DEVELOPMENT OF A SIMPLE DESIGN CHART AS AN EVALUATION OF SLOPE STABILITY

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Abstract. Landslides can damage public facilities and also have a negative impact on the community. This impact will be able to minimize when knowing the slope stability by carrying out the analysis to determine the factor of safety against landslide. The most accurate results usually get from calculation through computer software, but sometime it will take time and also not all of the designer have the sophisticated software. Another method in predicting the slope stability is using design chart as carried out in this study. The aim of this study is as a sustainable development of a simple chart to help the designer in predicting the landslide possibility. The graph will consist of the relationship between the slope height and the factor of safety for several soil strength parameter and slope angles. The slope stability analysis method will be based on LEM (Limit Equilibrium Method) through Bishop's equation. The result is then being tested through case study and comparing with the other existing design chart and show a satisfactory result.

Key Words: Slope, Slope Stability, Simple Chart, Limit Equilibrium Method, Bishop

1. Background

Landslide is a natural phenomenon in the form of soil mass movement in search of a new balance due to external disturbances that cause a decrease in soil shear strength (c) and changes in the angle of shear in the soil (φ) [16].

The negative impact of landslides is able to cause casualties, a lot of damaged infrastructure and damaged environmental sanitation such as the cut off of waterways due to landslides, besides that it also has an impact on the economy of the affected communities such as farmers, fields, rice fields or where they grow crops, buried in the soil and cannot be cultivated for a period of time.

From the influential parameters such as slope height, slope angle and soil parameters (c and φ), slope stability analysis can be carried out. The purpose of the slope stability analysis itself is to determine the safety factor of the slope against the potential landslide. Slope stability analysis can be done by various methods, including using a simple design chart. In a previous study, a design chart was made by Steward et al (2011)[13]. In this study, a simple design chart will be created base on the result of computer software and then comparing it with the other existing charts.
2. Methodology

The purpose of this study is to provide the simple chart in determining the slope stability. The research will start by collecting the data i.e. soil parameter, slope height and slope angle. Then through computer software starting by modelling and calculation process, we will get the factor of safety of slope against landslide. Based on the computer results, a simple chart will be generated which consist of 3 variation of slope height i.e. 5 m, 10 m, and 15 m. Each slope height will cover 3 different of cohesion value, i.e. 5 kPa, 10 kPa, and 20 kPa and 5 series of friction angle i.e. 20°, 25°, 30°, 35°, and 40°.

![Research Methodology Diagram]

Figure 1. Research Methodology

3. Theoretical background

The simple chart generated in this research is based on Limit Equilibrium Method (LEM) i.e. using simplified Bishop’s theorem which introduced in 1955 by Alan Wilfred Bishop from the Imperial College in London. The approach is different with the Ordinary Method of slices in terms of the assumptions made of the forces act at interslice.

Three majors Bishop Equilibrium formulas:

- Moment equilibrium for the entire failure surface,
- Horizontal force equilibrium for the overall failure surface, and
- Vertical force equilibriums for each slice.
The factor of safety (FS) of slope against landslide then can be determined using the following equilibrium.

\[ FS = \frac{\text{Resisting Moment}}{\text{Driving Moment}} \]  

The resisting moment \((M_R)\) and the driving moment \((M_D)\) can be derived from the following equations.

\[ M_R = \sum_{i=1}^{n} T_i \times R \]  
\[ M_D = \sum_{i=1}^{n} W_i \times R \times \sin \alpha_i \]

Where:
- \(T_i\) = shear force of slice \(i\)
- \(R\) = radius of failure circle
- \(W_i\) = weight of slice \(i\)
- \(\alpha_i\) = tangential angle of slice \(i\)

The shear force of slice \(i\) \((T_i)\) acting at the base of slice \(i\) depend on the shear strength of soil (cohesion and internal friction angle), the normal force \(N\) and the factor of safety \(FS\), which show in the following equation.

\[ T = \frac{c_i L_i + N_i \tan \phi_i}{FS} \]

Where \(L_i\) is the arc length of slice \(i\)’s base and \(N_i\) is the normal force of slice \(i\).

Substitute equation (2), (3), and (4) into equation (1), we get:

\[ FS = \frac{\sum_{i=1}^{n} \left( \frac{c_i L_i + N_i \tan \phi_i}{FS} \right) \times R}{\sum_{i=1}^{n} W_i \times R \times \sin \alpha_i} \]  

or

\[ FS = \frac{\sum_{i=1}^{n} \left( \frac{c_i L_i + N_i \tan \phi_i}{FS} \right)}{\sum_{i=1}^{n} W_i \times \sin \alpha_i} \]

In case of the pore water pressure \((U)\) contribute in slope stability and \(L_i\) changed into \(B_i / \cos \alpha_i\), then the factor of safety of slope against landslide can be determined using the following equation.

\[ FS = \frac{\sum_{i=1}^{n} \left( \frac{c_i B_i}{FS} \left( \frac{U_i}{\tan \alpha_i} \right) \times \sec \alpha_i \right)}{\sum_{i=1}^{n} W_i \times \sin \alpha_i} \]
4. Result and Discussion

4.1. Slope Stability Analysis Result

The result of calculation is then plotted to simple chart of slope angle related to factor of safety for varies internal friction angle as shown in Figure 3 to Figure 8.

**Figure 3.** Simple Chart of Factor of Safety for Slope Height 5 m and Cohesion 5 kPa and 10 kPa
Figure 4. Simple Chart of Factor of Safety for Slope Height 5 m and Cohesion 20 kPa

Figure 5. Simple Chart of Factor of Safety for Slope Height 10 m and Cohesion 5 kPa
Figure 6. Simple Chart of Factor of Safety for Slope Height 10 m and Cohesion 10 kPa, and 20 kPa
Figure 7. Simple Chart of Factor of Safety for Slope Height 15 m and Cohesion 5 kPa, and 10 kPa
Figure 8. Simple Chart of Factor of Safety for Slope Height 15 m and Cohesion 20 kPa

Figure 3 to Figure 8 show the relationship between slope angles and internal friction angles of soil for various slope height and cohesion. The use of chart is very easy; we just need to plot the vertical line starting from the point of slope angle to the line of internal friction angle then continuing plot the horizontal line across the factor of safety vertical axis.

For example, say the slope height is 15 m with cohesion 20 kPa, the factor of safety of slope with angle 40 degrees and internal friction angle of soil 40 degrees is 2 (as shown in Figure 8).

4.2. Comparative Research
In previous studies by Taylor [17], Stewart et al.[13], and Kevin Lim et al. [10], a non-dimensional design chart was introduced, where the chart is not bound by dimensions and parameters so that users can use charts with varies slope dimensions and soil parameters.

In contrast to previous studies, the simple design chart produced in this study is tied to the dimensions of the slope and certain soil parameters available on the chart. Therefore, the results of the calculations in this study are plotted in a dimensionless graph and produce the image as shown in figure 9.

4.3. Case Study
To strengthen the results of this study, we will compare the results of the major safety factors sought using a simple chart in this study with previous research in an example case study.

Assumed the case study has slope height 10 m with slope angle 60 degrees. The slope is also assumed has homogeneous soil with unit weight (γ) = 16 kN/m³, cohesion 10 kPa and internal friction angle (φ) 20 degrees. We will try to determine the factor of safety of slope using chart provided by Kevin Lim et al, and the chart generated in this research.

a. Research by Kevin Lim et al.
In his research, Kevin Lim et al. create a design chart as follows. Whereby using the formula in the design chart, the safety factor can be determined:
Figure 9. Dimensionless Design Chart (Kevin Lim et al.)

Step 1: determining the value of $\frac{c}{\gamma HF}$

$$\frac{c}{\gamma H \cdot tan \phi} = \frac{10}{16 \cdot (10 \cdot tan 20)} = 0.17$$

Step 2: determining the value of $\frac{c}{\gamma HF}$ and we need to assume the value of F (the final value of F must be more or less equal with this assuming F). We assume the value of F is 0.74

$$\frac{c}{\gamma H \cdot F} = \frac{10}{16 \cdot (10)(0.74)} = 0.084$$

Step 3: determining the value $\frac{tan \phi}{F}$ using the chart provided by Kevin Lim et. al.

$\frac{tan \phi}{F} = 0.49$

Step 4: determining the factor of safety (F) through step 3

$$F = \frac{tan \phi}{0.49} = \frac{tan 20}{0.49} = 0.743 \approx \text{Initial assuming F}$$

The factor of safety the slope is then 0.74.

Figure 10. Determining factor of safety using chart provided by Kevin Lim et.al.
b. This research
Using the chart as shown in Figure 11, for slope angle 60 degrees and internal friction angle 20 degrees, we get the factor of safety of slope against landslide is 0.78.

![Figure 11. Determining factor of safety using chart generated in this research](image)

5. Conclusion
The conclusion of this research:
a. The results of the design chart in this research only apply to slopes with certain dimensions and parameters, whereas in previous studies the design chart is dimensionless where the safety factor can be calculated with a combination of slope dimensions and various soil parameters.
b. A simple design chart can be used to determine the value of the factor of safety of a slope, by determining which design chart is appropriate to use seen from the height of the slope and the value of the soil cohesion, then determine the shear angle in the soil to determine the curve used and also determine the slope angle, after that it can be seen what the value of the safety factor is.
c. A simple design chart can be used as an initial reference or initial assumption of an existing slope theoretically, so that it can be known whether the existing slope meets the minimum safety factor or not, and it is also known whether or not reinforcement is needed on the slope.

6. Suggestion
For further research, various variations of the data can be more diverse and then compared with the results in actual situation to get more accurate results.

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