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Research Article

Integrated Geophysical and Packer Test for the Water Tightness Evaluation of Gullele Botanic Garden Dam Site, Northwest of Addis Ababa, Ethiopia

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ABSTRACT

Gullele Botanic Garden is one of the largest botanical gardens in Ethiopia, which is found northwest of Addis Ababa. For this garden, a dam was proposed to be constructed for irrigation and recreational purposes. The intended dam will have a height of 30 m and a dam axis length of around 180 m. The main objective of this work is to investigate and evaluate the engineering geological aspects of the proposed dam site based on detailed geological, geotechnical and geophysical investigations. The investigation conducted in the area includes, electrical resistivity imaging, VES, borehole drilling and single packer permeability test. Geologically the area is covered by the different volcanic rock such as ignimbrite, rhyolite, tuff, basalt, and residual soil; and geological structures such as joint, fracture, flow banding, and cooling joint. The dominant orientations of geological structures are N-S and E-W directions. Results from different investigations revealed that three geotechnical layers were identified. These are overburden (completely weathered ignimbrite and soil), highly to moderately weathered ignimbrite and moderately to slightly weathered ignimbrite rock mass. The rock mass permeability test from six boreholes has Lugeon values ranging from 0 to 9. The maximum Lugeon (permeability of the rock mass) values investigated at the left abutment and riverbed of the proposed dam site showed wash out and dilation behavior respectively. The permeability result indicates that possible seepage problem at left abutment, riverbed and reserviour of the proposed dam. Therefore, during the construction of the dam, those specific locations, which are identified as problematic areas, need effective ground improvement works and special monitoring.

Keywords: Electrical resistivity imaging; Vertical electrical sounding; Single packer test; Borehole drilling; RQD; Seepage and ground improvement

INTRODUCTION

Engineering geological investigation for the dam site is the effective work before the construction of the dam. The engineering geological investigations that are performed for the certain dam site are done for various purposes. An important engineering properties of rocks and/soils that should be evaluated for dam site investigation are mainly permeability (frequently expressed in Lugeon units and cm/s), shear strength of the foundation (mass cohesion and friction in most cases), and deformability.

Seepage is a common problem in most dam sites where the impounded water seeks paths of least resistance through the dam, its foundation, reservoir and abutments. The ground conditions and the geological features of the dam site greatly influence the amount of seepage and its relevant effects. The problem of seepage was the main attention for many research fellows in the past decades. For example, Turkmen investigates the treatment of seepage problem at Kalecik dam in Turkey [1,2] evaluated the seepage through Karoon dam in Iran. The water leakage through soluble rocks beneath the dam was modeled by Romanov and Dreybrodt [3,4] studied the remedial measures to control seepage problems in the Kafrein dam, Jordan and the seepage problem of the same dam was also analyzed by Malkawi and Al-Sheriadeh in 2000. Controlling the quantity of seepage that occurs after construction is difficult and quite expensive. Typical methods are used to control the quantity of seepage like excavation of the permeable materials, the use of an upstream blanket, installation of cut-off wall or installation of grout curtain.

In Ethiopia, construction of micro-dams started in the late seventies to combat the recurrent drought in the country [5]. The

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construction of micro-dam reservoirs in arid and semi-arid areas like in Northern Ethiopia where the main socio-economic activity is rain fed agriculture is directly linked to the unpredictable and variable rainfall in time and space. According to Abdulkadir et al. [6], in the last two decades about 54 micro-dams have been constructed in Northern Ethiopia. However, due to technical and operational problems most of the micro-dams are not operating and functioning for the intended purpose. This researcher also investigated that the micro-dam reservoirs are under risk of insufficient inflow, excessive leakage and sedimentation, and some of them have structural and stability problems.

This papers deals about the integrated geophysical and geotechnical investigation for the water tightness of Gullele Botanic garden dam site Addis Ababa central Ethiopia. To come up with a comprehensive result, this dam site investigation undertake geophysical investigation (electrical resistivity imaging and VES), borehole drilling and packer tests. Geophysical investigation gives indirect information about the subsurface condition. The geophysical data are supported by the direct investigation from borehole drilling and packer tests. The geophysical investigation and packer tests were done by ECDSWC but the permission and consent of this organization, the researcher was actively involved during the entire site investigation, out of which valuable insights and recommendations are forwarded.

Water tightness is the essential parameter in the certain dam site. Because many hydraulic structure failed after the construction due to the seepage and other related problems. Therefore in order to minimize such types of problem the direct and indirect investigation is the first stage before the construction is started. According to this the main objective of this research work in engineering geological investigation and evaluation using integrated geophysical and packer (permeability) data for the water tightness of Gullele botanic garden dam site Addis Ababa central Ethiopia.

Location and geomorphology of the study area

The study area is located in north western part of Addis Ababa, central Ethiopia at Gullele Botanic Garden. It is found in the projected Adindan UTM Zone 37N grid and bounded between Easting (466,500 m and 471,500 m) and Northing (1,001,500 m and 1,005,500 m). The location map of the study area is shown in Figure 1. The morphology of Addis Ababa includes a complex Intoto Ridge in its northern part that has a rugged topography with steep slopes. Addis Ababa lies in the western margin of the main Ethiopian rift and consists of different volcanic rocks that range from basic to acidic in composition, belonging to the Trap Series.

Hydrology and climate of the area

Hydrogeological location of the study area is within in the Akaki River catchment. The long-term mean annual rainfall is 1254 mm

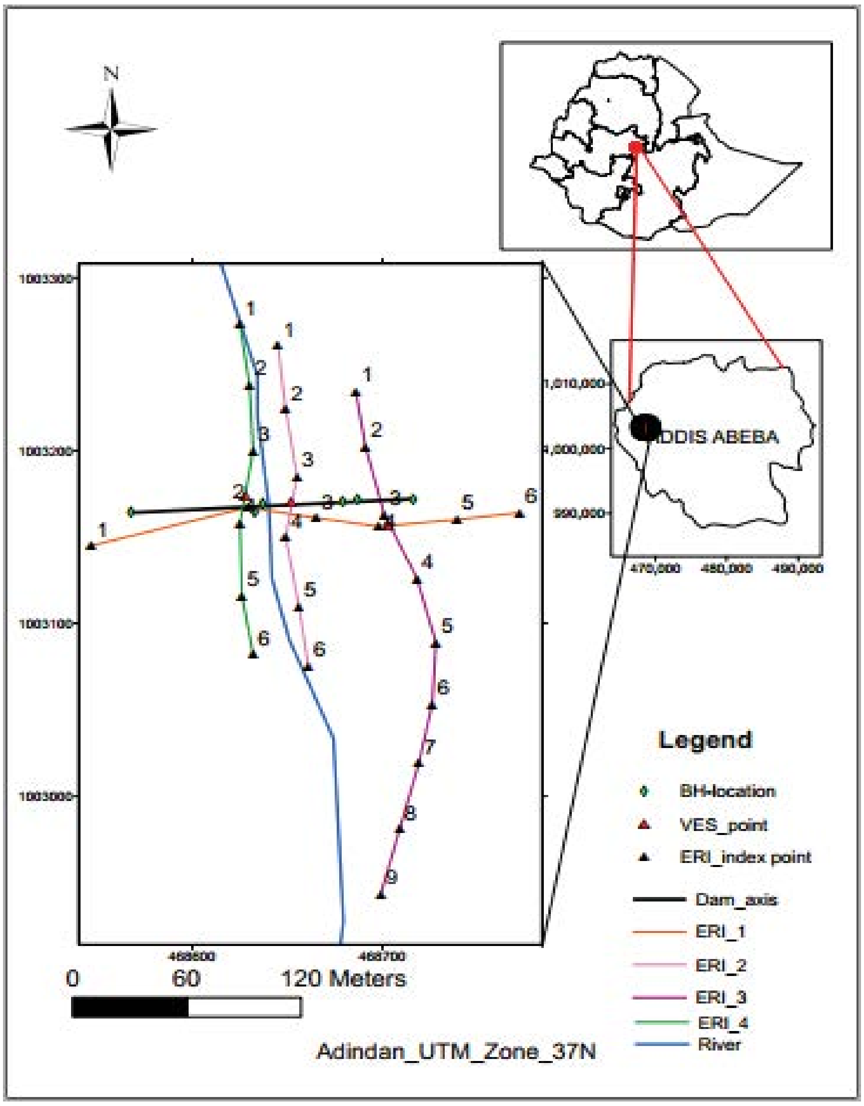

Figure 1: The location map of the study area north west of Addis Ababa, Ethiopia.

and maximum temperature varies on average between 20 °C in the wet season and 25 °C in dry season, while the variation of minimum temperature falls in the range of 7 °C to 12 °C throughout the year [7]. Wind speed is generally moderate in the area, taking average values in the range of 0.5 to 0.9 m/s. Average daily sunshine hours as high as 9.5 hours are observed in November and December, and this figure falls to 3 hours or less in July and August. Monthly pan evaporation records, obtained from documents of previous studies, reveal that the average monthly pan evaporation during the dry season (November) at is about 180 mm and this value falls to about 75 mm in wet season [7].

Geological rock unit of the study area

According to Getahun [8], the different rock units exposed in Addis Ababa include, Chilalo formation, Foota basalt, Olivine basalt, Wechecha- Furi-Yerer trachyte and trachy basalt, Repi trachy basalt and basalt, Cheleka basalt, Intoto mixed rocks, Intoto trachyte, Lower Ignimbrite and Wechecha-Yere-Furi ignimbrite. Intoto trachyte, which is exposed at Intoto Mountain, is the oldest rock in the area, then comes Intoto mixed rocks overlaying the Intoto trachyte. Foota basalt (Tarmaber basalt) which is the result of central volcanism is compositionally pyroxene phyric, stratified at the base and is younger than Intoto trachyte. The lower ignimbrite and pyroclastic rocks are formed from central volcanism and contain ignimbrite, agglomerate and ash deposited during the Upper Pliocene to Miocene period, then comes Wechecha-Yerer-Furi trachyte and trachy basalt, which is also formed from shield volcanic eruption, After Wechecha-Yerer -Furi trachy basalt and trachyte, Wechecha-Yere-Furi ignimbrite, is erupted. Finally, the Tertiary sediment, Quaternary tuff, basalt, and the lake sediment are occupying the top stratigraphic succession of the area. The present study was identified the different volcanic rocks that was previously named as intoto mixed rock. The study are consists the SW part of the main road at the Intoto mountain. The area geological characterized by different volcanic rock with different degree of weathering. The geological rock unit in the area includes rhyolite, ignimbrite, tuff, basalt and thick residual soil. The proposed dam site rest in the ignimbrite rock unit and the top part of the area coved by 2 m to 5 m thick red brownish residual soil, In this research work, the geophysical investigation was done in the dam axis, in the reservoir and along the river. The packer permeability test was conducted with six boreholes along the dam axis perpendicular to the direction of the river.

Geological structure and tectonic setting of the area

The Main Ethiopian Rift (MER) was the result of extensional tectonics that trends in NNE to SSW. Initial sagging of the MER started about 14 to 15 Ma and was followed by major episodes of rifting at 10,5,4 and 1.8 to 1.6 Ma. Each stage of rifting and down faulting was accompanied by a bimodal (silicic-mafic) volcanism in the rift and formation of basaltic and trachytic shield volcanoes on the rift shoulders & margins [9]. Even though the major geological structures in the country mostly parallel the rift system, some faults run transversally to it on Northwest Ethiopian Plateau. An example is the East -24^0 west oriented lineament that extends from Kassam River in the east through Addis Ababa to Ambo in the west. This lineament, called Ambo Fault Belt, starts from the western escarpment of the rift, and goes further to Wollega [9]. In the study area the two dominate orientations geological structure are observed. The dominate orientation of those geological structures area NNE to SSW and E to W. There for the geological structure in the area have relation with the main Ethiopian rift and the Ambo fault.

MATERIALS AND METHODS

Materials

There are different materials used for this research. The geophysical resistivity imaging, VES equipment and the drilling machines with all accessories from ECDSWC were used for this study. After the drilling is done by removing the core sample the single packer test was conducted. The nitrogen gas cylinder also used to apply the pressure to close the hole by the gland of the packer. Water flow meter and pressure gauge also used to measure the amount of intake water during the packer test and to control the amount of pressure exerted during the test respectively. Other standard geological equipments were also used to identify the rocks, to take measurements of geological structures and mapping.

METHODS

Various methods applied to investigate the water tightness of the Gullele botanic garden dam site. The methods are Geophysical (electrical resistivity imaging and VES), borehole drilling and packer (single packer) test.

Electrical resistivity imaging

Based on previous geological data, four electrical resistivity imaging survey lines with a total length of 912 m were conducted different part of the dam, The resistivity imaging surveys were carried out along the survey lines shown Figure 1. The investigation depth of this survey lines is 50 m and the electrode interval used is 5 m.

Vertical Electrical Sounding (VES)

In order to determine the attitudes of basement for the proposed dam, VES survey (VES1, VES2, and VES3) shown in Figure 1.

Borehole drilling

After the geophysical investigation, six boreholes was drilled to know the subsurface condition of geology and to perform the permeability test. The boreholes drilled in the site have the depth of ranges from 20 to 30 m.

Packer permeability test

According to Walter packer test conducted in porous or fractured medium includes a stage prior to the actual test in which packers are inflated. This method is the most effective to know the water tightness of the dam site. In the study area packer tests have been done in six boreholes with the interval of test, section ranges 3 to 5 m. This test procedure includes first the borehole is ready at the desired depth then insert the single packer half part of the packer rest in the core barren and half part of the packer put outside the core barren. Then exerting the pressure from the nitrogen gas to close the hole and make isolated the test section. Then if the test section is isolated, the test will start by arranging their different test pressure. In order to determine the test pressure knowing the unit weight of the rock and the depth of test section is mandatory. The test pressure will have applied to the packer test is the difference between the formation pressure and the column pressure. Formation pressure is the product of the unit weight of the rock and the depth of the hole from the surface i.e. FP=Unit weight of rock* height (depth). Column pressure is the product of the unit weight of water and the half of the test section i.e. CP=Unit weight of water*1/2(depth of upper test section +lower test section). The maximum test pressure will be the difference between the formation pressure and the column pressure (i.e. MTP=FP-CP). After the maximum test pressure is, determine the test have been conducted with five stages as shown in Table 1. Then record the amount of flow of water per minute with the corresponding pressure value. For each stage, five reading is taken in order to make the value more accurate. After the test is completed the Lugeon value is determine using the formula Lu=(10*Q)/ (P*L) (Lugeon,1932). LU=Lugeon Value (L/min*bar*m), Q=average water intake in L/min, P=Total pressure in bar and L=Length of test section in meter. Then from the value, it is possible to know the behavior of the fracture and the amount of hydraulic conductivities and finally analyze the water tightness of the area.

RESULT AND DISCUSSION

From the different direct and indirect investigation for the water tightness of the proposed dam site, the results are described as follow. The investigation line of geophysical investigation and borehole drilling are shown in Figure 2.

Electrical resistivity imaging

This investigation conducted at the different location of the dam with the code of (ERI_1) dam axis, (ERI_2) around river, (ERI_3) around spillway channel (left abutment), and (ERI_4) right abutment. The results of each resistivity investigation are described below. The location map of the electrical resistivity imaging vertical electrical sounding and boreholes are shown Figure 2.

Electrical resistivity imaging along dam axis (ERI_1)

One of the resistivity surveys conducted along the dam axis (Figure 2), the result of the resistivity imaging survey shown in Figure 3.

From the resistivity imaging section, the low resistivity values are reflected at the sub part marked with elliptical block between electrode number 40 and 48, which is considered the response of highly to moderately weathered ignimbrite. As shown on the resistivity imaging section, the high resistivity values are reflected at the upper part between electrode number 19 and 30 located at and around the river, and it is interpreted to be the response of moderately fractured ignimbrites. The resistivity responses ranging from about 36 Ω·m to less than 55 Ω·m reflected below this upper part with the relatively high resistivity values may be due to the existence of ground water in the inside of moderately fractured ignimbrite. In the other case, the resistivity responses ranging from about 39 Ω·m to less than 55 Ω·m reflected at the blocks between electrode number 1 and 18 located at the right side as well as between electrode number 31 and 40 located at the left side may be due to the moderately weathered and fractured ignimbrite. Analyzing the resistivity imaging section with VES survey data (VES1 and VES3), it is estimated that the thickness of

Table 1: Test stages and amount of pressure exerted during packer test.

Stage	Amount of test pressure applied for test
1st stage	1/3 of the maximum test pressure
2nd stage	2/3 maximum test pressure
3rd stage	The maximum pressure
4th stage	2/3 of the maximum pressure
5th stage	1/3 of the maximum pressure

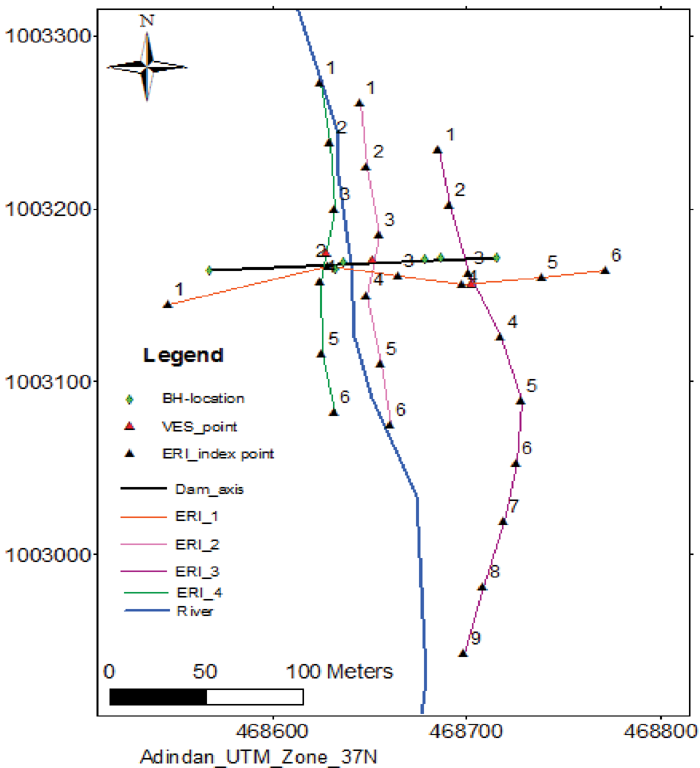

Figure 2: The above figure shows the investigation line on the proposed dam site.

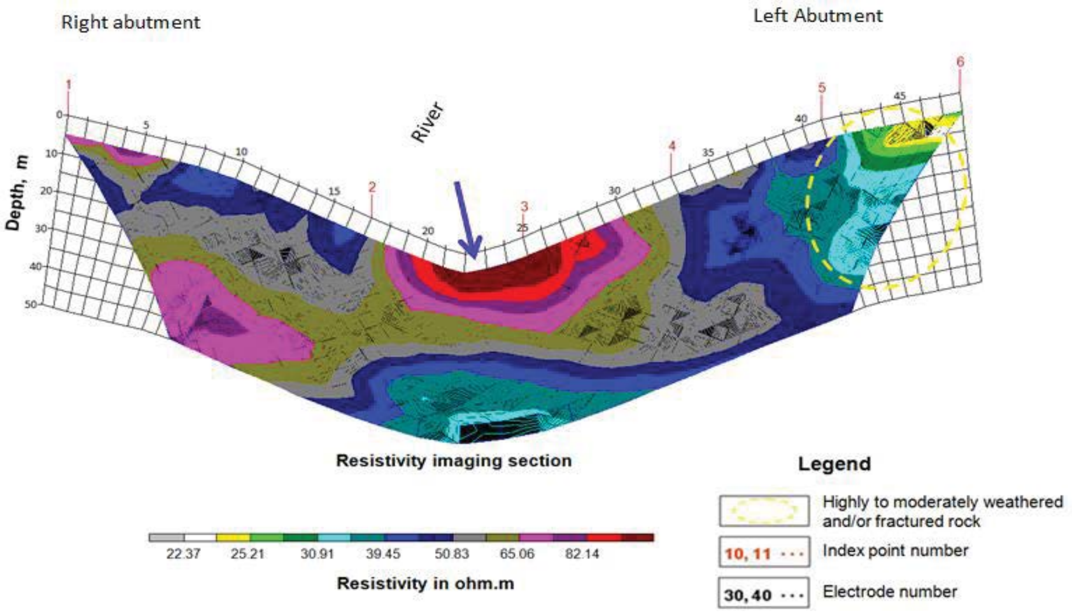

Figure 3: Resistivity imaging section along survey line ERI-1 (along of dam axis).

this ignimbrite is about 10 m around electrode number 16 located at the right side and less than 25 m around electrode number 35 located at the left side. There may be the moderately fractured ignimbrite below this ignimbrite. From the borehole and surface geological data it is confirmed that at the center of this survey line or at the river, it is covered by relatively massive and less fractured ignimbrite rock unit. However, with the fractured are intensive and saturated by water that why it shows low resistivity value.

Electrical resistivity imaging around river (ERI_2)

This survey line was conducted around the river shown as Figure 2. The resistivity imaging section is shown in Figure 4.

On the resistivity imaging section, the low resistivity values less than 43 Ω·m reflected at the sub part marked with elliptical block between electrode number 1 and 14 may be due to the highly to moderately weathered and fractured bedrock. The relatively high resistivity values observed at the upper part between electrode number 14 and 40 on the section may be because of the moderately fractured ignimbrite. The resistivity responses ranging from about 42 Ω·m to less than 55 Ω·m reflected below this upper part with the relatively high resistivity values may be due to the existence of ground water in the inside of moderately fractured ignimbrite.

Electrical resistivity imaging at left abutment ERI_3 (around the spillway)

This geophysical investigation survey line was conducted around the spillway channel located at the left abutment of proposed dam (Figure 2), The resistivity imaging along this section shown in Figure 5.

According to the resistivity imaging section, it is expected that there is geological structure around electrode number 11. Moreover, low resistivity zone with values less than 35 Ω·m reflected at the sub part marked with elliptical block between electrode number 45 and 64 is considered to be highly weathered and fractured ignimbrite. Particularly, the resistivity responses ranging from about 34 Ω·m to less than 46 Ω·m reflected at the block between electrode number 17 and 39 may be due to the moderately weathered and fractured ignimbrite.

Electrical resistivity imaging at right abutment of the dam (ERI_4)

This survey line was conducted at the right abutment of the proposed dam site (Figure 2). The resistivity imaging section is shown in Figure 6.

According to the resistivity imaging section on the ERI-4, the relatively low resistivity values (35 Ω·m ~ 48 Ω·m) are reflected at the sub section marked with elliptical block between electrode number 1 and 9 located at the upstream of propose dam, which is considered to be the response of highly to moderately weathered and fractured bedrock. It is also considered that there may be geological structure around electrode number 14. On the resistivity imaging section, the resistivity responses ranging from about 40 Ω·m to less than 57 Ω·m reflected at the block between electrode number 19 and 32 may be because of the moderately weathered and fractured ignimbrite.

Vertical electrical sounding

In order to determine the depth of bedrock for the proposed dam, VES survey (VES1, VES2 and VES3) ware conducted in the survey line shown from right abutment, riverbed and left abutment of the proposed. The model and the description of those VES point are shown in the following Figure 7 and Table 2.

Permeability (single packer test) of rock mass

The test, which derives its name from Maurice Lugeon [10], is a constant head type test that takes place in an isolated portion of a borehole. Water at constant pressure is injected into the rock mass through a slotted pipe bounded by pneumatic packers. To support the geophysical investigation, the direct investigation test is conducted in the study area. There are six-borehole drilled along the dam axis with the depth ranges from 20 to 30 m, and the packer test was conducted at different depths to evaluate the water tightness of the rock. The packer test, which is used in the investigation, is a single packer test with a length of 1.60 m. The single packer test was conducted as soon as the borehole is drilled and the core sample is removed. After the permeability of the rock mass is determined, rock mass permeability is classified into impermeable, low permeable, permeable and highly permeable classes [11] as shown in Tables 3 and 4.

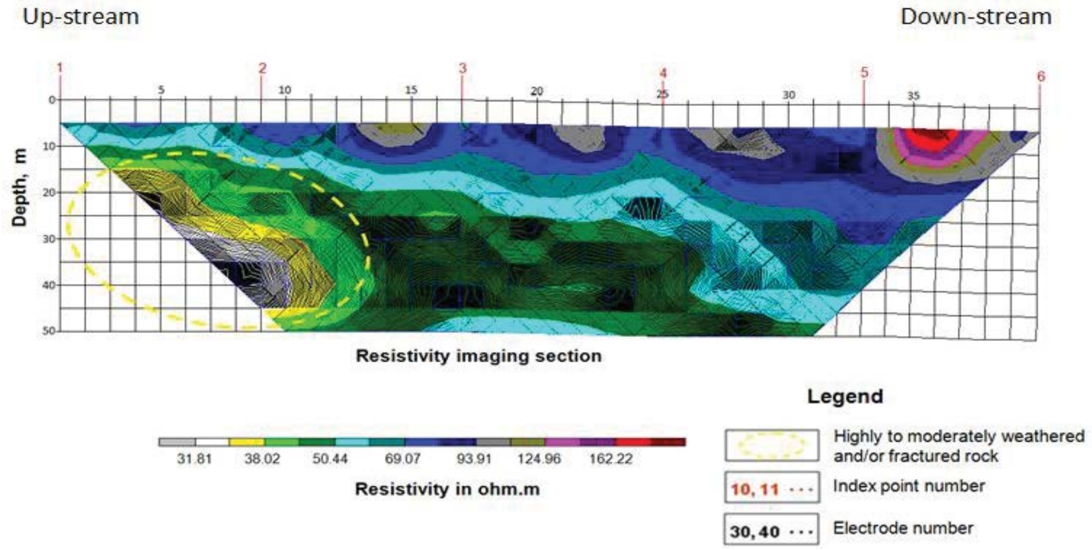

Figure 4: Resistivity imaging section along survey line ERI_2 (ECDSWC, 2017).

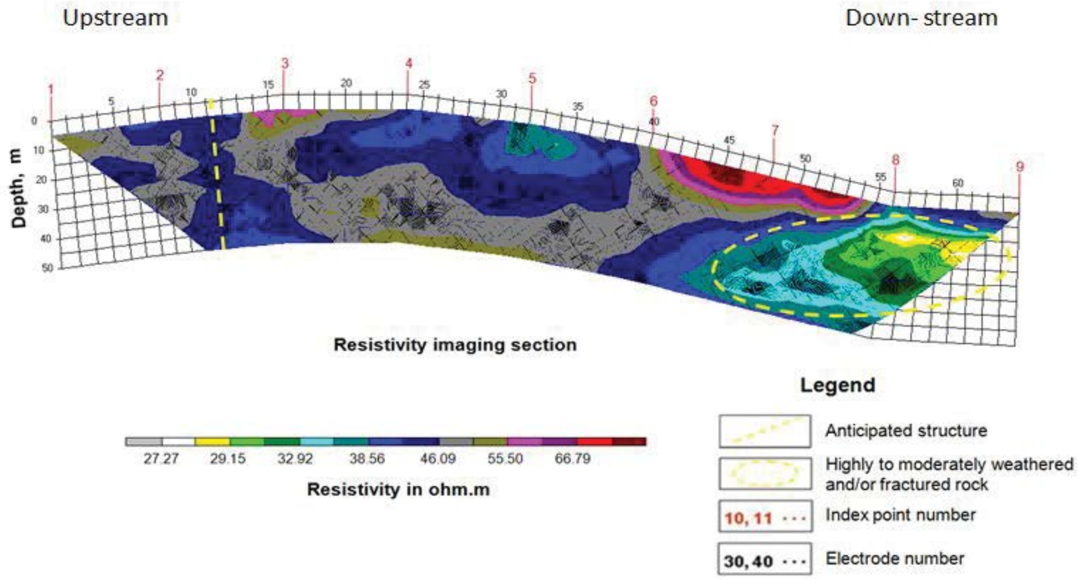

Figure 5: Resistivity imaging section along survey line ERI_3 (ECDSWC, 2017).

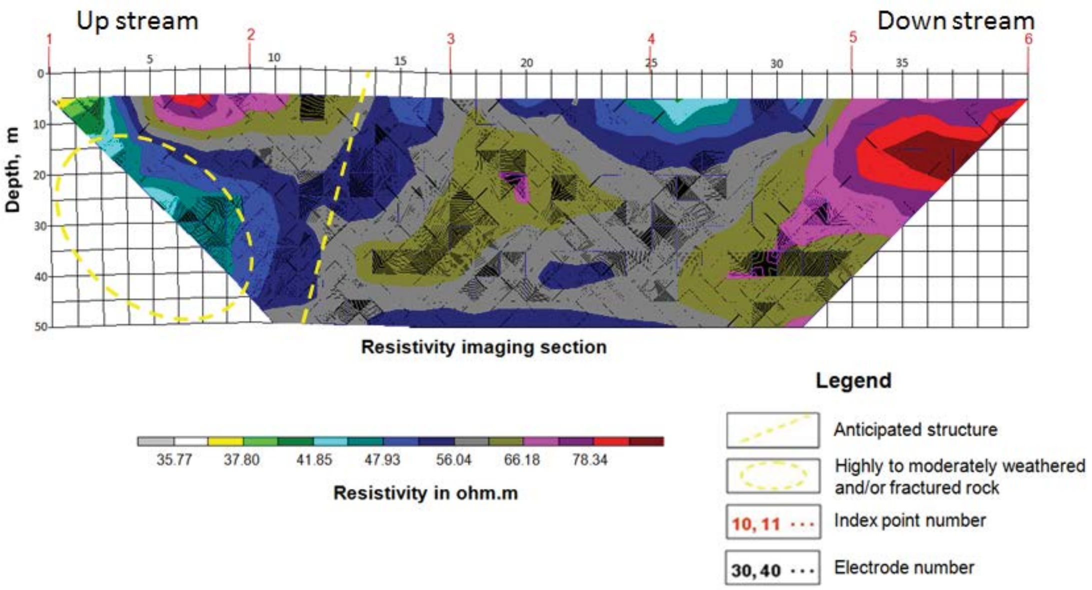

Figure 6: Resistivity imaging section along survey line ERI-4 (ECDSWC, 2017).

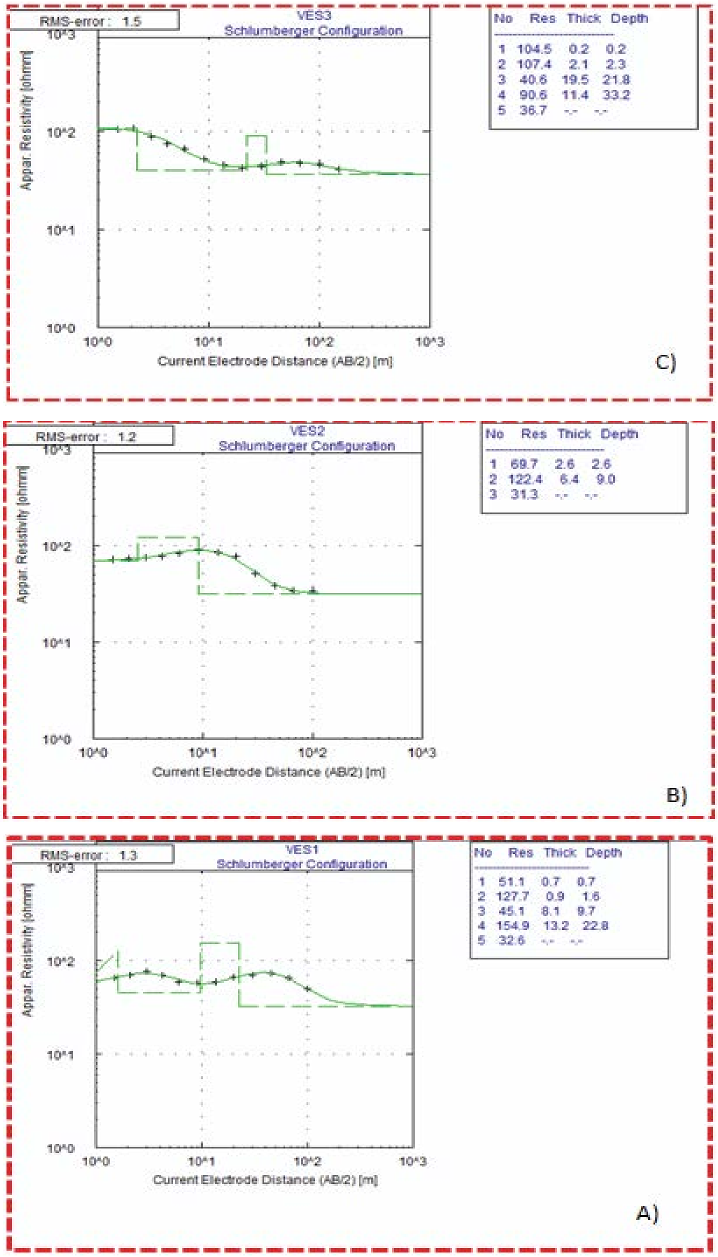

Figure 7: Model used the interpretation with vertical electrical sounding data (A), shows the model from VES_1, (B) shows the model from VES_2 and (C), shows the VES model from VES_3.

The packer tests were conducted at the left abutment (BH-3, BH-5 and BH-6), at river bed (BH-2) and at right abutment (BH-1 and BH-4). The result and interpretation of the packer test from different parts of the dam are discussed as follows.

Packer test at the left abutment of proposed dam

In the left abutment, packer tests were conducted at three borehole locations namely, BH-3, BH-5 and BH-6. The packer test result from different boreholes show different flow behavior and Lugeon values. The flow behaviors observed at this abutment are dilation, wash out, turbulent flow and void filling. The packer test at this abutment from borehole three (test interval 2.7 to 6 m and 15 to 20 m) and borehole five (test section 10 to 15 m and 15 to 20 m) it is investigated that the dilation types of flow behavior with difference Lugeon values. According to Houlsby [12], dilation behaviors that are characterized by similar hydraulic conductivities are observed at low and medium pressures. However, a much greater value is recorded at the maximum pressure. This behavior is also sometimes observed at medium pressures, occurs when the water pressure applied is greater than the minimum principal stress of the rock mass, thus causing a temporary dilatancy (hydro jacking) of the fissures within the rock mass. Dilatancy causes an increase in the cross sectional area available for water to flow, and there by increases the hydraulic conductivity. In this type of flow behavior the representative Lugeon value is the average of the 1st, 2nd, 4th and 5th stages. The following figures shows the dilation behavior of the left abutment in the proposed BH-3 in the test section between 15 m and 20 m (Figure 8).

The other packer test results in the left abutment from borehole three in the test section between 6 m to 9 m and from borehole six in the test section between 13 m to 20 m showed wash out behavior. According to Houlsby [12], wash out behavior is characterized by progressive increment of Lugeon values in the five stage tests without any return to the pre-peak pressure values after the peak value has passed. This type of flow behavior indicates that permanent washing-out of joint filling materials or permanent rock movements by the test. From the core sample, there are some soft filling materials inside fractures. The wash out of this

Table 2: Interpretation model of right abutment, riverbed and left abutment VES_1 (A), VES_2 (B) and VES_3(C).

Layer VES-1	Resistivity (Ω·m)	Thickness (m)	Depth (m)	Expected lithology (from geophysics)	Lithology from borehole data(BH1,BH4)
1	51.1	0.7	0.7	Top bed (soil, gravel and highly weathered ignimbrite)	Soil, slightly moist, moderately stiff.
2	127.7	0.9	1.6	-	-
3	45.1	8.1	9.7	Moderately weathered and fractured ignimbrite	Ignimbrite, highly weathered and closely to widely fractured, moderately strong rock.
4	154.9	13.2	22.8	Moderately fractured ignimbrite	Ignimbrite slightly weathered and widely fractured rock.
5	32.6	-	-	Moderately fractured ignimbrite (saturated)	Ignimbrite, slightly weathered, closely fractured rock.
Layer VES-2	**Resistivity (Ω·m)**	**Thickness (m)**	**Depth (m)**	**Expected lithology (from geophysics)**	**Lithology from borehole (BH2)**
1	69.7	2.6	2.6	Top bed (soil and fractured ignimbrite)	Silty clay, light brown, slightly moist, soft with rootlets.
2	122.4	6.4	9	Moderately fractured ignimbrite	Ignimbrite slightly weathered and widely fractured.
3	31.3	-	-	Moderately fractured ignimbrite (saturated)	Ignimbrite, moderately to highly weathered and closely to widely fracture.
Layer VES-3	**Resistivity (Ω·m)**	**Thickness (m)**	**Depth (m)**	**Expected lithology (From Geophysics)**	**Lithology from borehole (BH3,BH5,BH6)**
1	104.5	0.2	0.2	Top bed (soil, gravel and highly weathered ignimbrite)	Medium stiff, clayey silt with trace of sand , dry residual soil and tuff
2	107.4	2.1	2.3	-	-
3	40.6	19.5	21.8	Moderately weathered and fractured ignimbrite	Ignimbrite: Slightly to moderately weathered, medium strong, extremely closely to very closely fractured.
4	90.6	11.4	33.2	Moderately fractured ignimbrite	Fresh to slightly weathered ignimbrite.
5	36.7	-	-	Moderately fractured ignimbrite (saturated)	Ignimbrite: Fresh to slightly weathered, strong, very closely to moderately fractured.

Table 3: Permeability classification based on the Lugeon values of rock masses (Canoglu et.al, 2017).

Lugeon Values	Permeability Class
<1 Lugeon	Impermeable
1 - 5 Lugeon	Low permeable
5 - 25 Lugeon	Permeable
>25 Lugeon	Highly permeable

materials give the flow behavior, which continuously increase the Lugeon values from the first stage to the last stage. For these types of behavior, the representative Lugeon value is the last (5th stage). From the results, the wash out behavior is the most dangerous phenomenon in a certain dam site because the wash out of infilling materials will result the development of an open fracture that cause seepage problem. Therefore, site with this types of behavior need appropriate mitigation measure, must be taken during the construction of the dam. The following Figure 9, shows the wash out flow behavior from borehole three in the test section of 6 m to 10 m.

The other result from packer test investigation in the left abutment from borehole five in the test section between 7 m and 10 m showed turbulent type of flow behavior. According to Houlsby [12], this type of behavior is characterized by a decrease in hydraulic conductivity of the rock mass as the water pressure increases. This behavior is characteristic of rock masses exhibiting partly open to moderately wide cracks. When these types of behavior observed during the investigation the representative Lugeon values is a value corresponding to the 3rd stage. Figure 10 shows turbulent flow behavior from borehole five in the test section between 7 m and 10 m. This shows that the application of high pressure results in low Lugeon values. The packer test investigation in the left abutment also showed the void filling behavior of borehole five in the test section ranges between 20 m to 25 m and 25 m to 30 m and from borehole six in the test depth range between 4.5 m to 10.3 m. Void filling behavior is characterized by a decrease in the hydraulic conductivity as the test proceeds regardless of the changes in the water pressure. According to Houlsby [12] this behavior indicates that either, water progressively fills isolated/non-persistent discontinuities or swelling occurs in the discontinuities, or fines flow slowly into the discontinuities building up a cake layer that blocks them. From core sample, the soft filling materials were observed. Therefore, during the packer test, these materials are filling the fractures and the permeability of the rock mass decreases as the test proceeds from the first stage to the fifth stage. For this type of flow behavior, the representative Lugeon values are value corresponding to the 5th stage. The following Figure 10, shows void filling behavior from borehole five in the test section from 20 m to 25 m.

Packer test at the river bed

At the river bed (valley bottom), the packer test investigation from borehole two (test section from 3 to 7 m, 7 to 12 m, 12 to 17 m, and 17 to 22 m) result showed dilation types of flow behavior. The other test section from (22 to 27.5 m and 27.5 to 30.3 m) shows the

Table 4: The summarized packer test result of the proposed dam site (dam A), left abutment, riverbed and right abutment and the permeability class.

Location	Borehole Id	Depth	Behavior	Representative Lugeon value	Permeability class
Left abutment	BH-3	2.7-6 m	Dilation	3	Low Permeable
		6-10 m	Wash-out	9	Permeable
		15-20 m	Dilation	2	Low Permeable
	BH-5	7-10 m	Turbulent	1.6	Low Permeable
		10-15 m	Dilation	2	Low Permeable
	BH-6	15-20 m	Dilation	1.7	Low Permeable
		20-25 m	Void filling	0.4	Impermeable
		25-30 m	Void filling	0	Impermeable
		4.5-10.3 m	Void filling	0	Impermeable
		13-20 m	Wash-out	0.4	Impermeable
River bed	BH-2	3-7 m	Dilation	1	Low Permeable
		7-12 m	Dilation	2	Low Permeable
		12-17 m	Dilation	0	Impermeable
		17-22 m	Dilation	1	Low Permeable
		22-27.5 m	Void filing	0	Impermeable
		27.5-30.3 m	Void filing	1	Low Permeable
Right Abutment	BH-1	4-7 m	Dilation	3	Low Permeable
		7-12 m	Dilation	1	Low Permeable
		12-16.5 m	Dilation	0	Impermeable
		16.5-21.2 m	Dilation	8	Permeable
		21.2-27 m	Void filling	0	Impermeable
	BH-4	27-30 m	Void filling	5	Low Permeable
		7-10 m	Turbulent	2.5	Low Permeable
		10-15 m	Turbulent	0.9	Impermeable
		15-20 m	Turbulent	0.4	Impermeable

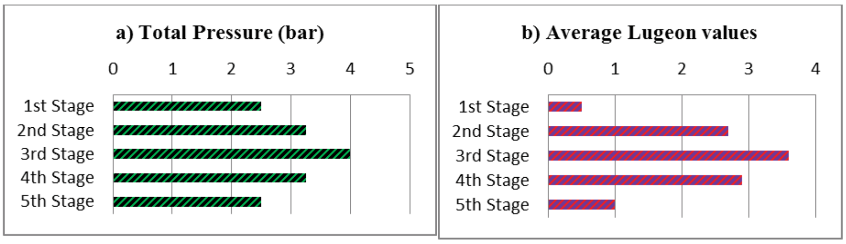

Figure 8: The dilation behavior from borehole three (test section 15 to 20 m), (a) the packer test pressures the test stage, (b) The average Lugeon values vs. test stages.

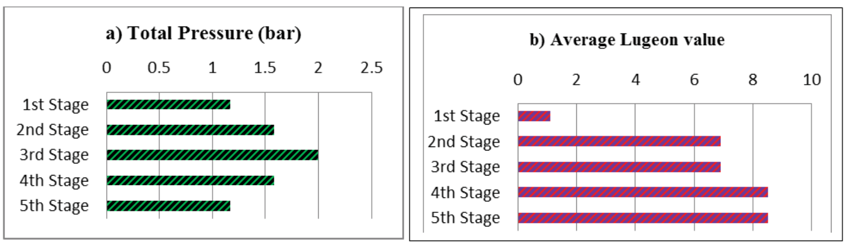

Figure 9: The above chart show the wash out behavior from borehole three in the test section 6m to 10m, (a) the packer test pressures *Vs.* the test stage, (b) The average Lugeon values *Vs.* test stages, this graph shows the behavior of the flow is Wash-out, and the representative Lugeon values is values corresponding to the 5th stage.

void filling types of behavior. The dilation and void filing behavior characteristics describe in above section in the discussion n part of left abutment in Figure 8, and Figure 11 respectively.

Packer test at the right abutment

At the river bed (valley bottom), the packer test investigation from borehole two (test section from 3 to 7 m, 7 to 12 m, 12 to 17 m, and 17 to 22 m) result showed dilation types of flow behavior. The other test section from (22 to 27.5 m and 27.5 to 30.3 m) shows the void filling types of behavior. The dilation and void filing behavior are described in the left abutment section which is discussed in Figure 8 and Figure 11 respectively. The relationship between depth and

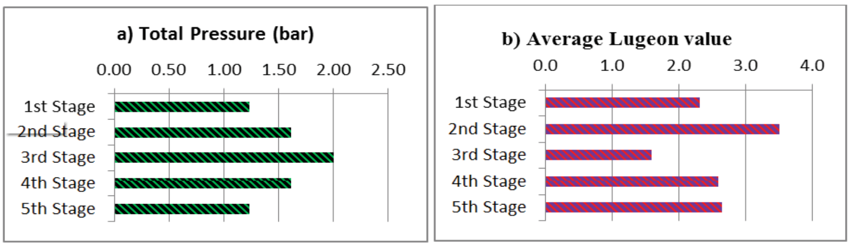

Figure 10: The above chart shows turbulent flow behavior from borehole five, (a) the packer test pressures the test stage, (b) the average Lugeon values *Vs* test stages.

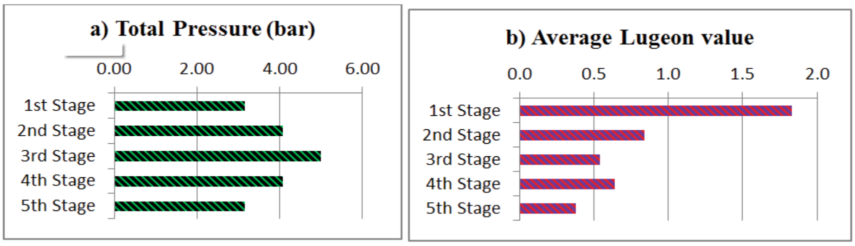

Figure 11: The above chart shows void filling behavior from borehole five (test section 20 to 25 m), (a) the packer test pressures the test stage. (b) The average Lugeon values *Vs* test stages.

permeability the rock mass in the proposed dam site has inverse relationships i.e. when depth increases the permeability of the rock mass decreases. The permeability of rock mass at the proposed dam site ranges from 0 to 9 Lugeon values. As shown in Figure 12, the permeability of rock classified into impermeable, low permeable and permeable. From packer test result the highest permeability values of rock mass were found at borehole three (depths from of 6 to 10 m) and borehole one (depths from 16.5 to 21.2 m) at the left and right abutment of the proposed dam respectively. Generally, from the packer test permeability results of the rock mass along the dam axis of GBG dam site (A), dilation, turbulent, void filling and wash out behaviors were observed. Among these behaviors, the most problematic one is washing out behavior that was investigated in the left abutment. The wash out behavior at the left abutment has 9 Lugeon value from borehole three and 0.4 Lugeon value from borehole six. Even if the permeability corresponding to this behavior is less since the filling materials are washed, the fracture will remain open and it will be the pathway for seepage. The other maximum permeability of rock mass, which was investigated in the right abutment close to the river bed, from borehole one in a depth range between 16.5 to 21.2 m is 8 Lugeon value. From the surface geological map at this location, vertical fractures are observed, as the same time from borehole sample the fractures are investigated. Since this borehole is close to the river, the existence of fracture will be the potential zone for seepage through the foundation of the proposed dam. The high permeability results from packer tests in the left abutment of the proposed dam and through the foundation along the river bed showed the presence of potential seepage problem. Hence, the foundation and the left abutment of the proposed dam need ground improvement before the construction of the dam. As the result obtained from the packer test investigation, the foundation and the left abutment of the proposed dam need ground improvement before the construction of the dam. The most appropriate ground improvement methods to avoid the expected potential seepage, curtain grout is recommended up to the impermeable zone of the layer.

Integration results of resistivity, RQD and packer test

The geophysical resistivity imaging along the dam axis and the corresponding boreholes location are shown in the Figure 11. From the geophysical investigation result the above located borehole give the representative information of the dam site. The general stratigraphy of the area from the bore whole data shows the top most 1 to 3 m depth covered by the residual soil relatively stiff and has rock fragments on it. Below this, it consists of ignimbrite rock unit with different degree of weathering and fractures. From the six boreholes the RQD values increase with depth and this indicates the degree of weathering is relatively decreased from the surface to depth. The relation between the resistivity, RQD and Lugeon values (Permeability of the rock mas are shown in Figures 13 and 14. The figures show the integrated result of VES, RQD and permeability of rock mass at right abutment of the proposed dam. Along this section the resistivity values at the top shows low values due to the presence of residual soil and highly weathered fractured ignimbrite, and the RQD also very low, from 7 to 10 m the resistivity response show relatively low value and the RQD also low, but the permeability shows relatively high. From this data the RQD and VES shows direct relation and invers relation with permeability. At the right abutment the VES, RQD and permeability values shows, the rock at the right abutment are characterized by relatively higher resistivity, high RQD and low permeability. Therefore from Figure 15 the right abutment of the proposed dam are less problematic interms of seepage.

Figure 15 shows the integrated result of different investigation at the right abutment close to the riverbed. From this abutment of the proposed dam it is observed that zero RQD value at 9.6 to 10.6 m, and 27 to 28.5 m depth. When we correlate with the resistivity data shows low resistivity values below 9 m depth, the permeability at this section at the top part low permeability this indicates even if the rock are fractured the fractures are not persistence that is the reason to show low permeability. However, at the lower section both RQD and permeability shows, low RQD and high permeability, it indicates that rock are highly fractured and persistence. In the other section, the relation is RQD increase, resistivity increase, Permeability decrease. The result from this location shows relatively permeable zone at the depth of 16.5 to 21.2 m, at the same time the RQD values are less and the resistivity are low, therefore at this location the potential seepage problem will be expected.

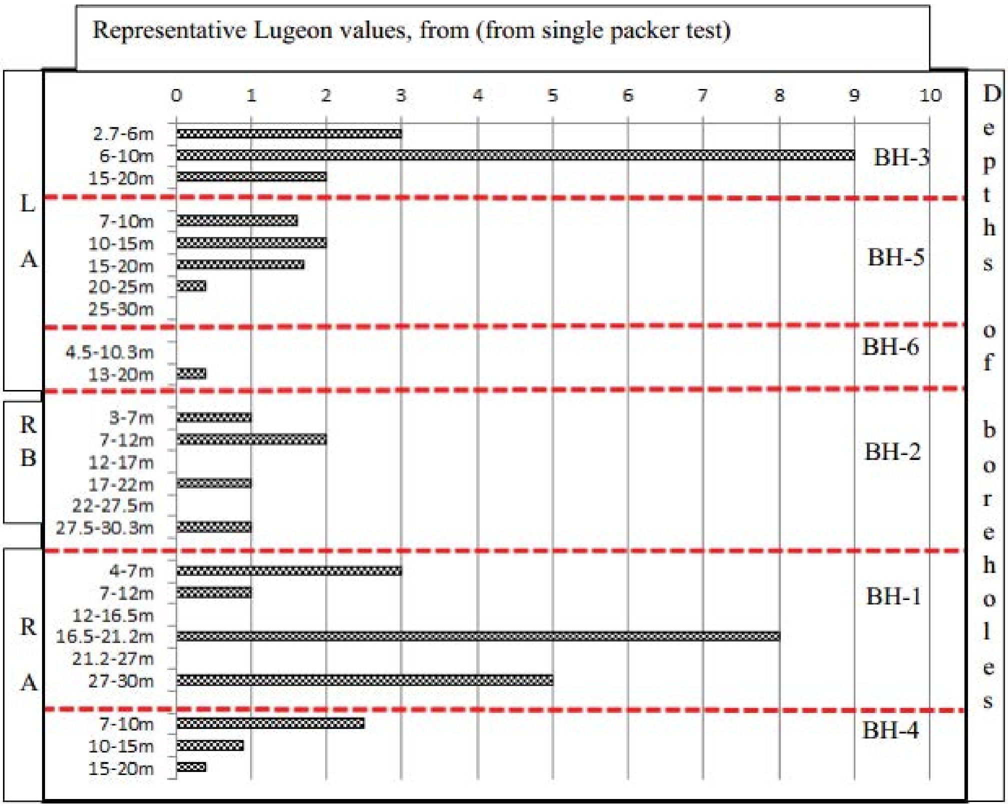

Figure 12: The relationship between rock mass permeability and depth, from proposed GBG dam site (dam A), where the abbreviation from the above figure are LA-left abutment, RB- river bed, RA-right abutment and BH-borehole.

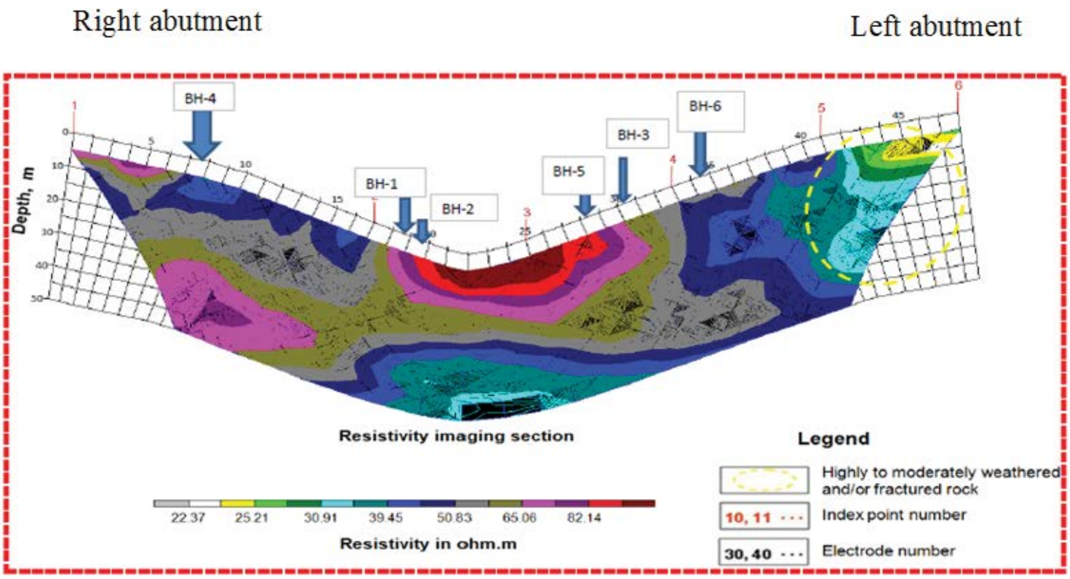

Figure 13: The Resistivity imaging section along dam axis and the Borehole location modified from ECDSWC, 2017.

Figure 16 shows the relationship between VES, RQD and permeability of rock mass at the riverbed. The relation of resistivity, RQD and permeability at this location show that below 9 m low resistivity, and RQD ranges from 0 to 64% and the permeability is 0 to 1 Lugeon, this shows that the rock are highly fractured weathered and but the discontinuity are not persistence, that make low permeability at this station. Figure 17 shows the relationship of VES, RQD and permeability result of rock mass at the left abutment of the proposed dam. From this section, it is interpreted that with the range of 6 to 10 m depth, the permeability values are relatively high. Corresponding to this the resistivity values also low and the RQD value s ranging between low at this depth. From the Lugeon test with the depth of 6 to 10 m it is observed that the wash out behavior and the most problematic zone interms of seepage. Generally, the relation of the three-investigation result shows that at this location the potential seepage will happen due to the existence of fractured low resistivity, low RQD and high permeability materials.

CONCLUSION

Integrated geophysical and geological as well as packer permeability test is the effective method to evaluate the water tightness of the dam site. The geophysical resistivity imaging data shows at the top of the area is covered by low resistivity material and it is verified by borehole and surface investigation the top 2 to 3 m along the dam axis is covered by the residual soil and it have low permeability.

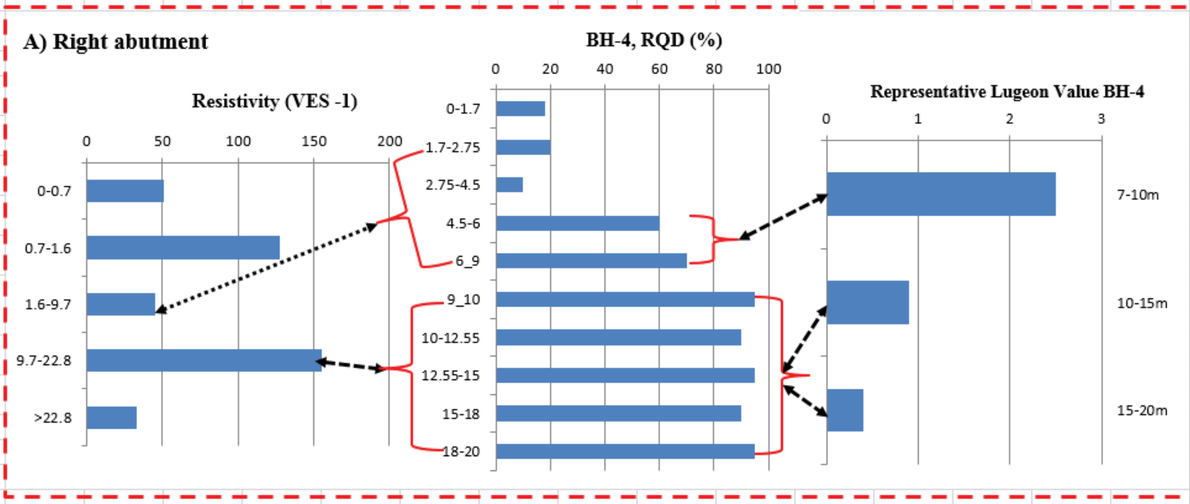

Figure 14: The integrated result of VES, RQD and permeability at the right abutment of the proposed dam.

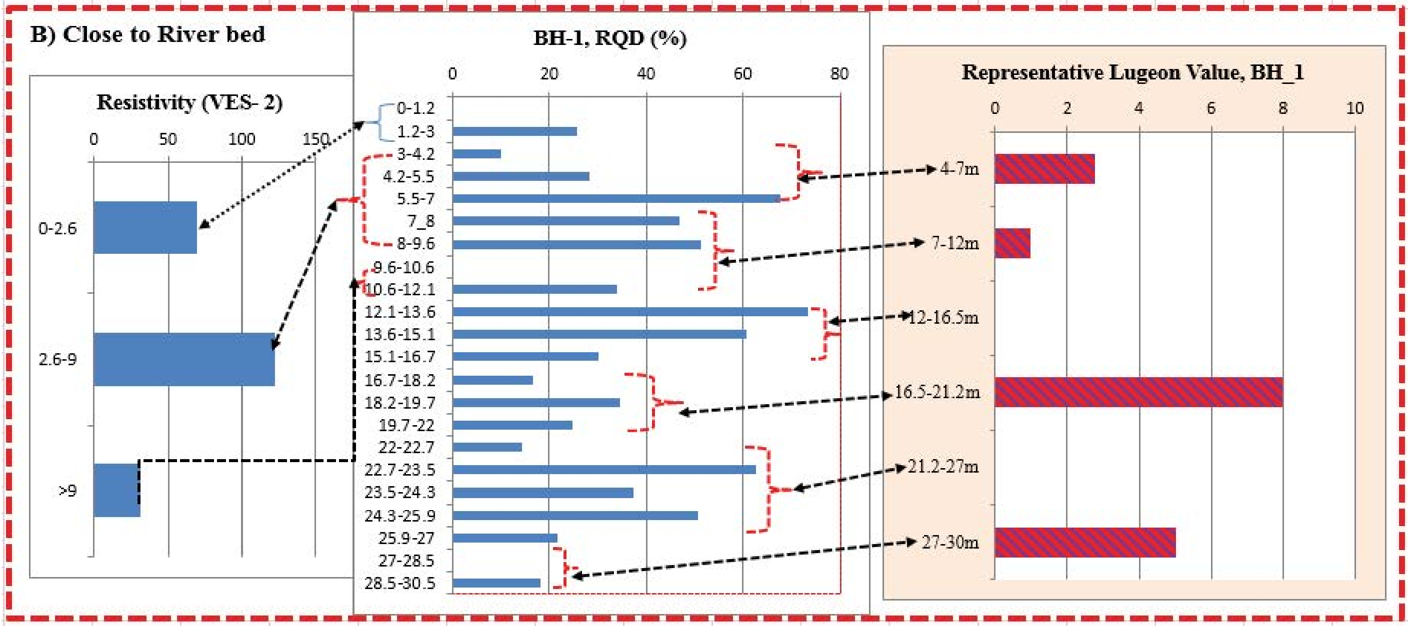

Figure 15: The integrated result of VES, RQD and permeability of rock mass at the right abutment close to riverbed.

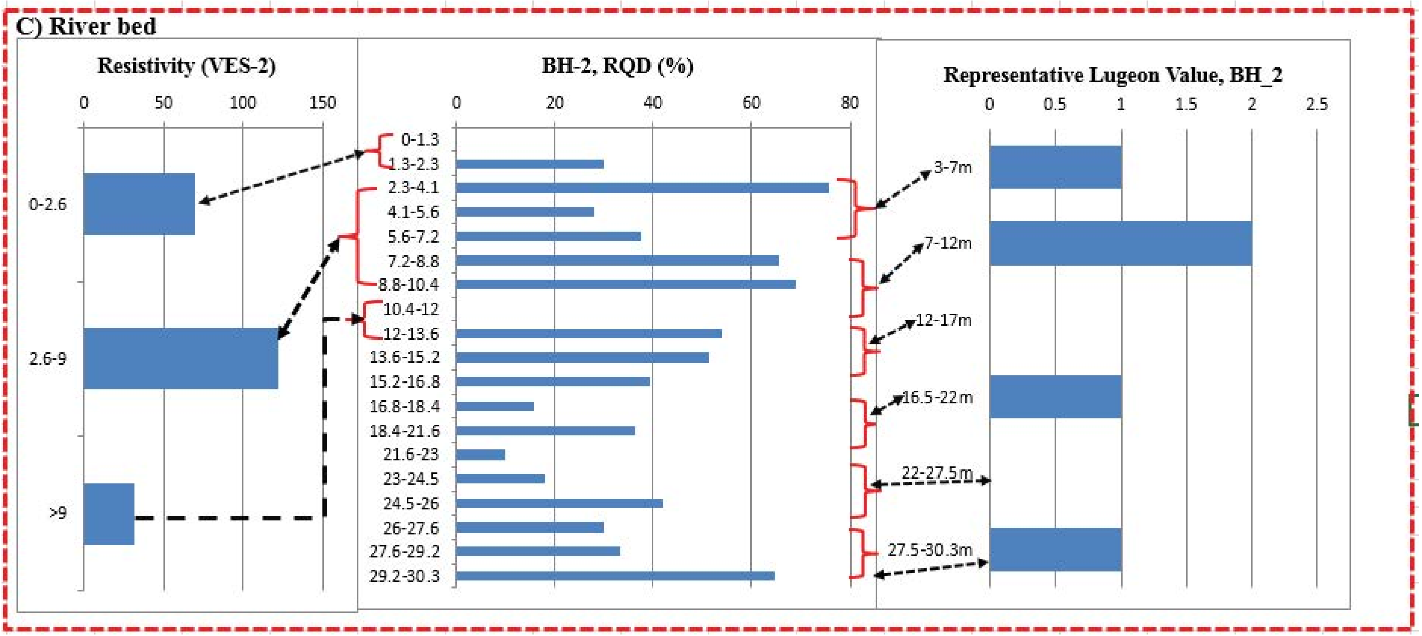

Figure 16: The above figure shows the relationship between VES, RQD and permeability of rock mass at the riverbed.

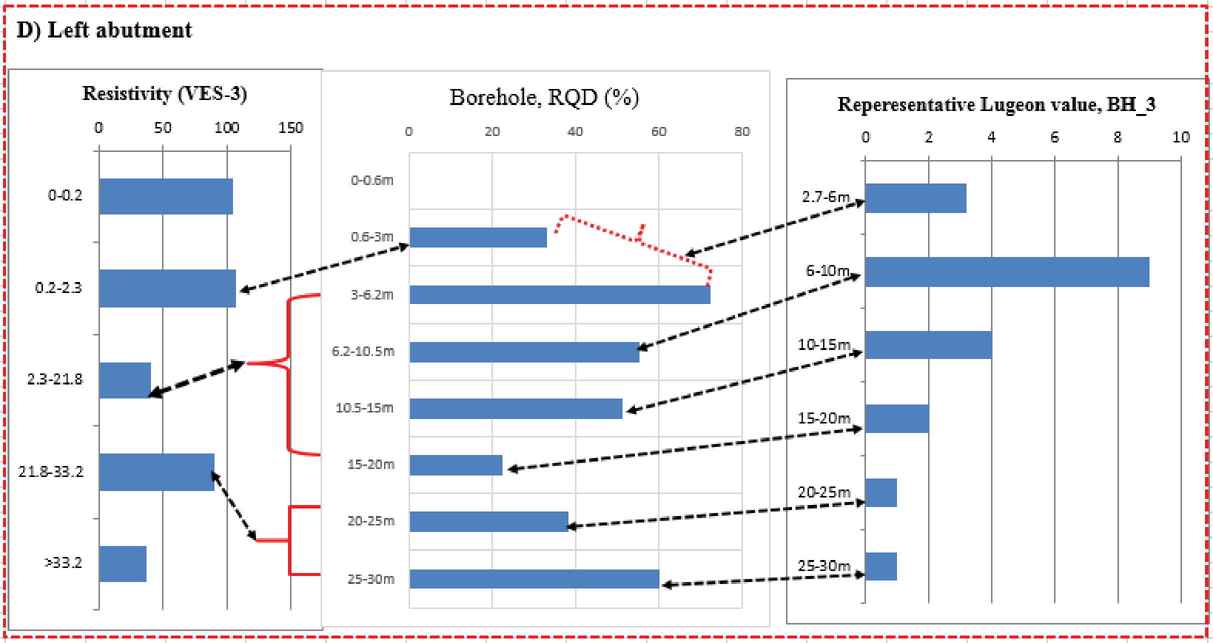

Figure 17: The relationship between VES, RQD and permeability of rock mass at left abutment of the proposed dam.

Below 5 m the area have almost similar geology, consist of ignimbrite rock unit with varies degree of weathering and degree of fracturing. From the six boreholes, the RQD value of the rock unit ranges from 0 to 100%. The RQD value from, BH-1 calculated ranges from 0 to 73.3%, BH-2 ranges from 0 to 75.6%, BH-3 ranges 0 to 92.7%, BH-4 ranges 0 to 95%, BH-5 ranges 0 to 100% and BH-6 ranges 0 to 70%. The RQD values of the rock in the dam axis are ranging from Very poor to Excellent. The packer test result expressed in Lugeon shows the result 0 to 9 Lugeon values. The permeability test results show the rocks are Low permeable to Permeable.

The relation between the electrical resistivity value, RQD and the packer test result, a resistivity and RQD value shows nearly the same characteristics. When the resistivity value increase the RQD values of the rock also increase but the permeability of the rock have different characteristics. When the resistivity increases the permeability of the rock is less and when the resistivity decrease the permeability of the rock is increase. Sometimes it is not true when the ground water is present, this means if there is water the resistivity values will be less and the permeability or the Lugeon value is low. Because if there is water it will saturate enough and it will not take much water during the permeability test. The other results shows from the investigation is when the RQD of the rock is increase the permeability of the rock is also increase this is due to some of the joint and fracture are even if it is widely fractured but the fracture are continues and connected. In other case also it is observed that when the RQD values decrease the permeability of the rock also decrease this is due to the infilling materials and the fractures are not connected each other.

Generally, from those integrated analysis at the riverbed and left abutment of the proposed dam the potential seepage problem will happen due to the existence of fractured and weathered ignimbrite rock having low resitivity, low RQD and relatively permeable. Packer test result is the direct test for the water tightness of the rock mass in the dam site. Therefor this test shows at the left abutment the maximum permeability values observed with wash out behavior and around riverbed with dilation behavior. Therefore, from the result of the investigation, the left abutment and the riverbed of the proposed dam site the potential seepage will happen and it need ground improvement.

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