Sensitivity Analysis of Soil Parameters on Slope Stability using Simplified Bishop Method (Case Study in Grobogan, Central Java, Indonesia)

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Abstract. Slope instability can occur due to the influence of soil parameter values. The value of soil parameters is a random phenomenon that is uncertain and tends to a certain range. This study attempts to analyze the sensitivity of soil parameters on a slope with a height of 6 m. Sensitivity analysis includes several ranges of soil parameter data based on the Soil Investigation Report in Grobogan, Central Java, Indonesia. Slope failure is based on Mohr-Coulomb theory and slope stability analysis using simplified Bishop method. The analysis will produce how much influence from the variation of soil parameter values to the safety factor on the slope. The results of the influence of the variation of parameter values are recapitulated and processed, so that the sensitivity percent of each soil parameter is obtained against the safety factor of slopes. The results showed that the most sensitive soil parameters were soil cohesion.

1. INTRODUCTION

In geotechnical engineering analysis and design, various sources of uncertainties are encountered and well recognized. Several features usually contribute to such uncertainties, like: 1). those associated with inherent randomness of natural processes; 2). model uncertainty reflecting the inability of the simulation model, design technique or empirical formula to represent the system’s true physical behavior, such as calculating the safety factor of slopes using limiting equilibrium methods of slices; 3). model parameter uncertainties resulting from inability to quantify accurately the model input parameters and 4). data uncertainties including (a) measurements error, (b) data inconsistency and non-homogeneity and (c) data handling. The instability of the slope can occur due to the influence of soil parameter values, which consist of the unit weight ($\gamma$), cohesion ($c$), and the friction angle ($\phi$). The soil parameters value is various and random, the value is difficult to determine with certainty, difficult to ensure that the parameter values can have the same value at each point. The values of soil parameters are tend to be in range values. Uncertainty of the soil parameter is a random phenomenon or random variables, where the value cannot be determined with certainty and tend to be in a certain
range of values[2]. This paper presents a sensitivity analysis of soil parameters and safety factor of the slope model with certain range of values soil properties. Safety factor calculated using simplified Bishop method.

2. LITERATURE REVIEW

The sensitivity analysis is used to determine the effect of various input parameters on slope stability. The effect of uncertainty or variability in the values of soil parameters can be explored. The most effect of soil parameters on stability of slope can be determined. Changes that may occur on the safety factor of slopes can be known and anticipated by conducting a sensitivity analysis. Safety factor is done by changing the value of a parameter at a time to, then be seen how it affects a system. Soil parameters that can affect the safety factor of slopes are unit weight, cohesion, friction angle. The other study about sensitivity analysis in slope stability is examined in the existing slope in the coal mining area. The most sensitive of soil parameter to safety factor is soil cohesion [3]. Another study on the sensitivity of soil parameters was carried out on the slopes in Kuala Lumpur. The analysis parameters in the form of range of cohesion values, friction angle, unit weight, and groundwater levels are made with three conditions (maximum, mean, and minimum). Sensitivity analysis is done by two methods, namely Spencer and General Limit Equilibrium. The most sensitive parameter sequence is groundwater level, friction angle, cohesion, and unit weight. The difference in sensitivity analysis methods has a relatively small effect, which is between 0.1571% to 0.1720% for all parameters [1].

3. Probability Density Function (PDF)

The probability density function (PDF) or f (x) refers to a function that has a continuous type of random variable. PDF can be used for various types of properties (x), the value of f (x) is proportional to the probability x. Areas that are under the probability distribution function are unity. The probability of a random variable x located between the values x_1 and x_2 is an integral of the probability distribution function taken between the two values.

\[ P(x_1 < x < x_2) = \int_{x_1}^{x_2} f(x)dx \] (1)

4. Failure criterion of Mohr-Coulomb

Shear strength is the ability of the soil to resist the shear stress that occurs when loaded. Soil shear failure occurs not due to the destruction of the soil grains but due to the relative motion between the soil grains. In the event of a slope means there has been a shift in the grain of the soil.

\[ \tau_f = c + \sigma \tan \phi \] (2)
\[ \phi = 0, \text{ then } \tau_f = c \] (3)
\[ c = 0, \text{ then } \tau_f = \sigma \tan \phi \] (4)

with: \(\tau_f=\)shear strength, \(\sigma=\) normal force in the plane of slope, \(c=\) cohesion, \(\phi=\) friction angle.

**Simplified Bishop Method**

The simplified Bishop method [4] considers that the type of slope on the slope is circular. The safety factor for this method can be formulated in the following equation:

\[ FS_b = \frac{1}{2W \sin \alpha} \cdot \Sigma \left[ (c' + \tan \phi' \cdot (W (1 - B) + (X_n - X_{n+1}) \cdot \frac{\sec \alpha}{1 + \tan \phi' \cdot \tan \alpha}) \right] \] (5)

with:
Xₙ, Xₙ₊₁ = vertical shear force, W = total weight of ground slices, c = cohesion, \( \varphi' \) = friction angle, F = trial and error safety factor, b = slice width, l = length BC, \( \alpha \) = angle between BC and horizontal, B = \( u / (W / b) \) with u = pore pressure.

5. METHODOLOGY

The methodology involved four stages: data input, slope geometry, analysis and result interpretation. The sampling location was carried out extensively and continuously from Mojoagung Village to Warukaranganyar, Grobogan District (Central Java Province), Indonesia. There are 50 sampling points, each point there are 2 undisturbed samples. The sample depth between 1 m to 7 m with soil description is clay with very soft consistency to the medium along the area. The area of study is shown in maps Figure 1(a). The data of the study was taken with locations located along the Mojoagung village to Warukaranganyar, Grobogan District, Central Java, Indonesia. Geometry using a single slope modeling with maximum height of 6 meters based on the typical slope in location as shown in Figure 1(b).

6. RESULT AND DISCUSSION

6.1. Sensitivity analysis of soil parameter

Sensitivity analysis is used to see the effect of each input parameter on changes in safety factor values by changing the parameter values based on minimum and maximum ranges, for other parameters to remain at the mean value. The mean of this analysis is considered as the middle value between minimum and maximum. Delta is the distance from the mean to the minimum or maximum value. Each pin is varied by uniform increments. Recapitulation of input parameters for sensitivity analysis is shown in Table 1.
Table 1. Input for sensitivity analysis

| Parameter        | Unit weight $\gamma$ (kN/m$^3$) | Cohesion c (kN/m$^2$) | Friction angle $\phi$ ($^\circ$) |
|------------------|----------------------------------|-----------------------|----------------------------------|
| distribution     | lognormal                        | normal                | lognormal                        |
| mean             | 16.02                            | 13.50                 | 11.00                            |
| minimum          | 14.60                            | 5.00                  | 4.00                             |
| maximum          | 17.43                            | 22.00                 | 18.00                            |
| delta            | 1.42                             | 8.50                  | 7.00                             |
| pin               | 10                               | 10                    | 10                               |
| increments       | 0.14                             | 0.85                  | 0.70                             |

The following is a graph of the probability distribution function for parameters of unit weight, cohesion and friction angle are shown in Figure 2, Figure 3, and Figure 4.

Based on the Figure 2, lognormal distribution of unit weight with mean value = 15.92 kN/m$^3$, standard deviation = 0.91, skewness = 0.65 (+/tend to right), kurtosis = 3.77. Based on the Figure 3, normal distribution of cohesion with mean value = 14.11 kN/m$^2$, standard deviation = 4.86, skewness = 0 (center), kurtosis = 3. Based on the Figure 4, lognormal distribution of friction angle with mean value = 8.02$^\circ$, standard deviation = 5.17, skewness = 3.47 (+/tend to right), kurtosis = 30.12.

Sensitivity analysis used 6 m high slope geometry and 45$^\circ$ to 85$^\circ$ angle variations. The results of the sensitivity analysis for the parameters of unit weight, cohesion, and friction angle are shown in the Figure 5.
FIGURE 5. The result of sensitivity analysis of soil parameter, a). Sensitivity of unit weight, b). Sensitivity of cohesion, c). Sensitivity of friction angle

Figure 5.a) shows that the sensitivity of the unit weight tends to decrease the safety factor. The changes in safety factors that occurred in the range of unit weight values with an average sensitivity of 14.35%. If the sensitivity of 100% means that the safety factor has increased or decreased twice the safety factor, then the safety factor that occurred in the unit weight range has decreased by 0.29 times. The range of unit weight parameter is considered to have a not too significant influenced on safety factor. Figure 5.b) shows changes in safety factors that occurred in the range of cohesion values with an average sensitivity of 178.55%. Safety factors that occurred in the range of cohesion parameter values experienced an increase of 3.57 times. The range of cohesion parameter are considered to have a significant influenced on safety factor values. Figure 5.c) shows changes in safety factors that occurred in the range of friction angle values with an average sensitivity of 36.95%. Safety factors that occurred in the range of friction angle values experienced an increase of 0.74 times. Based on the sensitivity values, the parameters of the friction angle had a greater influence than the unit weight, but smaller than cohesion.

Graph of the sensitivity of soil parameters for a 6 m slope condition with slope angle of 45°, is shown in the following Figure 6(a). For example, slip surface is shown in Figure 6(b) with the condition of each soil parameter have sensitivity in range 0.8.
Figure 6(a) is a graph of a combination of three soil parameters for 6 m slope conditions with a slope angle of 45°. The unit weight parameter makes the safety factor value decrease as the unit weight value decrease. The cohesion parameters and the friction angle make the safety factor value increased along with the increased in value in the range of cohesion parameters and the friction angle. This happened because the unit weight of soil contents on the slope becomes the driving force of the soil, while the cohesion and the friction angle in the soil strength as the slope resisting force. If the unit weight becomes larger, then the burden of the soil that must be covered by the slope increases and the value of safety factor decreases. If the value of cohesion and friction angle in increasing, the value of safety factor increases. Cohesion and friction angle are components of shear strength parameters that provide strength to the ground to resist slope failure. The average sensitivity that occurred between the range of minimum and maximum values for cohesion, friction angle and unit weight is 178.55%; 36.95% and 14.35%. Cohesion parameters are the parameters that most influenced the change in the safety factor value. Based on the data, for the data range of cohesion becomes the largest than the parameter value of the soil weight and the friction angle (see PDF). So it is very possible to produce large changes in safety factor due to the data in the field. Figure 6(b) is a slip surface for each parameter condition in range 0.8 from minimum and maximum range. The green line is the slip surface with SF = 1.20 when the unit weight is in the range 0.8 and the other parameters are constant at the mean. The red line is the slip surface with SF = 1.57 when the cohesion is in the range 0.8 and the other parameters are constant at the mean value. The blue line is the slip surface with SF 1.39 when the friction angle is in the range 0.8 and the other parameters are constant at the mean value.

7. CONCLUSION
A slope sensitivity analysis towards varying values of unit weight, cohesion and friction angle has been presented. The sensitivity of the unit weight tends to decrease the safety factor, while the cohesion and the friction angle tend to increase the safety factor. The most sensitive order of soil parameters to the safety factor is cohesion. This was followed by friction angle, and unit weight.

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