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Your manuscript entitled: **"Potential Hazard Analysis And Mechanism Of Landslide And Debris Flow In Semaka, Tanggamus "** has been peer-reviewed and accepted, Congratulations! Please be advised that your manuscript is recommended for publication in **(International Conference Proceedings (AIP) - Indexed Scopus)**. For further information, please visit our official website at https://ulicoste.unila.ac.id/.

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Potential hazard analysis and mechanism of landslide and debris flow in Semaka, Tanggamus

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Abstract. According to the Tanggamus Regional Disaster Management Agency, debris flow and landslides floods occurred three times throughout 2020 in Semaka, namely on January 10, August 5, and September 30, 2020. This landslide and debris flow destroy 483 houses and at least 300 hectares of farm fields. The phenomenon of debris flow was a recurring event because the efforts to reduce disaster risk have not been optimal. This study aims to provide data/information on field surveys, hydrological analysis, geotechnical investigation, and mitigation techniques to reduce the disaster risk. This research begins with a preliminary investigation, field survey, and data collection. The study aims to analyze and estimate the impact of landslide and debris flow risk. This study was conducted to determine the mechanism and causes of debris flow, landslides that preceded, and the potential hazard of debris flow and landslides in the future. Based on the study result and analysis, landslides that occur along the flow path are controlled by the geological conditions of the soil and rock layer. The soil layer consists of montmorillonite clay on the bedrock in the form of breccia andesite that is very susceptible to move when triggered by water. This Lanslide moves down the slope towards the river and transforms into a debris flow that carries landslide material in the form of soil, boulder, trees, and water. In addition, landslides can also block the flow path and become natural dams that at any time transform into fast floods. The potential landslides that can transform into debris flows or flash floods require structural mitigation efforts on unstable slopes.

Keywords: disaster risk reduction, landslide, Tanggamus, back analysis, hazard

INTRODUCTION

High rainfall is a significant factor that triggers landslides, debris flow, and flash floods. This kind of rainfall usually occurs in the wettest month of the rainy season in Indonesia, which can be observed from its high intensity or the prolonged duration which the influenced coming from the northwest-southeast monsoon pattern [1]. The National Disaster Mitigation Agency (BNPB) recorded 2,925 natural disasters that occurred in 2020. Hydrometeorological disasters, such as floods, flash floods, landslides, and *putting beliung* are the most frequent disaster event. Such amount disaster killed 370 people and hurt 536 people [2].

Consecutive and heavy rainfall not only triggers landslides directly but also induces the opening cracks on unstable slopes. It results in the slope lithology with a highly weathered and porous material, so that the active pressure increases and soil cohesion decreases. Furthermore, these unstable slopes become more vulnerable, and landslides can recur at any time when the next rainy season comes [3]. If it occurs on a deep slope, the groundwater level rises to the slip surface, then the soil particles will be damaged, the soil particles will be scattered and enter the groundwater layer. Thus, the soil mass is no longer bound as a soil structure but instead rides on a layer of liquid soil mass (liquefaction layer). This liquid-mixture soil layer flows as a debris flow with zero velocity at the bottom and maximum at the top [4].

This study was conducted to determine the mechanism and causes of debris flow, landslide events that preceded, and potential landslides, debris, and fast food. The study area is located in Sedayu and Waykerap Village, Semaka District, Tanggamus Regency. This study is also a follow-up to previous research on landslides in Way Kerap which was published in Syah et al., (2020).

STUDY SITE

This paper presents the result of site investigation at Pekon Sedayu and Pekon Waykerap, Tanggamus Regency, Lampung Province (Figure 1). The Landslides is located in the bottleneck and close to the alluvial fan. This landslide has 55 m to 90 m of height and is located at coordinates 5°30' of south latitude and 104°28' of east longitude. The landslide material hit residents' housing and the road to Bengkulu. A potential landslide can be observed near the river.

The study area is contained in the Geological Map of Kota Agung sheet. The rock formations are Alluvium (Qa), Young Quaternary Volcanic Rocks (Qhv), Semung Formation (QTse), Bal Formation (Tmba), Seblat Formation (Toms), Hulusimpang Formation (Toms), Instrusiver rocks (Tm) [5]. There are two types of rock at the landslide location, namely andesite, and breccia. Breccia is found as landslide material with other igneous rocks. Andesite rocks are the original rocks that make up the geology of this area. Based on the analysis of the volcanism of the Hulusimpang Formation (Tmoh), these two rocks can be estimated in the Late Oligocene to Early Miocene. Lithology consists of two types, namely andesite and volcanic breccia with a high level of weathering which forms a thick layer of soil [6]. Therefore, the potential landslides in this area are high.

In this study, potential landslides were identified as a source area. Affected areas of the landslide were estimated based on incident data on January 10, August 5, and September 30, 2020. Based on field investigation results, potential landslides have been found on the slopes along with the river flow. Landslide materials move to the river and transform into flash floods or debris flows (Figure 1). Based on testimonies from residents living in the affected area, the landslide followed by flooding occurred at night around 20.00 WIB, preceded by heavy rain from the afternoon. In the past, flash floods also took place in the same flow path and affected areas.

FIGURE 1. Study site at Pekon Sedayu, Semaka Distric, Tanggamus Regency, Lampung

FIGURE 2. Landslide and fastflood in Sedayu, Semaka Distric, Tanggamus Regency, Lampung

METHODOLOGY

Field surveys and investigations were carried out at landslide locations and areas affected by landslides and flash floods. The landslide material in the source area and the deposition area had been cleaned. Geological and geotechnical surveys were carried out to determine the lithological conditions of the landslide area, slope geometry survey, and soil sampling and laboratory analysis. UAV mapping with DJI Phantom 4 PRO was carried out to generate a Digital Surface Model (DSM) for post-landslide topography and aerial photo of landslide and flash flood areas. In addition, satellite images are also used to obtain an overview of the slope conditions in the past. The results of geological investigations and field surveys were analyzed using GIS to identify other areas that have potential landslides, debris flow, and fast floods. Laboratory tests were conducted to obtain index properties including water content, specific gravity, Atterberg limits, grain size, and engineering properties including shear strength parameters from direct shear and triaxial tests.

In this study, slope stability analysis was carried out using the Morgenstern-Price limit equilibrium method. Morgenstern and Price (1965) developed an analytical method considering parameters of shear strength and pore water pressure variation in the soil. Normal force and moment acting in equilibrium on each slice of the slip plane are illustrated in Figure 2. The equilibrium of forces and moments is calculated on one block and between blocks of material. The value used as a reference for slope stability is SF (factor of safety).

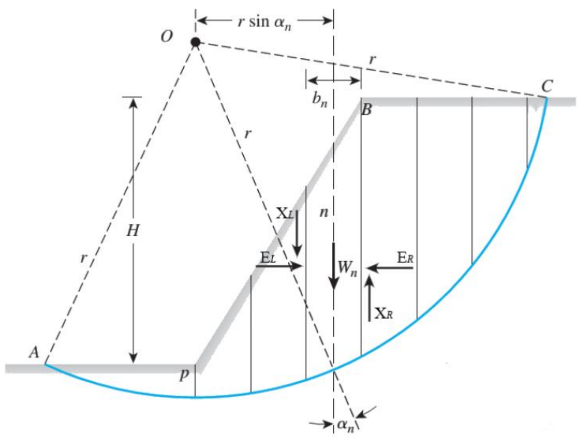


FIGURE 2. overall forces and moments acting in equilibrium state

The interslice shear forces in the general limit equilibrium (GLE) formulation are handled with an equation proposed by Morgenstern and Price (1965). The equation is [7]:

$$X = \lambda f(x) E \tag{1}$$

with $f(x)$ is a function, λ is the percentage (in decimal form) of the function used, E is the interslice normal force and X is the interslice shear force.

The GLE factor of the safety equation with respect to moment equilibrium is:

$$F_m = \frac{\sum\left[c'l + (p - ul)\tan\phi'\right]}{\sum W \sin\alpha} \tag{2}$$

The GLE factor of safety equation with respect to moment equilibrium is:

$$F_f = \frac{\sum\left[c'l + (p - ul)\tan\phi'\right]\cos\alpha}{\sum P \sin\alpha} \tag{3}$$

with c' is effective cohesion, ϕ is effective angle of friction, U is pore-water pressure, N is slice base normal force, W is slice weight, D is concentrated point load, β, R, x, f, d, ω is geometric parameters and α is inclination of slice base.

There are additional terms in these equations, but their definition is not required here for this discussion. The complete equations are presented in the theory chapter. One of the key variables in both equations is N, the normal at the base of each slice. This equation is obtained by the summation of vertical forces. Vertical force equilibrium is consequently satisfied. In equation form, the base normal is defined as:

$$P = \frac{\left[W_a - (X_R - X_L\right] - \frac{1}{SF}\left(c' l \sin\alpha - ul\right)}{\cos\alpha(l + \tan\alpha \frac{\tan\phi'}{SF})} \tag{4}$$

F is F_m when N is substituted into the moment factor of safety equation and F is F_f when N is substituted into the force factor of safety equation. The literature on slope stability analysis often refers to the denominator as m_α.

A back analysis is carried out on the landslide slope. Slope modeling is used to analyze the slope during a landslide (critical condition). A back analysis is used to determine the shear strength parameters at critical conditions [8]. The landslide mechanism is described based on data and analysis results on slope failure. Slip surface was obtained based on topography and the results of the analysis of morphological conditions.

Landslide movements that move to river flow paths can transform into flash floods or debris flows. Landslides can also block the flow path and become a natural dam. This natural dam has a very high destructive in the event of a collapse. Hydrological and hydraulic analysis was performed using HEC-RAS. The watershed boundary is determined using the WMS Version 10.1 software with topographic data as input. A hydraulic analysis is applied to determine the flood discharge, as well as to determine the depth of the flood at a certain return period.

In this study, the return period is determined by frequency analysis to determine the type of distribution that represents the maximum daily rainfall distribution in the watershed. Frequency analysis was performed using the formula according to Ven Te Chow, et al (1988) [9]. Rainfall is determined periodically using Gumbel's method with the following equation:

$$\mathrm{X_T} = \mathrm{m} + \mathrm{K_T} \times \mathrm{s} \tag{5}$$

with X_T is return period $_T$, K_T is Frequency Factor, m is mean, and s is Standard deviation of the Sample Size.

Flood discharge is determined by several steps, namely determining the time of concentration. The time of concentration is the time required for runoff to travel from the hydraulically most distant point in the watershed to the outlet. The time of concentration can be calculated if the length of the river and the average slope of the river bed are known. In this study, Kirpich's equation can be used to calculate the concentration-time, namely:

$$t_c = 0{,}0195 \times \left(\frac{L}{S^{0{,}5}}\right)^{0{,}77} \tag{6}$$

with, t_c is time of concentration (minute), L is the channel flow length (meter), S is the dimensionless main-channel slope.

Lag time is needed for flood hydrograph calculations, and the time of concentration is needed to calculate peak flows by the rational method. According to The Natural Resources Conservation Service (NRCS) in an average natural watershed with an approximately uniform distribution of runoff, lag time and time of concentration are related by:

$$t_p = 0{,}6 \times t_c \tag{7}$$

with, t_p is lag time [10]

RESULT AND DISCUSSION

Morphology before the landslide was obtained from Google Earth satellite data and DEMNAS imagery data with a resolution size of 8 m. land use in the area around landslides and floods did not change significantly. In November 2014, the upstream of the river was still dense vegetation. The flow path was visible, and no landslides or erosion along the river bank (Figure 4). In August 2016, the slope of the right side of the river channel was exposed for 100 m. The landslide material moves to the river channel. In February 2019, the landslide occurred on the left side of the river bank and seemed to be getting bigger in August 2020. The landslide material moves to the river and can transform into a debris flow or flash floods.

The landslide located at an elevation of 55 m to 90 m while the river flow is at an elevation of 50 to 450 m. Morphology after erosion is derived from UAV data with resolution size of 1 m. DEMNAS and DEM data from the UAV were combined to obtain an overview of the landslide area, river channel and affected area (Figure 5).

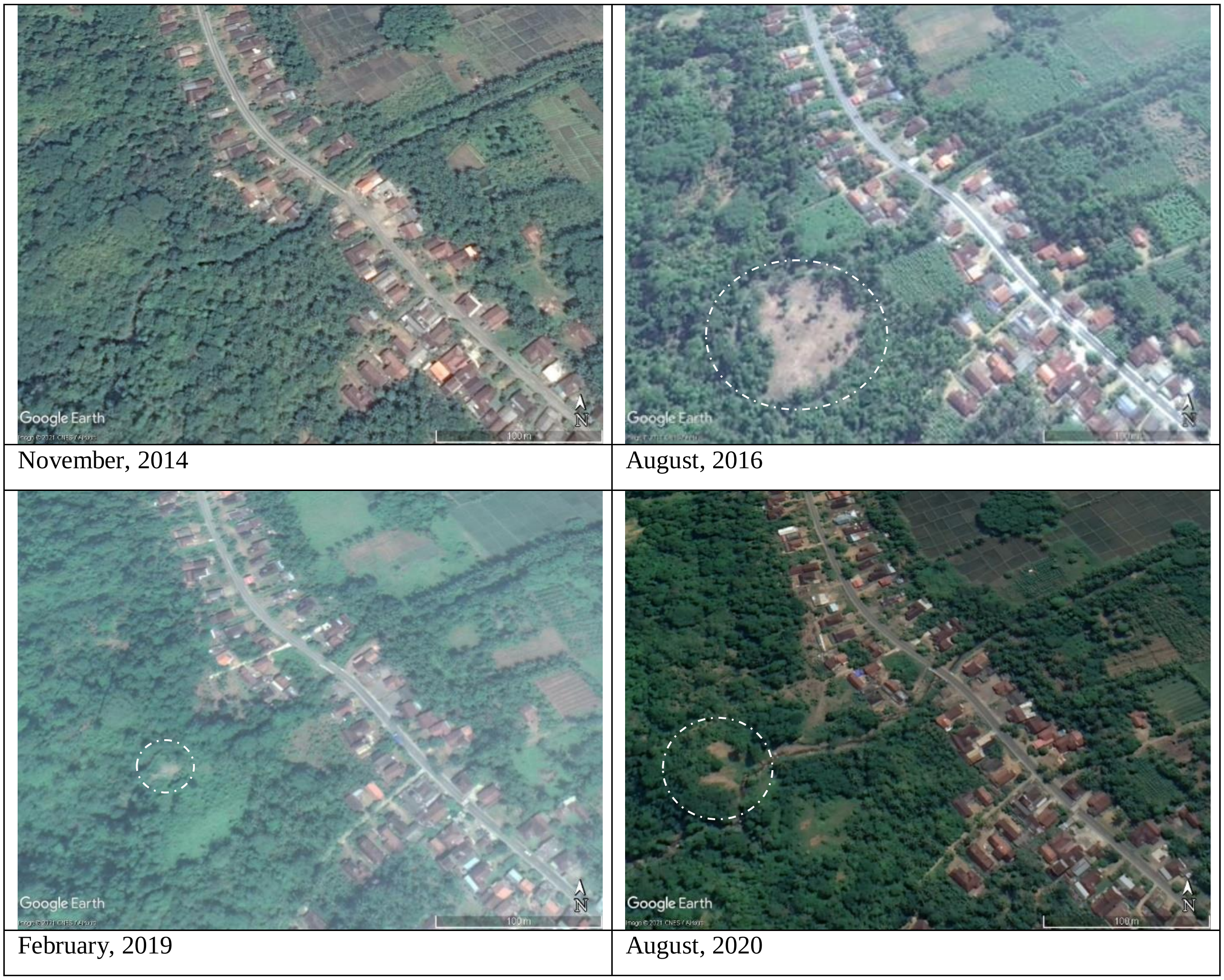


FIGURE 4. Geomorphology before and after lansdlide

Geological and geotechnical condition

In this research area, there are two types of rock, namely andesite, and breccia. Breccia is found as avalanche material mixed with other igneous rocks. Andesite rocks are the original rocks that make up the geology of this area. Based on the geological structure, this area is traversed by faults and lineaments so that it has potential landslides. The geological structure of the study area is characterized by lineament patterns resulting from morphological formations controlled by endogenic activity. Lithology in the form of andesite and landslide material in the form of volcanic breccia with a high level of weathering produced a thick layer of soil. The soil layer consists of montmorillonite clay which is on top of bedrock in the form of andesite which is very susceptible to causing soil movement when triggered by water.

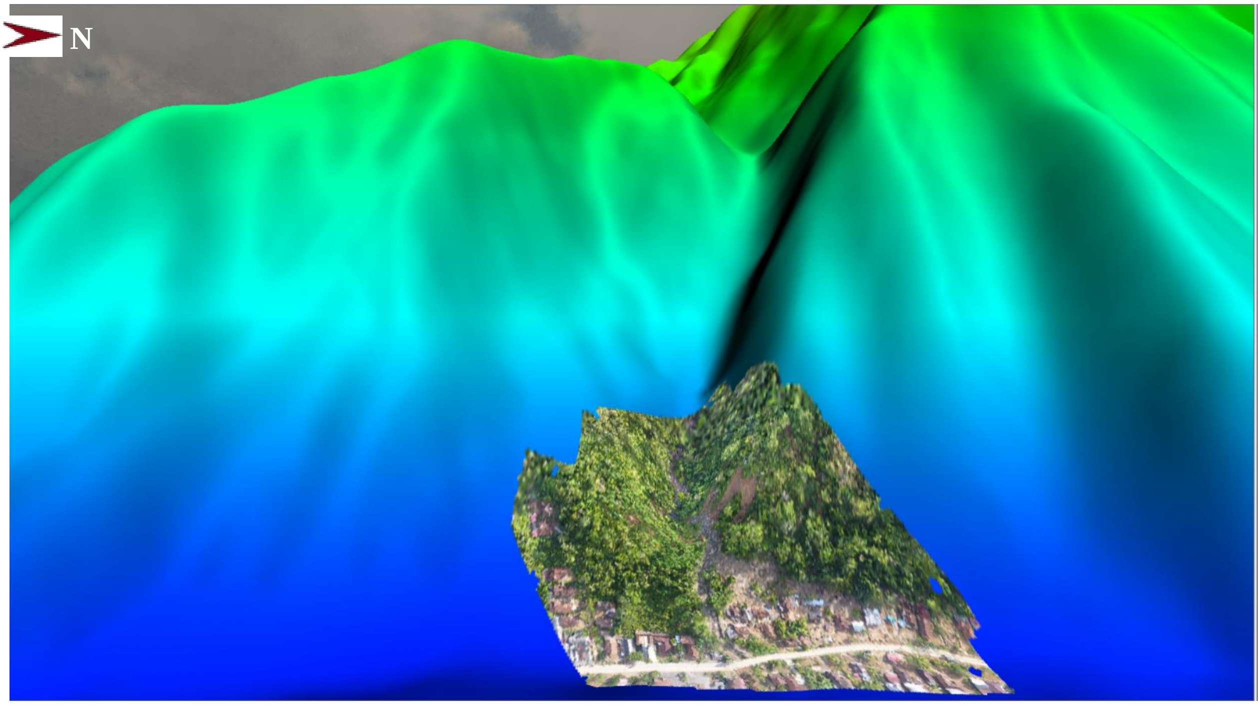


FIGURE 5. Combination of DEMNAS and UAV imaginary data

Based on field investigation and laboratory analysis, the study area consists of 2 geotechnical units, i.e., silty sand, sand-silt mixture (SM), and Inorganic clays (low to medium plasticity); gravelly clays; sandy clays; silty clays; lean clays (CL). Silty sand and sandy clay have engineering properties such as water content around 27.53–38.96%, the specific gravity of 2.49–2.67, liquid limit around 32.71– 47.88, liquid limit of 45.37–54.95, plasticity index around 9.15–19.03, unit weight around 16.66–19.12 kN/m3, cohesion around 9.4–23.6 kPa and internal friction angle of 11.0°-30.7°.

Slope model

Landslide geometry is constructed based on a comparison of morphology pre-landslide with post-landslide and geotechnical properties of landslide. The upper layer is composed of sandy clay, and the lower layer is composed of andesite breccia. In this study, two slopes are modeled and analyzed using the limit equilibrium method. The two slopes are on the left and right sides of the river bank and are shown in the yellow line (Figure 6). The slopes are at an altitude of 55 to 90 m.

In this study, the slip surface is assumed to be a complex type. The slip surface is non-circular and a combination of rotational and translational. The top layer is sandy clay soil while the bottom layer is andesite breccia. The actual landslide slip surface was obtained from the UAV data after the landslide and was used as the initial condition of the slope geometry.

Back Analysis

A back analysis is carried out to analyzed the condition of the slope at the time of collapse (critical). The results of morphological, geological, and topographical surveys before and after landslides are simulated to create a slope model as the actual conditions in the field. Shear strength parameters were obtained from the modeling results using the limit equilibrium method. In Mohr Coulomb's failure, the shear strength parameters that determine slope stability are internal friction (ϕ) and cohesion (c). In addition, groundwater levels and seismic loads are also considered in the analysis.

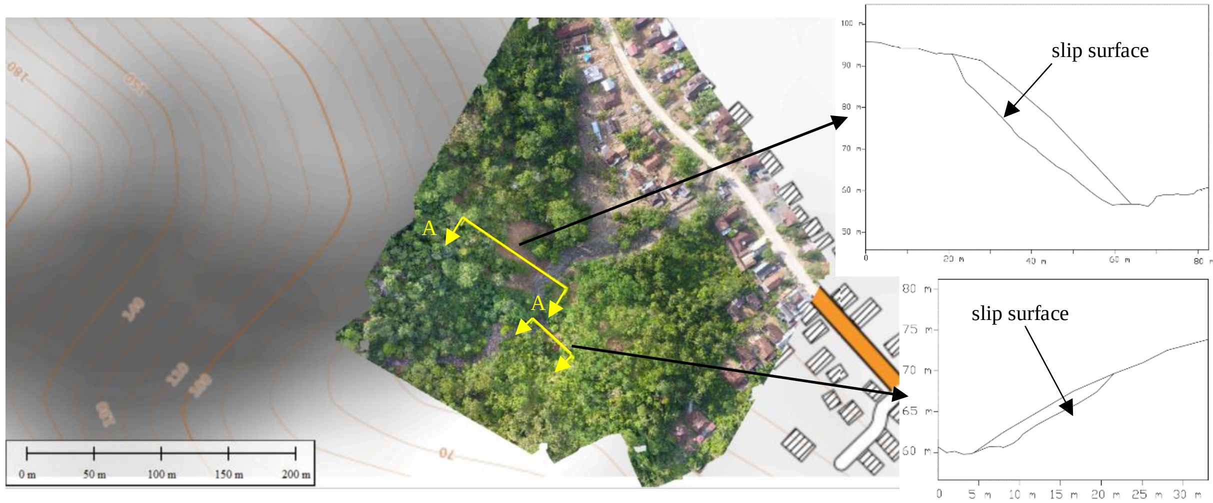
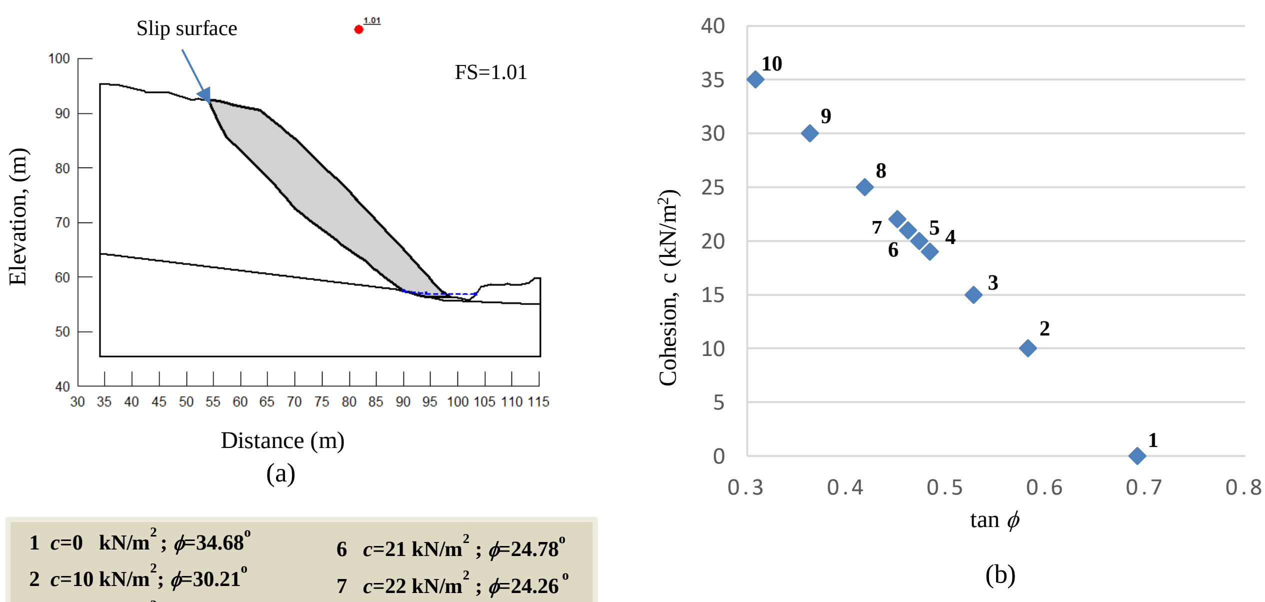


FIGURE 6. The cross section of Sedayu landslide

In the initial model, the slope is modeled with the groundwater level approaching the river water level, which is about 1 m. Cohesion and internal friction angle were analyzed by trial and error with the closest condition to the actual condition during it collapsed. The shear strength parameters from the triaxial test and direct shear test can be used as a reference to conduct trial and error on the cohesion and internal friction angle.

The result of slope stability analysis using the limit equilibrium method in the actual condition during collapse is shown in Figure 7a. Slip surface is simulated similar to that occurs in the field based on the field surveys and mapping. The values of c and ϕ were tried to result from the same slope model with field conditions. The relationship between the values of c and tan ϕ is linear as shown in Figure 7b. The value of the internal friction (ϕ) and cohesion (c) which results in the value of FS=1 is number 5 in Figure 7c. The results of the analysis show that the value of the soil shear strength parameter for the slope is c=20 kN/m^2; ϕ=24.78°. The soil shear strength parameter as a result of the back analysis is still in the range of laboratory test results.



1 c=0 kN/m^2; ϕ=34.68°	6 c=21 kN/m^2 ; ϕ=24.78°
2 c=10 kN/m^2; ϕ=30.21°	7 c=22 kN/m^2 ; ϕ=24.26°
3 c=15 kN/m^2 ; ϕ=27.81°	8 c=22 kN/m^2 ; ϕ=22.68°
4 c=19 kN/m^2 ; ϕ=25.81°	9 c=25 kN/m^2 ; ϕ=19.96°
$\boxed{5\ c=20\ \text{kN/m}^2 ;\ \phi=25.30^\circ}$	10 c=30 kN/m^2 ; ϕ= 17.13°

(c)

FIGURE 7. Back analysis with limit equilibrium method

Landslide - debris flow mechanism and potential hazard

The shear strength parameter from the back analysis is used to analyze the slope stability of the area around the landslide. Slope stability analysis was conducted to determine the potential for slope failure along with the river flow. The effects of groundwater level rise and seismic loads on the slopes were also analyzed with the limit equilibrium method.

The result of modeling on the actual condition shows that the value of SF without any increase in groundwater level is 1.1. It means that the slope has not yet collapsed, even though it is in a critical condition. If there is an increase in seismic load, for example, an earthquake the slope becomes unstable with a safety factor value of 0.9 (Figure 8a). High intensity or long-duration rainfall can cause groundwater level rise. High intensity or prolonged rainfall can cause groundwater levels to rise and slopes to become unstable or collapse. SF decreased from 1.1 to 1.0 and 0.9 due to the increase in groundwater level as shown in Figure 8b.

Landslide materials move to the river and can transform into flash floods or debris flows. With a channel width that is not too large, landslide material can block the flow path. This event resulted in the occurrence of a natural dam, if it collapses it can transform into a flash flood. Landslides and floods that occurred in the past caused the Kota Agung-Bengkulu road's broken and inundate residents' houses as high as 1-1.5 m. Therefore, structural mitigation in the form of slope protection, reinforcement and drainage improvement on unstable slopes needs to be done to reduce the risk of disasters caused

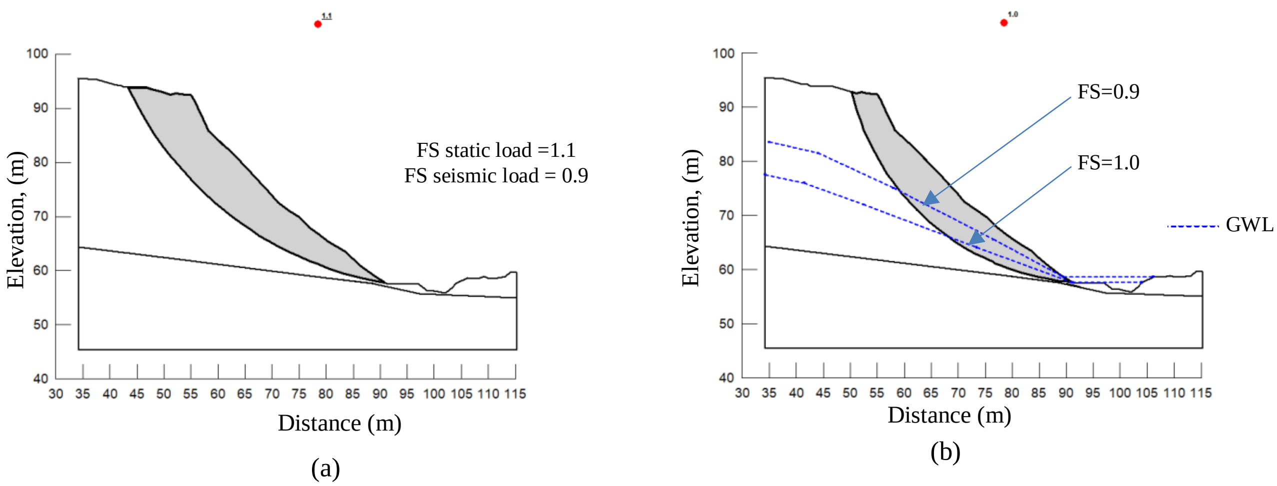


FIGURE 8. earthquake or groundwater induced slope failure

The watershed boundary is determined based on watershed analysis with topographic data as input. The watershed boundary is shown in Figure 9. Rainfall data required for analysis is in the form of daily rainfall data for a minimum of 10 years. The existing rain station is located far outside the watershed boundary, so the rainfall data is collected from the satellite.

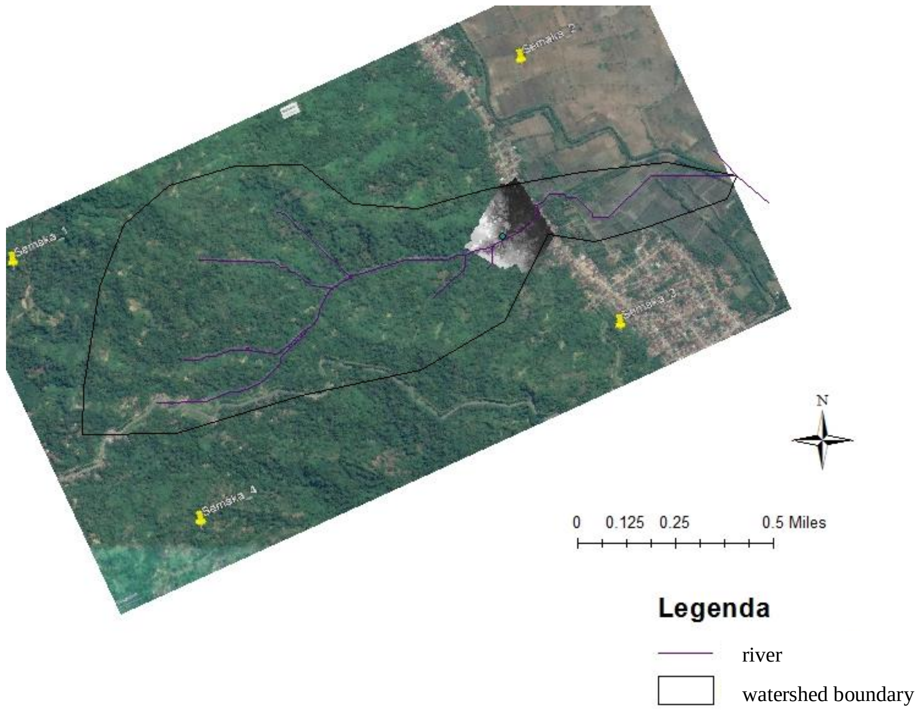


FIGURE 9. Catchment area

The hourly rainfall is determined for the planned rainfall return period every few hours. In this study, the hourly rainfall was determined for 5 hours. Based on the analysis, the design rainfall is shown in the following table.

TABLE 1. hourly rainfall distribution

time	ratio	hourly rainfall (mm)			
		2	5	10	25
1	0.58	8.146676	18.490	27.2583	35.579
2	0.16	2.247359	5.100	7.5195	9.814
3	0.10	1.404599	3.188	4.699	6.134
4	0.08	1.123679	2.550	3.759	4.907
5	0.08	1.123679	2.550	3.759	4.907

Based on design rainfall, the planned discharge is determined by several steps, determining the time of concentration. Based on the formula Eq.7 to Eq.8 the amount of the planned discharge can be determined. The discharge plan for the return period is shown in the following table.

TABLE 2. Design discharge for the return period

return period (year)	rainfall (mm)	discharge m^3/s
2	93.64	2.5
5	106.27	4.8
10	114.63	6.8
25	125.19	8.7

With a river width that reaches 6 to 10 m, the flood discharge for a certain return period is still too small compared to the events that occurred. In August 2020, the depth of flooding and debris in residential areas reached 1-1.5 m and passed through highways that had an elevation of more than 4 m from the riverbed. Thus, it is clear that the disaster that hit the study area was not only a flood due to rainfall but also a landslide that occurred on the river bank. The landslide movement moves to the river and transforms into a debris flow. Landslide material, boulder, trees, and water moves to the deposition area as a debris flow. In addition, landslides can also block the flow path and become natural dams which can transform into fast floods.

Besides structural mitigation, disaster risk reduction efforts can also be carried out non-structurally. Early Warning Systems and Continuous Monitoring, Community-based Coordination for Rapid Response are also effective to reduce potential losses caused by disasters.

CONCLUSION

The soil layer consists of montmorillonite clay on top of bedrock in the form of andesite. Based on field investigation results, the geological condition of the area consists of an andesitic breccia unit and volcanic breccia with a high level of weathering to form a thick layer of soil. Based on laboratory analysis, the study area consists of two geotechnical units, i.e., silty sand, sand-silt mixture (SM), and Inorganic clays (low to medium plasticity); gravelly clays; sandy clays; silty clays; lean clays (CL). The cohesion of this soil is around 9.4–23.6 kPa and internal friction angle of 11.0°-30.7°. CL is interpreted as a result of weathering of andesitic breccia and tuffaceous sandstones which have moderate to high plasticity. Andesitic breccia units have very high shear strength.

Landslides occur of the condition of the soil layer consists of montmorillonite clay which is on top of a bad rock in the form of andesite which is very susceptible to causing soil movement when triggered by water. The slip surface is non-circular and a combination of rotational and translational. The result of the back analysis shows that soil cohesion is c=20 kN/m2 and internal friction =24.78°. The potential landslides are still high if triggered by rising groundwater or earthquakes. The landslide moves down the slope towards the river and transforms into debris flow that carries landslide material in the form of soil, boulder, rock, trees, and water. In addition, landslides can also block the rivers and become natural dams. landslides can also block the flow path and become natural dams that at any time transform into fast floods. Structural mitigation efforts on unstable slopes need to be applied by slope protection, reinforcement, and drainage improvement on unstable slopes. Besides structural mitigation, disaster risk reduction efforts can also be carried out non-structurally. Early Warning Systems and Continuous Monitoring, Community-based Coordination for Rapid Response are also effective to reduce potential losses caused by disasters.

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