Correlation Between Geological Structures and Kinematic Analysis to Identify the Vulnerability Zone of Slope Failures on Samigaluh and Borobudur District

by Barlian Dwinagara

Correlation Between Geological Structures and Kinematic Analysis to Identify the Vulnerability Zone of Slope Failures on Samigaluh and Borobudur District

Istifari Husna Rekinagara[1a)], Sari Bahagiarti Kusumayudha[2b)], Jatmika Setiawan[2c)], Oktarian W. Lusantono[3d)], Barlian Dwinagara[3d)]

[1] *PT Studio Mineral Batubara, Mining Consultant – Jl. Gang Mulia VI No 67, Ngaglik, Sleman, Yogyakarta*
[2] *Department of Geological Engineering, UPN "Veteran" Yogyakarta – Jl. Padjajaran (SWK 104), Condongcatur Sleman, Yogyakarta*
[3] *Department of Mining Engineering, UPN "Veteran" Yogyakarta – Jl. Padjajaran (SWK 104), Condongcatur Sleman, Yogyakarta*

[a)] istifari@mcsindonesia.co.id
[b)] saribk@upnyk.ac.id
[c)] jatmikosetiawan@yahoo.com
[d)] oktarian.lusantono@upnyk.ac.id
[e)] barliandn@upnyk.ac.id

Abstract. Menoreh Hills lies within the western region of Kulon Progo Regency, Yogyakarta and the southern region of Magelang Regency, which belongs to landslide subscriptions region in nearly each wet season. An association of geological conditions, including geomorphology, lithology, and geological structures, turns into the problem of a mass movement in this area. Mostly, this area is consisting of volcanic rocks. They are breccia and lava from Kaligesing and Dukuh Formation with the rock's physical condition is commonly weathered. The appearance of geological structures in the form of joints and faults are caused by the primary stress that has North-South direction relatively. This paper's objective is to propose a correlation between geological structure and kinematic analysis, where it has an essential role in figuring out the potential type of slope failure. Kinematic analysis conducted using Markland methods, there are seven slopes that have failure potential of a wedge and topple type. Then these analysis result processed as a vulnerability zone of slope failure. Generally, the potential slope failures are situated at the alongside or passed by the fault strike. It proves that the geological structures have an essential role as a variable to the kinematic analysis.

Keywords: geological structures, kinematic analysis, slope failure, vulnerability zone

INTRODUCTION

Kulon Progo and Magelang Regency are dominantly located on a hilly morphology, which has a variety of slopes from flat to very steep. Administratively, the research region is in two regions; they are Samigaluh District, Kulon Progo Regency, Yogyakarta Special Province and Borobudur District, Magelang Regency, Central Java Province **(FIGURE-1)**. These areas are easily happened to landslides in the wet season that cause activity and property losses. It was recorded in the natural disaster recapitulation of the Regional Disaster Management Agency of Kulon Progo and Magelang Regency, that there were some landslides in round January – March 2020. The landslide's influence was the landslide material attack the citizens' building and path, which disturb people's activities. In order to limit all those losses caused by a landslide disaster, it is primary to create disaster mitigation in engineering perspective in the form of applying geotechnical methods. This research is a development from previous research [1], where there is a knowledge gap about the vulnerability zone obtained from the analysis of rock and soil slopes that have been carried out. Therefore, the analysis on slope stability based on geotechnical data will be more representative with the vulnerability zones data. Potential type of slope failure can be identified by geological structure, rock's mechanic and physical properties, then analyzed with kinematic analysis.

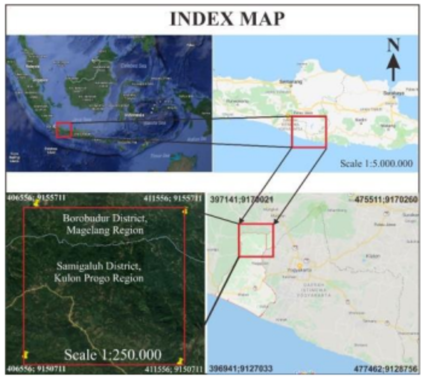


FIGURE 1. Index map of research location (Google Earth)

LITERATURE REVIEW

Mass Movement

Previous studies [2] have shown that a slope force system could be broken down into a resisting force and pushing force. A calculation that compares the magnitude of resistance and driving forces is required to determine the stability of a slope. It will cause mass movements if the equilibrium force is broken. Many factors, including rock physical and mechanical properties, such as friction angle and cohesion, affect the equilibrium force on the slope. As well as external variables, such as water pressure in the pores of soil and rock, additional slope loads are also included. The angle slope, however, will be very decisive, because the greater angle slope is caused by the higher gravity vector.

Quantitatively, the stability of the slope is expressed in the Factor of Safety (FoS). The calculation assumed in the determination of FoS that the slope length is infinite and generally stated as:

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

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).

Lithostratigraphic Unit

The research area's litostatigraphic unit is basically referred to Pringgoprawiro (1987) [3] **(FIGURE-2)**. The oldest formation was Nanggulan Formation, dominated by layered quartz sandstones with clay and lignite (coaly shale). In this outcrop, the primary characteristic of lignite is black, flaky, and the rock has a carbon odor. Nanggulan Formation [3] has age around Middle Eocene - Early Oligocene. The stratigraphic relationship Nanggulan Sandstone Unit with Kaligesing and Dukuh Andesite Breccia Unit is unconformity.

The formation of Kaligesing consists of mono-mixed breccia with ignesious of andesite fragment, lava (autobreccia), basalt, and andesite. It is composed of materials from the Middle Oligocene-Early Miocene period of ancient volcanic activity [3]. Kaligesing Formation has a sedimentary environment as a result from ancient volcanic activity. The stratigraphic relationship of Dukuh and Kaligesing Formation (Old Andesite Formation) is interfingering (Middle Oligocene-Early Miocene).

Dukuh Formation consists of breccia with fragments of andesite and dacite, pyroclastic breccia with fragments of igneous rock, lapillus and tuff matrix, lapillus and tuff pyroclastic rocks, and the presence of andesitic lava. Middle Oligocene-Early Miocene is the age of Dukuh Formation [3]. The formation of Kaligesing and Dukuh is the result of volcanic activity in Kulon Progo from three ancient mountains, namely Mount Gadjah that located in the centre. Meanwhile Mount Ijo situated in the southern part of Mount Gadjah, then Menoreh mountain that generates hornblende-andesitic lava, dacite intrusion, andesite.

Reef limestone, reef limestone with lignite insertion, and clastic limestone are part of the Jonggrangan Formation. The age of Jonggrangan Formation is Middle Miocene - Late Miocene, characterized by the appearance of macrofossils in the form of Scalaspira strumosa. Jonggrangan Formation seedimented unconformity above the Kaligesing-Dukuh Formation.

Andesite Intrusion Rock was found to be located in the research area's northern part. This instrrusion distribution covers 15 percent of the tudy area. The topography of this Andesite Intrusion is wavy, along with massive structure and sheeting joint due to the lithological element and geological structures in the form of faults and fractures. The Early Oligocene-Early Miocene is the age of this intrusion. It was interpreted as a volcanic neck, which is one of the origins of volcanic activity complex of Kulon Progo mountain.

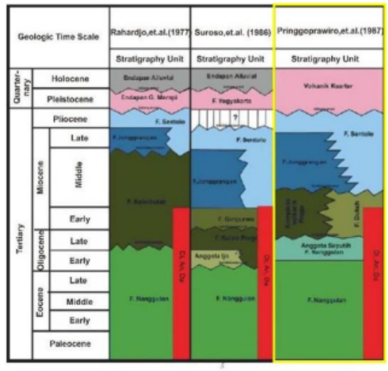


FIGURE 2. Kulon Progo Stratigraphic Column [3]

METHODOLOGY

This research was carried out on the basis of surveys and mapping observations in the area, using descriptive and empirical methods. The implementation of this study was divided into literature reviews, research structure making, and then field research in order to achiece the intened objectives. The collected data from field (i.e., lithology, morphology, structural, and the samples) were primary data for processing and analysis.

To evaluate the probability and the type of failure on each slope, the rock slope stability was performed using the Markland method. Determination of Factor of Safety (FoS) on rock slopes was carried out by Phase 2 software and determination of FoS on soil slopes used Slide software. All processed data recapitulated in the form of a vulnerability zone of slope failure using ArcGIS software.

Kinematic Analysis – Markland Method

In some cases of rock mass motion, the landslide slip planes are often discontinuity planes, as described by Markland in stereographic projections reflecting different types of rock mass motion **(FIGURE-3)** [4] are: (1) a slope where the slip plane is circular, the projection of the slip plane inside the stereonet will be points that spread irregularly. Therefore, the Markland method can not be applied; (2) a slope where the sliding area is planar, if the slope of the slope surface is greater than the slope of sliding plane, the slope has potential for landslides; (3) a slope where the sliding area is a wedge, if the slip direction is in the same direction (forming an angle <10^{o}) to the slope, then the slope has potential for landslides; and (4) if the direction of discontinuity planes is opposite to the slope surface direction and each has a slope of more than 70^{o}, then the slope has potential for toppling.

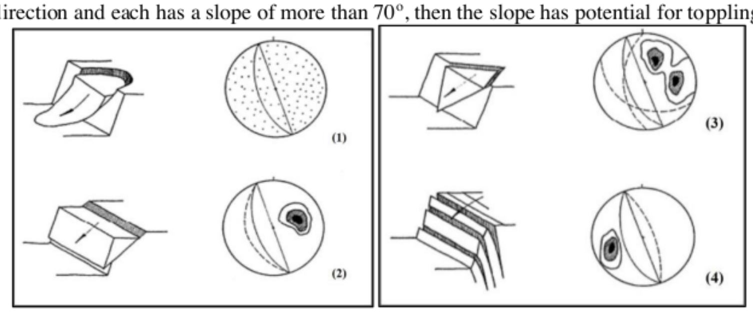


FIGURE 3. Kinematic conditions of slope failure based on fracture plane (left: failure type; right: stereographic projection; (1) Rotational failure, (2) Planar failure, (3) Wedge failure, (4) Toppling failure [4]

RESULTS AND DISCUSSION

Geological Structure

Four structures in the shape of a shear joint have been found based on field data **(FIGURE-4)**. Three fratures with the main stress direction (sigma 1) N245^{0}E, N187^{0}E, and N149^{0}E, respectively, were found in Dukuh Andesite Breccia. In the Andesite Instrusion Rocks, a fracture in the direction of sigma 1 N096^{0}E was found. According to Rickard, 1972, these studies were intended to assess the classification of the fault [5].

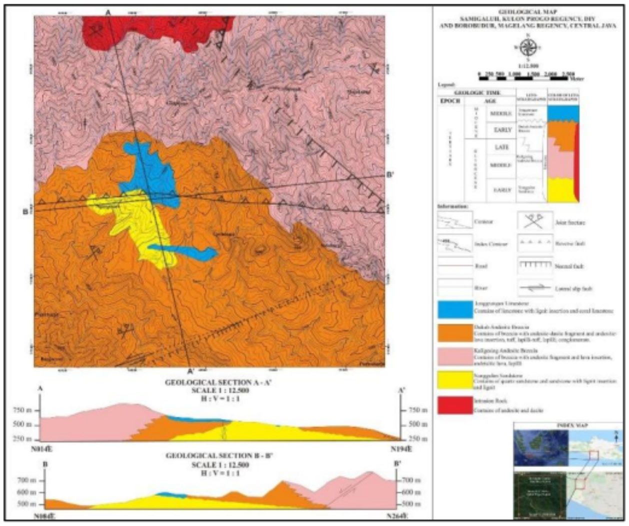
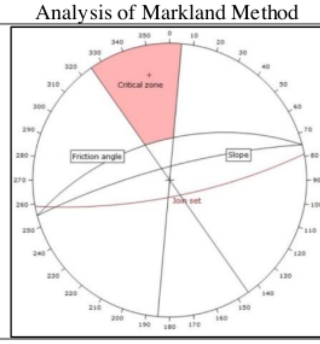


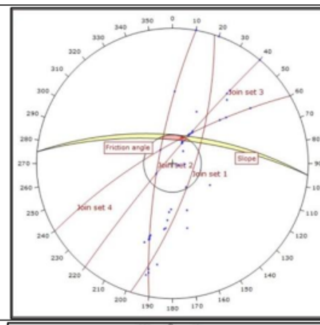
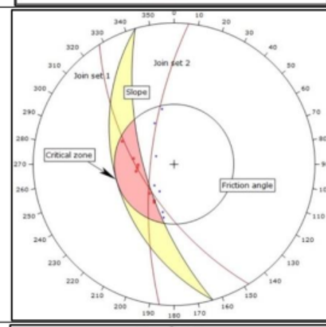
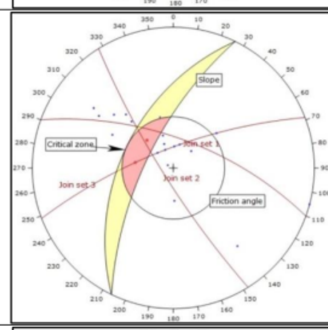
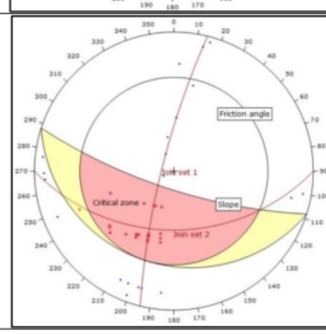
FIGURE 4. Geological Map

Kinematics Analysis – Rock and Soil Slopes

There are seven slopes with failure slope potential based on the result of kinematics analysis on rock slopes with Markland Method. Slidign and toppling wedges are become the possible forms of slope failure in the study area **(TABLE-1)**. Besides, there were two areas have soil sliding potential **(TABLE-2** and **TABLE-3).** These 2 of soil slope have critical and unsafe FoS; they were 1.204 **(FIGURE-5)** and 0.641 **(FIGURE-6)**, respectively.

TABLE 1. Rock slope kinematic analysis

No.	Slope condition		Analysis of Markland Method
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%)	

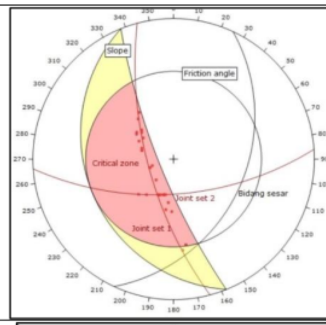
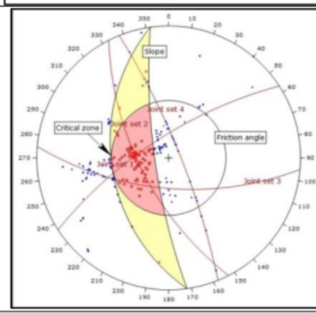
	Failure Direction	N210^{0}E	
7	Location	LP 10	
	Rock Type	Tuff-lapilli	
	Failure Type	Wedge (46.75%)	
	Failure Direction	N270^{0}E and N205^{0}E	

TABLE 2. Soil sope field observation

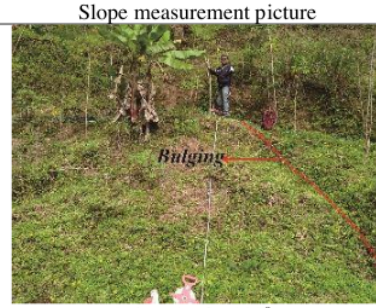
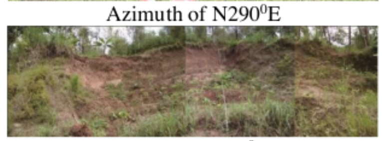
No.	Slope Conditons		Slope measurement picture
1	Location	LP 1 X: 406738; Y: 9153360; Z: 550 Ngargosari Village area, Samigaluh District, Kulon Progo Regency, DIY	 Azimuth of N290^{0}E
	Slope properties	Slope length: 12 m Slope height: 10 m Slope angle: 56^0	
	Slope condition	• Bulging • It lies on the Northwest from the main road and settlement	
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 **(FIGURE-5)**	• With a steep slope, bulging symptoms occur. • The slope classification is also comparatively steep.	H: 10 m L: 12 m *Slope:* 56^0 c: 0,29 kg/cm^2 Φ: 22^0 γ: 2,18 gr/cm^3	*Debris fall* -FK$_{saturated}$: **0,947 (unsafe)** -FK$_{half\text{-}saturated}$: **1,204 (critical)** -FK$_{dry}$: **1,355 (safe)**	It is located in the Northwest from inter-village roads and settlements.	- Reducing the angle of the slope (tiered slope). - Monitoring the surface water (drainage) so that the water content in the soil forms a proper slope. - Reduce the slope's pressure by not building above it.
Soil Slope 4 Ngargosari Village, Samigaluh Regency ((**FIGURE-6)**	It used to happen int his region with landslide disaster. This slope classification is also comparatively steep.	H: 21,83 m L: 24,5 m *Slope:* 63^0 c: 0,12 kg/cm^2 Φ: $68{,}43^0$ γ: 1,68 gr/cm^3	*Earth slides* -FK$_{saturated}$: **0,03 (unsafe)** -FK$_{half\text{-}saturated}$: **0,641 (critical)** -FK$_{dry}$: **2,12 (safe)**	It is located near inter-village roads and settlements.	

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

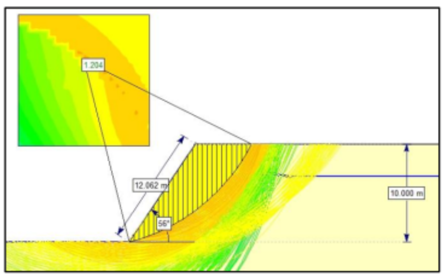


FIGURE 5. The FoS on soil slope with half-saturated condition: **1.204 (critical)**

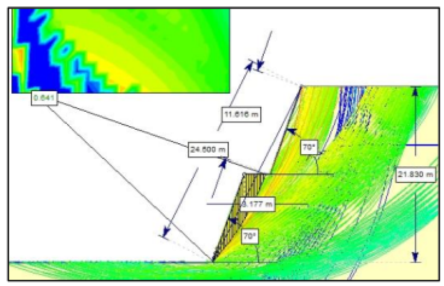


FIGURE 6. The FoS on soil slope with a half-saturated condition: **0.641 (critical)**

Vulnerability Zone of Slope Failures

The vulnerability zone of slope failure in research area divided into three zones; they are high (red), intermediate (yellow), and low (green) landslide potential zone. This classification was based on the distribution of soil and rock slope that have been identified with both kinematic and slope stability analysis. The result stated that high landslide potential zone located on the Northern of research area with FoS <1.07; intermediate landslide potential zone located in the outer zone of the research area with 1.07<FoS<1.25; and low landslide potential zone located on the middle of research area with FoS>1.25 **(FIGURE-7).**

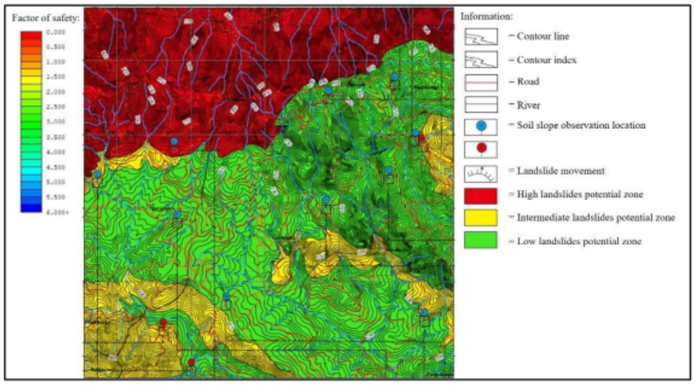


FIGURE 7. Vulnerability Zone Map

Correlation between Geological Structure on Slope Failures

Bedding Planes and Joints

With a certain angle and direction, the lithostratigraphy on a slope may cause the rock blocks to slide from the slope face. For example, if the direction of the planar plane is ± 20^o from the direction of the slope, slope angle> planar slope angle, and slope angle> inner shear angle (φ) slope forming rock, it can occur in a planar type slope failure. On the other hand, a discontinuity zone is a fracture on a slope, which can also cause the potential for failure. For wedge type slope failure, for instance. If two fractures cross each other, this will occur. The intersecting slope must be flatter than the angle slope itself, but the angle slope must be greater than the inner shear angle (φ). In addition, there is also slope failure toppling type where this failure involves rotation of rock blocks that have fracture directions opposite to the slope direction.

Faults

In a slope failure, the fault structure plays a part. This is caused by the fracture created by two rock blocks moving, which would become a zone of discontinuity. Therefore, the weak zones will make water flow within. It would be easier for weathering to occur and the friction of the rock slope will be lower.

CONCLUSIONS

Based on the results in this research, it can be inferred as follows:

1. In the study area, the geological system that forms consists of fractures and faults:
   a. The position of rock bed is N110^{0}E / 6^0 and N085^{0}E / 60^0, generally.
   b. Fractures on the research area have primary stress relatively oriented towards North-South direction with Sigma 1 N026^{0}E, N002^{0}E, and N004^{0}E; Northeast - Southwest N042^{0}E.
   c. Right-lateral slip fault, left lateral slip fault, reverse fault, right-reverse fault, left-reverse fault, and right-normal fault are the faults on the study area.
2. Based on the kinematics analysis result on rock slopes with Markland Method, there are 7 slopes with potential types of slope failure are dominantly of wedges and toppling type.
3. The most at a risk zone (red zone) is located on the northern part of research area, because of the intensive structure that lying there. While the intermediate landslide potential (yellow zone) caused by the weak physical and mechanical properties from the weathered andesite and pyroclastic rocks.
4. Bedrock layer, fractures, and faults are having essential role that can influenced the rock and soil slope stability. Therefore, the slopes on fracture and fault zone will be more potential for landslides.

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