



The Relationship of Physical Properties of Rock to The Slope Stability of The Progo River Cliff in Sentolo-Sedayu, Kulon Progo, Yogyakarta, Indonesia

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Abstract

To support the increasingly advanced development of the Kulon Progo area, road access via the Progo River bridge needs to be maintained in instability. To support this, an engineering geological survey was carried out to find out the relationship between the physical properties of rocks and the stability of slopes on the cliffs of the Progo River. The research method begins with a field survey to obtain lithology and slope geometry data. Scanlines at selected locations were carried out to determine discontinuity areas and interpret rock weathering using a Schmidt hammer. Physical laboratory tests are useful for determining the bulk density and porosity of rocks, while from rock mechanical tests (shear strength) cohesion and friction angle values are obtained. The results of the safety factor analysis using the Slide program show that the slopes generally have a medium-high level of severity ($F_k < 1.2$), supported by quite a lot of joint areas, varying porosity (4.12 – 25.10%) and the level of weathering is at level III-IV. Rock porosity is less related to slope strength, while weathering generally reduces slope stability.

Keywords: discontinuity; geotechnical; porosity; slope stability; weathering

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INTRODUCTION

This geotechnical study was carried out on the Progo River route in the Sentolo and Sedayu areas, Kulon Progo and Bantul Regencies, Yogyakarta Province (**Figure 1**). This research was carried out to support the development of the Kulon Progo Regency area which is currently increasing rapidly with the presence of a new airport. The Bantar Bridge, which meets the Progo River and Jalan Wates, is the main access for people heading to the airport from Yogyakarta City. Therefore, the stability of the slopes around the bridge needs to be maintained (Ng et al., 2012). This research is expected to support the stability of the slope.

The research area is included in the Central Java Depression Zone, especially the Solo Zone which is an alluvial plain morphology (Van Bemmelen, 1970). The rocks that cover this area are deposits of the Young Merapi volcano (Nakada et al., 2019). However, outcrops of Tertiary bedrock which are part of the geology of the Kulon Progo Hills are also found on the banks of the Progo River and form slopes that need to be studied. R.A et al., (2023) said that in the Kulon Progo Hills area, there are many lineaments of geological structures, indicating that the rocks in the Kulon Progo area

have experienced many active tectonics. This geological structure will of course affect the stability of the slope.

To support the stability of the slopes around the Progo River. So geological and geotechnical surveys need to be carried out to understand the nature of the rocks that make up the slope. The stability of a slope is largely determined by the physical and mechanical properties of the rock/soil, including porosity (Macchi et al., 2016; Nafian et al., 2022). The presence of discontinuity areas and rock weathering will also affect slope strength. Therefore, this study attempts to examine the physical properties of rocks, especially regarding discontinuity, weathering, and porosity, and their relationship to slope stability (Barberio et al., 2017; M. Easton & Bock, 2015).

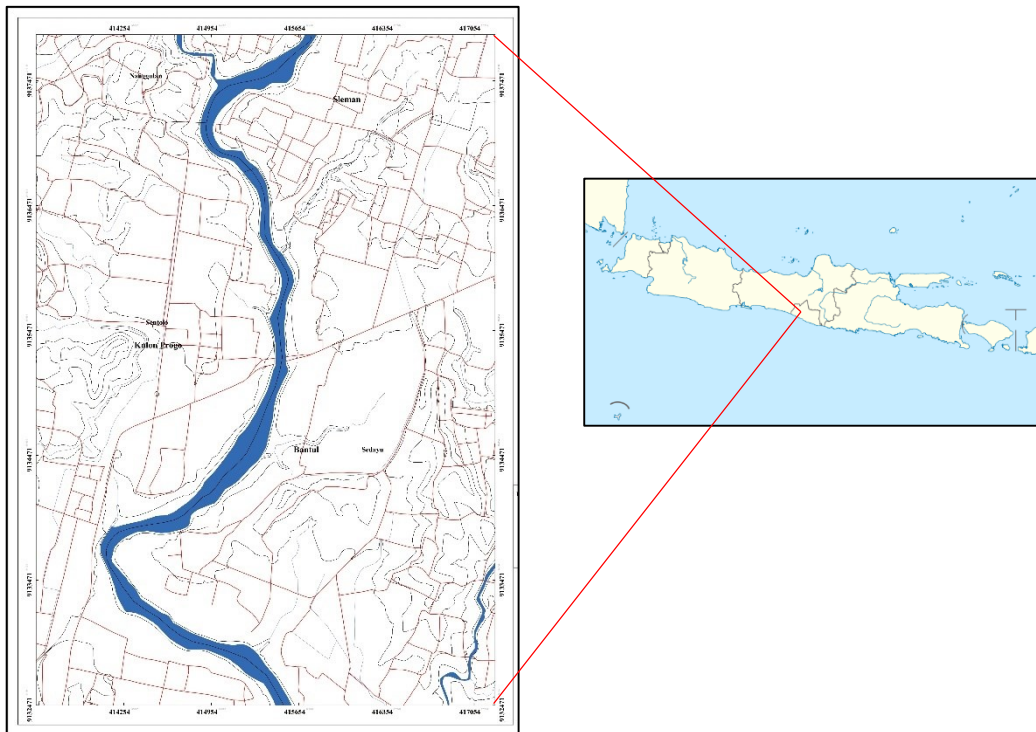


Figure 1. Research location in the western part of Yogyakarta Province, Indonesia compared to a map of Java (Hariyono & Sari, 2018). conductivity changes. The magnitude of this influence on surface potential is influenced by the size, location, shape and conductivity of the material below the earth's surface. In this way, information about subsurface distribution will be obtained by measuring the electrical potential on the surface.

METHOD

In the initial stage, a field survey was carried out to obtain geological data, including geomorphology, lithology, and geological structures on the slope. The tools used are standard geological equipment (hammer and compass).

Geotechnical aspects are the main study in this survey (**Figure 2**). This geotechnical survey was carried out by observing slopes, measuring discontinuity areas using the scanline method, and equipped with rock sampling. Slope data includes the constituent lithology and slope geometry. Data collection on discontinuity areas was also accompanied by measuring the reflection value (R) using a Schmidt hammer (Hirose et al., 2008). This reflectance value is then used to interpret the level of rock weathering. Data collection on discontinuity areas includes, among other things, number, type, position, persistence, roughness, and infilling of discontinuity areas.

Furthermore, physical and mechanical rock laboratory tests are carried out to obtain physical data (density, porosity) and mechanics (cohesion, friction angle). The results of this laboratory test are then processed to obtain safety factor values using the *Slide* program.

Technically, the slope material being analyzed is homogeneous, so the strength type analysis used is Mohr-Coulomb (Liu et al., 2008). The GLE Morgensten-Price analysis method is used to find the value of the safety factor because this method is very supportive both in terms of force balance and moment balance (Al-ahmadi & El-Fiky, 2009; Matsubaya et al., 1973; Team, 2016).

The rocks that make up the slopes consist of two different mineral materials, namely andesite and calcarenite. The surface analysis process for andesite rock uses the circular grid search method because the rock is isotropic, while for calcarenite the block search method is used because the rock is anisotropic. Water condition analysis uses a surface water table because the orientation of the slope being studied is directly facing the flowing river area. Next, the results of field and laboratory data collection are processed to see the relationship between physical properties and safety factor values which are a reflection of slope stability.

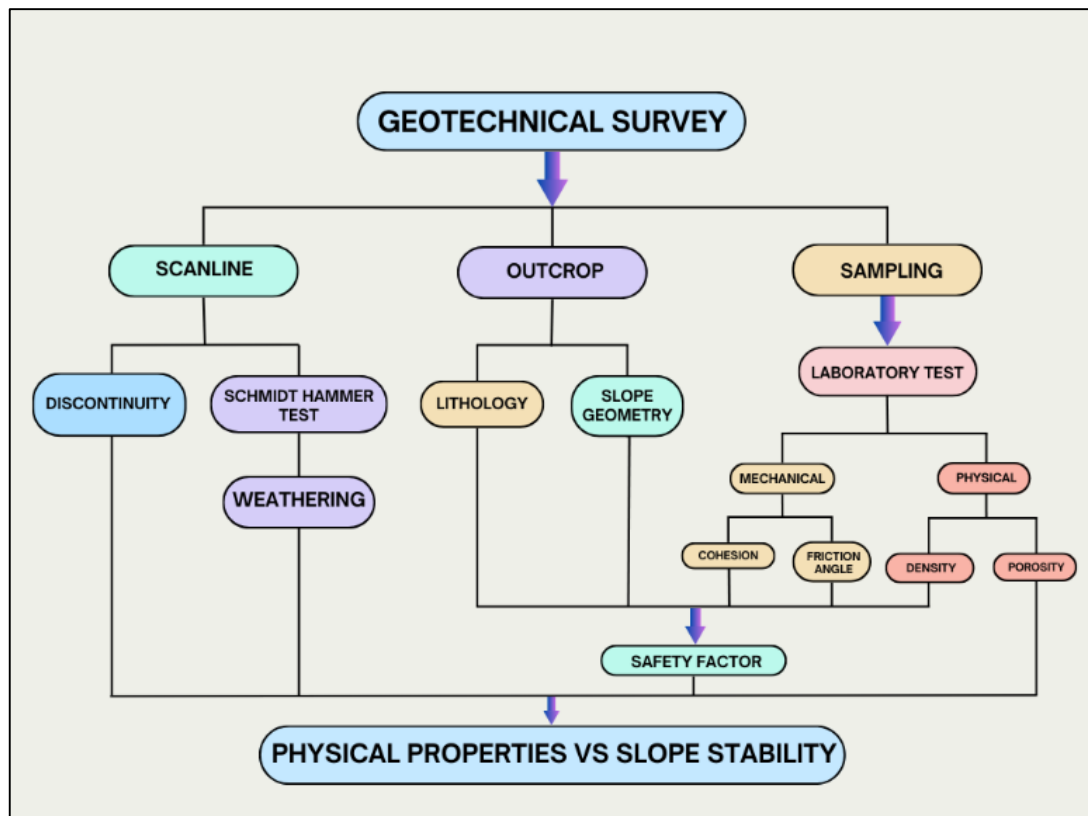


Figure 2. Flow diagram of research method.e

RESULTS AND DISCUSSION

Slope Conditions

Slope measurements were carried out with a scanline at eight points, namely at Sc. 1 – Sc. 8. The Slope at points Sc. 01 and Sc. 02 (Figure 3) is composed of layered limestone (calcarenite), while in the other six locations it is composed of andesite breccia. Calcarenite is a Tertiary sedimentary rock from the Sentolo Formation, which is compact and hard, with thin – medium layers. Meanwhile, andesite breccia generally has a massive structure. On all slopes studied, the rocks show a considerable amount of joints.

The locations chosen for rock sampling were Sc. 1, Sc. 4, Sc. 6, and Sc. 7. Slope at location Sc. 1 is 6.5 m high; Meanwhile, the rocks that make up the slopes on Sc. 4, 6 and 7 respectively form slopes 11.5, 4.5 and 8 m high. The slopes studied are generally single. The survey was carried out during the dry season, so all the slopes observed were dry.



Figure 3. Slope composed of calcarenite at location Sc. 2 (left) and andesite breccia at location Sc. 6 (right).

Scanline Results

Discontinuities in rocks generally affect slope stability (Gao & Jia, 2020; Tsay et al., 2017), therefore, measurements of discontinuity areas need to be carried out in more detail using scanlines. Scanlines on slopes are useful for determining the characteristics of discontinuity areas, both in the form of layers and joints (Figure 4). This measurement is accompanied by a measurement of rock strength which is represented by the rebound value (R) on the Schmidt hammer type N (Figure 5). Observing the condition of the jointed slope can be useful for knowing the characteristics of the joints and their influence on slope stability (Ibrahim et al., 2019; Stern, 2002). Furthermore, the orientation of geological structures as areas of discontinuity can give rise to various types of landslides (Ibrahim et al., 2019; Kimura, 1990; Pratiwi et al., 2019).



Figure 4. The discontinuity area in calcarenite (Sc. 2) is in the form of layers and joints (left), while in andesite breccia (Sc. 8) it is dominated by joints (right).



Figure 5. Example of measuring rock strength using a Schmidt hammer on calcarenite at the Sc location. 1 (left) and in andesite breccia at location Sc. 6 (right).

An example of the results of data collection on discontinuity areas is presented in **Table 1** and **Table 2**. Slopes on calcarenite limestone have discontinuities in the form of layers and joints, while slopes on andesite breccia rocks only have joints. The joint areas found are generally not persistent, open (openings 2-50 mm), with sand infilling (Li et al., 2018; Togibasa et al., 2018).

The data on the strength of the slope rocks based on the Schmidt hammer test shows that the R-value varies. Examples of rock strength data can be seen in **Table 3**. From this data, rock weathering conditions can be determined by referring to Brindha & Elango, (2012) and Orwin, (1998) classification. Based on this classification, it is known that the rocks that make up the slopes, whether in the form of calcarenite or andesite breccia, have varying degrees of weathering (class I – IV), with weathering stages from fresh to weakened rock (**Table 4**). For the four samples selected for laboratory tests, the average R-value was used to analyze the relationship between weathering and slope strength (**Table 5**).

Table 1. Scanline of slope at location Sc. 2 (calcarenite).

No.	Position (m)	Type	Strike	Dip	Persistence		Opening (mm)	Infilling	Asperities		Water Flow
					Yes/No	Length (m)			Waviness (m)	Roughness	
1	1.5	layers	145	20	Yes	>>	-	-	-	-	Dry
2	2.7	layers	135	35	Yes	>>	-	-	-	-	Dry
3	3.1	joints	210	60	No	0.45	20	Sand	0.15-0.35	8-10	Dry
4	3.9	joints	215	70	No	0.25	8	Sand	0.15-0.35	8-10	Dry
5	4.2	joints	235	40	No	>2	12	Sand	0.15-0.35	8-10	Dry
6	5.3	joints	240	60	No	>1	6	Sand	0.15-0.35	8-10	Dry
7	5.7	joints	214	60	No	0.35	8	Sand	0.15-0.35	8-10	Dry
8	6.3	joints	220	62	No	0.20	4	Sand	0.15-0.35	8-10	Dry
9	8.9	joints	270	72	No	0.25	9	Sand	0.15-0.35	8-10	Dry

Source : Data of this study

Table 2. Scanline of slope at location Sc. 8 (andesite breccia).

No.	Position (m)	Type	Strike	Dip	Persistence		Opening (mm)	Infilling	Asperities		Water Flow
					Yes/No	Length (m)			Waviness (m)	Roughness	
1	0.35	joints	240	55	No	>3	20	Sand	0.5-0.9	18-20	Dry
2	0.9	joints	240	60	No	>1	15	Sand	0.5-0.9	18-20	Dry
3	3	joints	235	60	No	>1	12	Sand	0.5-0.9	18-20	Dry
4	3.3	joints	220	60	No	0.3	4	Sand	0.5-0.9	18-20	Dry
5	4.4	joints	185	55	No	0.2	2	Sand	0.5-0.9	18-20	Dry
6	4.6	joints	210	65	No	0.15	2	Sand	0.5-0.9	18-20	Dry
7	5.4	joints	210	60	No	>1	5	Sand	0.5-0.9	18-20	Dry
8	6.2	joints	205	60	No	0.22	4	Sand	0.5-0.9	18-20	Dry
9	7.8	joints	230	60	No	0.28	2	Sand	0.5-0.9	18-20	Dry
10	8.2	joints	235	70	No	0.15	2	Sand	0.5-0.9	18-20	Dry
11	8.3	joints	250	60	No	0.3	2	Sand	0.5-0.9	18-20	Dry
12	8.7	joints	250	60	No	>1	10	Sand	0.5-0.9	18-20	Dry
13	9.1	joints	210	65	No	>1	8	Sand	0.5-0.9	18-20	Dry
14	9.6	joints	210	60	No	0.32	4	Sand	0.5-0.9	18-20	Dry

Source : Data of this study

Table 3. Example of rock strength measurement data on the slope of Sc. 1 and Sc.3.

No.	Sc. 1 (Calcarenite)			Sc. 3 (Andesite breccia)			
	Distance (m)	R-value	UCS (MPa)	Distance (m)	R-value	UCS (MPa)	
						Fragments	Matrix
1.	1.2	48.5	42.5	0.7	31.5	14.5	
2.	2.1	30.5	13.5	2.4	28	11.5	
3.	3.7	19	11	3.3	21		7.5
4.	4.6	20.5	7	4.1	23		8.5
5.	5.5	54	60.5	5.4	30	13	
6.	6.3	32.5	9	6.1	22		8
7.	7.2	62	100.5	7	39	23	
8.	8.3	45	34	8	19		7
9.	9.5	21	7.5	9.1	44	32	
10.	10	59	83	10	24.5		9

Source : Data of this study

Table 4. Weathering conditions of slope rocks based on the R-value in the Schmidt hammer test.

Scanlines	Lithology	R-value	Weathering	
			Class	Stages
1	Calcarenite	19-62	I - IV	Fresh rock - weakening
2	Calcarenite	19.5-38.5	III - IV	Rocks change color - weaken
3	Andesite breccia	19-44	II-IV	Color changes slightly - weakens
4	Andesite breccia	18.5-59.5	I - IV	Fresh rock - weakening
5	Andesite breccia	19-62	I - IV	Fresh rock - weakening
6	Andesite breccia	19.5-38.5	III - IV	Rocks change color - weaken
7	Andesite breccia	21-45.5	II-IV	Color changes slightly - weakens
8	Andesite breccia	21-30.5	III - IV	Rocks change color - weaken

Source : Data of this study

Physical and Mechanical Properties of Rocks

The test results for the physical properties of the rock in the form of porosity are given in **Table 5**. Meanwhile, the physical properties in the form of unit weight and mechanical properties which include cohesion and friction angle are then processed to obtain the value of the slope safety factor (Fs).

Table 5. Porosity data, R-value, and slope safety factor (Fs).

Samples	Lithology	Porosity (%)	R-value	Fs		
				Static	Dynamic 0.05 g	Dynamic 0.08 g
Sc. 1	Calcarenite	25.1	39.2	1.599	1.194	1.043
Sc. 4	Andesite	4.12	37.6	1.27	1.079	1.039
Sc. 6	Andesite	13.21	15	1.245	1.015	1.031
Sc. 7	Andesite	7.87	15.25	1.924	1.388	1.127

Source : Data of this study

Analysis of the Relationship between Discontinuity, Weathering, and Porosity Fields on Slope Stability

The large number of joints and layers that constitute areas of discontinuity will cause the strength of the slope to decrease. This discontinuity area also has the potential to be a means of water flow, thereby further increasing rock weathering. This is supported by the condition of the joint fields which are generally open and filled with sand. Even though it is not persistent, the opening of the

joint plane will facilitate shifting if seismic loads occur, so that the potential for landslides will be higher in dynamic conditions.

The data in **Table 5** is then processed using a linear regression graph as shown in **Figure 5**. From this graph, it appears that the slope safety factor tends to decrease with increasing rock weathering, where this condition is more clearly visible in static conditions. The correlation graph between the two variables is not very clear, perhaps because the rock samples on the andesite breccia slopes are only represented by rock fragments in the form of andesite. These andesite breccia fragments were found fresh to slightly weathered. Meanwhile, the breccia matrix is generally more weathered, and sometimes it has even turned into soil.

The relationship between porosity and slope safety factor is relatively stable. In dynamic conditions where the slope receives a seismic load of 0.05 g or 0.08 g, an increase in porosity results in a decrease in the safety factor. However, in static conditions, an increase in porosity is accompanied by an increase in the safety factor. This anomaly occurs because the porosity of calcarenite is quite large, and seems to be less comparable to andesite igneous rocks. Under static conditions, an increase in porosity is not always accompanied by a decrease in the safety factor. The difference in relationships in static and dynamic conditions shows that the relationship between porosity and safety factors is not strong. This means that slope stability is less correlated with the porosity of the rocks that make up the slope.

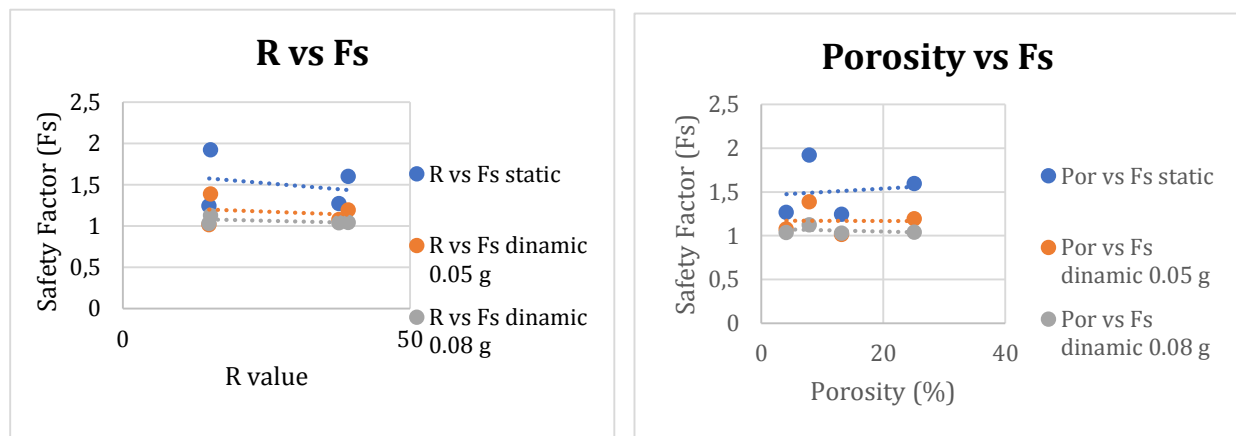


Figure 5. The relationship between weathering and rock porosity and slope safety factors.

CONCLUSION

The cliff slopes of the Progo River have been studied by taking eight scanline locations and from four of them the rocks have been tested physically and mechanically. The results of the field survey showed that the slopes studied were composed of Sentolo layered limestone (calcarenite) and Merapi Muda andesite breccia. Slopes are generally single slopes, with a height of 4.5 – 11 m. Calcarenite has a layered structure, with some joints forming areas of discontinuity. The slopes composed of andesite breccia also experience a lot of rifting. The large number of open joint areas on all slopes will have the potential to reduce slope stability. Rock weathering tends to reduce slope stability. Even though the relationship is not strong, increasing weathering tends to be accompanied by a decrease in the safety factor, both in static and dynamic conditions. The inverse relationship between porosity and safety factor is only visible in dynamic conditions. In general, porosity and safety factors are not strongly correlated. This means that slope stability in the study area is less influenced by rock porosity.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest concerning the publication of this article. The authors also confirm that the data and the article are free of plagiarism.

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