Slope stability analysis in The Babahrot-Blangkejeren road section sta. 13 + 885

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Abstract. The Babahrot - Blangkejeren road section located in Aceh Barat Daya Regency is one of the roads in Aceh Province that often experience landslides because of its location, especially on the Singgah Mata Mountain track, which is in hilly areas. Landslides often occur at STA 13 + 885 at the foot of Singgah Mata Mount. Access to this lane is used for economic, educational, and social activities from Gayo Lues Regency to Blang Pidie, Aceh Barat Daya Regency. The impact of landslides is the disconnection of Gayo Lues community access to Southwest Aceh and vice versa. Therefore, it is necessary to do a slope reinforcement study at the top of the road construction. The analysis used to find the safety factor (FK) was Bishop Slicing Method. For comparison, the safety factor was also analyzed by using an application program (Plaxis). The results of the analysis of slope stability in the initial conditions using manual methods (Bishop Slicing Method) and using the application program (Plaxis) show that the average safety factor against landslides is smaller than 1. Thus, it can be said that, in the existing conditions, the slope is unstable. So, it is necessary to do slope reinforcement to prevent landslides. Based on the results obtained after the improvements to the slope angle and the use of reinforcement slopes with cantilever retaining walls, the value of the safety factor for landslides increased from 0.810 to 1.620.

1. Introduction

Indonesia is a country that experiences landslides many times. This is because most parts of Indonesia are in mountainous and hilly areas, so it is very vulnerable to landslides, specifically in the rainy season. As a result, it can cause enormous losses for the Indonesian people, especially the loss of life.

The Babahrot-Blangkejeren road section located in Aceh Barat Daya Regency is one of the provincial road segments in one of the Provinces in Indonesia, namely Aceh. This road section experiences landslides many times because of its location in hilly areas, especially on the Singgah Mata Mountain track. Landslides often occur, resulting in the obstruction of the middle lane of the Aceh Province road system and the obstruction of economic, educational, or social activities from the Gayo Lues Regency to Blang Pidie, Aceh Barat Daya Regency. The impact of landslides resulted in the disconnection of Gayo Lues community access to Southwest Aceh and vice versa. It is necessary to handle the slopes to prevent the occurrence of landslides on these roads.

The slope stability analysis on the existing condition of the lower slope in Babahrot-Blangkejeren road section using manual method (Fellenius method) and application (Geoslope) obtained that safety
factors at all points of the review were unsafe. After strengthening with the counterfort type retaining wall and changing the slope angle < 20°, a safety factor becomes more than 1.5, which is safe [1].

The calculation of the initial slope conditions with the Fellenius method obtained a safety factor of 1.4701 and, with the application (Plaxis), obtained the value of the safety factor of 1.3476. The value of the safety factor still less than the requirement for slope stability, which is 1.5. Alternative handling is done in two ways: the first one uses a counterfort wall plus bored piles along 10 meters, and the second one uses bored piles along 11 meters. The results show that the use of 11 meter bored piles can increase the safety factor to 1.6383, which is more than 1.5 and safe [2].

To support the analysis, supporting data is needed in the form of soil parameter data. The soil parameter data used is the secondary data obtained from the Aceh Highways Agency.

2. Research method
The study was conducted at STA 13 + 885 Babahrot-Blangkejeren section in the Southwest Aceh District. This road is a provincial road link that connects Southwest Aceh District and Gayo Lues District. Two methods were used to analyze slope stability. The methods are a manual method using the Bishop slice method and the application using Plaxis. This is to obtain the safety factors of existing conditions and safety factors of the post-reinforced conditions.

2.1. Sampling and testing of soil samples
The study was conducted at STA 13 + 885 Babahrot-Blangkejeren section in the Southwest Aceh District. This road is a provincial road link that connects Southwest Aceh District and Gayo Lues District. Taking undisturbed samples is done when testing boring at a certain depth. The sampling method follows the applicable SNI and ASTM procedures. The number of samples at that point is 1 (one) tube that taken at a depth close to the end of drilling. The tube is then taken to the laboratory to be tested for soil physical and mechanical properties. The tube carried will be coded according to the drill point and its depth. In addition, soil sampling is disrupted using the test pit method. The test pit work is to find out the type and thickness of the layer below the topsoil. Soil sampling for the pit 1 test was taken at STA 13 + 885 on the upper slope of coordinates of 03°56'41.8” N and 096°45'53.3” E.

Laboratory tests carried out on all disturbed soil samples and undisturbed soil samples. The disturbed soil samples were obtained at the test wells in Test Pit (TP) testing, whereas the undisturbed soil samples were obtained at Bored Hole (BH) in boring tests. Laboratory testing consists of testing the physical and mechanical properties of the soil. The whole test is based on the American Society for Testing and Materials (ASTM) standard.

Examination of the physical properties or the properties of soil indices, called properties test index, includes:
- Unit weight,
- Natural moisture or water content,
- Specific gravity,
- Atterberg limit, and
- Grain size distribution.

Meanwhile, for testing the mechanical properties of the soil (mechanical properties test), the testing of shear strength with the direct shear test includes cohesion (c), shear angle (φ), angle dilatancy (Ψ), modulus young (E), and poison ratio (v).

2.2. Test result data
Based on the soil parameter data obtained, it is assumed that the land in that location is homogeneous. The homogenous land assumption was formed by averaging existing soil data into three types of soil, as found in table 1. The soil parameter values obtained in table 1 are used as input to the Plaxis program. The soil permeability coefficient ‘kx’ and ‘ky’ are assumed to be the same and are obtained from the results of interpretation with the soil type.
Table 1. Data on soil parameters.

| Soil Parameters       | Layer 1 silt clay soil (Blue) | Layer 2 sedimentary rock with a silt (Red) | Layer 3 solid sedimentary rocks (Yellow) | Unit |
|-----------------------|-------------------------------|-------------------------------------------|------------------------------------------|------|
| Material model        | MC                            | MC                                        | MC                                       | -    |
| Type of behaviour     | Drained                       | Drained                                   | Drained                                  | -    |
| Dry soil weight ($\gamma_{sat}$) | 16.31                        | 21.56                                     | 23.52                                    | kN/m³ |
| Saturated soil weight ($\gamma_{sat}$) | 18.91                        | 23.52                                     | 25.48                                    | kN/m³ |
| Horizontal permeability ($k_x$) | 0.000198                    | 0.0831                                    | 0.0831                                   | m/day |
| Vertical permeability ($k_y$) | 0.000198                    | 0.0831                                    | 0.0831                                   | m/day |
| Young’s modulus ($E_{rof}$) | 2942.1                       | 1271618                                   | 12000000                                 | kN/m² |
| Poisson’s ratio ($\nu$)  | 0.4                           | 0.3658                                    | 0.3658                                   | -    |
| Cohesion ($c$)         | 2.03                          | 1915                                      | 3351                                     | kN/m² |
| Friction angle ($\phi$) | 24.32                        | 22                                        | 25                                       | °    |
| Dilatancy angle ($\psi$) | 0                           | 2                                         | 4                                        | °    |
| Shear Modulus(G)       | -                             | 465520                                    | 4270934                                  | kN/m² |

The distribution of soil types on the slopes can be seen in figure 1. The blue layer is clayey silt soil; the red layer is a layer of sedimentary rock with silt; the yellow layer is a layer of solid sedimentary rock.

2.3. Application program (Plaxis)

Plaxis is a program in the geotechnical field that uses the Finite Element Method for geotechnical applications; in this program, soil models are used to simulate the behavior of the soil. The material model described in the Plaxis program is a form of a mathematical equation that describes the relationship between stress and strain. This material model is often expressed in terms of added stress and added strain [3].

Plaxis can be used to conduct modeling and analysis of all geotechnical problems such as slope stability, seepage, and consolidation. In addition, Plaxis can also model and analyze geotechnical structures and soil interactions with structures such as shallow foundations, deep foundations, retaining walls, anchors, etc. It should be noted in the use of Plaxis that the user must master the theories and concepts concerning soil mechanics and foundation engineering. This is very important because Plaxis will still perform calculations and output even if the input data is incorrect.

The next discussion is the analysis of the initial slope conditions and slope conditions after the improvement of the slope angle and slope reinforcement using a retaining wall on the slope above the road. The initial conditions of the slope, for more details, can be seen in figure 2 below.
Figure 2. Initial slope conditions.

In figure 2, it shows that the landslide field in the initial condition of the slope. A landslide is found on the slope above the road body. The red layer shows a potential landslide layer of soil, while the blue layer shows a stable or safe soil or rock layer.

Figure 3. Slope condition after improvement of slope angle and addition of soil retaining walls.

Figure 3 shows the slope conditions after improvements to the slope angle and the addition of a retaining wall. It shows the condition of the slopes that have been stable against the threat of landslides.

2.4. Manual method (Bishop)

The Calculation of slope stability analysis on the body of this road uses a simplified Bishop slice method because the solution is more precise and will get a more appropriate safety factor. The Bishop method is the method introduced by A.W. Bishop, who uses a cut method in which the forces act on each piece, as shown in figure 4 and figure 5. The Bishop method is used to analyze the slip surface in a circular shape. In this method, it is assumed that the total normal forces work at the center of the cut and can be determined by describing the forces on the pieces vertically or normally. Balance requirements are used on the pieces that make up the slope. The Bishop method assumes that the forces acting on the slices have a resultant zero in the vertical direction. The cross-section of the landslide is divided into several sections or slices in the vertical direction, and the effect of forces on the edges of each slice is also taken into account [5].

Safety factor equation of the Bishop slice method used is as follows:

\[
F = \frac{\sum_{i=1}^{n} [c'b_i + W_i(1 - r_u)\tan \phi']}{\sum_{i=1}^{n} W_i \sin \theta_i} \left( \frac{1}{\cos \theta_i(1 + \tan \theta_i \tan \phi')} \right)
\]

(1)
3. Result and discussion

The results of this method are the safety factors obtained using the Bishop method and using the Plaxis applications. The results can be seen in table 2 below.

Table 2. Safety factors for initial slope conditions.

| Point (STA) | Safety Factor (Bishop) | Safety Factor (Plaxis) |
|-------------|------------------------|------------------------|
| 13 + 885    | 0.822                  | 0.810                  |

From table 2, it can be observed that, in the initial condition of the slope, the safety factor obtained both by manual method and application is below 1 (SF <1). This means that all slopes are in critical condition. Therefore, efforts must be made to deal with it, so that there is no landslide.

The results of slope stability analysis in three conditions, which are initial condition, after reinforcement condition, and additional handling condition, using Plaxis applications, can be seen in table 3 below.

Table 3. Safety factors for initial slope conditions and after strengthening.

| Cantilever Retaining Wall Stability | Safety Factor | Information |
|-----------------------------------|---------------|-------------|
| Initial Condition                 | 0.810         | Unsafe      |
| After Strengthening Condition     | 1.620         | Safe        |
From table 3, it can be observed that the initial conditions of the slope are not safe because, based on the results of calculation, the safety factor is smaller than 1 (SF <1). Then, after repairing the slope angle and using reinforcement slopes with retaining walls, the value of the safety factor for landslides increased from 0.810 to 1.620 or increased to double.

Based on the data displayed and the calculation results on potential landslides, it can be explained that there are three causes of potential landslides on the Babahrot-Blangkejeren road section in STA 13 + 885, namely:

- The condition of the slopes is steep about 35°
- There is a slip (rock layer) under the water-resistant soil surface
- There is enough water (rain) that enters the soil pores so that the soil pressure increases

These results are consistent with those stated by Brook [5] that landslides will occur if three conditions are met, namely: the slope is quite steep, there is a field of launch (rock) under the water-resistant soil surface, and there is enough water (rain) which enters the soil pores above the impermeable rock layer so that the soil pressure on the slope increases. This result is also supported by Bowles [6], stating that rainfall as one component of the climate will affect water content and saturation. Rain can increase the water content in the soil, and further will cause the physical condition of the slope's body to change. The increase in soil water content will weaken the physical-mechanical properties of the soil (affect the internal condition of the body of the slope) and reduce the slope safety factor. The analysis of the landslides in cililin also found that landslides occurrence are influenced by two factors, namely the control factor (the physical property of rock or soil making up slope, geological structure, slope, and hydrology) and the trigger factors (rainfall, vegetation cover, land use, and earthquake vibration) [7].

Based on the data used in the analysis of slope stability on each slope reviewed, in the initial conditions, the slopes at the Babahrot-Blangkejeren road section are in a critical condition. After repairing the slope angle and utilizing slope reinforcement with retaining walls, then the slopes are in a safe condition. This is in accordance with the function of the retaining wall, as stated by Bowles [8], that the retaining wall is one of the concepts of soil reinforcement that is widely used in civil engineering work to hold soil loads vertically or to certain slopes. Retaining walls are the constructions that are used to provide stability to the soil or other materials whose conditions do not have a natural slope. This result is also in line with the research conducted by Ciptaning [1] that the use of soil retaining walls by improving the slope angle can increase the safety factor of the slope to be more than 1.5, which is safe. Research conducted by Pratama [2] also found a similar thing, that the use of bored piles with a height of 11 meters can increase the safety factor to 1.6343, which is more than 1.5 (safe).

4. Conclusions
Based on the results and discussion of slope stability analysis on the Babahrot-Blangkejeren road section on STA 13 + 885, conclusions can be drawn as follow:

- Factors causing landslides on the Babahrot-Blangkejeren road include a reasonably steep slope, a sliding field which is a rock layer under the water-resistant soil surface, and enough water or rain that enters the soil pores and increases the pressure land;
- In the initial conditions, after being calculated using manual Bishop method and the application program (Plaxis), slope safety factors become less than 1 (SF <1); and
- Safety factor, calculated after slope reinforcement with soil retaining wall and after cutting or improving slope angle, increased from 0.810 to 1.620, which is more than 1.5 (safe).

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