Slope stability analysis in Lusi River, Kedungrejo using limit equilibrium method

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Abstract. The slope is a ground has a certain angle to the horizontal plane. The stability of slope depends on the magnitude of the retaining force and the driving force present in the slip. Characteristics of soil mass are determined by laboratory test of core drilling method is conducted to determine the subsurface condition at the area of study. Assessment of slope stability is using limit equilibrium method with comparing Bishop, Janbu, and Spencer method using Slide 6.0 Program. In this study area is composed of clay with the firm to stff structure. The result of the analysis slope stability using manual method using Bishop simplified method obtained the factor of safety is 1,680 and 1,14 and based on Slide 6.0 program, the Janbu simplified method is resulting the smallest factor of safety 1,130. Therefore it can be classified as unstable condition according to the terzaghi and peck (1976) factor of safety criteria. It means that reinforcement is required to improving the slope stability. Then, the result of analysis provide information that simulation model using micropiles reinforcement is the most effetive to improving the factor of safety value. The increasing of safety factor became 1.630 on treated slope using micropiles with the space between piles is 1 m.

1. Introduction

Much of soil mechanics is concerned with the response of soils to the stresses developed in them by loads caused by footings or foundations at ground surface. It is desirable, in practice, to know something about two soil behavior under the application of stresses, there are the amount of deformation which will occur and will lead to the settlement or distortion of structures constructed on or in the soil and relates to the maximum value of the load or stresses which can be imposed on the ground before the soil failure (Scout, 1968). A variety of engineering activities require excavation of rock cuts both in civil engineering and mining. The slope is a ground has a certain angle to the horizontal plane. The stability of slope depends on the magnitude of the retaining force and the driving force present in the slip. Stability analysis of slopes susceptible to different types of failures can be conducted in different techniques. Slopes failures involve such a variety of processes and causative factors.

For stability analysis of slope, the factor of safety is usually used to obtain the critical limit equilibrium state of slope in the limit equilibrium method (LEM). The methods of slices that is
2. Methods

2.1. Study Area

The stability analysis was performed for the slope in Lusi riverbank that located in coordinate 7.101487 °LS; 110.95266 °BT, Kedungrejo, Grobogan, Central Java. The slope failure has occurred since 2014, and the occurrence of landslide became widespread. It has length of about 67 m. The height of slope is around 5 m and average slope angle 40°–50°.

Based on geological map (Datun et al, 1996), regional area of study is contain of alluvial deposits, formation of Tambak Kromo, Mundu, and Kalibeng. Litology in this area study are clay and sand which is the alluvial deposit. Structure of clay material is firm until stiff with the N SPT value 7–15.

2.2. Analysis Tools

2.2.1. Types of Slope Failure and Mechanism of Instability

Different soil types and slope characteristics have varied levels of impact on parameters involved in analyzing stability of slopes. Slopes failures involve such a variety of processes and causative factors. Slope failure occurs when the downward movements of material due to gravity and shear stresses exceeds the shear strength. Different processes can lead to reduction in the shear strengths of rock mass. There are many conditions that affect slope failures depending on the soil type, soil stratification, ground water, seepage, and the slope geometry (Budhu, 2000). For instance, they can be divided according to the form of failures, the type of materials moved, the age, the stage of development, or the cause of movements.

- a. movement of soil mass along a thin layer of weak soil
- b. base soil
Landslide mechanism refers to the “geometry” of the surfaces along with failure takes place. Landslides are generally classified according to whether they are slides (failing on discrete surfaces), falls (detached material from steep slopes-frequent in cut slopes), flows (often fast moving movements containing high water content). The instability condition can be obtained through two mechanisms (Duncan and Wright, 2005), there are the first mechanism a decrease in the shear strength, the maximum shear stress that the can withstand, and the second mechanism an increase in the shear stress.

2.2.2. Stability Analysis Method

A shear failure is most likely to occur along a discrete surface as assumed in stability analysis. Failure of soil element at a certain location does not mean failure of the system. It could be mean a reduction in the resistance. Based on concepts of slope stability, the stability of slope can be expressed in one of them with factor of safety that is comparison between resisting force and driving force.

\[
\text{FoS} = \frac{\text{Resisting Force}}{\text{Driving Force}} \tag{2.1}
\]

FoS is stability quantified by limit equilibrium of the slope, which is stable if \( FS > 1 \) (Duncan, 2006). The ranges of minimum total factors of safety by Terzaghi and Peck (1976) and the Canadian Geotechnical Society (1992) are as follows:

| Failure type                  | Category                              | Safety Factor |
|-------------------------------|---------------------------------------|---------------|
| Shearing                      | Earthworks                            | 1.3 – 1.5     |
|                               | Earth retaining structures, excavations| 1.5 – 2.0     |
|                               | Foundations                           | 2.0 – 3.0     |

Sliding analysis methods can use static or dynamic equilibrium equations. Static equilibrium analysis, carried out using the limit equilibrium method that uses equilibrium force principal. Firstly, analysis method assumes a possible plane of sliding are circular and non-circular plane of sliding (planar). For all shear type failures, this is can be assumed to be a Mohr-Coulomb material.
\[ \tau = c + \sigma_n \tan \phi \] (2.2)

and equation (2.2) can be expressed as

\[ \tau = c + \frac{w \cos \alpha}{A} \tan \phi \] (2.3)

\[ \sigma_n = \frac{w \cos \alpha}{A} \]

\[ A \] is defined by the following equation,

\[ m_{\alpha(n)} = \frac{\cos \alpha_n + \tan \phi \sin \alpha_n}{F_S} \] (2.7)

Factor of safety calculated from the equation 2.7 satisfy equilibrium of moments about the center of a circle. Because the value of the term \( m_{\alpha} \) depends on the factor of safety, the factor of safety appears on both sides this equation.
The aim of a rock slope stabilization design with structural elements are to help the rock mass to support itself and to apply external structure which are not part of the rock mass, but support it externally. Methods of slope stabilization fall into three categories, there are reinforcement, rock removal, and protection.

3. Result and Discussion
Collected in-situ soil samples are clay that was taken in several different location of the slope above and below the road section for determining its unit weight at different moisture content and specific gravity. The important engineering properties of the slope materials were also determined which were then utilized for stability analysis of the slope. An average unit weight is 15.7 KN/m$^3$ and the average cohesion and friction angle are 21 KPa and 14°. Significant test results are presented in tables below.

Table 2. Physical and Engineering Properties of The Clay Materials.

| No. | Hole No. | Depth (m) | Description              | Water content (%) | Unit weight gr/cm$^3$ | Unit weight dry gr/cm$^3$ | SG Gs | Direct shear c kg/cm$^2$ | Direct shear $\phi$ degree |
|-----|----------|-----------|---------------------------|-------------------|-----------------------|----------------------------|-------|--------------------------|---------------------------|
| 1.  | BH-1     | 07.00-07.50 | Clay, brownish grey, stiff | 35.47             | 1.57                  | 1.16                       | 2.56  | 0.213                    | 14                        |
| 2.  | BH-1     | 14.50-15.00 | Clay, grey, stiff         | 30.87             | 1.58                  | 1.2                        | 2.59  | 0.281                    | 16                        |
| 3.  | BH-2     | 07.00-07.50 | Clay, brownish grey, stiff | 38.88             | 1.55                  | 1.12                       | 2.55  | 0.202                    | 16                        |
| 4.  | BH-2     | 14.50-15.00 | Clay, brownish grey, stiff | 29.95             | 1.60                  | 1.23                       | 2.62  | 0.269                    | 17                        |

In this study, the factors of safety and the locations of critical failure surfaces have been obtained by the limit equilibrium method is considered using the simplified Bishop method which assumes zero X$_i$ forces between slices. In this present study, the factor of safety calculated manually using simplified bishop method and Slide 6.0.

The first step to determine the safety of factor using limit equilibrium method is a determination the geometry of plane failure and number of slice are used into the plane failure. On manual calculation using simplified bishop method, the number of slices is divided into 10 and 15 slices.
From this calculation obtained the value of FoS, then to get the appropriate FoS value, the iteration method is used by replacing the assumption of the value of $FS = 0.8$ with $FS = FoS$ until the value of $FoS - FS \leq 0.001$. The following table is the results of iteration calculation.

### Table 5. Results of Iteration Calculation.

| Iteration | FoS (Number of slices = 10) | FoS (Number of slices = 15) |
|-----------|-----------------------------|-----------------------------|
| 1         | 0.8                         | 0.8                         |
| 2         | 1.580                       | 1.090                       |
| 3         | 1.674                       | 1.134                       |
| 4         | 1.680                       | 1.139                       |
| 5         |                             | 1.140                       |
Along with soil properties, the overall slope angle approximately $45^0$ has used the Slide Software 6.0 Program, to measure the factor of safety for the varied number of slice yielding the values of 1.311, 1.304, 1.302, and 1.301 respectively in Bishop simplified method. From this analysis shows that number of slices is influence to the factor of safety using Bishop simplified method. Trial analysis shows that in Bishop simplified method, the number of slices that yields a stable safety factor value is from 20 to 25 slice.

The comparison of factor of safety in each limit equilibrium method shows the number of slices that resulting the same value is 25 slice. The following result of the factor of safety in each method is obtained that Janbu simlified method has smallest safety factor value compared to other methods.

Figure 5. Simulated Model Factor of safety using of Bishop Simplified Method (a) Number of Slices = 5; (b) Number of Slices = 10; (c) Number of Slices = 15; (d) Number of Slices = 20; (e) Number of Slices = 25.
In present study, Slide 6.0 has been used for the limit equilibrium analysis for untreated and treated slopes with pile and grouting reinforcements. Material properties of the grouting and anchored reinforcement are: unit weight = 15 kN/m$^3$, cohesion = 30 Kpa, and friction angle = 14$^0$, properties of anchored consist of plane spacing 3 m and anchored capacity 200 kN. Simulated model piles and grouting reinforcement in this study to improving the overall factor safety of the slope. The diameter and length of the piles in model simulation is 300 mm and 6 m, with the shear strength 200 kN. The results of simulation model of micropiles space is obtained as follows:

| Space between piles (m) | FoS   |
|-------------------------|-------|
| 0.5                     | 2.707 |
| 1.0                     | 1.630 |
| 1.5                     | 1.431 |
| 2.0                     | 1.431 |

Based from this analysis, the factor of safety on untreated slope is improving. The factor of safety based on simulation of micropiles model indicates that the most efficient spacing for reinforcement of the slope is 1 m, with the factor of safety value 1.630. The simulation reinforcement model using grouting and end anchored method is obtained the factor of safety 1.271.

4. Conclusion
Through this study show that the different number of slices on limit equilibrium analysis would be influenced of the factor of safety value, in this study obtained that the value of safety factor does not change if the number of slice in Bishop simplified method equal to 25 or more. The results of the analysis on each method also show that the most effective number of slices 25. The linear correlation between manual analysis and Slide 6.0 Program to calculating factor of safety which is explain that the more number of slices will be obtained the smaller factor of safety.

Based on the Slide 6.0 Program analysis, Janbu simplified method has the smallest factor of safety compared to other method. The simulation model of reinforcement shows that micropiles is the most effective reinforcement.

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