Safety factors and stability analysis of escape hill critical high towards tsunami free-board and run-up level

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Abstract. Earthquake threats that had caused tsunami hazards with a lack of optimal efforts in the construction of evacuation sites, it is necessary to conduct studies on evacuation sites as escape hill. One method of overcoming building construction on the effect of freeboard and run-up level of vertical walls in one of tsunami evacuation models that need to be analyzed for the maximum height that is suitable against the lateral force of tsunami wave. This study's purpose is to calculate the stability of slope and embankment high on escape hill and calculate the safety factor of soil bearing capacity. The data obtained from the undisturbed sample are then taken to the laboratory for physical and mechanical properties analysis and slope failure of escape hill calculated using the finite element method. This study of maximum embankment height the escape hill for evacuation site, stability obtained at an altitude of 10.0 m and safety factors are 2.14 to 2.84 which is very safe. From the material set design that has been done, it is shown that the modeling of materials set with variations of soil cohesion value (c) and the value of the shear angle in the soil (φ) the safety factor of 2.412.

1. Introduction
Indonesia as an archipelago is geographically vulnerable to tsunami natural disasters. Most earthquakes epicenter on the bottom of the Indian Ocean and some of them caused large ocean waves (tsunami). One of the provinces of Aceh was Banda Aceh, including the tsunami-affected area on December 26, 2004, with the strength of the Mw 9.0 earthquake or Mw 9.3 [1], [2]. Given the various earthquake threats that have caused tsunami [3] and the lack of optimal efforts in the construction of evacuation sites in open areas [1], it is necessary to conduct studies on temporary evacuation sites, namely escape hills [4].

One way of overcoming building construction to the effect of the maximum height of the coming wave (freeboard) and when the creeping waves hit a structure crawling up the escape hill surface (run-up level) is the use of upright walls as can be seen in figure 1 (sketch of escape hill based on geotechnical consideration). The critical embankment height issue states that the soil which will be

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built the construction above must have special treatment or must be engineered so that the soil bearing capacity is sufficient to the planned load. Safety risk analysis should be considered as suggested by [5] and [6] If the weight and height exceed the value of subgrade support, it is possible for the lateral collapse and movement to occur. Vertical wall or retaining wall serves to resist the amount of soil pressure due to lateral forces [4]. The escape hill design is an addition of a higher tsunami wave run-up level and freeboard height.

![Diagram of escape hill construction](image1.png)

**Figure 1.** The height of the wall as escape hill construction on freeboard problems, run-up level and depth of the foundation

2. Methodology
The research data from this article are extended research of [4]. Based on the review and data obtained from the tsunami, the location of the review was carried out in Tibang Village, Syiah Kuala sub-district, the maximum run-up at the time of the 2004 tsunami reached 3.70 m. The built escape hill must represent the distance of the local population to evacuate within a sufficient radius or distance [7].

![Map of distance measurement](image2.png)

**Figure 2.** Map of Distance Measurement from the 2004 Tsunami Earthquake Epicentre to Escape Hill Location
To prevent the sliding and spreading around the embankment on subgrade under saturated conditions, it is necessary to know the collapse of the bearing capacity of the subgrade due to embankment [8], [9]. The easiest way to do is by calculating the height of the critical embankment ($H_{\text{crit}}$). Run-up levels, namely when waves come in against a structure, water carried by its momentum is pushed up and creeps up to the surface of the structure. The maximum height of the wave that comes is called freeboard.

**Table 1.** Soil parameter value of *Escape Hill design*

| Parameter                     | Name | Subgrade | Landfill | Unit   |
|-------------------------------|------|----------|----------|--------|
|                               |      | Sand     | Sand     | Sand   | Sand   |
|                               |      | Silty    | Silty    | Silty  | > 3m   |
| Type of behavior              | Type | Undrained| Undrained| Undrained| Drained|
| Dry soil weight               | $\gamma$ dry | 8.90    | 10.10   | 10.40  | 16.10  | kN/m$^3$ |
| Wet soil wet                  | $\gamma$ wet | 22.84  | 22.76   | 22.96  | 19.24  | kN/m$^3$ |
| Horizontal permeability       | kx   | 8.64E-03 | 8.64E-03 | 8.64E-03 | 4.53E-03 | m/day |
| Vertical permeability         | ky   | 8.64E-03 | 8.64E-03 | 8.64E-03 | 4.53E-03 | m/day |
| Young’s modulus               | $E_{\text{ref}}$ | 15000  | 10000   | 8000   | 10000  | kN/m$^2$ |
| Poisson’s Ratio               | $\nu$ | 0.33    | 0.33    | 0.33   | 0.30   | -      |
| Cohesion                      | $C_{\text{ref}}$ | 8.60   | 12.90   | 10.70  | 0.043  | kN/m$^2$ |
| Friction angle                | $\phi$ | 31.60   | 29.00   | 32.30  | 30.923 | °      |
| Dilatancy angle               | $\Psi$ | 0       | 0       | 0      | 0      | -      |

**Figure 3.** Tsunami height memorial poles 3.7 m run-up at X: 5°58’33.91”; Y: 95°35’06.37”
Soil parameter value from soil sampling in finite element analysis used is based on Table 1 and Table 2. The height of the maximum tsunami wave experienced was based on tsunami height memorial poles of 3.7 m run-up as can be seen in figure 3.

3. Result and Discussion
The estimated escape distance and evacuation time have been calculated. Based on the data of the December 26, 2004 tsunami earthquake, the distance of the epicenter to the escape hill location was 619.17 km with a tsunami wave speed of 500 Km/h up to 700 Km/h as shown in Figure 2. Moreover, the distance of the epicenter (Andaman-Nicobar Island) to the location of escape hill is 682.87 Km by Tsunami Wave speed 700Km/h is 58.53 minute.

| Table 2. Soil parameter modeling |
|----------------------------------|
| c variant modeling               | φ variant modeling | Safety Factor (SF) with a heap height of 10 m | Safety Factor (SF) with a heap height of 12 m |
| c                                | φ                  | 2.412                                           | 2.351                                           |
| c + 25%                          | φ - 5%             | 2.546                                           | 2.484                                           |
| c + 50%                          | φ - 10%            | 2.269                                           | 2.207                                           |
| c + 75%                          | φ - 15%            | 2.140                                           | 2.075                                           |
| c - 25%                          | φ + 5%             | 2.691                                           | 2.614                                           |
| c - 50%                          | φ + 10%            | 2.834                                           | 2.517                                           |

The results of slope stability analysis by reviewing the strengthening conditions using a counterfort wall type of retaining wall were analyzed using the plaxis program, the slope angle used was the permissible angle of 15°. The following are the results of variations in soil parameter modeling in table 2 with heaps of 10 m and 12 m. Table 2 shows the results of variations in soil parameter modeling, the smaller the cohesion value and the greater the value of the shear angle, the value of the safety factor increases compared to the high cohesion value and the small shear angle value. Based on these results, the highest value of safety factors is chosen. From the modeling that has been done, the most stable conditions are obtained in the modeling of c+50% dan φ-10%. The result of the calculation derived from modeling with the heap height of the 12 meters is shown as in Figure 4.

In Figure 4, calculations are made by the plaxis program with variations in the modeling by increasing the cohesion value (c) and decreasing the shear angle value (φ) to obtain a condition that is safer than natural conditions. From the modeling that has been done, the most stable conditions are obtained in the modeling of c+50% dan φ-10%. The calculation results from modeling with a heap height of 12 meters.

4. Conclusion
Based on the calculation of slope stability using the counterfort wall type of retaining wall displayed by the plaxis program, it is safe, the safety factor obtained at the condition of the 12 m heap height is 2.207 meaning that the slope has met the appropriate safety number requirements. Firstly, the results of vertical wall stability analysis on the temporary tsunami evacuation model against freeboard and run-up level using counterfort wall type retaining wall can improve slope stability, the safety factor obtained at the condition of 12 m heap height is 2.207, in soil modeling with a variation of c+50% and φ-10%.
Secondly, from the modeling that has been done, it shows that the modeling of site materials with variations of $c+50\%$ and $\phi-10\%$ with a safety factor of 2.207 produces the highest safety factor compared to variations $c$ and $\phi$; $c+25\%$ and $\phi-5\%$; $c+50\%$ and $\phi-10\%$; $c+75\%$ and $\phi-15\%$; $c-50\%$ and $\phi+10\%$ with safety factors 2.351; 2.484; 2.207; 2.075; 2.517. Lastly, the values of soil parameters (material set) with variations of $c = 0.032 \text{kN/m}^2$ and $\phi = 32.469^\circ$ could be proposed to determine the Term of Reference (TOR) and Work Plan and Requirement in implementing this escape hill construction at this location.

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