

Safety factor analysis of landslides hazard

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3 Safety factor analysis of landslides hazard as a result of rain condition infiltration on Buyan-Beratan Ancient Mountain

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Abstract. Disaster of soil movement from NDMA (National Disaster Management Authority) of Indonesia mention from 2003-2017 shows the increasing. Investigation of potential ground motion based on sampling data of boring test on slopes along the Denpasar-Singaraja road around Gitgit Village which provides the greatest threat to settlements and public facilities. This research is expected to show the influence of rainfall on slope stability. This research is expected to show the influence of rainfall on slope stability. Furthermore, safety factor analysis based on daily rainfall data and numerical analysis was assisted by SLOPE/W and SEEP/W software tools. The analysis was carried out using a normal, heavy, and very heavy rain model. Safety factor declined after the 3rd day of rain after that the safety factor dropped to the 6th day with a safety factor 1.141 indicating the condition to be critical. The result shows the effect of rainfall decreasing safety factor after the second day of rain and the fourth day of safety factor shows a value of 1.003 where the slope is in a critical condition leading to failure, these results can be used to make early warning system of landslide hazard.

1. Introduction

The principle of an early warning system is to provide information quickly, accurately, on target, easily accepted and understood, reliable and sustainable. An early warning system is carried out considering that structural mitigation efforts require considerable costs, so early warning systems need to be implemented to improve community preparedness in the face of disasters. The concept of a community-centred early warning system will be used by people who are vulnerable to landslides, and by government agencies and non-governmental organisations at the central, provincial, village/city, sub-district and village levels [1,2].

The relationship between rainfall intensity and duration triggers soil movement, analysis using the Pradel and Raad method which is based on the Green-Ampt infiltration model is to determine the character of rainfall triggering soil movement is needed in the development of soil movement disaster mitigation systems [3]. The intensity of moderate to high rainfall and lasts longer will increase the saturation of the soil layer on the slope so that it plays a role in triggering the movement of mass of soil and/or rocks. Continuous rain for five days with an intensity of 90 mm/day or more can increase the frequency of landslides [4]. Previous research about slope stability mention the failure of slope occurred a day after the extreme rain that occurred for 4 days around the Kintamani District in February. The high



level of damage that occurs needs to be carried out by engineering analysis to find out the cause of the collapse through observation and observation in the field and the data from related department [5].

The area of Buleleng Regency is 136.588 hectare, 31.56% is at an altitude between 100 – 499 meter above mean sea level, the area which has a height between 500 – 499 meter above mean sea level is around 26.36%, and the rest is lowland land (0 - 25m). Variety of slope levels; flat land 8.98%, sloping land 51.41%, the rest is steep land which is around 23.9%. Such topographical conditions indicate that the Buleleng Regency area is mostly a hilly area. These hills stretch in the southern part of Buleleng Regency where there are seven volcanoes. The highest mountain is Mount Lesong while the lowest is Gunung Prapat Agung. The northern part of Buleleng Regency, along the coast, is a very fertile area, traversed by 56 rivers although some of them only flow during the rainy season.

Based on previous research, the research is a back analysis case of the effect of infiltration on the threat of soil movement in Sukasada District in Gitgit Village (1427 hectare). The selection of the village, based on the Bali Province NDMA report and the Buleleng Regency NDMA, is included as a routine area and most often experiences landslides in the rainy season and rural roads that connect Denpasar-Singaraja crosses the village. The dominant rainfall analysis is based on hourly rainfall and numerical analysis with the help of Seep/W and Slope/W software. The results of this study can provide information as an effort to mitigate the natural disasters of soil movement in the prevention and prevention of disasters to be used as guidelines for the government and the community in structuring their territories.

2. Landslide hazard assessment

The weighting method for triggering the parameters of soil movement should be modified according to the characteristics of the study area and numerical analysis beginning with observations and geotechnical investigations. The modification of each parameter is strongly influenced by the experience of the individual analysing so that it can be stated that the weighting method is subjective and requires numerical analysis [6]. Infiltration of water into the slope if it occurs continuously with a period and a sufficient amount will cause the groundmass to be pushed and trigger a landslide. The mechanism of rain in triggering the occurrence of soil movement through four stages, namely; 1). Heavy rain occurs; 2) Rainwater infiltration process and 3) Increased groundwater level in the slope which will automatically increase the pore water pressure in the soil, resulting in a reduction in the strength of soil shear on the slope; 4) The process of movement of soil mass in slopes [7,8].

The concept of plastic boundary balance on slope stability analysis using the principle of equilibrium force, the equilibrium conditions of the force are as follows: (1) the balance of the force of vertical direction or perpendicular to the plane of slip; (2) the balance of the horizontal or parallel direction force of the landslide field; (3) balance of moment forces. The assumption of the plastic equilibrium limit method is as follows; (1) landslides occur along specific landslide fields which can be considered as two-dimensional field problems; (2) landslide masses are considered as massive fields; (3) shear strength is considered isotropic where the safety factor with respect to shear stress and average shear strength [9,10].

The limit equilibrium method has limitations in manually iterating, and software assistance is needed, one of which is slope stability analysis software using GEO-STUDIO. This software has SLOPE/W for safety factor analysis and SEEP/W for analysis of the effect of water infiltration on slope stability, at SLOPE/W there are several balance boundary methods, including those used in this study are Bishop, Ordinary, Janbu and Morgenstern-Price methods [1,4].

Infiltration analysis in SEEP/W uses the principle of soil capacity in storing water through a volumetric water content function with matric suction [11]. Another function included in the relationship between changes in permeability and matric suction. This function is related to the ability of the soil to pass through water and the soil suction stress to water. In addition to the two functions above, the input data entered in SEEP/W is the amount of rainfall intensity in the time function.

The equation for the flow of water in the soil used in SEEP/W software for a complete analysis of two-dimensional transients and seepage can be shown in Equation 1.

$$m_w^2 \gamma_w \frac{\partial h_w}{\partial t} = \frac{\partial}{\partial x} \left(-k_{wx} \frac{\partial h_w}{\partial x} \right) + \frac{\partial}{\partial y} \left(-k_{wy} \frac{\partial h_w}{\partial y} \right) + q \quad (1)$$

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Where m_w^2 = slope soil-water relationship characteristic curves; γ_w = unit weight of water; h_w = total head; k_{wx} = soil permeability coefficient of water in the x-direction; k_{wy} = soil permeability coefficient of water in the y-direction; q = flux boundary; t = time.

Two essential 17 parameters used in the SEEP/W analysis are functions of soil permeability coefficients and Soil Water Characteristic Curve (SWCC). The equation of shear strength for unsaturated soil used in slope stability analysis, SLOPE/W, is shown as Equation 2. This equation generally combines soil shear strength as a result of negative pore water pressure and unsaturated soil suction. To obtain the safety factor (SF) in the SLOPE/W analysis using the Morgenstern-Price method.

$$\tau = c' + (\sigma_n - u_w) \tan \phi' + (u_a - u_w) \tan \phi^b \quad (2)$$

Where τ = unsaturated soil shear strength; c' = cohesion; σ_n = total normal stress; u_a = pore air pressure; ϕ = internal friction angle; u_w = pore-water pressure; $(u_a - u_w)$ = matrix suction.

3. Method

The research was carried out in the case of the effect of infiltration on the threat of soil movement carried out in Gitgit Village (1427 hectare), especially along the Denpasar-Singaraja rural road. The selection of the village, based on the NDMA (National Disaster Management Authority) of Bali Province and the NDMA of Buleleng Regency, the area or region is included as a routine area and most often experiences landslides in the rainy season.

Sampling with the location of Figure 1 is done by hand drill at an average depth of 1.0-3.5 meter to hard ground. Some slope outcrops were also observed to determine the shape and type of soil. Figure 2 shows the slope section to analyse slope stability. Figure 3 shows soil layer of section 1-1.

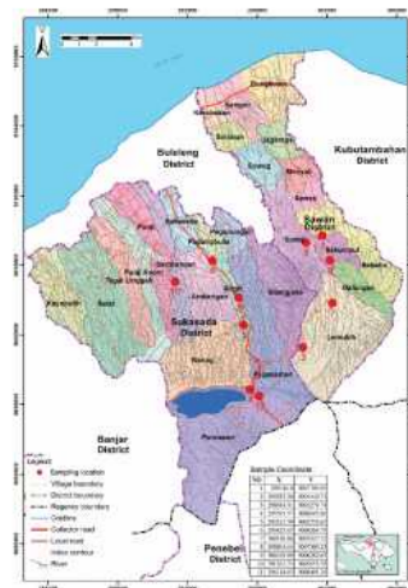


Figure 1. Sampling location.

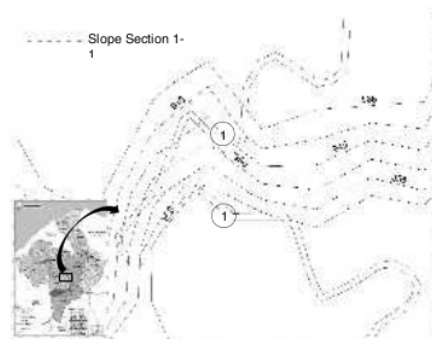


Figure 2. Contour of research location.

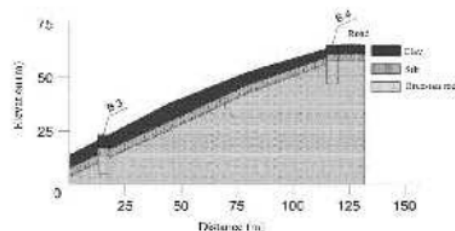


Figure 3. Location for taking the sample.

Based on the three-point sampling data, it can be seen that the soil properties in the study location included organic silt with low plasticity and fine sand, with a dry soil volume weight (γ_d) = 1.17 gr/cm³, Specific Gravity = 2.63, Soil Permeability = 2.15×10^{-6} m/sec, soil cohesion value (c) = 3.21 kPa and friction angle in the soil [16] = 34.56°.

The geomorphology of the study area is a hilly area with an altitude between 404–1455 meters above sea level. The study area has a relatively tight and rather steep contour pattern, and such topographic conditions indicate that the area is mostly a hilly area.

The design rain in this study used the Alternating Block Method (ABM) method to obtain an hourly rain distribution because the available data is daily rainfall data. Furthermore, the hourly rain distribution will be included in numerical analysis. Numerical analysis was assisted by SLOPE/W and SEEP/W software tools, and the analysis was carried out with a normal, heavy, and very heavy rain model. The value of soil shear strength parameters based on suction values based on calculation predictions with the equations Ho and Fredlund [12].

4. Results and discussion

Numerical analysis is done in Gitgit Village on contour pieces at point 8°12'34.48" South Latitude, 115°8'39.05" West Longitude as in Figure 2, the slope analysed is the slope of the A-B slice. Soil parameters as in Table 1 with layers of organic clay, sandy silt, and bedrock in the form of volcanic breccia. Laboratory parameters of Breccia were not tested laboratory, parameter values based on empirical approach with internal friction angle value $\phi = 45^\circ$, cohesion (c) = 0.17 kg/cm², wet volume weight (γ_b) = 1.94 kg/cm³. The slope height is ± 100 meter with a horizontal distance of ± 125 m. Numerical analysis is carried out to analyse A-B section because it has the potential to endanger the structure of the road above the slope.

Input model in SLOPE/W and SEEP/W software with 2-dimensional analysis such as Figure 3 and material data as in Table 1.

Table 1. Material input.

Parameter	Material	
	Organic Clay	Sandy Silt
γ_b (kg/cm ³)	1.85	1.76
ϕ (°)	31.77	32.68
c (kg/cm ²)	0.25	0.22
Diameter Pass 10 (mm)	0.006	0.0075
Diameter Pass 60 (mm)	0.04	0.15
Liquid limit (%)	50.48	47.21
Permeability (m/sec)	1.3×10^{-5}	1.4×10^{-5}
Specific gravity	2.63	2.57
Water Content (%)	31.13	34.00

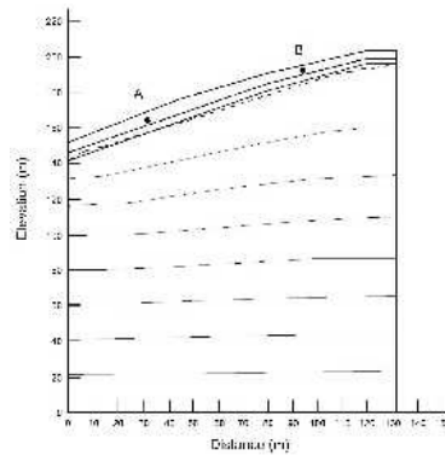


Figure 4. Saturation observation point at SEEP/W.

Numerical analysis using SEEP/W, rain behaviour is modelled on the slope. Modelling on normal rainfall, heavy rain and very heavy rain shows changes in water level rise and soil saturation. In this modelling 2 points A and B were taken as shown in Figure 4 to observe the increase in saturation that occurred on the slope reviewed. Based on the duration of rain in Sukasada Subdistrict for normal rain = 13 days, heavy rain 6 days and very heavy rain = 5 days, while the highest rainfall intensity in each duration of rain with rain conditions is; normal rain = 49.10 mm/day, heavy rain = 87.33 mm/day and very heavy rain 155.38 mm/day [12]. SEEP/W analysis shows changes in behaviour, where there is an increase in saturation that varies depending on rainfall intensity, duration of rain and degree of initial saturation of the soil. Figure 5 shows changes in saturation in each rainfall model in general from observation points A and B.

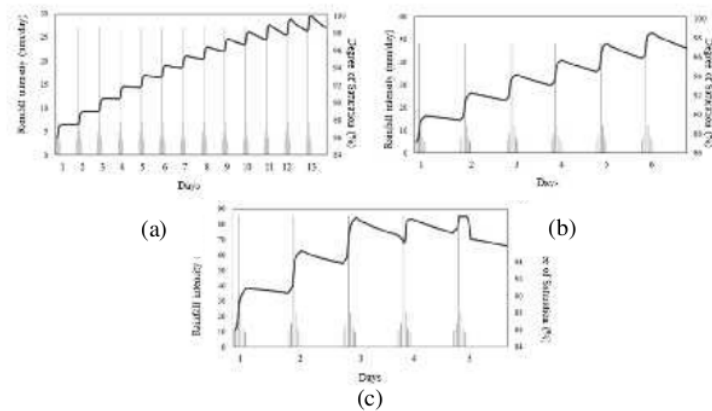


Figure 5. Degree of saturation (a) normal rain (b) heavy rain (c) very heavy rain.

Figure 6 (a) shows that safety factor declined after the 4th day of rain, after that the safety factor dropped during the rain and again increased when the rain stopped. The decrease in the safety factor occurs due to the entry of water into the soil pore which increases the water level and saturates the soil. When the rain stops the water level will drop and the soil saturation decreases, but even though the rain stops the water is still stored in the ground and cannot return to its initial condition. On the 13th day, the safety factor at section 1-1 shows 1.289 which is near critical. Figure 6 (b) shows that the safety factor decreases after the 3rd day of rain then after that the safety factor drops to the 6th day with a safety factor value of 1.141 indicating the condition to be critical. Figure 6 (c) the safety factor decreases after the second day of rain, and the fourth day the safety factor at slope section shows the value 1.003, the critical slope leading to collapse.

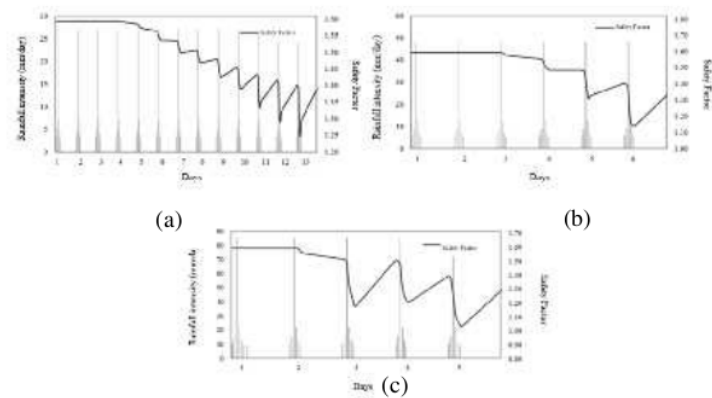


Figure 6. Degree changes in safety factor (a) normal rain (b) heavy rain (c) very heavy rain.

5. Conclusions

The high intensity of rain causes softening of slope forming material which consists mainly of weathering ¹⁵ volcanic rocks mixed with organic matter as in the study area increasing soil water content resulting in a reduction in average soil shear strength. The higher the intensity of the rain and the longer the duration of the rain, the more infiltration of water enters the slope, thereby increasing the saturation and pore pressure. Porewater pressure which is initially negative will increase to zero and then rise, so

it is positive. Changes in porewater pressure result in changes in soil shear strength parameters, namely cohesion values and internal friction angles. Changes of parameters causes a safety factor of slope decrease so that the landslides hazard gets higher. Numerical analysis shows that the threat of high-threat location classified soil movement with a safety factor value of 1.3 days with the highest rainfall intensity of 49.10 mm/day is 1.298, in heavy rain with a duration of 6 days and the highest rainfall intensity is 87.33 mm/day safety factor of 1.141, in very heavy rain with a duration of 5 days of rain with the highest rainfall intensity of 155.38 mm/day amounting to 1.003, so in this case when heavy rains lead to very thick, the hazard of movement is very high, where the slope has begun to collapse.

Safety factor declined after the 3rd day of rain after that the safety factor dropped to the 6th day with a safety factor 1.141 indicating the condition to be critical. The result show rainfall make safety factor of slope decrease after the second day of rain and the fourth day of safety factor shows a value of 1.003 where the slope is in a critical condition leading to collapse, these results can be used to make early warning system of landslide hazard.

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