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KINEMATICS ANALYSIS AND THE ROLE OF GEOLOGICAL STRUCTURES ON SLOPE FAILURES OF MENOREH HILLS, CASE STUDY: SAMIGALUH DISTRICT, KULON PROGO REGENCY AND, BOROBUDUR DISTRICT, MAGELANG REGENCY, INDONESIA


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ABSTRACT: Menoreh Hills in the Kulonprogo Regency of Yogyakarta Special Territory, Magelang Regency and Purworejo Regency in Central Java belongs to landslide subscriptions area in almost every rainy season. The most recent landslides occur during late November 2018 to early January 2019. Problem of mass movements in the Menoreh Hills is a manifestation of geological conditions, including geomorphology, lithology, and especially geological structures. The lithology composing the study area is dominated by a group of volcanic rocks consisting of breccia and lava from the Kaligesing Formation and Dukuh Formation. The physical condition of these rocks is generally weathered to form soil with a thickness reaching 5 m. The geological structures exist in the study area are joints and faults caused by the main stress relative to the North-South direction. Faults in the study area can be classified into right lateral slip fault, left lateral slip fault, reverse fault, right-reverse fault, left-reverse fault, and right-normal fault. Based on the results of kinematics analysis on rock slopes with Markland method, there are 7 slopes have the potential for fail with wedge and topple types. While the result of soil slope analysis with the Spencer method, there are 4 slopes that prospective for landslides, they are located in Ngargosari village and Purwoharjo village. Almost all of the potential slope failure are situated at the adjacent or passed by the fault strike. It proves that the geological structures have a very important role as the cause of slope failures in the Menoreh Hills.

Keywords: Kinematics analysis, geological structures, joint, fault, slope failure

INTRODUCTION

Most parts of Kulon Progo Regency and Magelang Regency is locaten on a hilly morphology which has a variety of slopes from flat to very steep. Therefore in the rainy season, these areas are easily happened to landslides that makes life and material losses. It Recorded in the natural disaster recapitulation of the Regional Disaster Management Agency of Kulon Progo and Magelang Regency, that there were some landslides in late November 2018 - beginning of January 2019. The impacts were the landslide material attack the residents' houses and roads, which disrupted people's access and activities.

To reduce the life and material losses caused by a landslide disaster, it is necessary to create disaster mitigation in engineering perspective, which apply technical geology method. Therefore, research about the analysis on slope stability based on engineering geological data to overcome the mass movement disaster becomes important. This research carried out stability analyses both on rock and soil slopes.

Administratively, the research area is located in two regions, they are Samigaluh District, Kulon Progo Regency, Yogyakarta Special Province and Borobudur District, Magelang Regency, Central Java Province. The study area is 5 x 5 km2 (25,000 m^2) (Figure 1).

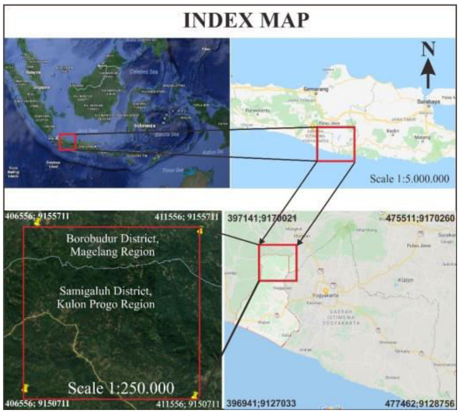


Figure 1. Index Map of Research Location (Google Earth, 2019)

METHOD OF STUDY

This research was carried out by applying descriptive and analytical methods, based on the results of surveys and mapping in the field. To achieve the expected goals, the implementation of this research is divided into literature studies, then making a research framework in the form of a research flow chart, followed by the field research stage which is data collection as primary data for data processing and analysis. The processing of this data use ArcGIS software to be processed into geomorphological maps, geological maps, and zoning maps of mass movement vulnerability. Then for the rock slope stability analysis, it was done by using the Markland method to determine the probability and type of failure on each slope. Determination of Factor of Safety (FS) on rock slopes used Phase 2 software and determination of FS on soil slopes used Slide software.

Basically, force system on the slope can be broken down into a resisting force and driving force. To find out the stability of a slope, need a calculation that compares the magnitude of resisting and driving forces. If the equilibrium force is disrupted, it will cause mass movements (Citrabhuwana, et. al, 2016).

The equilibrium force on the slope is influenced by many things including physical properties of rock, such as friction angle and rock cohesion. As well as external factors, like water pressure in both soil and rock pores, also additional loads on the slope. However, the angle slope will very decisive, because the greater angle slope, the greater gravity vector caused (Citrabhuwana, et. al., 2016).

Quantitatively, slope stability expressed in Factor of Safety (FS). In determining FS, the calculation is based on the assumption that the slope length is infinite and generally stated a: (1)

$$Factor\ of\ Safety\ (FS) = \frac{\Sigma\ Resisting\ Force}{\Sigma\ Driving\ Force}$$

If the FS value > 1.25 means the slope is safe; 1.07> FK> 1.25 means critical; and FS <1.07 means unstable (unsafe) (Bowles, 1989).

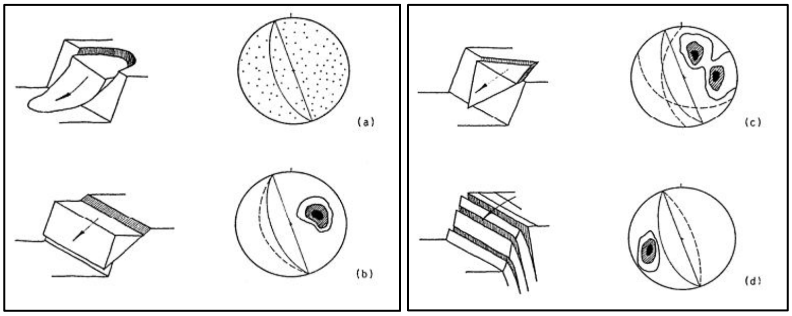


Figure 2. Kinematic conditions of slope failure based on fracture plane (left: failure type; right: stereographic projection; (a) Rotational failure, (b) Planar failure, (c) Wedge failure, (d) Toppling failure (Hoek & Bray, 1981)

GEOLOGY OF THE MENOREH HILLS

1. Geomorphology

   The landform units of the research area are based on geomorphological aspects according to Van Zuidam (1983), divided into 5 (five) units of landform, they are river, structural hills, structural slopes, scarp structural valleys, and intrusion slopes.

   a. River Landform

   The river landform is located on elevation of 287-325 meters which ~~is~~ the main river (Kali Tinalah) shows sub-dendritic drainage pattern, has the shape of a “U” valley, with a high level of precipitation. Based on morphogenesis aspects, this unit is influenced by sedimentation process and river erosion.

   b. Structural Hills Landform

   This structural hills landform extends relatively North-South which is cut off by valleys resulting from erosion. This landform has an elevation between 475-600 meters, with a sub-dendritic flow pattern and a “U-V” valley shape. Also it consists of dominant lithology in the form of breccia andesite fragments, therefore it has high resistance. The exogenous process is in the form of weathering and erosion.

   c. Structural Slopes Landform

   Structural slope landforms extends west-east with valleys formed by erosion. This landform has an elevation between 462-825 meters, with parallel drainage patterns and a ”V” shape. Based on morphogenesis aspects, this landform is influenced by a sloping lithology with a non-uniform position, with the dominant lithology in the form of breccia. Therefore, it has strong resistance, with exogenous processes in the form of weathering, and erosion. The geological structure that controls are fault and fracture.

   d. Scarp Landform

Scarp landform has very steep slopes (30-70%) extending Northwest-Southeast with valleys formed from erosion. This unit has an elevation between 425-650 meters, with a sub-dendritic drainage pattern and the shape of the "U-V" valley

e. Structural Valley Landform

Structural valley landforms lies on between gawir in the Eastern part of research location. This landform has an elevation between 350-400 meters, with a trellis drainage pattern with the shape of "U-V" valley with sloping slopes. This landform has moderate-weak resistance and moderate erosion rates, with exogenous processes such as weathering and erosion.

f. Volcanic Slope Landform

This volcanic slope landform has the shape of a hillside with valleys formed from erosion. This landform has an elevation between 462-550 meters with parallel drainage pattern and "V" shape valley and has a steep slope. Based on morphogenesis aspects, this landform is influenced by a sloping lithology, with andesite igneous rock which is the result of intrusion on the slope. Exogenous processes that occur in the form of weathering, and erosion. The geological structure that controls the landform are fault and fracture.

2. Stratigrahy

Lithostratigraphic unit of the research area is basically referenced to Pringgoprawiro (1987) (Figure 3), with a unit naming system based on unofficial lithographic in the form of formation.

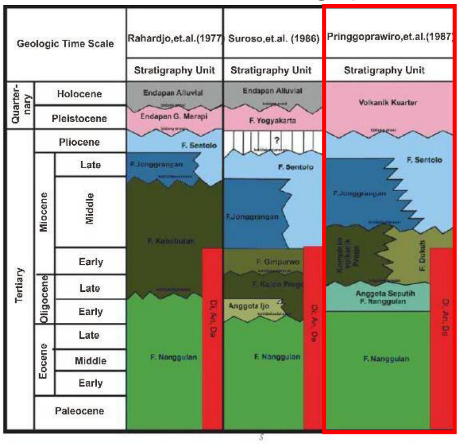


Figure 3. Kulon Progo Stratigraphic Column (Pringgoprawiro&Riyanto,1987)

a. Nanggulan Sandstone Unit

Nanggulan Sandstone Unit is dominated by the layered quartz sandstones with clay and lignite (coaly shale). The main characteristic of lignite in this outcrop is black, flaky, and has a carbon odor in the rock. Nanggulan Sandstone Unit (Pringgoprawiro&Riyanto, 1987) has age around Middle Eocene - Early Oligocene. The stratigraphic relationship between Nanggulan Sandstone Unit with Kaligesing and Dukuh Andesite Breccia Unit is unconformity.

b. Kaligesing Andesite Breccia Unit

Kaligesing Breccia Unit at the research area consist of monomixed breccia with andesite fargment, lava (autobreccia), basalt, and andesite igneous rocks. It is composed of materials from ancient volcanic activity that were in the Middle Oligocene-Early Miocene age (Pringgoprawiro&Riyanto, 1987). Sedimentary environment of Kaligesing Formation is in the land environment resulting from ancient volcanic volcanic activity. The stratigraphic relationship of Dukuh and Kaligesing Formation (Old Andesite Formation) is interfingering with the age of Middle Oligocene-Early Miocene.

c. Dukuh Andesite Breccia Unit

Dukuh Formation at research area consist of breccia with andesite and dacite fragments, pyroclastic breccia with igneous rock fragments, lapilli and tuff matrix, pyroclastic rocks in the form of lapillus and tuffs, and the presence of andesitic lava. According to Pringgoprawiro&Riyanto (1987), Dukuh Formation's age is Middle Oligocene-Early Miocene. Kaligesing and Dukuh Formation is the result of volcanic activity from 3 ancient mountains in Kulon Progo, namely Mount Gadjah located in the middle, Mount Ijo located in the southern part of Mount Gadjah, Menoreh mountain which produces hornblende-andesitic lava, dacite intrusion then the last is andesite. The pyroclastic material encountered can be in the form of flow deposits, surges, and falls. According to Widagdo (2016), this formation is approximately 600 meters.

d. Jonggrangan Limestone Unit

Jonggrangan Limestone Unit at the research area consists of reef limestone, reef limestone with lignite insertion, and clastic limestone. Based on the macropaleontological analysis that taken from this sample's outcrop, the age of Jonggrangan Formation is Middle Miocene - Late Miocene, was characterized by the presence of macro fossils in the form of Scalaspira strumosa. Jonggrangan Formation is located unconformity above the Kaligesing-Dukuh Formation. The thickness of the Jonggrangan Formation reaches around 250 meters (Van Bemmelen, 1949).

e. Andesite Intrusion Rock

Andesite Intrusion Rock was found lies in the Northern part of the research area. Distribution of this intrusion covers 15% of the area of the study area. The topography of this Andesite Intrusion is wavy because of lithological factors and geological structures in the form of faults and fractures, also has a massive structure and sheeting joint. In addition, there is also a spheroidal weathering structure. The age of this intrusion is around Early Oligocene-Early Miocene. It is interpreted as a volcanic neck which is one of the sources of Kulon Progo mountain volcanic activity complex.

3. Geological Structure

Based on field data, it was found 4 fractures in the form of a shear joint. In Dukuh Andesite Breccia Unit was found 3 fractures with the main stress direction (sigma 1) N245^{0}E, N187^{0}E, and N149^{0}E respectively. In Andesite Intrusion Rocks were found in the form of fracture with direction of sigma 1 N096^{0}E. We use these structure analysis according to Rickard, 1972 to determine the classification of fault.

a. Right Lateral Slip Fault

This structure is located right in contact between breccia and andesite igneous rock. The analysis shows the of fault is N045^{0}E / 89^0 (Northeast - Southwest) with the direction of sigma 1 (the major stress) is N135^{0}E / 19^0 (Southeast - Northwest).

b. Left Lateral Slip Fault

This structure is located in the river and andesite igneous lithology. The analysis shows the direction of fault N070^{0}E / 85^0 (Northeast - Southwest) with plunge / bearing: 76^0, N231^{0}E and rake: 19^0.

c. Reverse Slip Fault

This fault condition is already weathered, consist of lithology of sandstone with clay insertion and lignite. The analysis result show the direction N261^{0}E / 64^0 (West - East) fault field with plunge/ bearing: 63^0, N358^{0}E and rake: 88^0.

d. Right Reverse Fault

This structure is found in andesite rocks located on rivers. The analysis shows the direction N270^{0}E / 54^0 (West - East) with slickensided in the form of plunge/ bearing: 19^0/ N075^{0}E and rake: 75^0.

e. Left Reverse Fault

This structure is found in andesite rocks located on cliffs. The analysis result shows that the strike is N195^{0}E / 61^0 (North - South), fault plane with plunge/ bearing: 58^0, N312^{0}E and rake: 61^0. This left reverse fault also found in the lithology of andesite rocks located on the Kluban river. The analysis result shows the strike N028^{0}E / 53^0 (North - South) with plunge/ bearing: 26^0/ N186^{0}E and rake: 70^0.

f. Right Normal Fault

This structure is found in breccia and andesite located on the Tinalah River. The analysis result shows the direction of the fault is N066^{0}E / 64^0 (Northeast - Southwest) with plunge/ bearing: 50^0, N030^{0}E and rake: 68^0. The other fault on andesite has direction of N126^{0}E / 57^0 fault area (Southeast - Northwest) with plunge/ bearing: 33^0/ N280^{0}E and rake: 69^0.

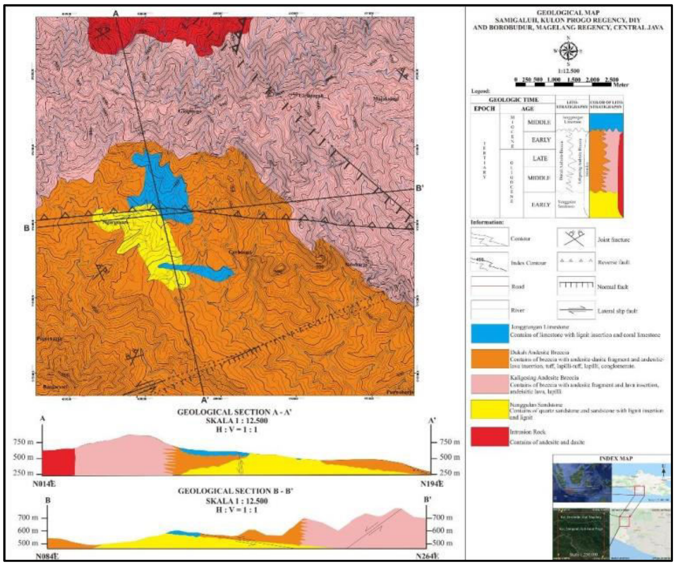


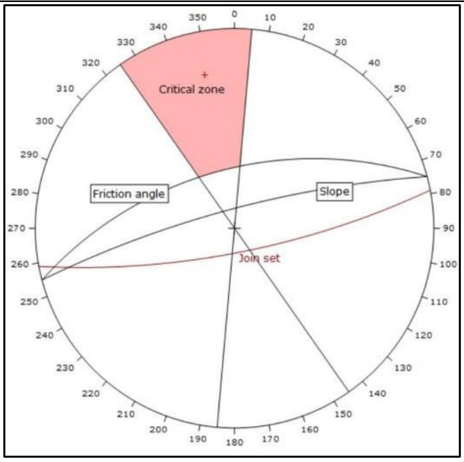
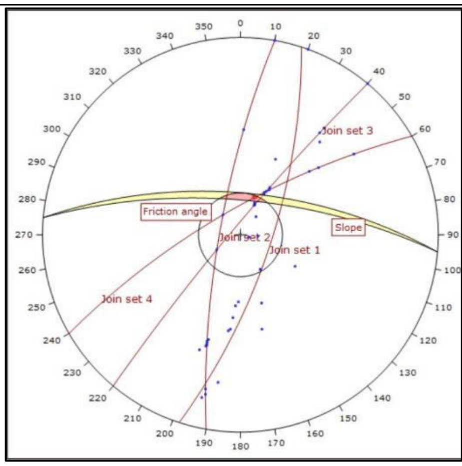
Figure 4. Geological Map

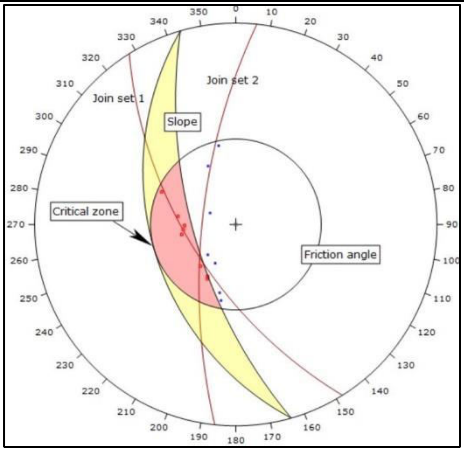
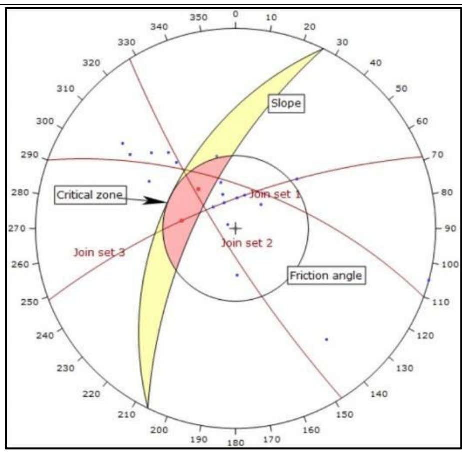
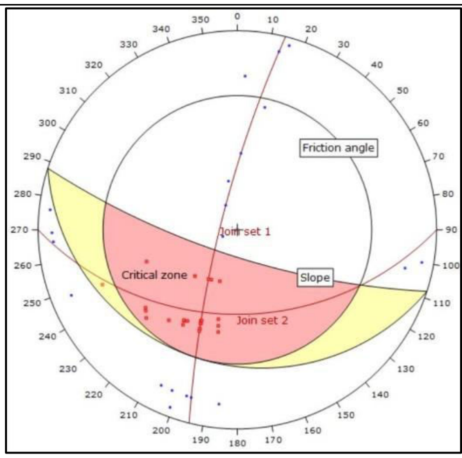
KINEMATICS ANALYSES

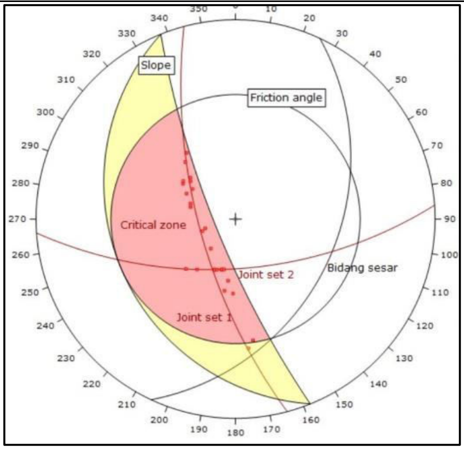
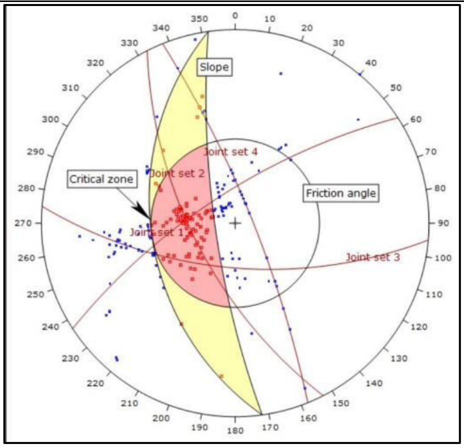
Rock Slopes

Based on the results of kinematics analysis on rock slopes with Markland Method, from 10 slopes observation on the research area, there are 7 slopes that have failure slope potential. Potential types of slope failure in the study area are sliding and toppling wedges.

Table 1. Kinematic analysis on rock slope

No.	Slope condition		Markland Analysis
1	Location	LP 2	
	Rock Type	Lapilli pyroclastic	
	Failure Type	Toppling (100%)	
	Failure Direction	N345^{0}E	
2	Location	LP 4	
	Rock Type	Andesite	
	Failure Type	Wedge (4.44%)	
	Failure Direction	N050^{0}E	

3	Location	LP 5	
	Rock Type	Andesite	
	Failure Type	Wedge (53.55%)	
	Failure Direction	N235^{0}E	
4	Location	LP 6	
	Rock Type	Andesite	
	Failure Type	Wedge (9.52%)	
	Failure Direction	N295^{0}E	
5	Location	LP 8	
	Rock Type	Weathered andesite	
	Failure Type	Wedge (55.56%)	
	Failure Direction	N205^{0}E	

6	Location	LP 9	
	Rock Type	Weathered andesite	
	Failure Type	Wedge (77.78%)	
	Failure Direction	N210^{0}E	
7	Location	LP 10	
	Rock Type	Tuff-lapilli	
	Failure Type	Wedge (46.75%)	
	Failure Direction	N270^{0}E and N205^{0}E	

Soil Slopes

Table 2. Field observation on soil slope

No.	Slope Conditon		Slope measurement picture
1	Location	LP 1 X: 406738; Y: 9153360; Z: 550 Ngargosari Village area, Samigaluh District, Kulon Progo Regency, DIY	 Azimuth of N290^{0}E
	Slope properties	Slope length: 12 m Slope height: 10 m Slope angle: 56^0	
	Slope condition	• Bulging • It lies on the Northwest from the	

		main road and settlemen	
2	Location	LP 4 X: 407777; Y: 9153802; Z: 625 Ngargosari Village area, Samigaluh District, Kulon Progo Regency, DIY	 Azimuth N345^{0}E
	Slope properties	Slope length: 24.5 m Slope height: 21.83 m Slope angle: 63^0	
	Slope condition	The presence of a landslide that leaves a circular shape jutting in on the slope	

Table 3. Soil slope analysis

Location	Geological and slope condition	Soil properties	Type of failure potential	Information	Recommendation
Soil Slope 1 Ngargosari Village, Samigaluh Regency	• There is bulging symptoms with a fairly steep slope. • Also the slope classification is relatively steep.	H: 10 m L: 12 m *Slope:* 56^0 c: 0,29 kg/cm^2 Φ: 22^0 ɣ: 2,18 gr/cm^3	*Debris fall* -FK$_{saturated}$: 0,947 (unsafe) -FK$_{half\text{-}saturated}$: 1,204 (critical) -FK$_{dry}$: 1,355 (safe)	Located in the Northwest from inter-village roads and settlements.	- Reducing the slope angle (tiered slope). - Control the surface water (drainage), so that the water content in the soil makin up the slope is sufficient. - Reduce the burden on the slope by not build above it.
Soil Slope 4 Ngargosari Village, Samigaluh Regency	It used to be happened landslide disaster on this area. Also this slope classification is relatively steep.T	H: 21,83 m L: 24,5 m *Slope:* 63^0 c: 0,12 kg/cm^2 Φ: 68,43^0 ɣ: 1,68 gr/cm^3	*Earth slides* -FK$_{saturated}$: 0,03 (unsafe) -FK$_{half\text{-}saturated}$: 0,641 (critical) -FK$_{dry}$: 2,12 (safe)	Located near inter-village roads and settlements.	

Information: H=height of slope; L=length of slope; c=soil cohession; Φ=soil friction angle; ɣ=soil unit weight in gr/cm^3

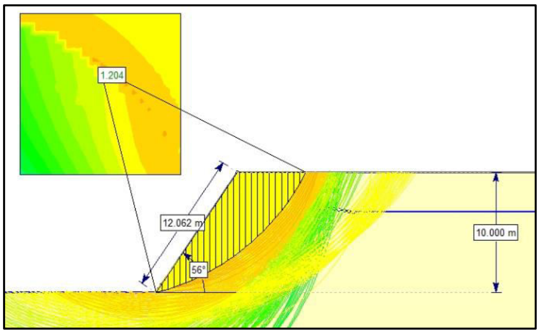


Figure 6. Factor of safety on soil slope with half-saturated condition: 1.204 (critical)

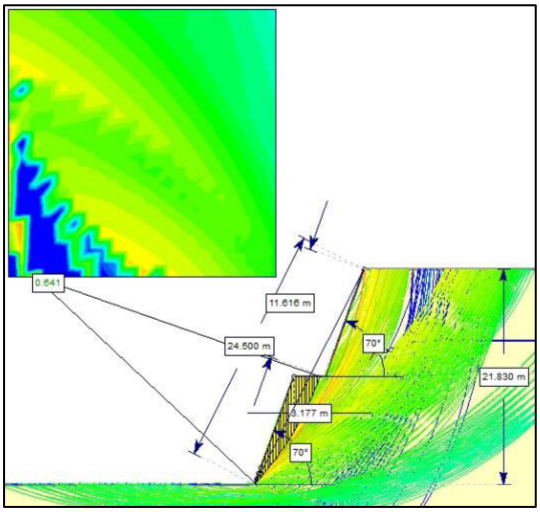


Figure 7. Factor of safety on soil slope with half-saturated condition: 0.641 (critical)

ROLE OF GEOLOGIC STRUCTURES ON SLOPES FAILURES

Bedding Planes and Joints

The litostratigraphy on a slope with certain of an angle and direction can cause the rock blocks to slide from the slope face. For example, in planar type slope failure, it can occur if the direction of planar plane is ± 20^{o} from slope direction, slope angle> planar slope angle, and slope angle> inner shear angle (φ) slope forming rock.

On the other hand, fracture on a slope will be a discontinuity zone which can also cause failure potential. For example, for wedge type slope failure. It will occur if two fracture intersect each other. The slope of the intersecting must be more gentle (or flat) than the angle slope itself, but the angle slope must be greater than the inner shear angle (φ). In addition, there is also a toppling type slope failure. Where this failure involves rotation of rock blocks that have fracture directions opposite to the slope direction.

Faults

Fault structure play a role in a slope failure. This is caused by the fracture that formed by the movement of two rock blocks, which will become a discontinuity zone. Therefore, the weak zones can make water to flow in. In addition, weathering will be easier to happen and friction angle of the rock slope will be smaller.

CONCLUSSIONS

1. The research area is divided into 6 landform units, they are River landforms (F1); Structural hilly landforms (S1), Structural slope landforms (S2), Gawir landforms (S3), Structural valley landforms (S4); and Intrusion slope landform (V1).
2. Stratigraphy at the research area consist of 5 rock units, from young – old are Nanggulan Sandstone Unit (Early Middle-Oligocene Eocene), Kaligesing and Dukuh Andesite Breccia Unit (Early Middle-Miocene Oligocene), Jonggrangan Limestone Unit (Middle-Miocene Middle Miocene) End), and Andesite Intrusion Unit.

3. The geological structure that develops at the research area consists of fractures and faults.
    a. The rock bed position has a general position N110^{0}E / 6^0 and N085^{0}E / 60^0.
    b. Fractures on the research area has main stress relatively directed to the North-South direction with Sigma 1 N026^{0}E, N002^{0}E, and N004^{0}E; Northeast - Southwest N042^{0}E.
    c. Faults on the research area are into right lateral slip fault, left lateral slip fault, reverse fault, right-reverse fault, left-reverse fault, and right-normal fault.
4. Based on the kinematics analysis result on rock slopes with Markland Method, from 10 slope observation, there are 7 slopes that have slope failure potential. 3 slopes located in Samigaluh District, Kulon Progo Regency, DIY: Ngargosari Village (1 slope); Banjarsari Village (1 slope); Majaksingi Village (1 slope). While 4 slopes are in Giripurno Village, Borobudur District, Melang Regency, Central Java. Potential types of slope failure in the research area are sliding and toppling wedges.
5. Bedrock layer, fractures, and faults are really have important role that can influenced the rock and soil slope stability. So that, the slopes on fracture and fault zone will be more potential for landslides.

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