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Effect of Slope on Landslide Potential at Kuranji Watershed

Andriani, Hendri Gusti Putra, Masril Syukur and Ulung Sadewo

Civil Engineering Departement, Andalas University, Padang, Indonesia

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ABSTRACT

The Kuranji watershed is one of the largest watersheds in the city of Padang. Several landslides and floods have been reported in this area. Many factors cause landslides, both natural and non-natural factors. One of the natural factors that cause landslides is the topography/slope condition. The sloping/steep topography in the downstream area of the Kuranji watershed causes a high potential for landslides in this area. Landslides occur due to balance disturbances that cause the movement of soil and rock masses from a higher place to a lower place. Therefore, it is necessary to analyze slope stability to determine the effect of slope conditions on the potential for landslides. In this study, an analysis of the potential for slopes stability was carried out using the Ordinary Method of Slices. The analysis is carried out by making different slopes so that the value of the safety factor will be obtained from each slope. The slope variation used in this study is the ratio of height to slope width of 1:5, 1:4, 1:3, 1:2, 1:1, 1:0.5, 1:0.25. The results showed that the smaller the slope and the height of the slope, the more stable the slope will be, on the contrary, the larger the slope, the more unstable the slope. This can be assessed from the value safety factor (SF) of slope stability which is obtained from the calculation, which is getting smaller as the slope and height of the slope decrease.

***Key words**: Landslide, Slope, Safety factor, Slice ordinary.*

Introduction

West Sumatra is one of the provinces in Indonesia which has a land area with a sloping and hilly topography at an altitude of 0 – 3805 meters above sea level. The ground surface does not always form a flat plane and has a different elevation between one place and another so that it forms a slope. The elevation differences in the West Sumatra region so that under certain conditions it can cause a landslide disaster. Therefore, a slope stability analysis is needed. Landslides are an event that usually occurs on natural slopes and on man-made slopes. Indonesia's natural conditions such as topography, geology, and climatology are the dominant factors causing disasters, the movement of soil masses. Soil mass movement or landslide is a disaster that often occurs in hilly areas, valleys and volcanoes (Arsjad *et al.*, 2014). Landslide is the movement of slope-forming material in the form of rock, debris or mixed material that moves down or out of the slope. The movement of the slope-forming material that moves out of the slope is due to water seeping into the soil until it penetrates the impermeable layer which acts as a slip plane, causing an increase in soil weight. Landslide events will have a direct or indirect impact on the ecological condition of an area (Keffer and Wilson, 1989).

Landslides that often occur in Indonesia are a type of soil mass movement on natural slopes (Sarma, 1973). If the moving mass is dominated by soil mass and its movement through a plane on the slope, either in the form of an inclined plane or a curve, then the movement process is referred to as a landslide (Rolo *et al.*, 2004). The occurrence of natural disasters such as landslides is mainly due to natural disturbances in the stability of the soil and or rocks that make up the slopes, both natural and non-natural. Most landslide events occur with the shape of the landslide field in the form of cylindrical. The curvature of the landslide field can be in the form of a flat plane, a circular landslide field, a non-circular landslide field and a combination landslide field (Schaefer and Duncan, 1988; Wright and Duncan, 1991). Landslides or landslides will be categorized as disasters if they occur in areas inhabited by humans or in areas where human activities are carried out (Sartohardi, 2008; Angillieri and Esper, 2012). So the aspect of human presence or the influence of human activities is very important in determining whether a landslide or landslide is considered a disaster or not.

The morphometric characteristics of the Kuranji watershed with high relief with short watershed length and steep slopes are 54.66%. High river density and steep slopes in the Kuranji watershed have an influence on surface runoff, erosion and sedimentation so that this will trigger the potential for landslides in the Kuranji watershed. Changes in land use in the Kuranji watershed are increasing due to an increase in population. As the population increases, the demand for land also increases. This was triggered by the development of the economic sector in the service sector and after the earthquake that hit Padang City in 2009 and the threat of a megathrust earthquake triggered by the tsunami.

Research Location

The Kuranji River Basin is one of the rivers that stretches in the city of Padang. The area of the watershed is ± 205.6 km^2. Figure 1 shows the research location.

The Batang Kuranji watershed consists of 5 sub-watersheds, namely Batang Sungai Sapiah, Batang Danau Limau Manih, Batang Sungkai, Batang Bukik Tindawan and Batang Padang Janiah. The Kuranji watershed flows from the upstream of Bukit Barisan with the highest elevation of ±1,605 masl at Bukit Tinjau Laut and empties into the Padang coast with a length of the main river ±32.41 km and the total length and all its tributaries is 274.75 km.

Methodology

The soil parameters used for slope stability research (SF) are field data that have been examined at the Soil Mechanics Laboratory, Faculty of Engineering, Andalas University. Table 1 shows the results of soil testing around the Kuranji watershed area.

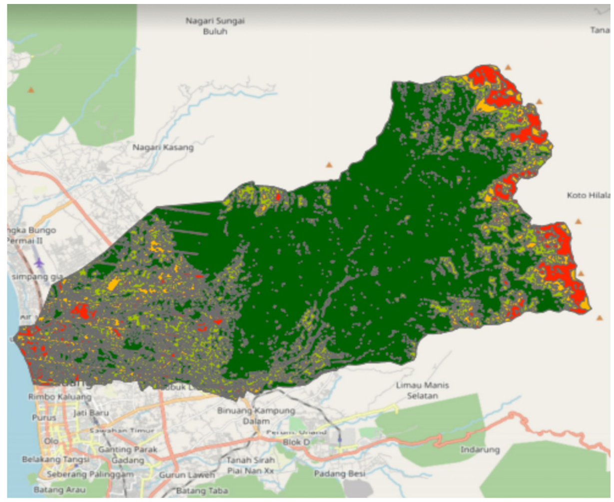

Fig. 1. Research location at Kuranji Watershed

Table 1. The Results of Testing Soil in the Laboratory.

Type of Testing	Results
Water content, W (%)	60.101
Volume Weight, ã (ton/m^3)	1.626
Specific Gravity, Gs	2.623
Atterberg Limit	
- Liquid Limit, LL (%)	106.996
- Plasticity Limit, PL (%)	61.852
- Plasticity Index, PI (%)	45.144
Unconfined Compressive Strength Test (UCST)	
- q_u undistrubed (kg/cm^2)	1.266
- q_u remoulded (kg/cm^2)	0.639
%	
- Gravel	0.433
- Sand	7.467
- Clay	92.100
Direct shear	
- Cohession, c (kg/cm^2)	0.533
- Friction angle, ϕ (^{o})	8.777

After testing the physical and mechanical properties of the soil, the slope modeling is carried out. The slope is made to vary with height and width. The slope variations used are 1:5, 1:4, 1:3, 1:2, 1:1, 1:0.5 and 1:0.25. The safety factor analysis of each variation was carried out using the ordinary slice method. Figure 2 shows one of the models used to find the safety factor of the slope. In this study, all soil parameters are the same, the only difference is the slope (tilt angle). The landslide analysis was carried out using the ordinary slice method, which is shown in Figure 2.

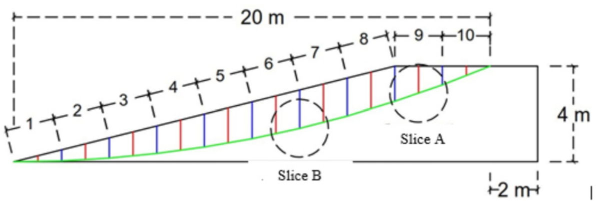

Fig. 2. Modeling of Slope according to Height Ratio.

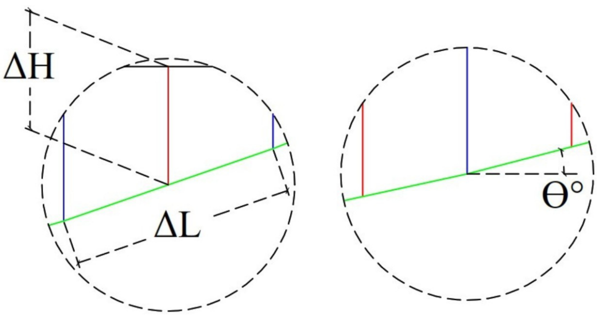

Fig. 3. Methods for obtaining values of ΔL, ΔH and Ø.

Using of the ordinary slice method with shear strength expressed in terms of effective stress, the equation used to calculate the safety factor is using formula 1.

$$FK = \frac{\sum\left[\left(W\cos\alpha - u\Delta l\cos^2\alpha\right)\phi' + c'\Delta l\right]}{\sum W\sin\alpha} \quad (1)$$

Where as :

Weight areas of landslides :

$$W = \gamma \times \Delta L \times \Delta H \quad (2)$$

Normal force :

$$N = W \times \text{Cos } \alpha \quad (3)$$

Force parallel to the plane of collapse Gaya :

$$T = W \times \text{Sin } \alpha \quad (4)$$

The area of the collapsed plane segment :

$$\Delta A = \Delta L \,/\, \text{Cos } \alpha \quad (5)$$

Resistant force on failure plane :

$$T_{max} = c \times \Delta A + N \text{ Tan } \varphi \quad (6)$$

Safety Factor :

$$SF = \Sigma T_{max} \,/\, \Sigma T \quad (7)$$

Results and Discussion

In general, the Kuranji watershed has a hilly to mountainous topography in the upstream (36.94%) and relatively flat in the downstream (32.68%). Table 2 shows the slope conditions in the Kuranji watershed. If there is a built up area in the upstream area, it will cause a high potential for landslides in the upstream part of the Kuranji watershed, therefore an analysis of the slope safety factor needs to be analyzed to prevent the occurrence of landslide hazards.

Table 2. Percentage of Slope in the Kuranji Watershed

No	Slope (%)	Topography/ Relief	Percentage (%)
1.	0 – 8	flat	32.68
2.	> 8 – 15	Rolling	2.74
3.	> 15 – 25	Hillocky	9.93
4.	> 25 – 40	Hilly	17.72
5.	> 40	Mountainous	36.94
		Total (%)	**100**

Landslides are natural phenomena that cause technical and non-technical impacts on humans. The causes of landslides on slopes mechanically can be understood using the principle of slope stability approach. With this principle will be known the forces that control the stability of a slope. The stability of the slope is determined by the driving forces of the soil or rock and the resisting forces that try to keep the soil or rock in position. The magnitude of the shear strength of soil or rock is controlled by the cohesion (c) and the internal friction angle between the particles that make up the soil or rock (φ). The amount of cohesion value depends on the strength of the bonds between the atoms or molecules that make up soil or rock particles or depends on the strength of cementation between soil or rock particles. The internal friction angle is a value that expresses the frictional strength between the particles that make up the soil or rock. The stability of a slope is the ratio between the resisting forces and the forces causing the landslide. If the one causing the landslide is greater than the one holding it back, a landslide will occur. The slope is in stable condition, if $SF > 1$; slope is in critical condition, if $SF = 1$; the slope is in an unstable condition or has landslide, if $SF < 1$. Table 1 shows the magnitude of the safety value obtained from the slope stability analysis.

Table 3 and Figure 4 show that the hilly and mountainous the slope have the smaller the value of the safety factor (SF), but if the area flat so the greater the SF value. The greater the slope, the greater the self-weight that must be held by the soil, causing the soil mass to become unstable and tend to move. The heavier the mass of the soil, the greater the driving force so that the stability of the slope will decrease due to the reduced force that holds the weight of the soil and the greater the driving force

Table 3. The Results of Slope Safety Factor Calculation.

Number of Model	Ratio of height and width of slope	Safety Factor
1	1 : 5	2.744
2	1 : 4	2.213
3	1 : 3	1.687
4	1 : 2	1.221
5	1 : 1	0.846
6	1 : 0,5	0.719
7	1 : 0.25	0.708

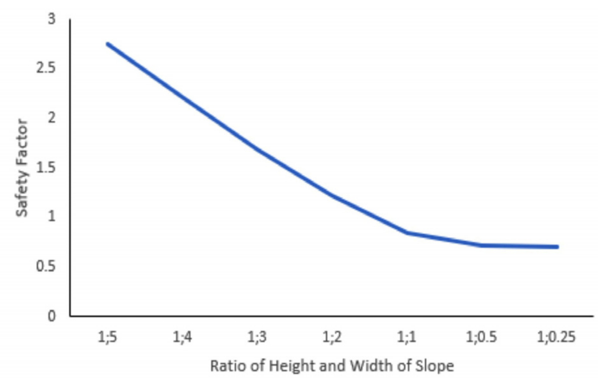

Fig. 4. The Results of Safety Factor at Various Angles of Inclination using the Ordinary Slice Method.

so that at some point the slope will collapse. The results of this study strengthen previous research which states that the smaller the slope and the height of the slope, the more stable the slope will be, on the contrary, the greater the slope and the height of the slope, the more unstable the slope (Rozos *et al*., 2010; Alexakis *et al*., 2013; Laldintluanga *et al*., 2016; Abedini *et al.*, 2017).

Conclusion

The safety factor value shows that the slope has an effect on the potential for landslides, the the slope, the smaller the SF value so the greater the potential for landslides. The SF value obtained decreases as the slope steepness increases. For further research in determining the SF value, this research can be continued using other methods besides the ordinary method of slices such as the swedish circle method ($\phi = 0$) or the simplified bishop method (simplified bishop method).

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