Slope stability analysis using sheet pile reinforcement with the Bishop method

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Abstract. Slope is a sloping ground surface, and forms a certain angle to a horizontal plane and is unprotected. With non-horizontal soil conditions, a component of gravity will tend to move the ground down, so that landslides cannot longer be avoided. The location of this research is located at 150 KV substation, Payabungan. The selection of sheet piles as an alternative treatment is expected to minimize the occurrence of landslides at the substation, where if there is a landslide at that location will have an impact on the power outages that will disrupt the activities of residents around. This research was conducted with Bishop’s analytical method, aiming to determine the safety factor of the slope before and after reinforcement. In this analysis, sheet pile reinforcement is done with three conditions. From the calculations obtained the value of the safety factor using the Bishop method obtained by 1.11. The value of the safety factor under conditions 1, 2 and 3 was 1.45; 1.50; 1.58. From this study, it was concluded that adding sheet pile as reinforcement would increase the value of the safety factor in order for the slope to be stable compared to the slope without any reinforcement.

1. Introduction

Landslide problems are often encountered in the field of geotechnical science. Landslide events or also known as land mass movements, rocks or their combinations often occur on natural or artificial slopes. Slides on slopes are generally caused by a decrease in the shear strength of the soil, hence it is not capable to carry the burden acting on it [1][2].

Instability can result from rainfall, groundwater levels and changes in geological activities such as faults, fractures and lineages. Likewise, natural slopes that have been stable for years may suddenly fail due to changes in geometry, external forces and loss of shear strength. In addition, long-term stability is also related to weathering and chemical effects that can reduce shear strength and cause shear strength tension cracks. In these circumstances, evaluation of slope stability conditions is quite important. In choosing the type of landslide countermeasure, there will be several alternatives. For this reason, this study tries to provide an alternative to slope reinforcement that can be used as a solution to overcome slides on slopes. The type of slope reinforcement used as an alternative in this study is sheet pile.

Sheet pile is designed to withstand lateral (horizontal) soil pressure when there is a change in land elevation. that exceeds the at-rest angle in the soil. Lateral soil pressure behind the retaining wall depends on the friction angle in the ground (φ) and cohesion (c). Lateral pressure increases from the top to the very bottom of the retaining wall. If not well planned, soil pressure will push the retaining wall causing failure of construction and landslides [3][4].

The slope analysis in this study was conducted to minimize the occurrence of landslides in the substation, where if there is a landslide at that location will have an impact on the power outages that will disrupt the activities of residents around. Primary data needed for the analysis of slope stability are

1.11
1.45
1.50
1.58
CPT data, unit weight (γ), friction angle (ϕ), cohesion (c), permeability coefficient (k). The secondary data used is the project location map and slope layout. This analysis uses initial conditions and slope conditions after being given sheet pile reinforcement.

The Bishop Method is a method that was introduced by A.W. Bishop that uses the cutting method in which the forces acting on each piece Bishop Method is used to analyse circular slip surfaces. In this method, it is assumed that the total normal forces are at the center of the piece and can be determined by describing the forces on the piece vertically or normally. Balance requirements are applied to the pieces that make up the slope. The Bishop Method assumes that the forces acting on the slide have zero resultant in the vertical direction [5][6][7].

In general, there are three kinds of assumptions that can be made namely, assumptions about the normal stress distribution along the surface of the slip, assumptions regarding the inclination of the forces between the pieces, and assumptions about the position of the resultant lines of the forces between the pieces. In most analytical methods, the normal force is assumed to work in the center of the base of each piece, due to the thin section. This applied to a number of assumptions. This Bishop Method uses as many assumptions as (2n – 1) [7]. The Bishop method is a calculation method based on the Limit Equilibrium Method using slices in a circular landslide field. Before the calculation is performed, an attempt is made beforehand to calculate the center point of the landslide. After that, the slope safety factor is performed for the initial conditions and conditions with Geogrid reinforcement by trial and error until the appropriate safety factor is obtained.

The equation used to find the safety factor in the Bishop method is as follows:

\[ SF = \frac{\sum [c \cdot b + (W - u \cdot b) \tan \phi] \left( \frac{1}{M_i} \right)}{\sum W \sin a} \]

Where:
- \( c \) : cohesion
- \( \phi \) : friction angle
- \( F \) : FK (safety factor)
- \( w \) : unit weight of each element
- \( b \) : width of each element
- \( M_i \) : coefficient value

\[ M_i = \left( \frac{1}{\cos a \left( 1 + \tan \phi \tan \beta \right)} \right) \]

2. Methodology

This research was conducted at Panyabungan Substation 150 KV. The data needed is data from the results of soil investigations namely, the Cone Penetrometer and hand boring, where laboratory testing is carried out to obtain the soil property index value of the analytical method that is used to analyze slope stability, the Simplified Bishop Method. The Simplified Bishop Method assumes where the landslide field is considered to be in the form of a circular arc and then the mass above the landslide field is divided into a number of vertical slices. This method also assumes friction forces acting on the slice can be ignored so that only horizontal forces are calculated.

Step of Methodology on Bishop Method
1. Determine the center point of the landslide and the value of R
2. Determine the point of landslide with a circle
3. Divide the landslide area into 10 parts
4. Calculate the area and weight of each segment/slices
5. Find the calculated value of the variable for safety factor
6. Determine the value of 1 / \( M_i \) (\( \alpha \))
7. Draw a line from point R geometry
8. Find to safety factor value (SF)
3. Research results

3.1 Slope condition with sheet pile reinforcement (original slope condition)

In this condition the sheet piles are mounted at the edge of the slope plane with the coordinate of X=68.43m and Y=43.92m along 30m as shown in Figure 1.

![Figure 1. Divisions of Landslide Planes in the Form of Slices](image)

Table 1. Tabulation of Safety Factor Calculations Using Bishop Method for original condition

| W tan Φ | cΔx+W tan Φ | Mi | (cΔx+W tan Φ) / Mi | rm | dm |
|---------|--------------|-----|---------------------|----|----|
| 113,54  | 151,79       | 42.72| 6485.96             | 670.20 | 753.47 |
| 585,84  | 589,02       | 15.02| 39.19               | 1360.57 | 1602.85 |
| 1310,21 | 1314,37      | 7.97 | 164.75              | 2267.35 | 2412.25 |
| 2151,11 | 2156,21      | 4.33 | 497.86              | 2864.07 | 2663.68 |
| 3151,04 | 3157,30      | 2.81 | 1120.33             | 3483.30 | 2044.30 |
| 3225,77 | 3232,03      | 2.14 | 1507.61             | 3183.33 | 1590.08 |
| 3026,58 | 3033,98      | 1.69 | 1784.88             | 2753.25 | 1210.96 |
| 2341,59 | 2349,28      | 1.48 | 1582.02             | 2066.96 | 820.46 |
| 1275,94 | 1284,03      | 1.26 | 1018.19             | 1130.09 | 424.87 |
| 220,85  | 229,17       | 1.14 | 199.69              | 208.12  | 88.84 |
3.2 Calculation Analysis with sheet pile reinforcement.

In this analysis with sheet pile reinforcement, 3 (three) conditions of sheet pile mounting were attempted at the points with the greatest deformation. The planning used sheet piles with predetermined length of 30 m.

3.2.1 Condition 1. In this condition, sheet piles are mounted at the edge of slope plane with the coordinate of X=68.43m and Y=43.92m along 30m as shown in Figure 4.

**Figure 3.** Dimensions of Slope Slices with Sheet Piles in Condition 1

**Figure 4.** Mounting points of sheet piles in the form of slices
3.2.2 Condition 2. In this condition, sheet piles are mounted at the edge of slope planes with the coordinate of \( X=71,85 \text{ m} \) and \( Y=41 \text{ m} \) along \( 30 \text{ m} \) as shown in Figure 6.

![Figure 5. Dimensions of Slope Slices with Sheet Piles in Condition 2](image)

![Figure 6. Mounting points of Sheet Pile in the form of slices](image)

Tabulation of calculations for the analysis of slopes with sheet piles in condition 2 can be seen in the Table 2. The initial value of safety factor that was attempted (trial and error) was 1.51.

**Table 2. Tabulation of Safety Factor Calculations in Condition 2**

| \( W \tan \Phi \) | \( c \Delta x+W \tan \Phi \) | \( Mi \) | \( \frac{(c \Delta x+W \tan \Phi)}{Mi} \) | \( rf \) | \( df \) |
|-----------------|-----------------|--------|-----------------|-------|-------|
| 297,17          | 327,92          | 95.20  | 31218.75        | 2865.58 | 1014.31 |
| 1002,88         | 1006,18         | 16.65  | 60.40           | 3346.99 | 2066.78 |
| 2110,67         | 2115,61         | 6.11   | 345.59          | 4337.16 | 3094.13 |
| 3450,88         | 3457,24         | 3.07   | 1122.94         | 5028.23 | 2849.91 |
| 4934,41         | 4942,00         | 2.017  | 2449.63         | 5715.15 | 3301.55 |
| 6191,72         | 6200,30         | 1.57   | 3926.13         | 6281.61 | 1898.09 |
| 6293,33         | 6302,80         | 1.31   | 4799.14         | 5908.68 | 900.14  |
| 4981,13         | 4990,88         | 1.14   | 4347.05         | 4629.78 | 67.93   |
| 2922,13         | 2932,11         | 1.00   | 2932.11         | 2932.11 | 0       |
| 841,17          | 851,02          | 1.00   | 851.02          | 851.02  | 0       |
| **Jumlah**      | **52053.08**    | **41896.35** | **15192.89**  |       | 1.51   |
3.2.3 Condition 3. In this condition, sheet piles are mounted at the edge of the plane with the coordinate of \(x=73.68\,m\) and \(y=39\,m\) along 30m as shown in Figure 8.

![Figure 7. Dimensions of Slope Slices with Sheet Pile in Condition 3](image1)

![Figure 8. Mounting points of sheet piles in the form of slices](image2)

Tabulation of the calculations for the analysis of slopes with sheet piles in condition 3 can be seen in the Table 3. The initial value of safety factor that was attempted (trial and error) was 1.58.

| \(W \tan \Phi\) | \(cA + W \tan \Phi\) | \(M_i\) | \((cA + W \tan \Phi) / M_i\) | \(rf\) | \(df\) |
|-----------------|-----------------|--------|------------------|-------|-------|
| 308.37          | 482.25          | 234.98 | 113321.48        | 6497.42| 1014.31|
| 885.32          | 888.11          | 30.23  | 29.37            | 4025.45| 2066.78|
| 1996.27         | 2000.79         | 7.79   | 256.65           | 4803.22| 3094.13|
| 3388.44         | 3394.52         | 3.53   | 959.58           | 5507.90| 2849.91|
| 4925.15         | 4932.59         | 2.11   | 2337.21          | 6023.21| 3301.55|
| 6475.85         | 6484.47         | 1.55   | 4174.34          | 6649.96| 1898.09|
| 6413.62         | 6422.97         | 1.29   | 4943.22          | 6073.90| 900.14 |
| 5151.33         | 5161.26         | 1.12   | 4573.61          | 4822.44| 67.93  |
| 2960.34         | 2970.41         | 1.00   | 2970.41          | 2970.41| 0      |
| 862.34          | 872.06          | 1.00   | 872.06           | 872.06| 0      |
| **Total**       | **134437.97**   |        | **48246**        | **15192.89** |        |

Table 3. Tabulation of Safety Factor Calculations in Condition 3
Of the three conditions above where the condition of one sheet pile mounted on the slope with $X = 68.43$ m and $Y = 43.92$ m along 30 meters obtained safety factor value is 1.1. Condition two the value $X = 71.85$ m and $Y = 41$ m along 30 m obtained by safety factor value is 1.50, and condition three with value $X = 73.68$ m and $Y = 39$ m along 30 m obtained safety factor value is 1.58.

4. Conclusion
The value of Safety Factor in the initial condition of the slope using the Bishop method is 1.11 and the condition of the slope with sheet pile reinforcement in Condition 1, 2, and 3 are 1.45; 1.50; 1.58, respectively where the value of the biggest safety factor in condition 3 with a value of 1.58.

5. References
[1] Wulandari P S and Tjandra D, 2015 Analysis of geotextile reinforced road embankment using PLAXIS 2D, Procedia Eng., vol. 125, pp. 358–362, 2015.
[2] Hardiyatmo H C, 2006 Penanganan Tanah Longsor & Erosi. Yogyakarta: Gadjah Mada University Press, 2006.
[3] Hastuty I P, Roesyanto, and Sihite A B, 2018 The decline of soil due to the pile of highway project Medan-Kualanamu (STA 35 + 901) with the finite element method, IOP Conf. Ser. Mater. Sci. Eng., vol. 308, no. 1.
[4] Roesyanto, Iskandar, Silalahi S A, and Fadliansyah, 2018 Soil settlement analysis in soft soil by using preloading system and prefabricated vertical draining runway of Kualanamu Airport, IOP Conf. Ser. Mater. Sci. Eng., vol. 309, no. 1.
[5] Das B M and Sobhan K, 2014 Principles of Geotechnical Engineering, SI Version, Animal Genetics.
[6] Hardiyatmo H C, 1992 Mekanika Tanah I.
[7] Bowles J, 1979 Physical and Geotechnical Properties of Soils. McGraw-Hill, Tokyo