

Slope Safety Factor and Its Relationship with Angle of Slope Gradient to Support Landslide Mitigation at Jatinangor Education Area, Sumedang, West Java, Indonesia

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Abstract. In several studies on slope stability analysis, the FS (Factor of Safety) value plays an important role in determining the meaning of slope stability. Based on several landslide events, Table of Bowles (1989) gives $FS < 1.07$ for the usual occurrence of slope collapse, $1.07 < FS < 1.25$ for slope collapse ever occurred, and $FS > 1.25$ for collapse events are rare. FS is influenced by the angle of the slope (α , degree), then Table of Bowles (1989) can be modified based on analysis of relationship between FS value with slope angle. The result of stability analysis of soil slope in Jatinangor Education Area is found the equation $\alpha = 7.2300.FS^{-0.474}$, at outside of drainage area, but in drainage area shows a variety of different safety factors. So that the meaning of labile, critical, and stable in slope stability analysis at out of drainage area gives $\alpha > 56^\circ$ for the usual occurrence of slope collapse (or labile slope); $56^\circ > \alpha > 41^\circ$ for slope collapse ever occurred (or critical slope), and $\alpha < 41^\circ$ for collapse events are rare (or relative stable slope). Furthermore, this modification can be used for landslide mitigation.

1. Introduction

Jatinangor area (figure 1) is an area that continues to grow with the presence of several universities in the vicinity, namely, Ikopin, Unpad, IPDN, and ITB Jatinangor, so this area is referred as Jatinangor Education Area. The need for space for development can develop towards the slopes in this area, so this area needs to be identified whether it can be vulnerable to earth movement in the form of landslides that have negative impacts.

Efforts to reduce the impact of landslides are mitigation. One mitigation model is the *Starlet Model* (*Stabilisasi dan Rancangbangun Lereng Terpadu*, stabilization and integrated slope design by Zakaria, 2010) in [1]. This model combines engineering and social aspects through environmental management and monitoring. This paper is a review of one of the stabilization model sections above, which is the study of slope stability analysis, especially the study on the value of slope safety, the meaning of safety factor (FS, Factor of Safety), and its relationship to the slope. Safety factors play an important role in slope stability analysis as well as in slope engineering design. Angle of slope always determine of slope stability mean. In this study, Table of Bowles (1989) [2] will be modified to determine angle of slope at stable, critical and labile stage.



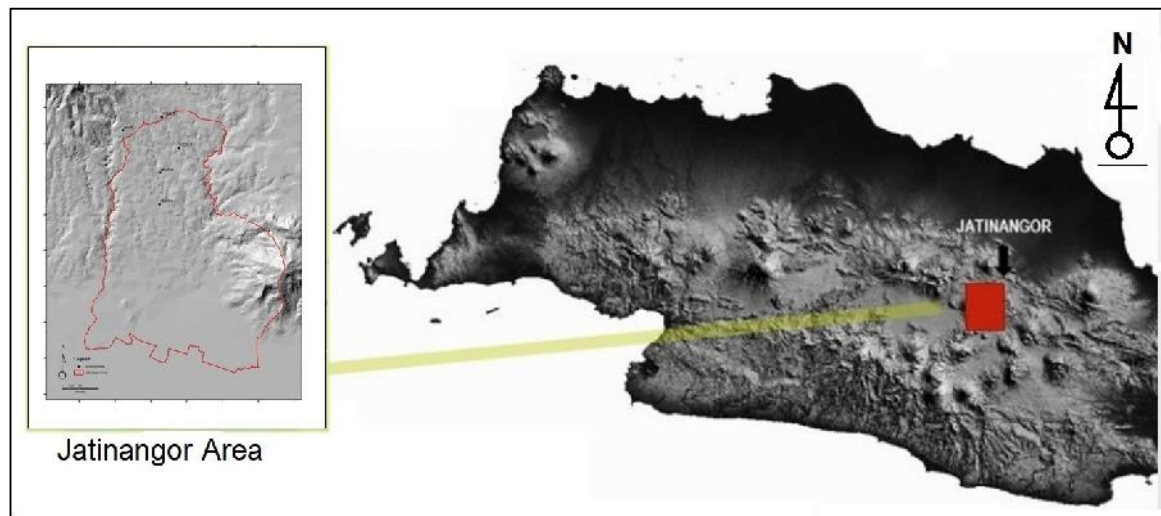


Figure 1. Research location at Jatinangor Education Area, West Java, Indonesia

2. Methods

2.1. Starlet model

Starlet model is a model of slope stabilization as well as for soil movement mitigation. There are four stages of works in this model:

- Mapping of engineering geology based on Dearman (1991) [3]. Mapping of engineering geology in landslide prone areas is urgently required [4] as a basis for further study.
- Analysis of slope stability [5]. This analysis involves the study of the physical properties and mechanical or geotechnical properties of slope materials.
- Design of stable slopes ([1], [5]).
- Environmental management and environmental monitoring [1].

In this paper, a stability analysis of the slope is performed. The steps taken are: 1) Literature study to knowing the condition of study area, 2) Field survey to knowing the condition of the field, 3) Undisturbed soil sampling, 4) Soil analysis and soil test in soil mechanical laboratory, 5) Calculate Slope Safety Factor under various conditions of slope angle, 6) Analysis of the relationship between slope angle and slope safety factor, 7) Modification Table of Bowles (1989).

2.2. Engineering geology

Jatinangor, is an area that will continue to develop. The development plan of Techno Science Park by Universitas Padjadjaran requires a geotechnical study, especially if development is carried out on slopes that will change the stability of slope. Several studies on the Jatinangor region are conducted by researchers. Some of these studies are as follows:

- Engineering geology mapping around Jatinangor Universitas Padjadjaran Campus complex [6]
- Mapping of engineering geology to a wider area of Jatinangor is implemented by post graduate student [7]
- Simulation of slope stability in the rainy and dry conditions at Jatinangor area [8]
- Soil bearing capacity under static conditions in the Jatinangor Education Area [9]
- Soil bearing capacity in seismic influence in the Jatinangor Education Area [10]
- Potential of expansive soil in the Jatinangor region [11]

The study by researchers is very useful in studying engineering conditions in Jatinangor Education Area, making soil dispersion map in Jatinangor, analysis of soil bearing capacity, and slope stability analysis, as an effort to mitigate landslide disaster.

2.3. Landslide disaster

Landslide disaster is one of the most common geological disasters in Indonesia. Indonesia's position at the meeting of three tectonic plates (Eurasian Plate, Indo-Australian Plate, & Pacific Plate), led to the formation of geological disaster zones: earthquake zones, tsunami zones, volcano zone, and soil movement zones. Some areas in Indonesia are prone to landslides, mainly because they are triggered by seismic or earthquakes, high rainfall, human activities. Steep topographic conditions and tropical conditions of Indonesia are the areas that are prone to landslides. Earth movement consist of rocks slide or rock fall, landslides, or debris fall or debris slide.

Slope body material can be formed by soil or rocks. The analysis methods of soil slope is different from the analysis of rock slope, Gunthew and Thiel (2009) in [12], compile an approach to evaluate both the structurally-controlled rock slope failure susceptibility, and the topographically-controlled shallow landslide susceptibility. Some studies on rock slopes can be approximated by the slope mass rating (SMR) method. SMR utilizes the Rock Mass Rating (RMR). Some researchers provides different SMR calculation methods (Hall [13], Laubscher [14], Orr [15], Romano [16]). These four researchers were combined and modified into MSMR (Modified of Slope Mass Rating, by Zakaria, *et.al*, 2016) in [17].

In soil erosion, the cause of landslide in general is: the residual soil that is thick, the slope of the steep slope, ground water level increases due to rainfall, stratigraphy layer of rock in the direction of slope, etc. Based on research [8], increasing rainfall will decreases slope stability. The value of slope stability in the two conditions, the dry season (with a small rainfall) and the rainy season (with a large rainfall value), will produce a different value, and impact to slope safety factor (FS). Research on landslides and precipitation is carried out by other researchers [18]. The objectives of the study is to improve the characterization of rainfall-induced landslides through the development of a physically based integrated hydrology and landslides modelling continuum.

2.4. Safety factor

Many safety slope calculation formulas are introduced to determine the degree of slope stability [5]. The basic formula of the Safety Factor (FS) slope (for soil material) was introduced by Fellenius through the incision method, and later developed by many researchers such as Bishop, Janbu, Sarma, and others. Basically, the slope safety factor is the comparison between the resistance force and the driving force.

Safety factor is reflect the slope conditions. In several studies on slope stability analysis, the FS (Factor of Safety) value plays an important role in determining the meaning of slope stability. Based on several landslide events, table 1 from Bowles (1989) gives $FS < 1.07$ for the usual occurrence of slope collapse, $1.07 < FS < 1.25$ for slope collapse ever occurred, and $FS > 1.25$ for collapse events are rare.

Table 1. Safety factor and meaning of slope condition.

Safety Factor	Slope condition	Meaning
$FS < 1.07$	Usually occurrence of slope collapse	Labile
$1.07 < FS < 1.25$	Slope collapse ever occurred	Critical
$FS > 1.25$	Slope collapse events are rare	Stable

3. Results and Discussion

3.1. Morphometric

Based on the morphology, the natural slopes in Jatinangor and surrounding areas has a variety of slopes, ranging from flat to extreme steep. Slope conditions can be seen in figure 2 below. Natural slopes will change according to development. Slope cutting to get location for building needs to be studied first, because it will change the value of safety factor.

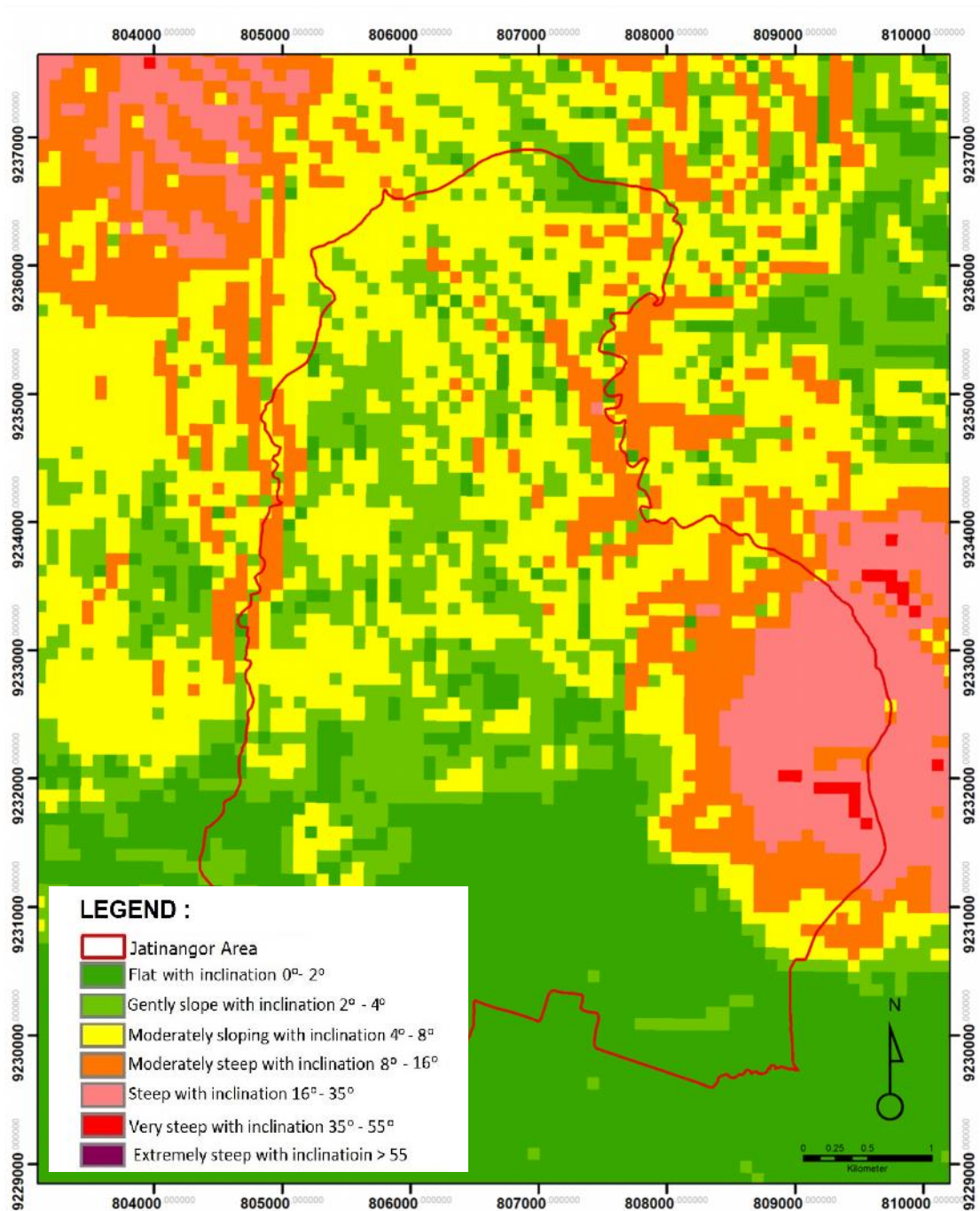


Figure 2. Map of morfometri (slope gadiant) at Jatinangor Area

Analysis of drainage density (Dd) found that there are three Dd zones, that: low drainage density ($Dd < 1.5$), moderate drainage density ($1.5 < Dd < 2$), and high drainage density ($Dd > 2$). Sampling is done in low drainage density location and in high drainage density that is in the area around river flow. Sampling is done also outside the drainage area. Figure 3 and 4 show the slope conditions around the hilltop.



Figure 3. Condition of slope behind the building that shows angle of repose



Figure 4. Slope condition before covered by hanging garden

3.2. Soil mechanical test results

The results of laboratory tests on soil samples are as follow as: Soil consists of clay with high plasticity (CH), silt with high plasticity (MH), and silt with low plasticity (ML). Physical and mechanical properties of soil obtained from soil mechanical tests in the laboratory can be seen in table 2.

Table 2. Samples of physical soil properties and mechanical properties.

SAMPLE		NGR-2	NGR-3	NGR-4	NGR-6	NGR-9
Unit Weight	T/M3	1.743	1.646	1.626	1.698	1.626
	KN/M3	17.093	16.142	15.946	16.652	15.946
Water content	%	41.49	46.62	42.99	53.15	39.92
Cohession	kg/Cm2	0.106	0.240	0.250	0.210	0.140
	KN/M2	10.395	23.536	24.517	20.594	13.729
Angle of internal friction	(o)	7.845	7.8	8.91	7.12	8.89
Soil	USCS	M H	CH	M H	ML	ML

3.3. Safety factor

Safety Factor (FS) is calculated based on physical and mechanics soil properties. Slope simulation is done to obtain the relationship between slope angle and FS value. The safety factor calculation results of five samples are shown in table 3.

Table 3. Result of simulation of safety factor on various slope conditions.

Slope (α , degree)	Safety factor (FS)				
	NGR-2	NGR-3	NGR-4	NGR-6	NGR-9
30	0.917	1.639	1.766	1.417	1.189
35	0.86	1.564	1.681	1.349	1.119
40	0.796	1.496	1.604	1.288	1.043
45	0.73	1.374	1.472	1.182	0.958
50	0.691	1.322	1.416	1.137	0.911
55	0.656	1.259	1.349	1.083	0.869
60	0.614	1.194	1.278	1.026	0.816

Samples NGR-2 and NGR-3 taken from low drainage density area. Samples NGR-4 and NGR-9, taken from high drainage density area. The soil samples for study in this paper are taken only from location outside drainage area. Location of NGR-6 is taken from area around the hilltop at campus Universitas Padjadjaran.

3.4. Discussion

Simulation of safety factor calculation from various slope conditions has shown variation of safety factors value. Samples of NGR-2 and NGR-9 are taken from same river stream. NGR2 at upstream, and NGR-9 at downstream. Samples of NGR-3 and NGR-4 Are taken from same river stream. NGR3 upstream, and downstream NGR-4. NGR-6 samples is taken at location outside of two streams. The simulation results show the relationship of FS with slope in table 4.

Table 4. Result of relationship of safety factor with slope.

Location	Equation
NGR-2	$FS = 6.8175 \alpha^{(-0.586)}$
NGR-3	$FS = 8.1469 \alpha^{(-0.466)}$
NGR-4	$FS = 9.0344 \alpha^{(-0.475)}$
NGR-9	$FS = 7.8156 \alpha^{(-0.550)}$
NGR-6	$FS = 7.2300 \alpha^{(-0.474)}$

Based on the relationship between safety factor (FS) with slope (α) on around of location NGR-6, Table of Bowles (1989) can modified. Meaning of slope stability condition at various degree of slope shows in table 5.

Table 5. Meaning of slope stability condition at various degree of slope.

Slope (degree)	Safety Factor	Slope condition	Meaning
$\alpha > 56$	$FS < 1.07$	Usually occurrence of slope collapse	Labile slope
$56 > \alpha > 41$	$1.07 < FS < 1.25$	Slope collapse ever occurred	Critical slope
$\alpha < 41$	$FS > 1.25$	Slope collapse events are rare	Stable slope

4. Conclusions

Based on sample at hilltop, the result of stability analysis of soil slope in Jatinangor Education Area is found the equation $\alpha = 7.2300 FS^{-0.474}$, at outside of drainage area, but in drainage area shows a variety of different safety factors, The meaning of labile, critical, and stable in slope stability analysis at out of drainage area gives $\alpha > 56^\circ$ for the usual occurrence of slope collapse (or labile slope); $56^\circ > \alpha > 41^\circ$ for slope collapse ever occurred (or critical slope), and $\alpha < 41^\circ$ for collapse events are rare (or relative stable slope). Furthermore, this modification can be used for landslide mitigation. Slopes with critical or labile angles need to be further investigated with sufficient samples, and sampling methods through drilling, so that data at a certain depth can be obtained.

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