Slope stability assessment and landslide vulnerability mapping of the Institut Teknologi Kalimantan area

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Abstract. Slope stability analysis was carried out in the Institut Teknologi Kalimantan which is an area with educational facilities that have a high risk of soil movement. The research area consists of slopes that often reported landslides, especially during the rains time. Evaluation is carried out to the important factors that affect slope stability such as slope geometry consist of 23 zones, soil parameters consist of 7 drilling holes, and past landslide occurrence. Slope stability was evaluated using back analysis based on soil parameters under critical conditions and field investigation and slope geometry using SLOPE/ W software to obtain the safety factor (SF) of a certain slope. Landslide vulnerability maps are created based on the risk and potential landslide or landslide occurrence. Based on the results of the stability analysis, there are 6 zones with unstable conditions and a high potential for landslides and 4 zones in critical conditions with moderate landslide potential. The modeling also shows that in the same soil parameter value with a steep slope, the value of the safety factor is getting smaller. This means that the potential for soil movement is greater. Besides, the loading at the top of the slope also causes a reduced safety factor.

1. Introduction

The Institut Teknologi Kalimantan campus area is located in a hilly area with different elevations, causing natural and engineered slopes to form as a result of slope cutting and filling of basins for the construction of educational facilities. Land movements or landslides occurred on several slopes in the Institut Teknologi Kalimantan area as shown in Figure 1. landslide is the movement of a mass of rock, debris or earth down a slope, under the influence of gravity(1). These landslides can cause damage to surrounding infrastructure, block road access, or damage the existing landscape. An assessment of the stability of a slope is an attempt to analyze the safety of the slope against the dangers of soil movement or landslides. Knowledge concerning landslide disasters is very important to reduce the risks. The Security of slope is valued by the safety factor(2). Slope stability assessment is a fundamental step in evaluating landslide hazard and for the safe design of structures and infrastructures(3). The assessment method is carried out by analyzing the field soil sample parameters, of which the data will be used as the basis for the analysis of landslide vulnerability. Vulnerability is defined as the potential degree of damage to a given element resulting from the occurrence of a natural phenomenon of a given magnitude(4). However, studies examining vulnerability to landslides are limited(5). This study aimed to estimate where landslides are likely to occur in the Institut Teknologi Kalimantan area.
2. Study Area
The slopes reviewed in this study could be seen in Figure 2. The slopes were chosen because these slopes are close to the lecture building which is considered prone to landslides. Other considerations are the availability of supporting data and the accessible area for field investigation. The reviewed slopes are divided into 2 parts, namely Slope 1 consisting of the slope of Building C to Building G and Slope 2 consisting of the slope of Building G to the entrance of Institut Teknologi Kalimantan.

2.1. Slope Stability Theory
Slope stability analysis is based on the mechanism of the motion of an object located on an inclined plane(6), in which the reviewed object is soil grains as shown in Figure 3. The figure analyzes the mechanism of motion of objects on an inclined plane and the forces that influence it. T is the mass of the landslide while the force that opposes landslides is R which is the shear force that occurs between the weight of the landslide (W) and the sloping load. Therefore, this can be said that if the ratio between R / T <1 then the object will move, R = T balanced condition and R / T> 1 then the object will be at rest.
2.2. The factor of Safety Concept

The safety number is the ratio between total resisting forces to disturbing moments in the case of circular slip surfaces. By following equation 1(7).

\[
SF = \frac{R \int S_u d_s}{W x}
\]

where \(S_u\) is the sum of resisting force and \(\tau\) is the summation of mobilized force, \(W\) is the weight of the landslide block and \(x\) is the distance of the center of landslide mass to the center of landslide plane circle. The values of the Safety Factor (SF) in terms of mitigation and consideration of uncertainty in the analysis data are shown in Table 1(8).

**Table 1. SF values as mitigation proposed by Hakam(8)**

| Safety factor | Condition | Potential | Remarks                           |
|---------------|-----------|-----------|-----------------------------------|
| > 2           | Stable    | Low       | Earth movements are rare.         |
| 1,5 <SF <2    | Critical  | Moderate  | Earth movements are occasional.   |
| <1,5          | Unstable  | High      | Earth movements are common/frequent. |

3. Material and Methods

3.1. Data

In the analysis, soil parameter data, loading, and slope geometry according to field conditions are needed. Slope stability analysis in the zone under review was carried out using soil data from field investigations and back analysis data on collapsed slopes (T.03). Soil parameters resulted from slope failure reverse analysis are more reliable than those obtained from laboratory tests or field tests(9). Data back analysis is used to represent the worst conditions. The value from the reverse analysis can also be used efficiently to analyze the stability of other slopes with similar characteristics(10). The sampling locations can be seen in Figure 4. The soil data used in the analysis were selected based on the location closest to the studied slope.
Field measurements with theodolite were carried out to determine the geometry of the reviewed slopes. Slope 1 is divided into 9 zones as shown in Figure 5 and slope 2 is divided into 14 zones as shown in Figure 6. The number of zones is determined based on the visual field observation results of steep, failed, and potentially failing slopes. Slopes with similar geometric shapes and minor geometric changes are grouped into one zone. Zone boundaries are determined based on significant changes in slope shape such as elevation and inclination. Based on the zonation, a sloping geometry which shows the height and inclination of the slope as one of the input parameters for Slope/ W will be created. SLOPE / W is a software product for calculating soil safety factors and rock/ soil slope(11). The loading on the slopes under review is carried out by following field conditions.

3.2. Slope Stability Analysis
Slope stability analysis was carried out with the help of the Slope/ W program for 9 slopes in Zone 1 and 14 slopes in Zone 2. Input parameters required in the modeling are the soil parameters obtained from 7 drilling points to model the slope soil constituent and data from the back analysis of the failed slope. The used soil data is based on the data closest to the slope under review to obtain soil parameters that represent slope conditions. The loads analyzed in the planning consist of a traffic load of 12 kPa and a building load of around 10 kPa (12). The geometric shape of the slope is obtained based on field measurements of 23 observed points. Slope/ W will analyze the input data and provide an output in the form of a slope safety value by which, conditions and potential movements that may occur on the slope can be determined. Furthermore, the results of the analysis can be mapped to provide basic information on mitigation and planning.
4. Result
The safety factor based on the results of the Slope/ W analysis shows that Slope in the study area is in a stable to unstable condition with low to high potential. Unstable slopes are dominated on slopes 1 zone 3-7 which are analyzed using back-analysis soil data and a loading of 12 kPa. Unstable slopes also occur on slope 2 zone 1 which is analyzed with soil data from field investigations at point T.07. These slopes have a fairly big angle compared to the two previously reviewed slopes, which is around 17° - 42° (30-90%).

Slopes with stable conditions and low landslide potential are found on most slopes of zone 2. The slopes are analyzed based on field investigation data. These zones have a gentler geometry than the
other slopes, which is around 8° - 22°. The recapitulation of safety factor value can be seen in the following Table 2.

Table 2. Slope safety factor recapitulation (Slope 1)

| Slope | Zone | Soil Sampling Point | Load (kPa) | Gradient (°) | SF  | Condition | Potential |
|-------|------|---------------------|------------|--------------|-----|-----------|-----------|
| 1     | 1    | T.03                | -          | 10           | 1.92| Stable    | Low       |
| 2     | 1    | T.03                | -          | 8            | 1.96| Stable    | Low       |
| 3     | 1    | T.03                | 12         | 17           | 1.10| Unstable  | High      |
| 4     | 1    | T.03                | 12         | 41           | 0.94| Unstable  | High      |
| 5     | 1    | T.03                | 12         | 33           | 1.05| Unstable  | High      |
| 6     | 1    | T.03                | 12         | 19           | 1.00| Unstable  | High      |
| 7     | 1    | T.03                | 12         | 39           | 1.1 | Unstable  | High      |
| 8     | 1    | T.02                | 12         | 18           | 2.37| Stable    | Low       |
| 9     | 1    | T.01                | 10         | 33           | 2.60| Stable    | Low       |
| 1     | 2    | T.07                | 12         | 26           | 1.21| Unstable  | High      |
| 2     | 2    | T.07                | 12         | 25           | 1.54| Critical  | Moderate  |
| 3     | 2    | T.07                | 12         | 16           | 3.95| Stable    | Low       |
| 4     | 2    | T.07                | 12         | 19           | 3.93| Stable    | Low       |
| 5     | 2    | T.06                | 12         | 22           | 2.10| Stable    | Low       |
| 6     | 2    | T.05                | 12         | 15           | 2.43| Stable    | Low       |
| 7     | 2    | T.05                | 12         | 15           | 2.78| Stable    | Low       |
| 8     | 2    | T.05                | 12         | 18           | 3.16| Stable    | Low       |
| 9     | 2    | T.05                | 12         | 14           | 2.33| Stable    | Low       |
| 10    | 2    | T.04                | 12         | 18           | 1.67| Critical  | Moderate  |
| 11    | 2    | T.04                | 12         | 18           | 1.82| Critical  | Moderate  |
| 12    | 2    | T.04                | 12         | 19           | 2.18| Stable    | Low       |
| 13    | 2    | T.04                | 12         | 21           | 1.83| Critical  | Moderate  |
| 14    | 2    | T.04                | 12         | 20           | 2.23| Stable    | Low       |

According to the values of the slope safety factor that recommend soil conditions and potential movement on the slopes, it can be mapped according to the following figure.
5. Discussion
This study aimed to predict where landslides are likely to occur in the Institut Teknologi Kalimantan area. The result of the analysis showed that slopes 1 zone 3-7 have a high potential for landslides because of the input parameters in analysis using back analysis data. Based on the modeling of the same degrees of the slope with different soil parameters, the safety factor value is getting smaller. This can be seen from the safety number value of slope 2 Zone 4 with a soil parameter based on field investigation (T.07) that has an SF of 3.39 then reduced by slope 1 Zone 6 with a soil parameter based on back analysis (T.03) to 1.00. It shows that the use of soil parameters from the back analysis results in a smaller SF value compared to the soil parameters from the analysis using field investigation. Soil parameters resulted from slope failure reverse analysis are more reliable than those obtained from laboratory tests or field tests(9). Therefore, in the slope reinforcement planning analysis, the soil parameters from the reverse slope analysis are used as soil data in the worst conditions and to anticipate possible slope failures.

On Slope 2 zone 1, the unstable conditions occurred because these slopes have a fairly big angle. The safety factor based on the results of the Slope/ W analysis shows that the same soil parameter value with a steep slope, the safety factor value is getting smaller. This can be seen from the safety number value of slope 2 Zone 12 with a slope of 19° that has an SF of 2.18 then reduced by Zone 13 with a slope of 21° to 1.83. This indicates that for the same soil parameter, degrees of the slopes affect the safety factor values. The decrease in the value of SF is caused by changes in slope angles that affect the stability of the soil. The steeper the slope, the greater driving force will be exerted to move the slope(14). Thus, this causes the SF value to be smaller. Besides, the existence of loading in the form of roads or buildings at the top of the slope causes an additional driving force that causes landslides on the slopes. Modeling was done to prove this, in which the slope 1 zone 3 was given 3 different loads, namely 0, 12, and 15 kPa. From the modeling results, the SF values for the three conditions were obtained, respectively, 1.13; 1.11; and 1.10.
6. Conclusion
According to the 23 Zones modeled, there are 6 zones with unstable conditions and high landslide potential and 4 zones in critical conditions with moderate landslide potential. This is caused by the combination of soil parameters for analysis, steep slopes, and loading at the top of the slope. Where the degrees of the slopes, soil parameter from back analysis, and the existence of loading in the form of roads or buildings at the top of the slope reduce the safety factor value. Reduce load on the slope, geometric modification by lowering the angle of the slope, and reinforcement measures, these several methods to increased safety factor value and reduce the risk of landslides.

7. References
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