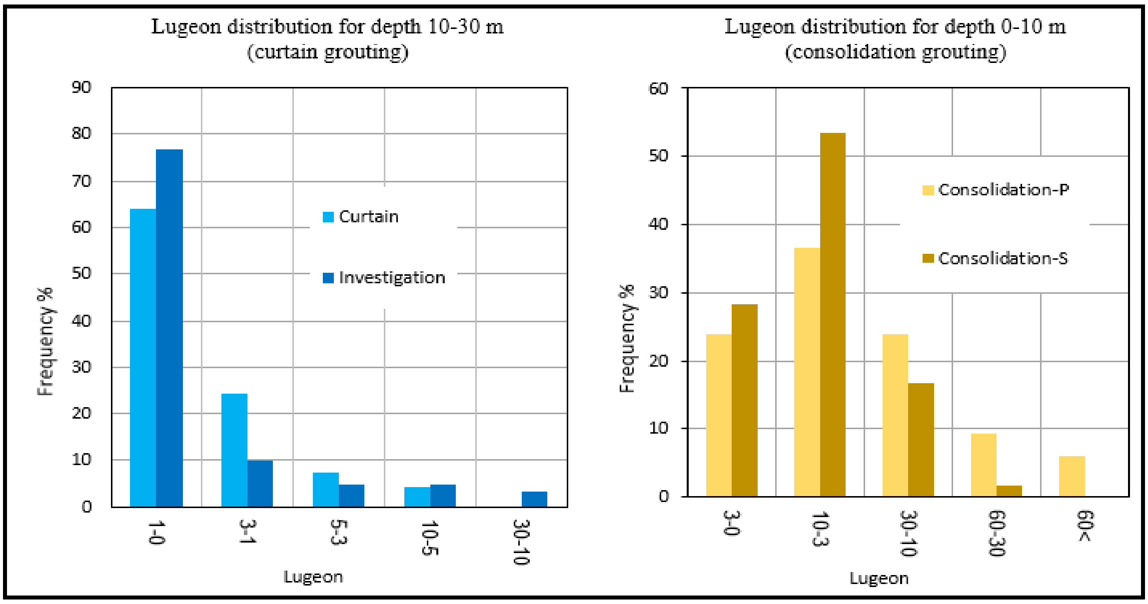

Figure 6: Lugeon test results for consolidation and curtain grouting.

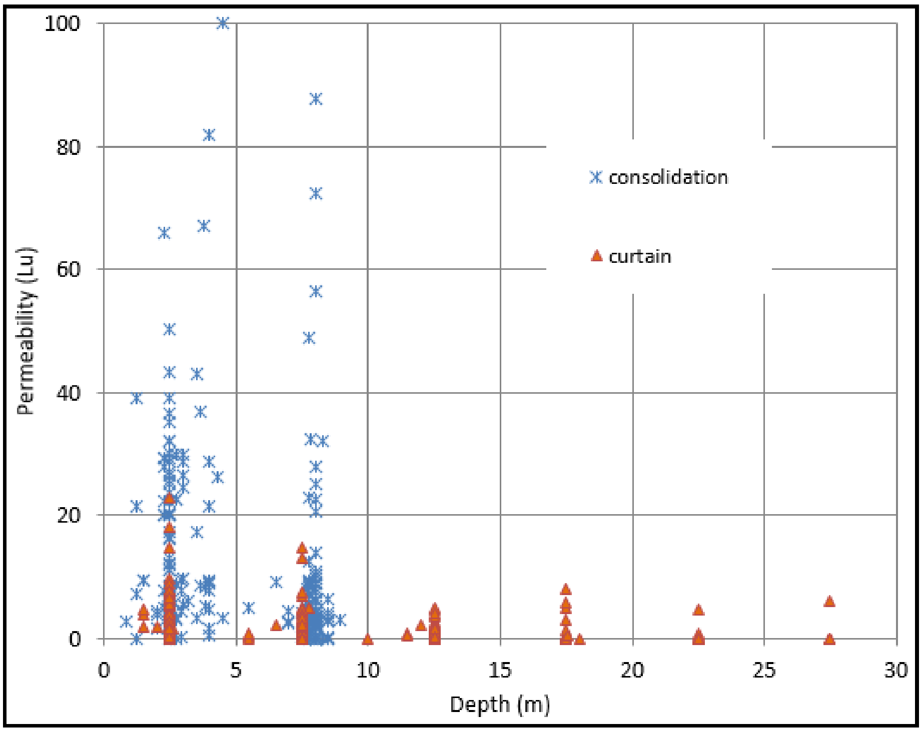

Figure 7: Plots of permeability (Lugeon) versus depth.

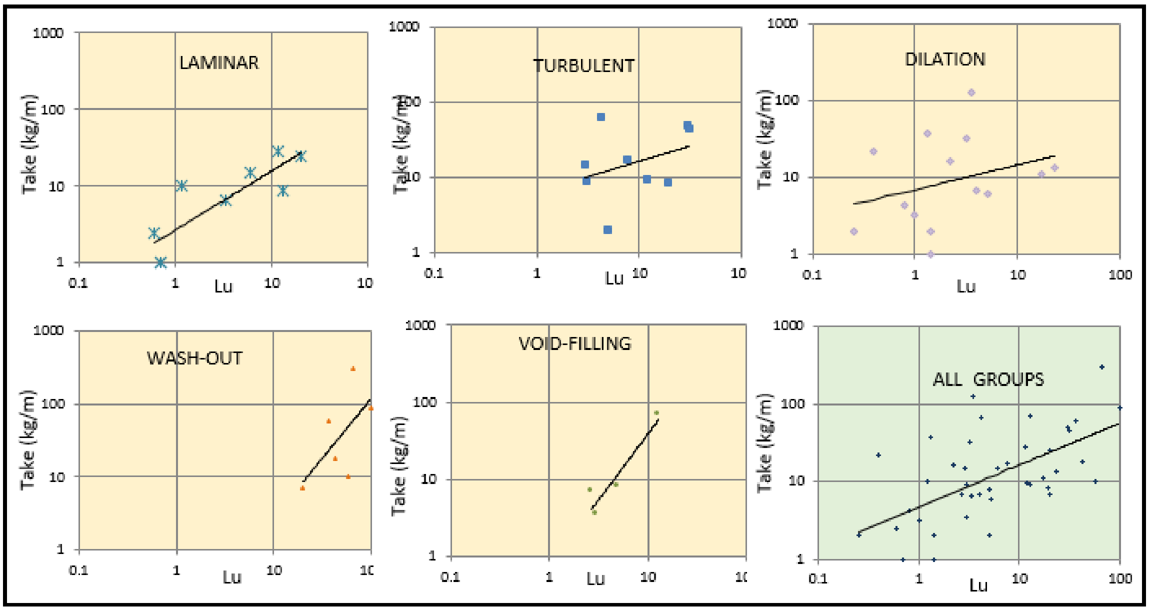

Figure 8: Plots of grout intake versus Lugeon values.

CONCLUSION

The following conclusions were derived from this research:

- The main geological features of the site are influenced by the effect of hydrothermal solution on decreasing the quality of the rock mass by disintegrating the minerals into weak deposits and expanding the joint apertures. The effect of hydrothermal is most dominant on the left abutment while on the right abutment, the effect of the hydrothermal solution is limited to filling the joint with quartz veins.

- The effect of the rock mass degradation and weathering is limited to a maximum depth of 10 m and below that the rock mass is strong and the effect of hydrothermal can be neglected.
- To improve the strength of the rock mass beneath the foundation of the clay core, about 14000 m^3 of consolidation grouting was used. The grouting holes were arranged in a triangle network of 2 m × 2 m and extended up to a depth of 10 m. The average grout intake was in the range of 22 kg/m for the first attempt and was reduced to 14 kg/m in the second attempt. The ratio of cement/ water was 1/1.
- Over 4400 m of curtain grouting were driven and the average grout intake was in the range of 11 kg/m at the depth of drilling was between 15 to 20 m.
- According to permeability test results, the consolidation grouting reduces the permeability of the site by almost 80% for depths below 10 m.
- Over 70% of boreholes show Lugeon values less than 1 for depth over 10 m. Only 8% of borehole indicates Lugeon over 5.3% shows Lugeon over 10 for depth over 10 m.

ACKNOWLEDGMENTS

The authors would like to thank Mohab Ghods Consultant Engineers company for their kind assistance in providing the required data.

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