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Preface

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Study of Mineralogy and Engineering Properties of Volcanic Rock at the Base of the Pamukkulu DAM Foundation, South Sulawesi, Indonesia

Study of Mineralogy and Engineering Properties of Volcanic Rock at the Base of the Pamukkulu DAM Foundation, South Sulawesi, Indonesia

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Abstract. At the location of the Pamukkulu dam, it has engineering geological characteristics that are less supportive of the construction above it, especially for the foundation of the dam. By taking data directly in the field and by laboratory testing, information is needed regarding the characterization of mineralogy and the engineering properties of rocks. Mineralogical analysis was performed with petrography and X-Ray Diffraction (XRD) while the engineering properties of the rock were performed with Plate Bearing Tests (PBT), Standard Penetration Tests (SPT), and Rock Mass Rating (RMR). Based on mineralogical data, rocks have undergone weathering and converted the chemical-physical properties of minerals into porous, fine-grained minerals, forming mineral oxides as well as clay minerals. The carrying capacity of surface soils in the dam area based on the plate bearing test is relatively poor. As for subsurface rocks, the weight of the rock mass rating belongs to the class (II) Good to (III) Medium. Meanwhile, from the density value of hard soils, there are different depths from a depth of 1 meter to 6 meters. Weathering conditions of rocks affect the engineering value of soils and rocks where due to weathering minerals formed in the form of porous clay minerals, they are not well consolidated.

1. Introduction

In order to improve the welfare of the people in Indonesia, especially in South Sulawesi, the government has made various efforts to provide various kinds of infrastructure. Currently, the acceleration of agricultural irrigation infrastructure work that is considered strategic and has a high urgency is carried out to be realized in a short period of time. One of the infrastructures presented to the people of South Sulawesi is the Pamukkulu Dam, located in Takalar Regency, South Sulawesi Province.

Dam is structure built across a stream, a river, or an estuary to retain water. As function, dams are built to provide water for human consumption, for irrigating arid and semiarid lands, or for use in industrial processes. With age, the dam will experience a decrease in quality both in terms of physique and function. For this reason, the design and manufacturing processes in planning must be taken into account properly to avoid the risk of failure or sub optimal function of the dam after the construction is completed.

The role of geological science for engineering purposes is very important to ensure the influence of geological factors on the location, design, construction, implementation of development (operation), and maintenance of the results of engineering work or engineering works. In engineering construction, geological analysis is required for construction planning [1].

The geological engineering investigations carried out in the construction of dams are to determine the geological state, including the distribution of soil and rocks, geological structures, natural processes that occur, the arrangement of rock layers (stratigraphy), geological structures, and physical properties of rocks for the purposes of civil engineering planning [3].

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The foundation of a dam in the form of compact and massive rocks can be considered a good foundation (ideal), but these conditions are rarely encountered [3]. In fact, these foundation rock layers often contain a number of fracturings, cracks, joint, weathered faults and discontinuities with other rocks, so geological investigations are needed to study the physical properties, techniques, and passage of water in the Baturappe-Cindako Volcanic Formation (Tpbv), composed of lava lithologies and volcanic breccia and basalt rocks [4].

The purpose of this study is to know the characteristics of rock mineralogy and the engineering properties of rocks for the base of dam foundations. Therefore, this research focuses on geological and geotechnical investigations of the main dam area at several points and laboratory testing of samples taken in the field. Furthermore, the benefit of this research in general for the wider community is that it serves as a reference for research on the study of engineering geology and gets a clearer picture of the geological conditions of subsurface engineering based on the main dam structure planned to be built as well as various geological engineering methods carried out in dam construction activities.

2. Geology Setting

Morphologically, the research area has two eroded cones which are more narrowly distributed in the western and northern parts of Mount Lompobatang. To the west is Mount Baturape, reaching a height of 1,124 m and to the north is Mount Cindako, reaching a height of 1500 m. These two eroded cone shapes are composed of Pliocene volcanic bottoms [4]. The area west of Mount Cindako and north of Mount Baturape is a rugged hilly area in the east and smooth in the west. The eastern part reaches a height of about 500 m, while the western part is less than 50 m above sea level and is almost a plain. This morphological form is composed of volcanic clastic rocks of Miocene age. The elongated hills scattered in this area lead to Mount Cindako and Mount Baturape in the form of basalt cracks.

The stratigraphy of the study area is composed of Baturape-Cindako Volcanic Rocks consisting of lava and volcanic breccias, with a few inserts of tuff and conglomerate [4]. Basal lava shows characteristics in the form of porphyry with pyroxene phenocrysts measuring more than 1 cm, dark gray green to black in color; the characteristics of the lava show partly joint and layered. Volcanic breccia rocks show fragments and matrices measuring 15 cm to 60 cm, mainly basalt and slightly andesite, with coarse-grained tuff cement to lapilli, rich in pyroxene minerals [4].

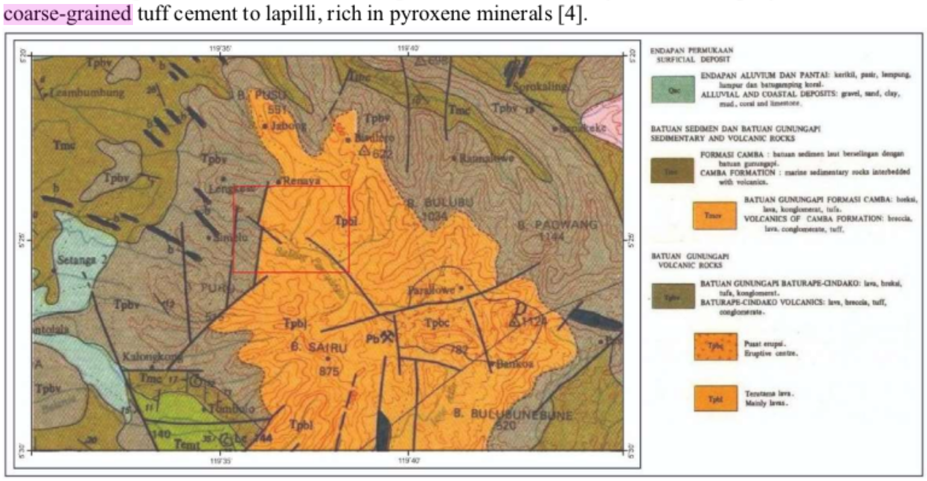

Figure 1 Map shows the Regional Geological of the Dam Area (Sukamto, R & Supriatna, S.1982)

Diorite complexes in the form of stocks and hacks at Baturape and Cindako are thought to have been former eruption centers (Tpbc); the surrounding rock is changed to be strong, amygdaloidal with secondary minerals zeolite and calcite. The galena mineral in Baturape is probably related to this diorite, and around the Baturape and Cindako areas the rocks are dominated by lava (Tpbl). This rock unit has a thickness of more than 1,250 m and is estimated to be of Late Pliocene age [4].

3. Data and Methods

The research method carried out to determine the mineralogy and engineering properties of rocks consists of taking surface and subsurface data. The method carried out is aimed at obtaining surface and subsurface data. Surface data is taken to determine the mineralogy and carrying capacity of surface rocks that are still in the form of weathered soil for the dam foundation. The subsurface data is known to find out the characteristics of the rocks for the base of dam foundation.

3.1 Surface Data

This study used surface data directly in the field, in the form of:

3.1.1. Geological Mapping. This geological mapping is carried out to obtain surface geological information on the dam area. In geological mapping, the data taken is in the form of geomorphological information, petrology, and geological structures. The result of this mapping is in the form of a geological map of the dam area. This data is data that is observed directly in the field.

3.1.2. Plate Bearing Test (PBT). PBT is a test method used to obtain soil carrying capacity values in the basic or subgrade soil layer simply by applying pressure to the soil [5].

The test was carried out using a circular bearing plate, which was then placed on a bearing plate that was pressed at a certain interval of time, and then the plate bearing test continued until the most maximum loading or the most maximum decrease.

The sampling on the surface is carried out to test the mineralogy of rocks by the method of:

3.1.2.1 Petrography. Petrography is carried out to optimize geological interpretation in the form of knowing the texture and structure of rock minerals, rock mineral composition, types, and names of rocks. This analysis was carried out by observations of thin incisions of rocks under a polarizing microscope to observe differences in the optical properties of minerals. Then it is determined the naming of rocks is based on the classification of rocks.

3.1.2.2 *X-Ray Diffraction (XRD).* XRD analysis is a method that can provide information about the types of minerals contained in a material. From the results of XRD, the mineral content of clay in the soil material in the dam area will be analyzed to know the weathering processes.

3.2. Subsurface Data

The test method of determining the boundaries between the soil layer and the rock layer using rock coring data, lithological determination, and Rock Mass Rating (RMR) and soil carrying capacity is used to collect subsurface data. Technical methods are as follows:

3.2.1. Core Drilling. Core drilling testing aims at further identification, including the determination of rock classes according to CRIEPI (1992) [6], mineral composition identification, and determination of layer thickness.

3.2.2. Standard Penetration Test (SPT). This aim SPT tool is to determine the dynamic resistance of the soil to the growth technique. This test is a dynamic experiment carried out in a borehole by inserting a sample tube using a pusher (hammer) period weighing 63.5 kg, which falls freely from a height of 760 mm. The number of blows of the hammer to insert the sample tube 305 deep is expressed as the value of N. The implementation is carried out in three stages, of which the first stage is a temporary stand. The number of strokes for entering the second and third stages is summed up to produce the value of the blow N, or the resistance of the tax return expressed in strokes per 30 cm.

3.2.3. Rock Mass Rating (RMR). RMR classification is a geomechanical classification that uses an empirical method to determine the weighting of rock masses to evaluate the resistance of rock masses by focusing on six parameters: rock compressive strength, Rock Quality Designation (RQD), joint space, joint conditions, groundwater conditions, and discontinuity orientation. The main reason for using RMR is its ease and flexibility for a variety of practical purposes in engineering [7].

4. Analysis and Discussion

4.1. Geology of the Surface

The grouping of geomorphological units in the study area is based on morphological and morphogenesic approaches. The morphographic approach, which is an approach based on the shape of the earth's surface found in the field, namely in the form of hilly topography, and this aspect needs to pay attention to the parameters of each topography, such as elevations, slope shapes, and valley shapes encountered in the field. Furthermore, geomorphology by morphogenesic approach are classified by the processes of formation and those affecting the development of landforms.

Based on the basis for naming the type of landscape unit, the study area is owned by one landscape unit, namely the Denudasional Hills landscape unit (Figure 2).

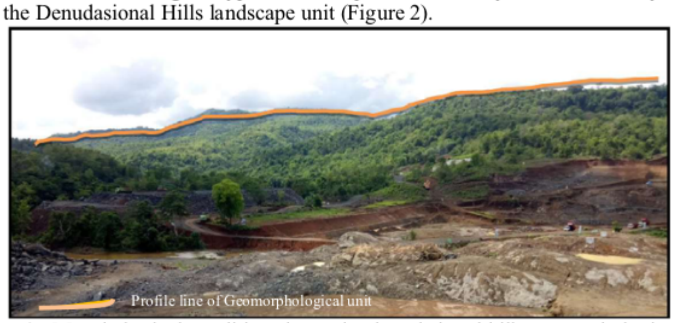

Figure 2. Morphological condition shows the denudational hill geomorphological unit of the Dam Area

The result of geological mapping is the describes of outcrops with physical characteristics with a fresh color of gray-black and a brownish-gray weathered color; the texture of hypocrystalline crystallinity; aphanitic granularity; subhedral-anhedral shape; inequigranular relations; and massive structure. Based on its physical characteristics, the name of this rock is *Basalt* (Travis, 1955).

Figure 3. Basalt Outcrops at As Dam area

Furthermore, it is found that the volcanic breccia outcrop megascopically has physical characteristics with a fresh gray color and a brownish-gray weathered color, which indicates a massif structure. It has basal fragments measuring 8–256 mm, with a matrix measuring 4–64 mm, and cement measuring 1/8–1/256 mm.

Figure 4. Volcanic Breccia Outcrop at As Dam area

4.2 Rock Mineralogy

Based on their physical appearance, the rocks of the dam area have undergone weathering. Weathering affects the carrying capacity of the rock for the foundation of the dam later. The minerals contained in these rocks can be seen microscopically using petrography analysis and also using XRD analysis.

There were four petrography samples tested from the rocks constituting the dam in the surface data. The four rocks based on petrography analysis are alkaline volcanic igneous rocks, namely Porphyry Basalt (ST-250 Basalt, ST-260 Basalt, and ST-260 Volcanic Breccia) and Amygdaloidal Basalt (ST-250 Breccia). Porphyritic textured rocks are composed of the minerals clinopyroxene (28-40%), plagioclase (24-24%), hornblende (10%), orthoclase (5-7%), opaque minerals (1-3%), and the base mass of volcanic glass (10–29%). Based on the formation of secondary minerals and individual physico-chemical changes of mineral crystals, rocks have undergone further processes due to deformation in the form of geological structures (faults) and interactions with the groundwater layer. Deformation processes that can form fracture or burial structures, identified by secondary mineral types, veins and fractures in crystals filled or unfilled by secondary minerals (ST-250 Basalt, ST-260 Basalt).

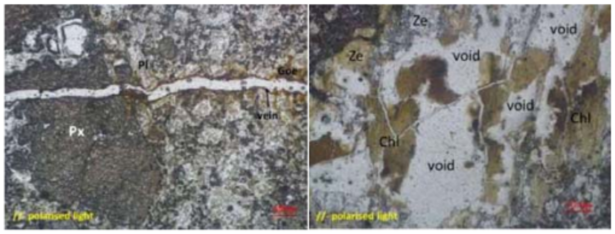

Figure 5. Photomicrographs showing secondary mineral types, vein and fractures on ST-250 and ST-260 Basalt samples

The secondary mineral zeolite alters the volcanic glass of the analcime type (ST.250 Basalt) and, at greater depths, forms the type of wairakite along with the mineral chlorite (ST-260 Basalt). The formation of these minerals is interpreted to be due to the presence of geological structures that cause low-level metamorphism with a temperature of 100–200^{0}C and a pressure of 0.2–0.6GPa. This zeolite mineral is a group of aluminum silicate whose mineral structure is similar to that of mineral clay, namely the porous structure, where in the layer the structure can accommodate H_2O [8]. The content of the zeolite mineral group in rocks between 10.1 and 20.9% can be at risk of landslides.

In the ST-260 Breccia sample, there were indications of rocks being intruded by younger rocks. Rocks close to intrusion are dark in color due to the backing effect. In addition, a metal mineral (oxide) is formed in the form of a subhedral measuring up to 0.15 mm.

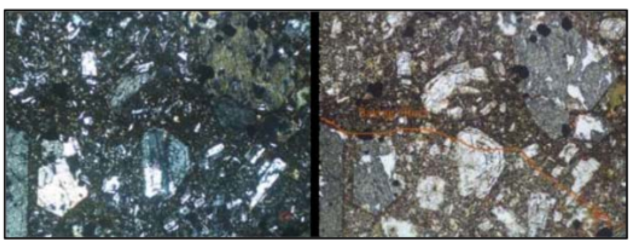

Figure 6. Photomicrograph showing rock close to intrusion are dark in color due to the backing effect on a ST-260 Breccia sample.

X-Ray diffraction analysis (XRD) has been conducted by a nondestructive technique that provides detailed information about the crystallographic structure, chemical composition, and physical properties of Basalt dan Volcanic Breccia rock. It is based on the constructive interference of monochromatic X-rays and a crystalline sample. Therefore, X-rays are shorter wavelength electromagnetic radiation that are generated when electrically charged particles with sufficient energy are decelerated.

The results of the XRD test were found in ST-250 which Basalt samples found clinopyroxene 68.4%, analcime 20.9%, cristobalite 9.8%, and montmorillonite 0.9%, which are clay mineral groups (Figure 7).

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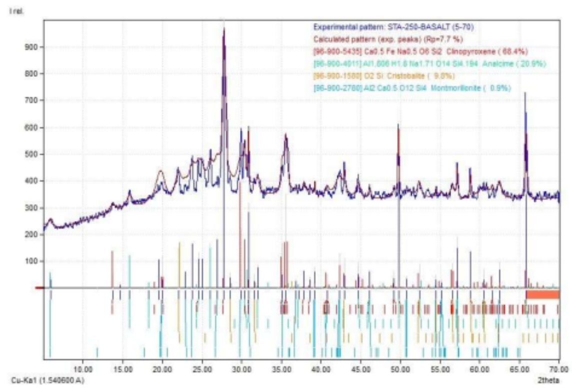

Figure 7. Graph showing XRD test of STA-250 Basalt Sample

The results of the XRD test on the STA-250 Breccia sample found feldspar 58.8%, caolinite 22%, cristobalite 9.8%, and montmotillonite 0.9%, which are clay mineral groups (Figure 8).

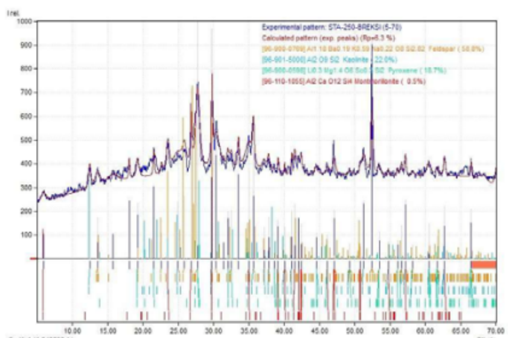

Figure 8. Graph showing XRD test of STA-250 Breccia

The results of the XRD test on the STA-260 Basalt sample found diopside 36.7%, feldspar 35.6%, chlorite 17.6%, and wairakite 10.1%, which are clay mineral groups (Figure 9).

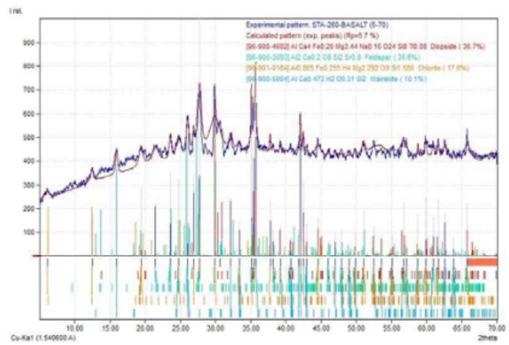

Figure 9. Graph showing XRD test of STA-260 Basalt Sample

The results of the XRD test on the STA-250 Breccia sample found Feldspar 58.8%, Caolinite 22%, Cristobalite 9.8%, and Montmorillonite 0.9%, which are clay mineral groups (Figure 10).

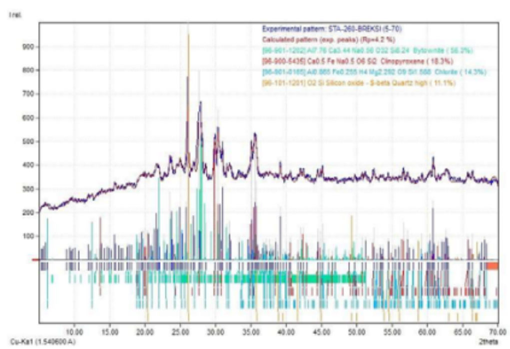

Figure 10. Graph showing XRD test of STA-260 Breccia

4.3. Carrying Capacity of the Soil

The carrying 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 as many as seven points in the main dam area (Table 1.). The value of the decrease and the value of the ultimate bearing capacity are known from these seven points. Ultimate bearing capacity is the minimum pressure that causes shear failure of the soil rapidly downwards.

The results of the plate bearing test showed that the value of the ultimate bearing capacity and its decrease at each point of investigation varied relatively. The results of the plate bearing test are presented in the table as follows.

Table 1. 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 at the seven points where the soil has a limit carrying capacity are achieved when the decrease ranges from 0.1 to 1.5 cm with pressures ranging from 3.7 kg / cm2 to 15 kg / cm2.

From the results of the plate bearing test (Table 1), it shows that the carrying capacity of the soil at all seven points has a value of 40 and is classified as poor based on the classification of bearing capacity (Yavuz and Atilla 2013) [9]. Poor soil carrying capacity is very much the foundation of the dam. If the soil carrying capacity is **poor**, then an excessive decrease or collapse of the soil can occur when pressured from the dam foundation.

4.4 Relationship of Mineralogy and Soil Carrying Capacity

Based on the results of soil carrying capacity tests that show poor carrying capacity, the condition of the rocks in the dam area has undergone strong weathering. All rock samples based on rock mineralogy have undergone surface weathering of up to 40%, which changes the physico-chemical properties of minerals to porous, fine-grained, formed mineral oxides and clay minerals. The openings or voids contained in almost all samples are caused by the release of mafic minerals due to an imbalance in their chemical content. The openings are partly filled with clay minerals and some are empty spaces that are very vulnerable to being filled by rainwater or water in the soil layer. Clay minerals formed in the form of montmorillonite and kaolinite are minerals that are not well consolidated and can accommodate water in their crystal structure, so the presence of these minerals can potentially cause a potential instability in the dam foundation.

4.5 Core Drilling

Based on the surface data of the dam area in the form of rock distribution, rock mineralogy, and soil carrying capacity, it is felt necessary to know subsurface conditions. Surface data indicates less favorable conditions for the foundation of the dam. Therefore, subsurface investigations are necessary to find out the carrying capacity of subsurface rocks against the foundation of the dam.

The method of retrieving subsurface data uses core drilling. This core drilling was carried out at eight points, including BW-10, BW-11, PL-21, PL-25, PL-26, PL-46, PL-52, and PL-60. The spread of these drill points can be seen on the map of Figure 2. Core drilling is carried out in order to obtain information on the characteristics of rocks, types of lithologies, rock classes, and depth of subsurface rocks.

The results of the core drilling can be seen in the drill log in **figure 11**. It is known that the subsurface rock layers of the dam area are predominantly composed of volcanic breccia. There is also basalt that appears locally. Rock classes range from very soft rocks (*D Class*) to fairly dense rocks (*CH Class*). D Class rock ranges from the surface to a depth of between 1.7-8 meters, while the CH class rock dominates the subsurface area of the axle dam to the limit of drilling depth.

The characteristics of each class of rock found from the results of core drilling include:

- A fairly dense rock with fresh to lightly weathered characteristics and a high hardness (CH Class).
- A soft rock with light to medium weathered characteristics and a medium hardness (CM Class).
- A soft rock with the characteristics of a rock that has been subjected to severe weathering (CL Class).
- A very soft rock with very weathered rock characteristics and no visible original rock texture (D Class).

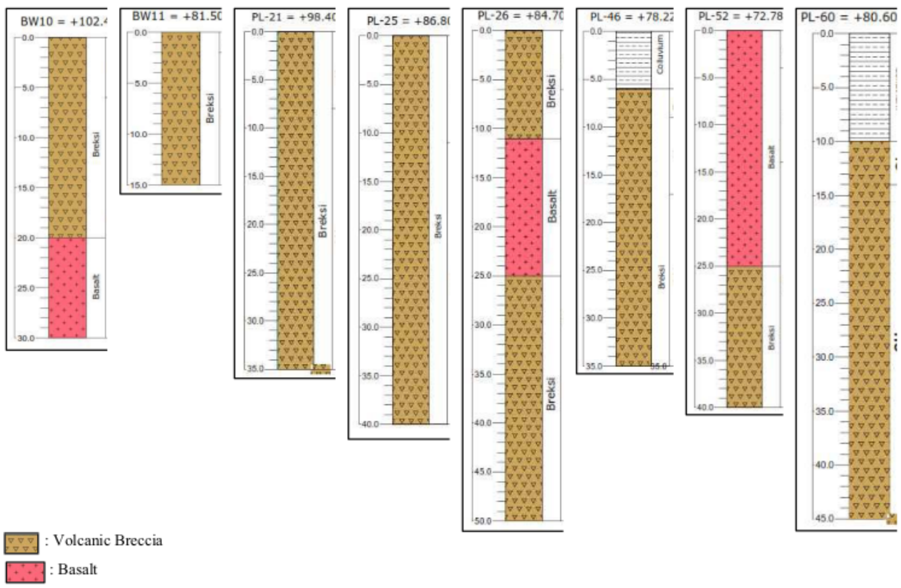

Figure 11. Core Drilling Log on Main DAM area

4.6 Rock Mass Rating (RMR)

The results of the core drilling work are also carried out and quality determination is based on the RMR classification. The weight of the RMR assessment is based on five parameters, namely whole rock strength, RQD, discontinuity spacing, discontinuity conditions, and groundwater discharge (Bieniawski, 1989). The weighting results of each RMR parameter are presented in the following graph.

On the weighting of the strength value of the rock, it is based on the value of the uniaxial compressive strength of the rock. The compressive strength value of rocks in basalt lithology is about 246 MPa, while the compressive strength value of volcanic breccia rocks is about 260 MPa. Based on this data, at all eight points the drill has a rock strength value of more than 250 and is given a weight of 15.

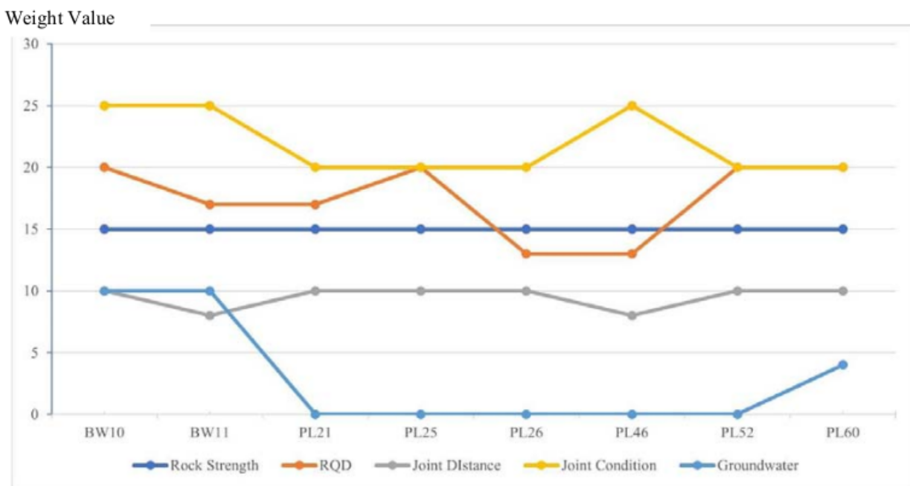

Figure 12. The Graph show the result of weighting of RMR parameters at each drill point.

In RQD weighting, it is obtained directly from measurements on core drilling samples. The average RQD value at each drill point is about 59 to 95. Based on such data, at all eight points the drill has a weight varying from 13 to 20. In the weighting of the joint distance, the value of the distance between the stocks is obtained from the perpendicular distance between two consecutive discontinuities along the measurement line. The average subsurface rock spacing distance at each drill point is about 10 cm to 60 cm. Based on such data, at all eight points the drill has a weight from 8 to 10.

In joint condition weighting, the value of the joint condition is obtained from the joint persistence, joint openings, joint roughness, stuffing and weathering rate. Each of these parameters is then added up and a general joint condition weight is obtained. Based on observations of joint conditions, at all eight points the drill has a weight from 8 to 10. In weighting the condition of groundwater, the value of the condition of groundwater is obtained by paying attention to the general condition with the category of dry, humid, wet, dripping, and flowing. The condition of the groundwater found at each drill point includes flowing, dripping, and moist. Based on observations of groundwater conditions, at all eight points the drill has a weight from 0 to 10.

Based on the weighting of RMR parameters, RMR weights were obtained at the bobor points of BW-10, BW-11, PL-21, PL-25, PL-26, PL-46, PL-52, and PL-60, respectively, namely 80, 75, 62, 65, 58, 61, 65, and 69. The rock masa class based on RMR values in subsurface rocks belongs to class (II) Good except at drill points PL-26, including class (III) Medium.

4.7 Soil Density

One of the parameters of the carrying capacity of a soil is the density of the soil. Soil density is obtained from the Standard Penetration Test (SPT) in the field. The results of the SPT test were subsequently correlated to the relative density of clay where the soil boundary was hard or had a tax return of more than 30 [10]. To get more detailed data with a wide spread, SPT was carried out in the main dam area with a total of 20 test points. Based on the results of the SPT test, each drill point gets a SPT value of more than 30 or hard soil at different depths, from a depth of 1 meter to 6 meters. These results become a reference for design changes and subsequent excavation work.

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Table 2. SPT test results

No.	Nama	Kedalaman (m)	Nilai SPT (N)	No.	Nama	Kedalaman (m)	Nilai SPT (N)
1	SPT-1	1	30	12	SPT-12	1	33
		2	53			2	19
		2.5	70			3	54
2	SPT-2	1	30			3,5	69
		1.5	87	13	SPT-13	1	35
3	SPT-3	1	13			2	32
		1,5	14			3	40
		2	18			3,5	56
		2,5	17	14	SPT-14	1	29
		3	14			2	35
		3,5	10			3	61
		4	4			3,5	77
		4,5	7	15	SPT-15	1	32
		5,5	22			2	50
		6	18			2,5	69
		6,5	48	16	SPT-16	1	30
		7	69			2	65
4	SPT-4	1	14			2,5	80
		2	26	17	SPT-17	1	35
		3	40			2	55
		3,5	68			2,5	69
5	SPT-5	30	1	18	SPT-18	1	28
		34	2			2	35
		66	3			3	40
		76	3,5			4,5	70
6	SPT-6	59	1			5	79
		86	1,5	19	SPT-19	1	27
7	SPT-7	1	33			2	28
		2	53			3	34
		2,5	48			4	36
8	SPT-8	1	48			4,5	54
		2	61			4.5	67
		2,5	82	20	SPT-20	1	37
9	SPT-9	1	15			2	30
		2	68			3	25
		2,5	87			4	22
10	SPT-10	1	69			5	28
11	SPT-11	1	34			6	39
		2	66			6.5	69

4.8 Rock Hardness

The investigation of the quality of the rocks was carried out on the basis of RMR and SPT. Based on the SPT value, it can be seen that at some point, the depth of soft soil (SPT< 30) ranges from 1 to 3 meters. This condition is the result of weathering of the rocks below.

From the results of the tax return that shows the quality of the soil, the results of soft weathering can be attributed to the RMR of the rock. The RMR value of rocks generally has a good value, but based on weighting, the weight of groundwater is low because it ranges from flowing to wet. These conditions are based on field conditions where the groundwater level is shallow so that it accelerates weathering at the bottom.

Weathering conditions that affect the value of SPT and RMR are caused by the mineralogy of rocks that have changed as a result of weathering. Weathered minerals form in the form of porous clay minerals. The mineral is not well consolidated, so it can form less stable areas.

5. Conclusion

The rocks in the dam area are porphyritic textured volcanic rocks, composed of the minerals clinopyroxene, plagioclase, hornblende, orthoclase, and opaque minerals, and the base mass of glass volcanic. From mineralogical analysis, rocks have undergone weathering and transformed the chemical-physical properties of minerals into porous, fine-grained minerals, forming mineral oxides as well as clay minerals.

The surface soil carrying capacity in the dam area based on the plate bearing test at seven points has a value of 40 and is classified as poor. As for the engineering properties of rocks in subsurface, the weight of the rock mass rating belongs to the class (II) Good to (III) Medium. While the density value of hard soils is different at different depths, from a depth of 1 meter to 6 meters. Weathering conditions of rocks affect the engineering value of rocks where the result of weathering minerals is formed in the form of clay minerals that are porous and not well consolidated.

Based on the results of core drilling, SPT, and PBT, weak areas were still found in the dam area caused by fairly high weathering in the rocks. This condition is feared to be a weak point that affects the stability of the dam. More detailed analysis is needed to find out the desired depth limit of hard rock.

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