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Weathering of Volcanic Rocks in Baturappe Formation and Its Implications for Foundation Planning of Pamukkulu Dam, South Sulawesi, Indonesia

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ABSTRACT The presence of weathered volcanic rocks in Pamukkulu area is important in determining the location and construction of the Pamukkulu main dam and plinth structure. In general, volcanic rocks have poor geotechnical characteristics due to varying degree of weathering, influence of groundwater, and systematic joints produced by cooling lava. This study aims to study the type and quality of weathered rock around the main dam and plinth area. First, mapping of surface geology was carried out. To evaluate the degree of weathering, rock resistivity data is used around the main dam area. Whereas for the plinth area, the bearing capacity of soil/rock is evaluated using Plate Bearing Test (PBT) and Standard Penetration Test (SPT). Bearing capacity obtained from PBT that were carried out on rock surface can be used to interpret rock weathering. In addition to SPT, the coring from rock drilling was also evaluated using Rock Quality Designation (RQD). It was found that the rock up to 20 m depth are of poor quality. It is recommended that the poor-quality rock is removed until moderately dense rock layer is found.

KEYWORDS Weathering, Volcanic Rock, Main Dam, RQD

1 INTRODUCTION

Chemical and Physical weathering are processes that affect the mechanical properties of rock material and rock mass at shallow depths (Arikan, 2012). Weathering depends on the external environmental agents such as climate, plant growth etc., which will vary from place to place. Depending on the external agents and duration of weathering, properties of rock material and rock mass can vary. For rock material, the properties that determine sensitivity (or resistance) to weathering are mineralogy (solubility and resistance to chemical weathering), grain size, porosity, and permeability. For rock mass the spacing, nature, persistence, and aperture of discontinuities together with the stress conditions would have a major influence on weathering (Hack and Price, 1995). Weathering is a very important process in earth sciences. In this study, the influence of weathering in infrastructure is presented.

In the construction of dams, it is necessary to plan for things related to construction, such as soil conditions, materials, surrounding environment, etc. The Pamukkulu Dam Development Project is located in Takalar Regency, South Sulawesi Province, Indonesia. The construction of the Pamukkulu Dam is planned to be a zoned type with a layer of waterproof concrete in the upstream called Membrane Rock Filling (UBM) or Concrete Face Rockfill Dam (CFRD). An embankment dam is built by stockpiling materials such as stones, gravel, sand, and soil in a certain composition to function as a buffer or lifting the surface of the water contained in the dam. The Pamukkulu Dam area is in a hilly area that is in the Baturappe-Cindako Volcanic Rock Formation (Tpbv), which is composed of lava, breccia lithology and Basalt cracks. The development project has been ongoing, but there are still issues regarding the geological conditions that has to be handled. While compact and massive rock can be considered a good (ideal) foundation for dam foundation, this condition is rarely found. In order to characterize the subsurface conditions, geological investigations are necessary.

Volcanic rocks are considered to have poor geotechnical characteristics which are caused by different degree of weathering, groundwater influence, and systematic joints formed by cooling lava. This study aims to (1) obtain information on the type and quality of rocks based on the degree of weathering, (2) interpretation of weathered rock based on rock resistivity data for the depth of the main dam and plinth area, and (3) evaluation of rock weathering on the surface and below the ground surface. To evaluate rock weathering on the surface, bearing capacity of the soil/rock by Plate Bearing Test (PBT) are used; as for rocks below the surface, RQD (Rock Quality Designation) values from drilling are used.

Classifying degree of weathering in rocks can be subjective, hence it is difficult to accurately quantify how weathered a rock is. Problems in weathered rocks (both in material and mass level) requires degree of weathering to be correctly interpreted for design to be done correctly. Unfortunately, the descriptive terms most commonly used for classifying weathered rocks are the index properties of rocks, which are subjective in nature.

2 METHODS

A total of four observation areas were selected in this study, covering the main dam, structural plinth, spill way, and tunnel area of the dam to be constructed on Volcanic Camba Formation. The study comprised of geological approach (geomorphology, lithology, and geological structures), seepage analyses, weathering degree analyses based on the bearing capacity test, and Rock Quality Designation (RQD) analysis. To evaluate rock conditions in larger area, geoelectric measurement was also used. The results of the study and its implication on the foundation for dam construction is also discussed.

The geological approach and seepage analyses were carried out on the field based on the visual recognition of rock weathering, seepage condition at surface, existence of original texture and joint staining. The bearing capacity test and RQD were obtained from Plate Bearing Test (PBT), and coring data.

2.1 Lateral and Vertical Distribution of Weathering Profiles in the Volcanic Rock

Line surveys of resistivity test, plate bearing test, and RQD calculations from rock coring were used to define the lateral variations due to weathering.

In the Pamukkulu dam area, geoelectric measurements were taken. Geoelectric measurements involve injecting current from a transmitter and reading the value of the potential differences at the receiver. The apparent resistivity can then be calculated, and the results can be plotted according to the datum position in the Sequence design. The calculation and data recording are done automatically by SYSCAL data logger. The results are plotted as 2D geoelectrical measurements (resistivity 2D) in the form of an apparent resistivity. The data measured by SYSCAL are the Self Potential (SP) that arises naturally due to the intrusion zone and weathering; the value I_n (in milli amperes, mA), which is the amount of electric current injected into the earth); the value V_{ab} (in milli volt, mV), which is the potential difference that arises at potential electrode as a result of the injection of electric current into the earth due to the presence of rocks containing a lot of water. By using Ohm's law, the resistivity (R) value can be calculated. The result is then multiplied by the geometry factor of the dipole-dipole configuration to obtain the apparent resistivity (R_{ho}) value. This R_{ho} value represents the resistivity of a material. From these material units we can make subsurface models, both in 2D and 3D.

2.2 Soil Bearing Capacity Values

Plate Bearing Test is a test method used to obtain soil bearing capacity values in the surface or subgrade soil layer simply by applying pressure onto the soil surface. The pressure is applied via a circular bearing plate. The pressure is continuously increased in fixed time intervals until the maximum loading is reached.

2.3 Rock Quality Designation (RQD) Analysis

The drilling in this study is carried out in accordance with ASTM D2113-14, ASSHO T225, and BS 4019-1. The drilling method used is rotary type drilling machine. For soft and shallow soil layers a manual rotary drilling machine is used, while for hard and deep drilling, where the pressure on the drill bit must be large and the long drill pipe will be heavy, a hydraulic rotary drilling machine is used.

From the core drilling, several data were collected on subsurface engineering geological conditions, namely rock class determination, Rock Quality Designation (RQD) calculations and rock permeability testing. The data collection is described as follows:

1. Determination of rock class. Determination of rock class is based on the classification of rock mass by CRIEPI (1992). The classification is based on visual observation to evaluate the degree of weathering and jointing of the rock coring, as well as rock testing by hitting it with a geological hammer.

2. RQD calculation is done by calculating the percentage of intact length of rock coring (which is longer than 10 cm) to the total core length, which is 1 meter. The RQD calculation ignores the joint or fracture caused by drilling activities. The formula for RQD is given by Deere et al. (1967, in Deere and Deere, 1989), as follows:

$$RQD = \frac{\sum length\ of\ core\ pieces > 10\ cm\ length}{Total\ length\ of\ core\ run}$$

The larger the RQD value, the smaller the crack frequency. The better the rock quality

3. RESULTS

3.1 Geomorphology and Rock Identification

The geomorphology of the research area is based on the morphographic aspect approach with a height of 150 meters, which is a hilly relief with a blunt peak shape (Figure 1). The geomorphological processes currently developing in the research area are dominated by denudation processes, namely weathering and erosion. Weathering processes that occur in the research area are in the form of physical, biological, and chemical weathering. Physical weathering in the field can be seen in the form of fragments that are separated from the original rock (Figure 2a). Biological weathering in this landscape is characterized by the presence of tree roots that penetrate the rock, making it no longer massive and eventually become soil. Chemical weathering is characterized by the presence of spheroidal weathering caused by the release of pressure on the rock due to pressure changes (Figure 2b).

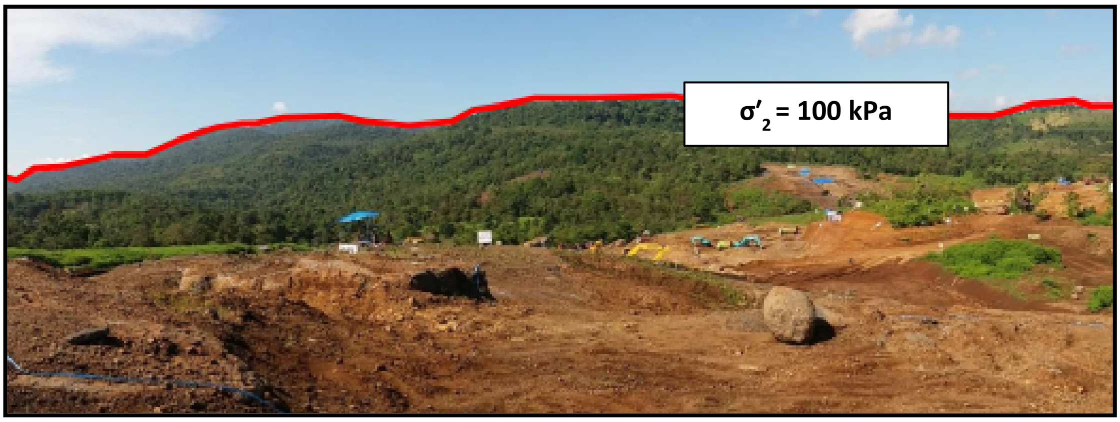


Figure 1. Hilly Landscape at Pamukkulu dam, South Sulawesi, Indonesia.

(a) (b)

Figure 2. Photograph of Weathering Mechanism: (a) Mechanical Weathering; (b) Chemical Weathering

The lithology of the study area is composed of basalt lithology and volcanic breccia, the megascopic appearance of this lithology can be seen in (Table 1).

Table 1. Description of megascopic lithology of the study area

ID	Station	Description	Figure
1	STA 0+200 from center of dam	Basalt. Physical characteristics: fresh color is blackish gray and weathered color is brownish gray, hypocrystalline crystallinity texture, aphanitic granularity, subhedral-anhedral shape, inequigranular relation, massive structure (Fenton and Fenton, 1940).	
2	STA 0+321 from center of dam	Volcanic Breccia. Physical characteristic: fresh color is gray and weathered color is brownish gray, massive structure has basal fragments measuring 16-256 mm, with a matrix measuring 4-64 mm, and cement measuring 1/8-1/256 mm.	

3.2 Fracture Zone and Seepage Observation

In the study area, cracks were found that extend from the center of dam to the plinth area. These cracks can cause seepage, as cracks that goes through the rock layers can extend to the surrounding rocks, resulting in fracture. Cracks observed in the study area were caused by igneous rock intrusion in the form of sills and dikes that broke through the pre-existing rocks. The dominant cracks that developed in the study area were andesitic basalt generally found in the form of dikes, where these hacks penetrated not in the direction of the rock layers. The rock that was broken through is sedimentary rock in the form of breccia, making it easily weathered and susceptible to seepage. However, in several places in the study area, rocks that were breached by the hack were found to have not experienced weathering, but instead had a zone of combustion or a backing effect**.**

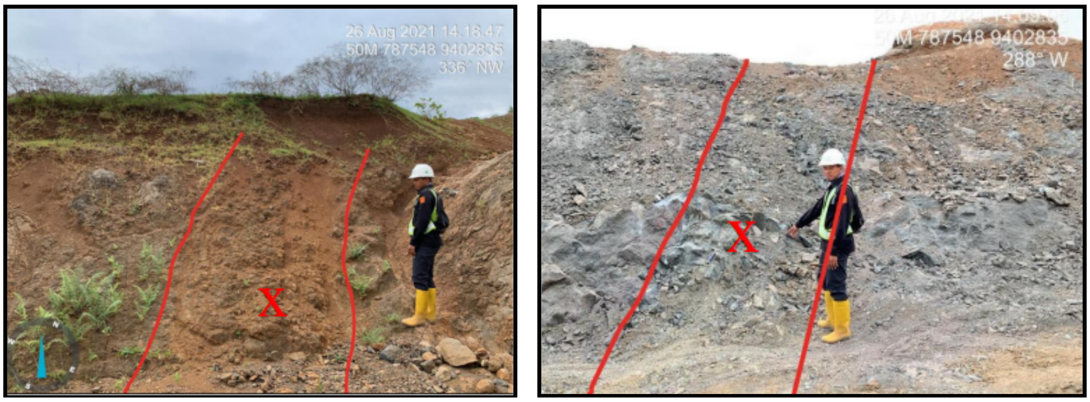


Figure 3. Dike in Basalt (X)

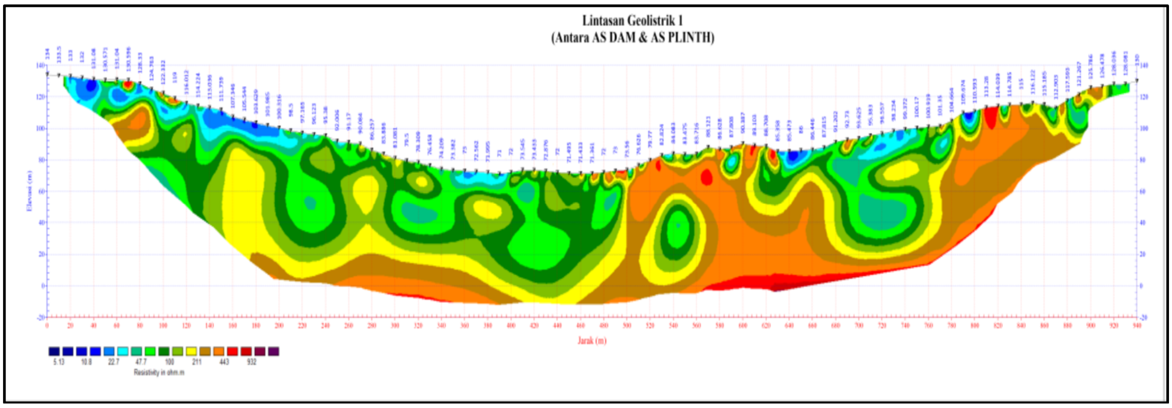
Cracks and continuous joints that undergo weathering can result in weak zone. As a result of this zone, surface seepage is found in several places, such as in the dam site area where the surface seepage zone is in hack X (Figure 2), surface seepage which has large discharge was found due to the rock having undergone very high weathering, causing the rock to turn into soil. Seepage zones were also found in plinth areas caused by continuous weathering of joints. Seepage zones can also be found in cracks and joints that have weathered into weak zones, causing the rock to contain water as seepage (Figure 4).


Figure 4. Seepage in Dike

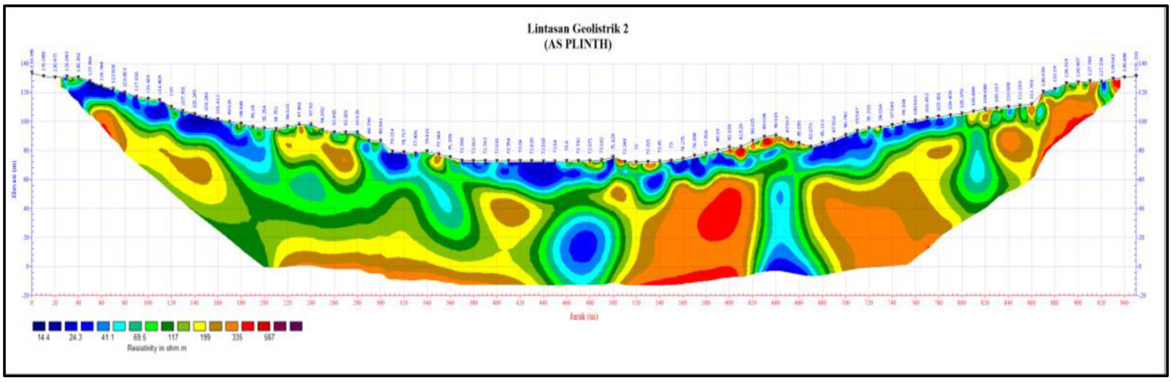
3.3 Weathering and Seepage Analysis Based on Resistivity Values

Based on the results of observations and resistivity tests on a track that has rock outcrops, it is determined that breccia rock has a resistivity scale >=100 Ohm.m. This value is used to interpretate the entire track. Value below 100 Ohm.m is categorized as a layer of soil or weathered rock.

Figure 5 shows the results of the geoelectric measurements. The measurement of low resistivity value is indicated by dark blue to light blue color. The low resistivity value is due to the presence of rocks containing water. The low resistivity value (below 100 Ohm.m) also indicates that the rock has been weathered, giving potential for seepage in the area. The geoelectrical cross-section obtained for the plinth and main dam area (Figure 5a), 7 points which have potential for seepage are found. Similarly, 7 points have the potential for seepage were also found for the geoelectrical cross section for the plinth (Figure 5b). The geoelectrical cross section for the tunnel shaft (Figure 5c) shows 4 points which have potential for seepage. The same number of seepage points were found on the cross section for intake (Figure 5d) For the spillway area (Figure 5e), the lowest resistivity value is found on the surface. The spillway area has 7 points which have indication for seepage. The locations of seepage points are summarized in Table 2.



(a)



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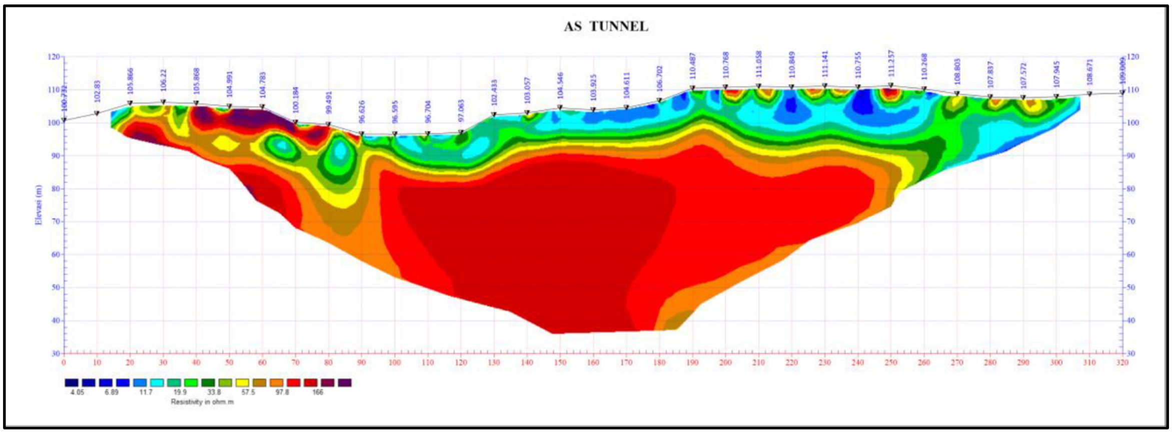

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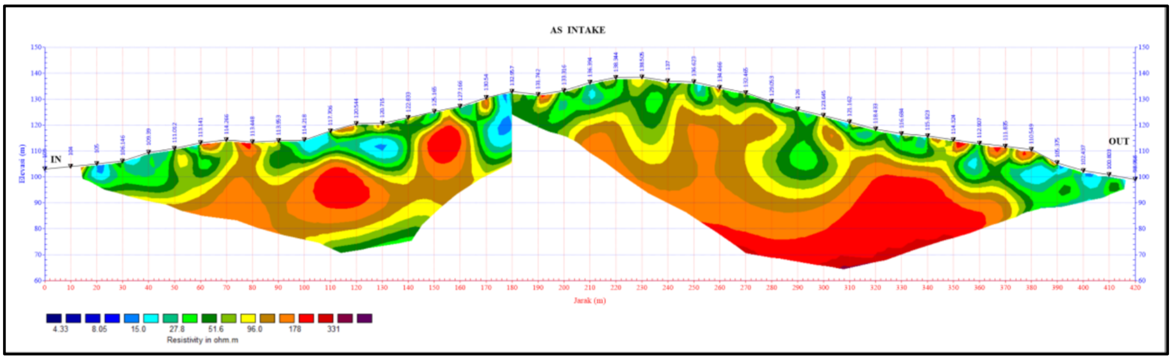

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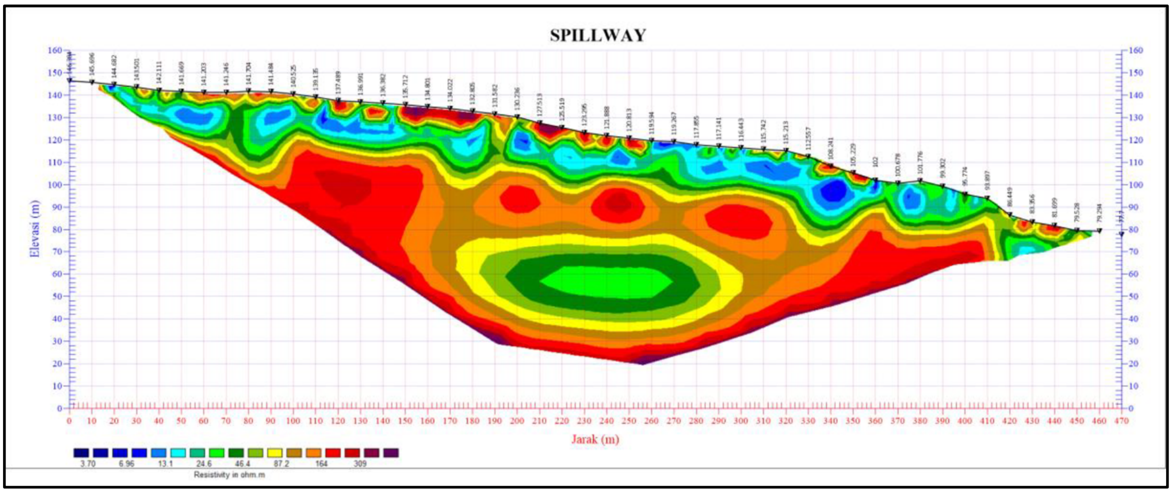


(e)

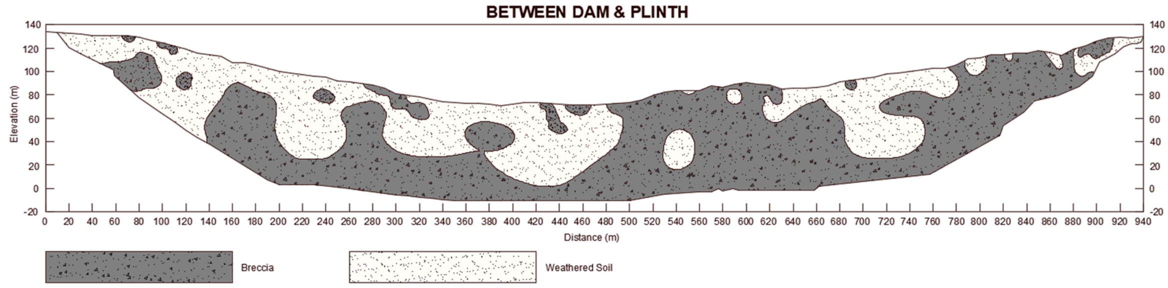
Figure 5. Geoelectric measurement: (a) main dam and center of plinth structure; (b) plinth structure; (c) tunnel; (d) intake; (e) spillway

Table 2 Seepage Points at the cross sections with geoelectric measurements

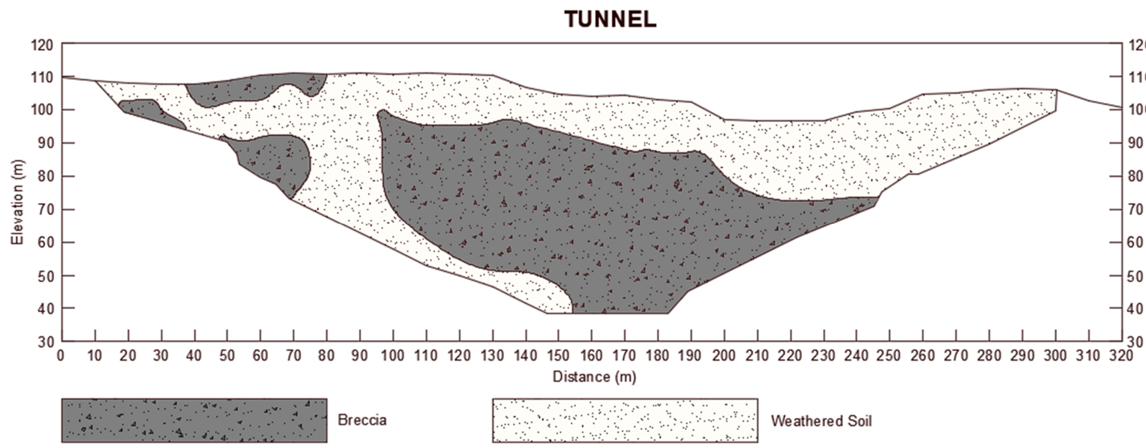
No	Cross Section Measured	Distance (m)	Elevation (m)
1		20 – 40	120 – 140
2		60 – 120	100 – 130
3		140 – 200	100 – 130
4	Main dam and plinth structure	300 – 400	55 – 95
5		620 – 680	80 – 90
6		700 – 740	35 – 100
7		785 - 800	100 – 130
1		40 – 100	120 – 140
2		300 – 340	75 – 85
3		340 – 480	80 – 100
4	Plinth structure	448 – 485	20 – 40
5		520 – 600	60 – 90
6		620 – 660	15 – 35
7		680 - 780	80 – 120

1	Tunnel	150 – 190	90 – 100
2		190 – 200	95 – 100
3		210 – 220	90 – 115
4		230 - 260	90 – 110
1	Intake	20 – 50	90 – 100
2		90 – 150	95 – 100
3		170 – 190	90 – 115
4		380 – 410	90 – 110
1	Spillway	40 – 180	120 – 140
2		300 – 340	75 – 85
3		340 – 480	80 – 100
4		448 – 485	20 – 40
5		520 – 600	60 – 90
6		620 – 660	15 – 35
7		680 - 780	80 – 120

The results of the lithology interpretation based on the resistivity values are presented in Figure 6.



(a)



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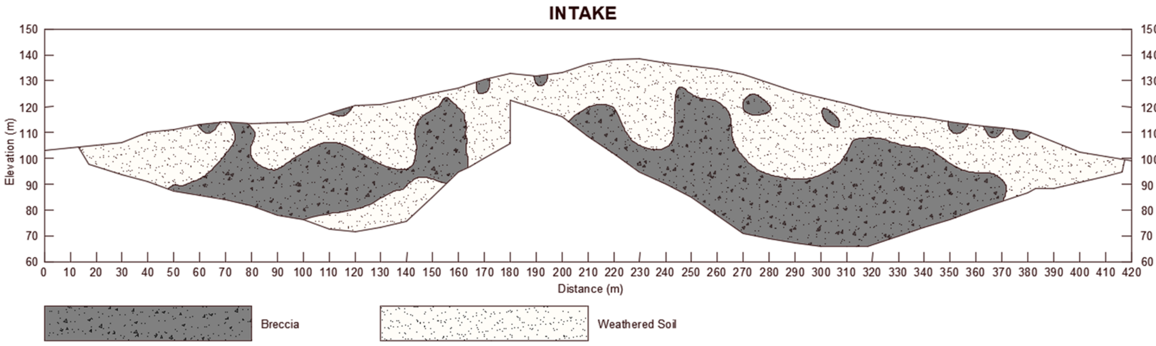

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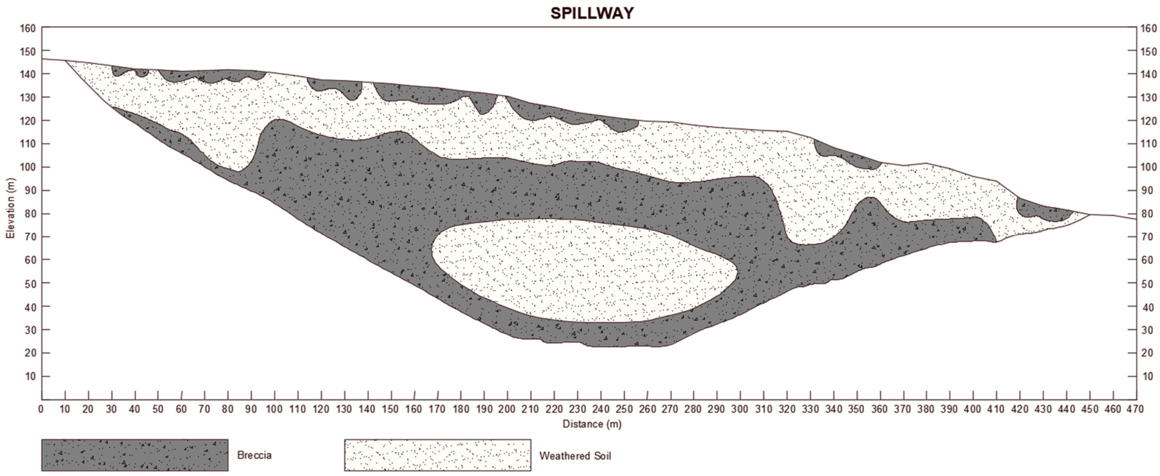

(d)

Figure 6. Lithological interpretation based on resistivity values: (a) main dam and center of plinth structure; (b) tunnel; (c) intake; (d) spillway

Connections between seepage paths is interpreted from the geoelectrical sections (Figure 5). Each cross sections are placed according to its coordinates, then the soil/rock with the same resistivity values are assumed to be connected, i.e., one soil/rock type. There is a common color that runs from the tunnel cross section to the plinth and main dam cross section. From these connections, it can be interpreted that the seepage is continuous and interconnected between all parts of the dam.

The subsurface of the plinth structure (Figure 5b) consists of rock with classes ranging from D (Decomposed rock) to CH (class high rock). The depth of Class D rocks varies from the surface to a depth of 2-10 meters. The decomposed rock is caused by weathering that occurs on the surface. The rock class CH dominates the subsurface of the plinth area up to the drilling depth limit.

The degree of weathering that occurs in the research area is quite high, as residual soil can be found in several places. The thickness of residual soil exposed on the surface varies between 1 to 10 meters (Figure 7). The color of the soil is light brown to dark brown with vegetation in the form of trees and shrubs on the surface of the soil.

Figure 7. Residual soil found in Pamukkulu dam area, South Sulawesi, Indonesia

3.4 Lithology Description and RQD Calculations Based on Drilling Data

Based on samples from each drilling point, the lithology of the study area consists of basalt and volcanic breccia which are described as follows:

1. Basalt (Travis, 1955). Fresh basalt is grayish black to black in colour, in weathered state it changes colour to brown. The basalt has porphyrogenites texture, hypocrystalline, pyroxene mineral composition, plagioclase and glass bottom mass, and massive rock structure.

2. Volcanic Breccia. Volcanic breccia in a fresh state is gray-black in colour, in weathered state it changes colour to brown. Volcanic breccia also has porphyrogenites texture, with rock composition consisting of fragments, matrix, and cement. Igneous rock fragments (basalt) and tuff with subangular-angular shapes with varying fragment sizes, namely gravel - shallow (4 - 64 mm), the matrix consists of pyroxene and tuff minerals, and silica cement in the form of volcanic ash. The rock structure is vesicular and amygdaloidal.

3.5 Minerology of Volcanic Rock

Table 3 shows the soil/rock classification based on geological drilling. The volcanic rocks cover an area of about 2 km^2. Characterization of Mineralogical and textural thin sections and analysis petrography of the formation of minerals have been conducted. The volcanic rocks consist of volcanic breccia and basalt. Petrographic analysis is intended to determine the carrier rock type and mineral weathering of rock fragments in the study area. In petrographic analysis the sample is made into a thin incision and analyzed under a Nikon ECLIPSE LV100ND POL polarizing microscope. The petrographic analysis was carried out at the Laboratory of Mineral Optics of the Department of Geology, Hasanuddin University. Mineralogy analysis is intended to determine the type and texture of volcanic rock minerals that exists in the study area.

Petrographic observation (Figure 8) shows that several minerals can be identified including plagioclase (25%), pyroxene (35%), quartz (20%), groundmass (10%), and others opaque minerals (10%). Basalt on the volcanic breccia rock in study areashows dark gray color, the texture consists of hypocrystalline crystallinity, the apanithic granularity with equigranular relations, while the crystal form is subhedral-anhedral.

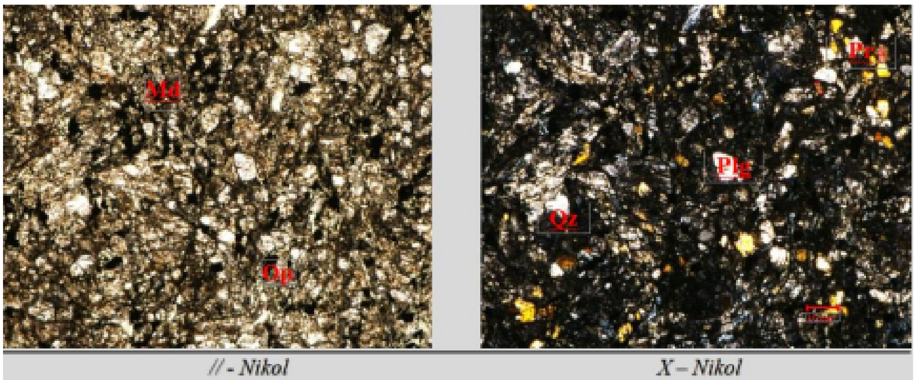

Figure 8. Petrographic Features of BW-11, mineral content: Plagioclase (Plg), Quartz (Qz), Pyroxene (Pr), Opaq (Op) dan Groundmass (Md).

Petrographic observation (Figure 9) shows that several minerals can be identified including plagioclase (33%), olivine (15%), quartz (7%), groundmass (30%), and other opaque minerals (15%). Basalt in study area shows dark gray color, the texture consists of hypocrystalline crystallinity, the apanithic granularity with equigranular relations, while the crystal form is subhedral-anhedral.

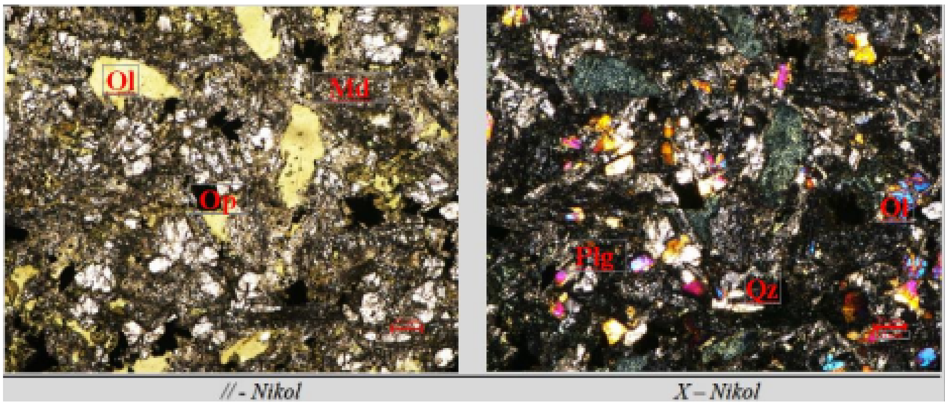

Figure 9**.** Petrographic Features of PL-26, mineral content: Quartz (Qz), Plagioclase (Plg), Olivine (Ol), Groundmass (Md), and Opaq (Op).

The results of the RQD calculations at each drilling location is presented in Table 3.

Table 3. RQD calculation results at core drilling points

Drill ID	Depth (m)	Lithology	Rock Class	Average RQD (%)	Rock Quality	Location
BW10	0 – 8	Volcanic Breccia	D	-	-	Plinth Structure
	8 – 20	Volcanic Breccia	CH	90	Very Good	
	20 – 30	Basalt	CH	83	Very Good	
BW11	0 – 1.7	Volcanic Breccia	D	-	-	
	1.7 – 15	Volcanic Breccia	CH	88	Very Good	
PL21	0 – 7.5	Volcanic Breccia	CL	-	-	Dam Area
	7.5 - 35	Volcanic Breccia	CH	85	Very Good	
PL25	0 – 11	Volcanic Breccia	CL	-	-	
	11 - 40	Volcanic Breccia	CH	98	Very Good	
PL26	0 – 5	Volcanic Breccia	CL	-	-	
	5 – 11	Volcanic Breccia	CH	83	Very Good	
	11 – 25	Basalt	CH	-	-	
	25 – 50	Volcanic Breccia	CH	85	Very Good	
PL46	0 – 6	Topsoil	D	-	-	
	6 – 10	Volcanic Breccia	CL	-	-	
	10 – 16	Volcanic Breccia	CH	59	Moderate	
	16 – 17	Volcanic Breccia	CL	-	-	
	17 – 35	Volcanic Breccia	CH	65	Good	
PL52	0 – 4	Basalt	D	-	-	
	4 – 14	Basalt	CL	-	-	
	14 – 25	Basalt	CH	75	Good	
	25 – 40	Volcanic Breccia	CH	95	Very Good	
PL60	0 – 10	Topsoil	-	-	-	
	10 – 13.6	Volcanic Breccia	CL	-	-	
	13.6 – 45	Volcanic Breccia	CH	91	Very Good	

Note: D = Decomposed rock; CL = Class low; CH = Class high

Based on the RQD obtained, an analysis is carried out to interpret the quality of the subsurface rock. Interpretation is done by connecting the rock RQD value of similar values from each drill point starting from dam to plinth areas. The rock quality in plinth area shows very good quality while in dam area, the rock quality shows good to very good quality. This information becomes the basis for rock excavation and help plan for the construction of the dam foundation.

3.6 Bearing Capacity of Soil

The bearing capacity of the soil in the dam area is obtained from the results of the Plate Bearing Test (PBT). The Plate Bearing Test was carried out in the field at seven points in the main dam area (Table 4). The test results provided information on the rate of settlement and the ultimate bearing capacity at these points. Ultimate bearing capacity refers to the minimum pressure required to cause rapid downward shear failure of the soil.

Table 4. PBT test results

No	Test Pit	Settlement (cm)	Ultimate Bearing Capacity (kg/cm^2)	Description
1	PB.4	0.10	3.7	Poor
2	PB.6	1.30	11.3	Poor
3	PB.7	0.40	15.0	Poor
4	PB.8	0.20	11.4	Poor
5	PB.3	1.00	15.0	Poor
6	PB.10	1.35	12.2	Poor
7	PB.2	1.50	7.9	Poor

The results of the plate bearing test conducted at seven points in main dam area show settlement from 0.1 to 1.5 cm with ultimate bearing capacity ranging from 3.7 kg /cm^2 to 15 kg /cm^2.

Based on the results shown in Table 4, it can be concluded that the bearing capacity of the soil at all seven points has a value of < 40 kg/cm^2 and is classified as poor based on the classification of bearing capacity (Yavuz and Atilla 2013). Poor soil bearing capacity is a concern for the foundation of the dam since excessive settlement or collapse of under the weight of dam foundation.

4. CONCLUSIONS

The geoelectrical results show a low resistivity value indicating poor rock quality up to a depth of 20 meters. At the research location, it was found that basalt cracks which pass through the right armrest of the dam have poor mineralogy properties, so that there is a potential for seepage through the weak area of the cracks.

Rock quality based on the value of Rock Quality Designation (RQD) in the dam area and plinth area from very poor rock quality to good rock quality which is in harmony with the rock class and joint conditions in the rock. The rock class CH dominates the subsurface area of as dams and as plinths, while the top layer in the form of rock class D varies from 1 to 10 meters. It is necessary to excavate to a depth of rock with rock class CH, both in the area of the dam and as plinths for the boundary of the dam foundation.

The results of the plate bearing test show that the value of the ultimate bearing capacity of soil found is of poor quality.

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