Hard bearing layers identification of escape hill design for facing tsunami – earthquake disaster at Deah Baroe rural area for natural disaster risk reduction

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Abstract. Aceh is surrounded by the Indo-Australia and Euro-Asia subduction plate, which has a profound effect on the occurrence of large tectonic earthquakes above 5 SR which may cause the tsunami. The tsunami which occurred in Aceh on December 26th, 2004 had the large number of the casualties during the 9.3 magnitude earthquake was affected by the lack of temporary evacuation like escape hill. The government's lack of preparedness for escape hill in order to deal with several serious threats such as the earthquake which may cause tsunami disaster in Banda Aceh. To deal with this serious threat, it is necessary to prepare a place of salvation to face the tsunami, in this case is an escape hill (artificial hill). The objective of this research is to determine the carrying capacity of the hard bearing layers identification of escape hill design and the amount of the settlement, due to the load of the embankment height (H_{crit}) and the safety factor value. This research is conducted in Ulee Lheue Banda Aceh which was calculated by the Plaxis 8.2 finite element analysis. The research results found that the settlement value of 17.45 cm still within in the tolerance limits and the bearing stratum is still able to withstand the embankment load. Furthermore, the safety factor value is 1.04 shows that the bearing stratum is still in the safe condition (hard soil) and it does not indicate the failure.

1. Introduction
Aceh Province is located directly on the path of two big earth plates namely the Indo-Australian and Eurasian plates. These plates are the main cause of the strong earthquake M 9.3 which may trigger the tsunami (Munirwansyah, 2018). According to the BMKG InaTEWS (Indonesia Tsunami Early Warning System for the Meteorology, Climatology and Geophysics Agency) (2008), a tsunami that occurred in Aceh on December 26, 2004 was caused by a 9.3 magnitude earthquake centered on UTM (Universal Transverse Mercator) coordinates 3.3 LU - 95.98 BT as shown in figure 1. Given the various earthquake threats that have caused tsunami and the lack of optimal efforts in the construction of evacuation sites in open area [1], it is necessary to conduct studies on temporary evacuation sites, namely escape hills.

Referring to the data taken from BNPB (National Disaster Management Agency), the tsunami disaster which caused the strong vibrations that propagate from the Andaman to the Aceh disaster cause
casualties 173,741 people died, 116,368 people were declared missing, it was also causing the thousands of houses and buildings damaged, and almost 500,000 people became refugees [2]. The high number of casualties was influenced by the lack of temporary evacuation sites in Aceh. The government lack of preparedness to provide temporary evacuation sites in Aceh to deal with this serious threat, such as the earthquake that caused the tsunami. However, it is necessary to prepare and build a rescue site, one of them is an escape hill.

![Figure 1. Tsunami distance from epicentre to Tibang escape hill Banda Aceh.](image)

Similar to the other Civil Engineering infrastructure developments, build the escape hill construction required safe and proper planning [3]. Several studies about slope remediation were already conducted by [4] and [5]. Compacted soil-cement fill was conducted by [4] whereas sheet pile with anchor reinforcement was applied by [5]. The temporary evacuation site needs to study the height of critical embankment and the stability of the escape hill slope which is expected to obtain the safety values that meet the stability requirements of the slope so that it will fulfill the appropriate stability value as an evacuation site for the residents to face the tsunami. This study is carried out by using the 8.2 Plaxis program method. The use of the Plaxis program is used to implement the implementation stages in the field into the stages of computational work. The work that describes the conditions of the initial construction which are expected that the implementation in the field can be approached as close and real as possible [6]. The response generated from the program is assumed as a reflection of the actual conditions that will occur in the field. It allows achieving the safe slope design which can be obtained a faster and efficient calculation process.
2. Material and methods
This part shows the method of carrying out the research done. The method implementation included several steps as shown in figure 2. In addition, the detail of each step is explained in the section.

![Figure 2. Steps of the research methods implementation.](image)

2.1. The soil parameter determination
This study applied the physical properties testing and the mechanical properties of the soil. In the physical properties testing. There are three classifications of soil used, namely ASTM (American Society for Testing Material), AASHTO (American Association of State Highway and Transportation Officials Classification) and the USCS (Unified Soil Classification System). The ASTM classification is used to determine the criteria for the subgrade material, while the embankment criteria refer to ASTM and AASHTO which is fit into the category from Excellent to Good, those are A-1, A-3, and A-2. The soil mechanical testing is carried out by the direct shear experiments to obtain the cohesion (c) and the friction angles (φ).

2.2. Geometry escape hill on the Plaxis program
The escape hill geometry modeling on plaxis program data entry is made based on the criteria of escape hill design. It is 35 m pile width and the embankment height are 12 m, the slope angle used is the maximum allowable angle which is 26.5°. This related to the Guidelines for Designing a Hill as the Tsunami Evacuation Site (TES) taken from BNPB [2]. Geometry modeling can be seen in figure 3.

![Figure 3. The Geometric escape hill modelling.](image)

2.3. The soil bearing capacity
To construct the escape hill, the carrying capacity of the soil shall be able to bear the pressure without having to collapse because of the shear which is also determined by the ground shear strength. The calculation of soil carrying capacity can be calculated based on Terzaghi's theory in equation (1).
The soil shear strength is the resistance force carried out by the soil grain against the shear force. In obtaining the value of the ground shear strength proposed by Coulomb can be determined by equation (2).

\[ \tau = c + \sigma \tan \phi \]  

(2)

2.5. The critical embankment height

In order to prevent the sliding and soil spreading around the embankment where the subgrade is under the saturated condition, it is highly necessary to study the collapse of the bearing capacity of the subgrade due to embankment [6]. And the easiest method to figure out this thing is by taking into account the height of the critical embankment as mentioned in equation (3).

\[ H_{\text{crit}} = \frac{C_u}{\gamma_{\text{embankment}}} \]  

(3)

2.6. The slope collapse criteria

[6] stated that the slope material has a tendency to occur due to the landslide shear pressure caused by gravity and other forces (water flow, tectonic pressure, earthquake). This tendency is detained by the shear strength of the slope material as it is explained by the Mohr Coulomb theory with this equation:

\[ S = c + \sigma_n \tan \phi \]  

(4)

![Figure 4](image-url). The Mohr-Coulomb collapse criteria slide test principle [6].

The Collapse Criteria explained by Mohr Coulomb on The Shear Test Principle can be seen in figure 4. Based on figure 4, it can be seen that (a) objects achieve a W force, then a reaction arises as much similar as the N, where the direction is opposite to W, The object (b) is given a horizontal force, and the F reaction arises where its magnitude depends on the surface roughness of the shear plane. The (c) Resultant (R) is the combination of the vector N and F, (d) If the P style is given the addition, the the friction force is also increase until it reaches the maximum value (limiting value F_{max}), then the object
will move, the combination between $F_{\text{max}}$ forms the angle of $\phi$, (e). (e) The relation between the normal voltage and the shear stress when collapsing \[7\].

2.7. The safety factor
Generally, the value of the safety factor is greater than one ($FS \geq 1$) to provide the estimation of the safety factor in the slope stability analysis \[3\]. However, it is important to ensure that slope design is safe to prevent unexpected factors during the analysis and construction is taking place \[8\]. The unexpected error which may occur is such as the incorrect data, lack of analysis, lack of work skills and the bad field supervision.

2.8. The material modeling
The critical embankment ($H_{\text{crit}}$) and slope stability study are using the plaxis program and calculated by trial and error. The material modeling is proportionally conducted by increasing the value of the soil parameters to obtain a stable and balanced condition.

| c variant model  | $\varphi$ variant model | $\varphi + 10\%$ | $\varphi + 20\%$ |
|------------------|-------------------------|------------------|------------------|
| $c$              | FS, $U_{\text{tot}}$    | FS, $U_{\text{tot}}$ | FS, $U_{\text{tot}}$ |
| $c + 50\%$      | FS, $U_{\text{tot}}$    | FS, $U_{\text{tot}}$ | FS, $U_{\text{tot}}$ |
| $c + 100\%$     | FS, $U_{\text{tot}}$    | FS, $U_{\text{tot}}$ | FS, $U_{\text{tot}}$ |

3. Results and discussion

3.1. The location observation
The location observation was conducted at Deah Baro Village, Meuraxa subdistrict Banda Aceh. The location is chosen based on the data from the previous research and the field review of the Tsunami Height Memorial Poles, with a maximum run-up when the tsunami occurred in 2004 in Desa Deah Baro reaching 7.0 m, larger than the other villages in Meuraxa where the height of the run-up was reaching up < 7.0 m height. The recorded height of the tsunami run-up wave in Meuraxa was 10 m height \[3\]. So, the escape hill which planned in this study is designed by purpose as shown in figure 3, and as high as > 10 m. For that, the place which can be reached easily and quickly by the people before the tsunami wave reaches was chosen as the location to establish the escape hill.

3.2. The soil parameter
The subgrade parameter and embankment soil used in this study are shown and can be seen in table 2. The parameter values of existing soil for the escape hill subgrade were obtained from the soil sample testing at the Syiah Kuala University Soil Mechanics Laboratory. As a result of physical properties on the existing soil, which obtained from the silty sand types. The land or soil which were used as the embankment material refers to the material classification criteria in building construction guidelines and tsunami testing hills. The soil type which is used as the escape hill heap material in this study is the land/soil with the type of sand covered by categories A-2-4 (AASHTO) and SM (USCS) type.

3.3. The results of escape hill analysis with the Plaxis program
In this study, the analysis of the Escape hill in Plaxis program used nine modelings by reviewing the ability to pxist (bearing capacity) subgrade to withstand the embankment load and the safest slope area. The Modeling is held by varying the value of the cohesion ($c$) and friction angle ($\varphi$) proportionally from the normal conditions of the soil embankment parameters. The result of the cohesion variant modeling
and friction angle modeling can be seen in Table 3. As the result from the first modeling with a pile height of 12 m where the phase calculation of the soil loading is calculated every 2.0 m increments then the declining number is 17.45 cm and safety factor = 1.04–1.

Table 2. The soil parameter values in the escape hill planning.

| Parameter                          | Name   | Sandy Silt 0-1 m | Sandy silt 2-3 m | Silty sand >2 m | Unit     |
|------------------------------------|--------|------------------|------------------|-----------------|----------|
| Material model                     | MC     | MC               | MC               | MC              | -        |
| Type of behavior                   | Type   | Undrained        | Undrained        | Drained         | -        |
| Dry soil weight                    | 𝜋ᵤ     | 9.7              | 10.3             | 11.5            | kN/m³    |
| Wet soil weight                    | 𝜋ₛ     | 21.74            | 21.75            | 21.50           | kN/m³    |
| Horizontal permeability            | 𝑘ₓ     | 8.640E-03        | 8.640            | 8.640E-05       | m²/day   |
| Vertical permeability              | 𝑘ᵧ     | 8.640E-03        | 8.640            | 8.640E-05       | m²/day   |
| Young’s modulus                    | Eₑₑₑ   | 15000            | 8000             | 5000            | kN/m²    |
| Poisson’s ratio                    | 𝜈       | 0.33             | 0.33             | 0.25            | -        |
| Cohesion                           | c       | 0.4              | 10.7             | 1.0             | kN/m²    |
| Friction angle                     | φ       | 37.6             | 32.3             | 25.0            | °        |
| Dilatancy angle                    | ψ       | 0                | 0                | 0               | °        |

Table 3. The cohesion modeling variants and shear angle.

| Cohesion (kN/m²) | Friction angle (°) | Total displacement (cm) | Safety factor (FK) |
|------------------|--------------------|-------------------------|-------------------|
| c                | φ                  | 25.0                    | 17.45             | 1.04              |
| c + 50%          | φ                  | 25.0                    | 17.04             | 1.10              |
| c + 100%         | φ                  | 25.0                    | 16.71             | 1.16              |
| c                | φ + 10%            | 27.5                    | 16.60             | 1.12              |
| c + 50%          | φ + 10%            | 27.5                    | 16.31             | 1.22              |
| c + 100%         | φ + 10%            | 27.5                    | 16.10             | 1.27              |
| C                | φ + 20%            | 30.0                    | 16.03             | 1.28              |
| c + 50%          | φ + 20%            | 30.0                    | 15.96             | 1.33              |
| c +100%          | φ +20%             | 30.0                    | 15.98             | 1.38              |

The second modeling is by increasing the cohesion value by 50%, then obtained a reduction rate of 17.04 cm and a safety factor = 1.10–1. The third modeling is conducted by adding 100% cohesion value, then it obtained a reduction rate of 16.71 cm and a safety factor of 1.16. The fourth modeling is conducted by adding a friction angle value of 10%, it obtained a reduction rate of 16.60 cm and a safety factor of 1.12. The fifth modeling is by increasing the cohesion value by 50% and the friction angle value by 10%, then it obtained a reduction rate of 16.31 cm and a safety factor of 1.22. The sixth modeling is by increasing the cohesion value by 100% and the friction angle value by 10%, obtained a decrease of 16.10 cm and a safety factor of 1.27. The seventh modeling is by adding a friction angle value of 20%, obtained a reduction rate of 16.03 cm and a safety factor of 1.28. The eighth modeling is by adding 50% cohesion value and 20% friction angle value, obtained a decrease of 15.96 cm and a safety factor of 1.33. The ninth modeling is by adding 100% cohesion value and 20% friction angle value, obtained a decrease of 15.98 cm and a safety factor of 1.38.
3.4. The results of the escape hill output with the Plaxis program

The following shows the output of the Plaxis program which is deformed mesh and arrow in the natural conditions and modeling by increasing the cohesion value and the friction angle value which is in the most stable condition.

Figure 6 shows an arrow that shows the direction of deformation motion from the embankment that is passed to the subgrade layer. The shearing force generated by the slope is still smaller than the shearing force of the soil so that the subgrade is still able to hold the embankment as high as 12 m.

Figure 7 shows the deformed mesh that occurred. In the calculation of Plaxis by increasing the height of the embankment 12 m from the existing height, it was found that at the stage construction the subgrade was still able to withstand the embankment load with settlement of 17.45 cm and the soil body has not to collapse and the safety factor value shows that the slope in safe condition does not show an indication of landslide with FS = 1.04.
Modeling of soil parameters is carried out by increasing the parameter value of embankment soil, namely cohesion value (c) and friction angle (φ) to obtain a safe condition than the calculated natural conditions [9]. From the various modeling that has been carried out, the most stable condition is obtained by modeling by increasing the value of cohesion (c) by 50% (1.5 kN/m$^2$) and the value of friction angle (φ) by 20% (30º).

As it is shown in figure 8, shows the arrow that shows the direction of deformation motion from the embankment is passed to the layer of the subgrade. The shear force generated by the slope is smaller than the shear force of the soil. So, the subgrade is able to hold the pile with 12 m height.

Figure 8. Total displacement with 12 m embankment height (c+50% dan φ+20%).

Figure 9 shows the results of the Plaxis output in the form of deformed mesh at 12 m embankment height from the original soil height where subgrade is still able to withstand the embankment with a
decrease of 15.96 cm. So that the soil has not been collapse and the safety factor value shows the slope is in stable condition with Safety Factor \((FK)\) is \(1.33 > 1\).

![Deformed Mesh](image)

**Figure 9.** The deformed mesh with 12 m embankment height \((c+50\% \text{ dan } \varphi+20\%)\).

3.5. Discussion

Based on the soil samples testing in the planned location, the researcher found that the subgrade used in this research is the sandy silt. The calculations have been conducted by using the 8.2 Plaxis program with the Mohr-Coulomb model to calculate the safety factor value of the embankment height based on soil the parameters. It is important to set the material that meets and fit to the escape hill planning specifications by the trial and error. The safe characteristic in the embankment is obtained by using the silty sand soil type as the main embankment material.

Based on the theory stated by Terzaghi’s, the soil bearing capacity, the forces acting are the forces due to the weight of the embankment load. An arrow shows that the load from the embankment is passed and pointed directly to the layer and can be deployed along the shear plane which does not exceed the subgrade’s strength. The soil settlement that occurs due to embankment load is still within the tolerance value so that the subgrade still tends to hold the embankment [9]. In the very natural conditions with the height of embankment is 12 m height \((h)\), the calculations conducted by using the Plaxis computation shows the settlement value condition is in the tolerance limit of 17.45 cm and the safety factor value FK is 1.04–1 which indicates the slope is still safe and do not indicate the slope slides. The modeling is conducted on the landfill parameters from the natural conditions in purpose to obtain the decreasing value and stable safety factor value. The most stable condition is shown in the modeling which increased the value of cohesion \((c)\) by 50% \((1.5 \text{ kN/m}^2)\) and the value of friction angle is \((\varphi)\) 20% \((30^\circ)\). So that the result is the value of the settlement at the height of embankment 12 m is 15.96 cm and also the value of the safety factor for the escape hill FK is \(1.33 > 1\).

4. Conclusion

Based on the analysis results, the researcher found that the subgrade was still able to withstand the load of the embankment. So that the soil had not been about to collapse and the slope condition is safe and did not indicate the landslides. The shear force which generated by the slope is still smaller than the ground shear force. So that the subgrade is able to withstand embankments with 12 m height. Even more, by increasing the cohesion value \((c)\) and the friction angle \((\varphi)\) increased the safety factor value \((FK)\) by of 0.023% in average and it decreased the average reduction value of 0.097%. This research is expected
to be used as a reference to espouse the correct design plan on building an escape hill as an evacuation site from an earthquake which may trigger the tsunami in Aceh. For the last, if the land does not meet the safety factor requirements at the research location, the researcher suppose to import the subgrade material from near borrow area, stabilize the subgrade and land reinforcement with geosynthetics and geogrid material.

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