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VOLCANIC ERUPTION PRODUCTS AND ITS SLOPE STABILITY IN MERAPI VOLCANO, YOGYAKARTA

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ABSTRACT: Banjarsari Village, of Cangkringan Sub District, Sleman Regency, Special Region of Yogyakarta (110°28'04" E, 7°39'11" S), in the geomorphological system, is known as the middle volcanic slope located in the southern area of Merapi Mount, as it is formed by the pyroclastic and lahar deposits. Such condition is attributed to the emergence of sand and stone quarries at many points. On this account, this research aims to identify the potency and type of mass movement on the sand-stone quarry deposits, in order to determine the best mitigation endeavor against the mass movement disaster. Methods of research in use are direct field observation, measurement of the type and position of the stratification, and slope dimension. Furthermore, soil mechanic laboratory analysis was done to the soil sample, consisting of bulk density of the soil (γ), cohesion parameter (c) and friction angle (Ø). The analysis of Safety Factor (FS) was done by using Geo-Slope version 9.0.3 software, aiming to define its stability class. This research resulted in 2 potential locations of a mass movement with debris slide type. According to the analysis of slope stability on the two location, it was revealed that these slopes were categorized into the unstable class with FS= 0.799, in the pyroclastic deposits and for the other location the slope was categorized into the critical classes with FS value = 1.117 in the lahar deposits. The main driving factor of mass movement was the increasing soil mass due to the effect of rainfall.

Keywords: Pyrocclastic, Lahar, Mass movement, Soil mechanic

1. INTRODUCTION

Merapi Volcano (110.442° E, 7.542° S) is one of the of the world's most active Quaternary volcano in Indonesia. This active and dangerous volcano has up to 2986 m high, with basalt to basaltic andesite volcanic complex lying in it, as it was formed by the northward subduction of the Indo-Australian Plate beneath the Eurasian Plate. It is situated ~25 km northward of the city of Yogyakarta in Central Java and surrounded by the geologically young stratovolcanoes Merbabu, Telomoyo and Ungaran to the north, and Sumbing, Sindoro and the Dieng complex to the northwest (Fig. 1). Merapi is best known for the generation of small volume pyroclastic flows from gravitational lava dome collapses [1].

Over the past two centuries or more, the volcanic activity of Merapi has been dominated by prolonged periods of lava dome growth at the summit of the steep-sided volcanic cone and intermittent gravitational or explosive dome failures to produce pyroclastic flows every few years [2]. These have posed a persistent threat to life, property, and infrastructure within the densely populated areas on the volcano flanks, as the catastrophic eruptive events in 2016 have once more demonstrated.

The lahar eruption from Mt Merapi has brought many adverse effects to the surrounding environment, such as destroying the settlements and putting the life of the people living nearby the lahar flows area in danger. Limited understanding of process and distribution of lahar and volcanic eruption results make the concept of the mass movement around the volcano area not optimal. Some previous researchers assume that the mass movement occurs on the southern slopes of Mt Merapi is a homogeneous mass movement [3]. This case makes it difficult to predict the slope stability on slopes with heterogeneous composition and varying cohesiveness. To understand more about potential and character of mass movements on the southern slopes of Mt Merapi requires specific research [1] [4].

2. METHODS

The research is divided into three phases. The first phase is field description and measurement. On this phase, researchers observed the volcanic material content, grains, and sedimentary structure to determine the type of volcanic deposits.

Measurement of field data covers making a geologic profile and geometry measurement of the slope, including the length, height and magnitude of the slope angle, and rock sampling. The second phase is laboratory analysis. The researcher analyzing mechanical soil to know basic properties and mechanical properties using direct shear test. This resulted in the data related to moisture content, natural weight, internal shear angle, and cohesion.

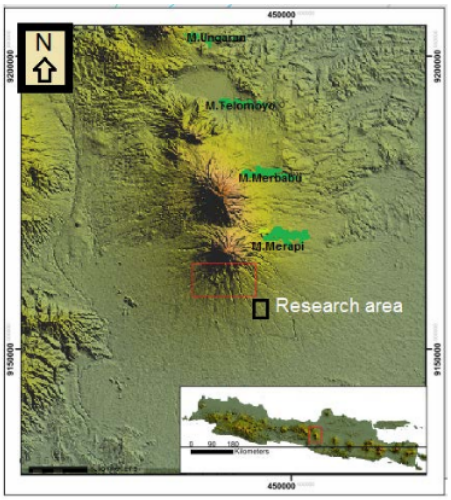

Figure 1. Map of the research area

This analysis must be working carefully because the result of this phase is important to the next phase. The different value of this result can make a different type of safety factor slope.

The third phase is studio processing. This phase was aimed to process the measurement data and field description to produce the technical geological characteristics map in the research area. And the final step is to calculate the slope stability of each type of volcanic sediment present in the research area. The analysis of slope stability was performed by the Limit Equilibrium Method, a method which uses the principle of force equilibrium. This analysis method initially assumes the potential failure that might occur. There are two assumptions upon such failures, such as circular failure and non-circular failure (also known as wedge failure).

The calculation was done by dividing the land area located within the failure into several slices as shown in Figure 2 – 4. Therefore, this method is also known as the method of the slice. Various different solutions for this method had been developed for years by Fellenius, Taylor, Bishop, Morgenstern-Price, Sarma and others.

This research used the Bishop Method, which applies the equilibrium limit method. This method is the most widely used method of slope stability analysis [5] [6].

Several assumptions were made in simplified Bishop method: The failure is assumed to occur by rotation of a mass of soil on a circular slip surface centered on a common point. The forces on the sides of the slice are assumed to be horizontal, thus, there is no shear stress between slices, and the total normal force is assumed to act at the center of the base of each slice.

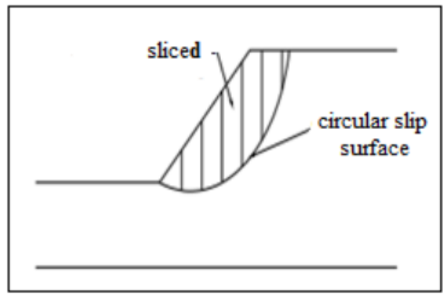

Figure 2. Circular Failure

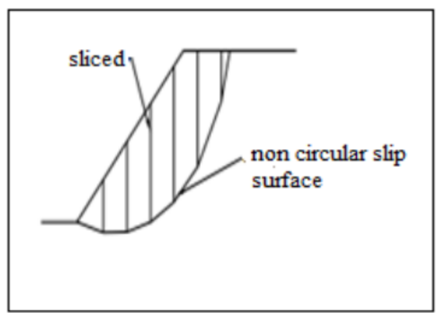

Figure 3. Non- Circular/ Wedge Failure

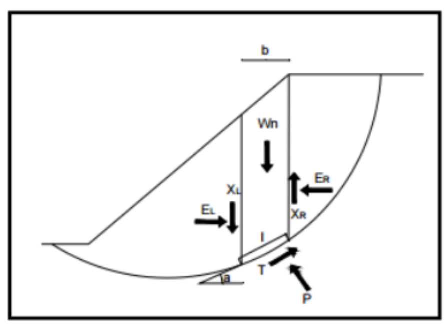

Figure 4. Force working on the sliced area.

The differences between one method to others depend on the limit of equilibrium method and the assumption of the interslice force calculated. After the FS rate was found, it was inputted into the classifications of Canmet (1979), namely Stable Class (FS >1.5), Critical Class (1 < FS <1.5) and Unstable Class (FS < 1) [7].

3. RESULT AND DISCUSSION

3.1 Geomorphology

By referring to the aspects of classification and having a direct field observation, it was revealed that geomorphology landform was generally controlled by geological structures, lithology, and erosion. Based on the classification, the research area has 2 landforms, namely:

2.1.1 Unit Foot Slope Landform (V2)

This landform unit occupies approximately 50% of the whole research area with rather steep to sloping relief from North to South with slope level of 25%-40%. It was located in the range of elevation 662.5 – 1050 m. This landform was formed out of volcanic activity since the shape of the Valley was deep enough and formed a "V" shape and parallel stream patterns as well as a combination of hills and volcano slopes. The volcanic activity report includes some villages, including the village of Kinahrejo Palemsari, Gondang Village, and Kedongjati Village.

2.1.2 Unit Volcanic Valley Landform (V3)

This landform unit occupies 30% of the whole research area with oblique relief-steep, generally leads to a North-South slope with 30%-45% level and has an elevation of 662.5 – 1187.5 m. This includes the morphology of Gendol River, Kuning River, and Adem River. This landform was formed by the activity of the volcanism and the area where volcanic activity resulted in material flow. This landform was dominated by pyroclastic breccia deposits of lahar, which is found on both sides of the cliff. This landform is usually used as a land of sand and stone mining.

Based on the results of the analysis of topographic maps and the circumstances in the field based on the shape and direction of the flow of the River, as well as control by lithology that flourished in the research area then the author can divide the flow pattern in the area of research into a parallel stream pattern. This is because the flow pattern formed by the streams aligned on a landscape that extends, and represent the slopes in a relatively uniform direction towards the South-East.

3.2 Stratigraphy

After making observations and data capture in the field such as data capture of column profiles/ stratigraphy on-site observations and constant proportionality by means of linking the same lithology characteristics [8], it was unveiled that the spread of lithology was predominant. In addition, there were some physical traits in common, which enabled the researcher to divide the research area into two (2) units of deposition, namely: (Figure 5)

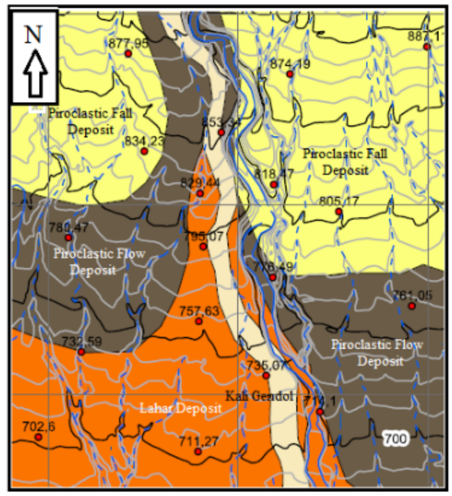

Figure.5 Geological map

3.2.1 Unit of Pyroclastic Breccia Deposits

The term of the unit of pyroclastic breccia deposits was based on physical characteristics and lithology, as well as the presence of welding on a rock that thrives on this unit. Physically it is characterized by the presence of cobbles-boulders-sized-breccia (2-256mm >). At some point in this unit, there is a welding and woods charcoal.

Physical properties above can be equated with the characteristics of pyroclastic, thus becoming the basis of writers in the naming of the unit. Having a close observation, it is apparent that this unit is dominated by pyroclastic breccia tuff, with the following characteristics, pyroclastic breccia, gray, closed down badly, disaggregated, angular, grain size 2 mm-5 cm, fragments of volcanic mineral composition, plagioclase, hornblende and cement of silica. Insert description as follows, tuff, color brownish-grey, disaggregated, open, medium grain size 2 mm – 1 cm, structure, fragments of volcanic mineral composition, plagioclase, quartz, hornblende and tend to erode.

Distribution and thickness of this unit occupy approximately 50% of the total area of research.. There are 2 types of pyroclastic in this research area, pyroclastic fall and pyroclastic flow. Pyroclastic units deposited in the land environment Kinahrejo volcanic activity report with the medial facies volcaniclastic. The facies is characterized by the slope of 5-20%. The constituted material is dominated by pyroclastic breccia deposits of sandstone and a bit of lava. On this unit, the authors did not conduct the analysis of age because it is deposited on the ground so that the environment is not analyzed by way of fossils. For the determination of the age of this unit, the author refers to some previous researchers data – data observations in the field.

This unit which has a Holocene age was the result of recent deposition of Merapi (< 1811). This deposition at the Merapi is relatively young (< 1811) [4]. Its relation with the units of Kinahrejo pyroclastic units is that the unit of Laharic deposited on the stage Kuning River Merapi is young and aligned.

3.2.2 Unit of Lahar Deposits

The unit of lahar deposits is named by referring to the previous researchers and based on direct observation in the field with the physical characteristics of the lithology of lahar breccia, floating fragments and the presence of giant Fragments whose size is more than 50 cm. This giant fragment on breccia has size cobbles – boulders (2-256mm >).

In some units at several locations, there are also lahar deposits of mud-flow which generally shows the appearance of the badded structure. On the basis of field observations, the researchers concluded that this unit is dominated by a lahar breccia lithology with the following physical characteristics: lahar breccia, gray, closed down badly, disaggregated, angular, grain size 2 mm – 10 cm, fragments: andesite, the composition of the minerals: hornblende, quartz, silica cement. Distribution and thickness of this unit occupy about 30% of the total area of research. Outcrops on this unit are spread evenly in the Northwest area of research with slope relative to the South-East.

Pyroclastic units deposited in the land environment Kinahrejo – volcanic activity report with the medial facies volcaniclastic. The facies is characterized by a slope of 5-20%. The constituted material is dominated by pyroclastic breccia deposits of sandstone and a bit of lava. On this unit, the authors do not do an analysis of age because it is deposited on the ground. To determine the age of this unit, the author refers to previous researchers through field data observation. The Holocene age of this unit was the result of recent deposition of Merapi (< 1811) [4]. It was deposited at the Merapi with a range of new age (< 1811). Relations with the unit of sediment deposition units and lahar with pyroclastic breccia which is deposited on the Merapi stage young is aligned.

4. ANALYSIS OF SLOPE STABILITY

On the research area, they tend to have mass movement since based on field observation there are 5 slopes of the mass movement that could potentially happen. The slopes are scattered in several villages in Cangkringan Subdistrict, among others, the village of Sidorejo, the village of Ngipiksari, and the village of Jambu.

Based on observations of the constituent material and the type of mass movement which occurs generally it can be grouped into Debris Slides [9]. The sample of rocks or soil was taken in the field and then tested in the laboratory of soil or rock mechanics to get physical and mechanical properties of rocks or soil [10].

The samples of soil testing were 6 samples. As for the parameter being tested include moisture content, unit weight of soils, cohesion, and angle of friction [11]. After acquiring the physical and mechanical testing of parameters of soil, the result parameter is used for slope analysis of safety factor using the software Geo-Slope version 9.0.3 [12], to determine whether the slopes are safe from movement of landslide or not, in order to be considered in overcoming and solving mass movement based on the classification.

4.1 Debris slides mass movement (slopes 1)

The location of the mass movement is located in the Village of Jambu, District Cangkringan. The land used area is in the form of land sand-stone mines, plantation, and tourism area.

This type of movement of the time grounded on-site observations are included in the types of movements of Debris Slides and the dimensions of its slopes and properties of soils which are as follows: (Table 1).

Table 1 .Dimensions and material properties of slope 1.

Dimensions of slopes	
High	8.12 m
Slope	72^o
Width	6.91 m
Sloping side	8.87 m
Material Properties	
Material	Laharic breccia
Cohesion (c)	13.5 kN/m^2
Shear angle (Ø)	43.5^o
Unit weight (γ)	15 kN/m^3

Based on the analysis of the factor of safety (Figure 6), of slopes on dry conditions it is revealed that the value of FS on the upper slopes is of 1.117 and is included in the critical classes with the possibility of frequent landslides.

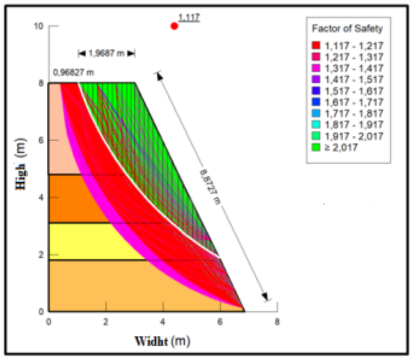

Figure 6. The results of the analysis of the factor of safety of slopes on slope 1

4.2 Debris slides mass movement (slopes 2)

This type of mass movement on site observations included in the types of debris slides mass movements, the dimensions of its slopes and properties of soils are as follows: (Table 2).

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Table 2. Dimensions and material properties of slope 2

Dimensions of slopes	
High	7.45 m
Slope	77^o
Width	6 m
Sloping side	6.51 m
Material Properties	
Material	Pyroclastic flow
Cohesion (c)	5.4 kN/m^2
Shear angle (Ø)	36^o
Unit Weight (γ)	18.3 N/m^3

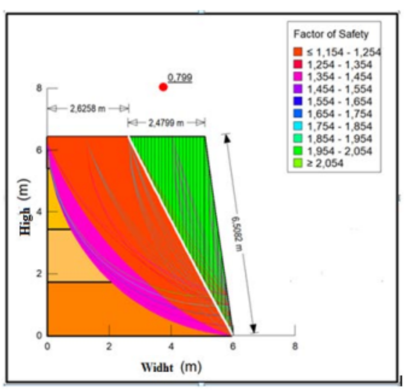

Figure 7. The results of the factor of safety analysis of slopes on slope 2.

Based on the analysis of the factor of safety of slopes (Figure 7) using the software Slide 6.0 [12], on dry conditions, it is indicated that the value of FS on the upper slopes is of 0.799 (unstable class) with the possibility of frequent landslides. The mass movement was driven by the increasing unit weight soil due to the rainfall [13].

5. CONCLUSION

On the basis of the research on the sand-stone quarry in Banjarsari, it is possible to conclude that 2 quarry locations have a potential mass movement with debris slide type. According to the analysis of slope stability, location slope 1 is categorized as the critical class with the FS value of = 1.117 in lahar deposit, and slope 2, are categorized as the unstable class with the FS value of = 0.799 in the pyroclastic deposit. So, in the pyroclastic deposit slopes (Slope 2) has FS value lower than lahar deposit slopes (Slope 1). The mass movement was driven by the increasing unit weight soil due to the rainfall.

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