Analysis of slope stability of a segmental concrete block wall and geogrid in Meulaboh–Geumpang road

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Abstract. Landslide disasters are often a threat to the smooth transportation and economy of the community. Meulaboh-Geumpang crossroad, located in the western coastal region of Aceh Province, is one of the landslides-prone areas. Thus, the appropriate solution is necessary for preventing and handling the landslides in this area. This study conducted slope reinforcement using segmental concrete blocks combined with geogrids. The planned vertical distance of the geogrid (Sv) was 0.2 m, 0.4 m, and 0.6 m, while the length of the geogrid plan was 1 meter outside the failure envelope of the slip surface at the existing condition. The slope of the planned slope angle for the installation of the concrete blocks was 45°, 60°, and 90°. The dimensions of segmental concrete blocks were 20 cm high, 30 cm wide, and 40 cm long. The safety factor, at the condition after overall reinforcement, reached an acceptable amount for handling, only at STA 84 + 280 with a slope of 90°. A reinforced concrete beam was not added to the foot of segmental concrete blocks because it did not meet the acceptable safety factor, which was 1.32. The result of this analysis is to provide useful information about the form of a landslide that occurred. It will also inform the best combination of concrete block wall reinforced with geogrid for the reinforcement on the slopes. Thus, relevant parties can use it for landslide handling in these locations.

1. Introduction

Landslide is one of the geological disasters that occurred due to the movement of various types of rocks or soil masses, such as falling rocks or large chunks of rocks. A landslide or known as the mass movements of earth, rocks, or both earth and rocks, often occurs on natural or artificial slopes. It is a natural phenomenon, that is, nature seeks a new balance due to interferences or influencing factors. There are internal and external factors causing landslides. Internal factors include the rising pore water pressure, the geotechnical condition, and the decreasing shear strength of the soil/rock. On the other hand, external factors are high rainfall [1], river erosion, and earthquakes.

Landslides frequently occur in Aceh, especially on the provincial roads [1]. In general, it begins with a high rainfall intensity a few days earlier. For example, a landslide occurred on Wednesday night (10/5/2017) around 11 pm, in which part of the road was eroded, as illustrated in Figure 1, leading to the disruption of the land transportation between Meulaboh and Geumpang on Thursday (11/5/2017) [2].

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Figure 1. The Landslide occurred on Wednesday night (10/5/2017)

Meulaboh-Geumpang road is a road connecting between West Aceh and Pidie districts. The residents use this road to bring staples or vegetables from Pidie district to West Aceh district, or vice versa. For smooth traffic between Meulaboh and Geumpang, an appropriate reinforcement solution is necessary to overcome the landslide issue to avoid similar incidents that will distract the economic growth in the area.

Slope stability analysis plays a critical role in the planning of civil constructions, especially on the roads located in slope-prone areas. It is essential for understanding their performance and, in particular, their stability, reliability, and deformations. Thus geotechnical engineers often seek to calculate values of quantitative indicators of performance, such as the factor of safety (safety factor), lateral deformation, and the probability of failure and reliability index [3]. Slope stability analysis is undertaken to produce a safe plan for both natural and artificial slopes. The parameters resulted from the slope stability analysis are the shape of the slip surface and the safety factor. The safety factor is to identify the slope stability, defined as the ratio between the shear strength of the soil and the shear stress on the earth mass [4].

Slopes-prone landslides can be strengthened using several reinforcement materials. One of the reinforcement materials is geogrid. Geogrid is a geosynthetic material consisting of connected parallel sets of intersecting ribs with apertures of sufficient size to allow strike-through of the surrounding soil, stone, or other geotechnical materials [5]. There are three categories of geogrids, as illustrates in Figure 2, that are currently available: (1) unitized polyolefin, (2) coated yarn, and (3) polyester rod (or strap).

This study used segmental concrete blocks [6] combined with geogrids. The planned vertical distance of the geogrid (Sv) was 0.2 m, 0.4 m, and 0.6 m, and the length of the geogrid plan was 1 meter outside the failure envelope of the slip surface at the existing condition. The planned slope angle of the concrete block installation was 45°, 60°, and 90°. The dimensions of the segmental concrete block were 20 cm high, 30 cm wide, 40 cm long.

This study aimed to analyze the stability of the existing and the reinforcement slope conditions using segmental concrete blocks combined with geogrids. The value of the safety factor after the overall reinforcement reached the permissible safety number for handling only at STA 84 + 280 with a slope of 90°. No reinforced concrete beam was added at the foot of the segmental concrete block as it did not satisfy the permitted safety factor of 1.32.
2. Materials and Method

This research was conducted at two points, namely Km 84 + 280 and Km 84 + 910. The coordinates of the research location are presented in Table 1.

| Point | STA   | Coordinate                  |
|-------|-------|-----------------------------|
| A     | 84 +280 | N 4° 30’ 39.68” - E 96° 7’ 46.56” |
| B     | 84+910  | N 4° 30’ 37.97” - E 96° 7’ 48.61” |

The data required for this study was in the primary and secondary data. Primary data included the measurements of slope geometry, location coordinates, documentation, data of soil sample testing in the laboratory, and modeling of the slope condition. The secondary data was the map of West Aceh district, map of the research location, the parameter of young modulus value, permeability, and Poisson ratio.

The data was used to analyze the slope stability employing the finite element method on the existing slope condition to determine the value of the safety factor and the shape of the slip surface. The finite Element Method is an elasto-plastic method widely accepted in geotechnical area. It is much economical and time effective with iterative capability [7] [8]. Furthermore, reinforcement was provided at the existing slope location that did not meet the safety factor of slope stability. The stages of slope stability analysis are described in the following section.

2.1. Data input stage

The analysis started by data input, consisting of slope geometry input, the geometric depiction of the slope, load input, material data input, and mesh generation. The data of the existing slope at STA 84 + 280 were, as follows: the height of the slope was 9 m, and a slope angle of 61°. Meanwhile, at STA 84 + 910, the slope height and angle were 8 m and 70°, respectively. Figures 3a and 3b illustrate the existing conditions at the research location.

![Figure 3. The existing conditions of the slope geometry (a) STA Km 84+280 and (b) STA Km 84+910](image)

The geogrids used in this study was a uniaxial geogrid, as shown in Figure 4. The planned vertical distance of the geogrid (Sv), as illustrated at Figure 4, was 0.2 m, 0.4 m, and 0.6 m while the length of the geogrid plan was 1 meter behind and below the failure envelope of the slip surface at the existing slope condition without reinforcement after being analyzed by the finite element method. Meanwhile, the concrete blocks used were fabricated segmented units with dimensions of 20 cm high, 30 cm wide, 40 cm long.
2.2. Data calculation stage
Data calculation conducted on the slope stability analysis consisted of several stages, including:
(i) The initial condition that was the calculations before load working
(ii) The construction stage, the parameter activated by $\Sigma M_{weight}$ and $\Sigma M_{load}$
(iii) The calculation of deformation and total displacement using the load advancement ultimate level.
(iv) The security factor analysis was using phi-c reduction.
(v) The reinforcement stage, that was the stress and strain phases due to the self-load, the external load and loads of concrete block and geogrid walls
(vi) The security value calculation process.

2.3. Data output stage
The output of the slope stability analysis consisted of, as follows:
(i) The safety factor of the existing condition and the condition of the segmental concrete blocks walls reinforced by geogrids;
(ii) Slope deformation is shown based on the total displacement;
(iii) The graph of safety factors

3. Results and discussion
The soil parameters used in this analysis are displayed in Table 2.

**Table 2.** The soil parameters of the research location

| Soil Parameter                  | Point | Unit       |
|--------------------------------|-------|------------|
|                                | A1    | A2    | A3    | B1    | B2    |         |
| Material model                 | MC    | MC    | MC    | MC    | MC    | -        |
| Type of behaviour              | Drained | Drained | Drained | Drained | Drained | -        |
| Dry soil weight ($g_{dry}$)    | 12.788 | 10.632 | 13.023 | 12.994 | 10.807 | kN/m$^3$ |
| Wet soil weight ($g_{wet}$)    | 17.054 | 14.877 | 15.877 | 16.132 | 16.152 | kN/m$^3$ |
| Horizontal permeability ($k_x$) | 0.0864 | 0.0864 | 0.000864 | 0.000864 | 0.00864 | m/day |
| Vertical permeability ($k_y$)  | 0.0864 | 0.0864 | 0.000864 | 0.000864 | 0.00864 | m/day |
| Young’s modulus ($E_{ref}$)    | 12262.5 | 12262.5 | 6867 | 6867 | 11772 | kN/m$^2$ |
| Poisson’s ratio ($\nu$)        | 0.25  | 0.25  | 0.3   | 0.3   | 0.25  | -        |
| Cohesion (c)                   | 24.53 | 25.5  | 23.54 | 17.16 | 14.12 | kN/m$^2$ |
| Friction angle ($\phi$)        | 19.3  | 19.8  | 20.3  | 25.6  | 27.9  | $^\circ$ |
| Dilatacy angle ($\Psi$)        | 0     | 0     | 0     | 0     | 0     | $^\circ$ |
3.1. The Results of Slope Stability Analysis

Initially, slope stability analysis was conducted on two different slope conditions without- and with-reinforcements. This analysis was carried out at two separate locations, which are at STA 84 + 280 and 84 + 910. Overall, the results indicated that the slope safety reached an acceptable safety factor on slope conditions with reinforcements, which was SF ≥ 1.5. The results are shown in Tables 3 to 5. The slope stability analysis of the existing conditions at STA 84 + 280 and STA 84+910 suggested critical to unsafe conditions with a safety factor of 1.14 and 1.16, respectively. Thus, reinforcement is required at both STA 84 + 280 and 84 + 910. The analysis results of the safety factors of the existing conditions at STA 84 + 280 and 84 + 910 are shown in Table 3.

| No. | STA (Km) | Safety Factor |
|-----|----------|---------------|
| 1   | 84+280   | 1.14          |
| 2   | 84+910   | 1.16          |

Further slope stability analysis was carried for the slope with reinforcement. Thirty-six (36) models of reinforcements were analyzed, as shown in Tables 4 and 5.

| STA (Km) | Safety Factor |
|----------|---------------|
|          | Slope of 45° | Slope of 60° | Slope of 90° |
|          | Sv           | Sv           | Sv           |
| 84+280   | 2.22         | 2.17         | 1.89         |
| 84+910   | 3.55         | 3.38         | 2.98         |
| 84+280   | 0.2          | 0.4          | 0.6          |
| 84+910   | 0.2          | 0.4          | 0.6          |

Table 4. The Results of the Safety Factor Analysis without a reinforced concrete beam

| STA (Km) | Safety Factor |
|----------|---------------|
|          | Slope of 45° | Slope of 60° | Slope of 90° |
|          | Sv           | Sv           | Sv           |
| 84+280   | 2.53         | 2.41         | 2.27         |
| 84+910   | 3.81         | 3.67         | 3.11         |
| 84+280   | 0.2          | 0.4          | 0.6          |
| 84+910   | 0.2          | 0.4          | 0.6          |

The results of this further slope stability analysis showed that the closer the geogrid vertical distance on the slope produces higher the slope safety factor, similarly for the slope of the concrete blocks. The more declivous of the concrete block results in higher the value of the safety factor. The addition of a reinforced concrete beam at the foot of the segmental concrete blocks also increased the safety factor value, as shown in Table 5.

Table 5. The Results of the Safety Factor Analysis with a reinforced concrete beam

| STA (Km) | Safety Factor |
|----------|---------------|
|          | Slope of 45° | Slope of 60° | Slope of 90° |
|          | Sv           | Sv           | Sv           |
| 84+280   | 2.53         | 2.41         | 2.27         |
| 84+910   | 3.81         | 3.67         | 3.11         |
| 84+280   | 0.2          | 0.4          | 0.6          |
| 84+910   | 0.2          | 0.4          | 0.6          |

3.2. The Comparison of Safety Factor, Vertical Geogrid Distance and Slope of Concrete Blocks Based on the Analysis of Finite Element Method

Another slope stability analysis was carried out by adding geogrid reinforcement. The slope stability analysis with additional geogrid reinforcement on the Meulaboh-Geumpang road, at STA 84 + 280 and 84 + 910, was conducted for the geogrid (Sv) vertical distance of 0.2 m, 0.4 m, and 0.6 m, and the slope of segmental concrete blocks of 45°, 60°, and 90° to achieve a safe and appropriate safety factor (Figure 5 and Figure 6).
Figure 5. The Relationship of the Vertical Geogrid Distance and the Slope of Segmental Concrete Blocks with or without a reinforced concrete beam at STA 84 + 280

Figure 6. The Relationship of the Vertical Geogrid Distance and the Slope of Segmental Concrete Blocks with or without a reinforced concrete beam at STA 84+910

Based on the analysis, the safety factor, at the geogrid vertical distance (Sv) of 0.2 m, is higher than the distance of 0.4 m and 0.6 m. Whereas for the slope of segmental concrete blocks, the safety factor of the 45° slope is higher than the slope of 60° and 90° because the higher vertical distance of the geogrid has less strength to bind the smaller soil particles. Meanwhile, as expected, landslides are more likely to occur at the steeper slopes compared to gentle slopes.

4. Discussion

Based on the soil and reinforcement parameters used in the slope stability analysis on each slope reviewed, the slopes on the Meulaboh-Geumpang road at STA 84 + 280 and STA 84 + 910 produced different safety factor values. The results of the slope stability analysis on the slopes of STA 84 + 280 employing the Plaxis program with the geogrid vertical distances (Sv) of 0.2 m, 0.4 m and 0.6 m and the slope of segmental concrete blocks of 45°, 60°, and 90° showed the highest safety factor at the geogrid vertical distance (Sv) of 0.2 m and the slope of segmental concrete blocks of 45° with a reinforced concrete beam on foot. This finding suggested that the geogrid vertical distance (Sv) of 0.2 m provided a higher strength to bind the soil particles compared to the vertical geogrid (Sv) distance of 0.4 m and 0.6 m. Only the value of the safety factor at STA 84 + 280 with the geogrid vertical distance condition of 0.6 m and the slope of 90° without using a reinforced concrete beam on the foot that did not satisfy the criteria of the safety factor, i.e., 1, 37 <1.5.
At STA 84 + 280, the safety factor values after reinforced using the geogrid vertical distances of 0.2 m, 0.4 m, and 0.6 m combined with the slope of segmental concrete blocks of 45° and a reinforced concrete beam at the foot are 2.53, 2.41, and 2.27, consecutively; or 2.22, 2.17, and 1.89, successively for those without a reinforced concrete beam. Furthermore, the safety factor values of the treatment using the same vertical distance along with the segmental concrete block slope of 60° and a reinforced concrete beam at the foot, were 2.43, 2.20, and 2.05, consecutively or 2.12, 1.87, and 1.73, correspondingly when no a reinforced concrete beam used. Next, the handling utilizing the same vertical distance and a segmental concrete block slope of 90° with a reinforced concrete beam at the foot resulted in the safety factor values of 2.18, 1.80, and 1.66, correspondingly or 1.71, 1.54, and 1.37 correspondingly without a reinforced concrete beam. The results showed that only the handling that employed a 0.6 m vertical geogrid distance and the segmental concrete block slope of the 90° that did not fulfill the requirements (SF ≤ 1.5).

At the STA 84 + 910, the treatment using a closer geogrid vertical distance led to a higher safety factor value. Similarly, for the slope of the concrete block, the less sloping the concrete block, the higher the safety factor.

5. Conclusion and Recommendation

Based on the results of the slope stability analysis, several conclusions and suggestions are presented in the following sections.

5.1. Conclusions
1. The types of landslide occurred at both STA 84 + 280, and STA 84 + 910 locations are rotational landslides, namely the movement of rock and soil mass in a curved surface of rupture
2. The values of the safety factor in existing conditions at both STA 84 + 280 and 84 + 910 are 1.14 and 1.16, respectively so that landslides occurred.
3. The highest safety factor is achieved if a reinforcement using either geogrid vertical distance (Sv) of 0.2 m or segmental concrete block slope of 45° with a reinforced concrete beam, which is 2.53 and 3.81 in STA 84 + 280 and STA 84 + 910, respectively.
4. The value of the safety factor in the condition after the overall reinforcement reached the acceptable safety number for handling, which is SF ≥ 1.5. Only the handling at the STA 84 + 280 that employed a 0.6 m vertical geogrid distance and the segmental concrete block slope of the 90° that did not fulfill the safety requirements of 1.5 (i.e., SF =1.32).
5. The closer the geogrid vertical distance led to a higher safety factor value. Similarly, for the slope of the concrete block, the less sloping the concrete block, the higher the safety factor. Adding a reinforced concrete beam at the foot of the concrete blocks will also increase the value of the safety factor.

5.2. Recommendations
1. The author recommends landslide handling using segmental concrete blocks combined with geogrids as they are very suitable for landslide management on sloped roads.
2. When installing the geogrid, the connection between the geogrids should be the primary concern as if the improper join will negatively influence the strength of the geogrids.
3. Including a dynamic load of an earthquake, is recommended in the further slope stability analysis.
4. When planning reinforcement using geogrids and segmental concrete blocks, the input data must be complete and accurate to obtain robust results.

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