Escape Hill as Geotechnical Quick Response Method in Facing Upcoming Tsunami Disaster

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Abstract. High number of casualties due to Aceh’s Tsunami in 26th December 2004 was because of lack of information regarding to the disaster among Aceh government and people at that time. Escape building as a quick response for tsunami disaster may become an inevitable action in shoreline of Banda Aceh in facing forthcoming disaster. Moreover, as a result of open space need due to environmentally friendly infrastructure campaign nowadays, the construction of green design of escape hill can be considered. Escape hill can also be functionalized as recreation zone like green park. This article study purpose is to design an escape hill with the rule of geotechnical engineering aspect namely bearing capacity of soil below the escape hill and slope soil stability for the designing escape hill. Deah Baro Village of Meura xa district was chosen as an escape hill design location. Several undisturbed soil samples were taken within this village for obtaining the existing soil parameters. There were eight hills modelling have been conducted by using Plaxis software. Based on the slope stability result from Plaxis software and by using natural soil as subgrade with soil classification of A-1-b as AASHTO method, the settlement value of final model dimension was 9.117 cm with safety factor of 1.507. The safety factor is still acceptable because of still larger that 1.5 as a standard value for slope safety factor. Escape hill geometry dimension is 12 m high which is larger than tsunami run up wave with soil pressure was calculate per layers of 2 m.

Keywords: Earthquake, construction, building, green-design.

1. Introduction

Aceh – Indonesia 26 December 2004 earthquake and tsunami disasters was considered as one of the deadliest disasters of Indonesia in century. This 9.3 Scala Richter magnitude earthquake and follow by huge tsunami waves not only occurred and effected Indonesia but also several neighbour countries like Thailand, Malaysia, Maldives, even the tsunami wave were able to reach distant countries namely Sri Lanka, Somalia and India. In Indonesia, more than 220,000 fatalities occurred because of this natural disaster event. The high number of casualties was because of lack of information regarding to the disaster among Aceh - Indonesia government and people at that time. Learn from the disaster, there have been an increasing of alertness for tsunami risk reduction among to coastal countries such as Indonesia and Japan. Even in 2011 Japan has been considered as the best prepared nation in the world for large tsunami attack survival [1]. Aceh – Indonesia already experienced several large magnitude earthquakes in recent century. As [2] and [3] Aceh also experienced fatal 6.4 Scala Richter earthquake in Pidie Jaya Aceh which also destroy quite a lot important constructions. Moreover [3] plotted based on spectral hazard map that Aceh location is in high risk zone of earthquake. As the result from several natural disaster in the past, best preparation for future disaster must be considered deeply as disaster mitigation in Aceh.
High number of casualties due to Aceh’s Tsunami in 26th December 2004 was because of lack of information regarding to the disaster among Aceh government and people at that time. Escape building as a quick response for tsunami disaster may become an inevitable action in shoreline of Banda Aceh in facing forthcoming disaster. Moreover, as a result of open space need due to environmentally friendly infrastructure campaign nowadays, the construction of green design of escape hill can be considered. Escape hill can also be functionalized as recreation zone like green park. Some researches in predicted of upcoming tsunami disaster were also conducted by [4] [5] and [6]. Existing breakwater toughness in Ulee Lheue harbour which is close to Deah Baro was analysis by doing some simulation of earthquake – tsunami [4]. The result shows that the breakwater able to hold up to 8.0 Mw follow by tsunami waves strike.

Several type of tsunami mitigation procedures have been considered nowadays such as constructing sea defence structures, land use management or designing evacuation procedures depending on specific local situations. The local situations which must be considered including society aging, population ratio, land availability, and reconstruction aims chosen by local communities [7]. Resilient construction by the Aceh government were expectantly should be applied for future [4] and [8]. The reinforcing procedure of break water foundation by steel sheet piles and gabions was studied by [8]. This article study purpose is to design an escape hill with the rule of geotechnical engineering aspect namely bearing capacity of soil below the escape hill and slope soil stability for the designing escape hill. Deah Baro Village of Meuraxa district was chosen as an escape hill design location. Several undisturbed soil samples were taken within this village for obtaining the existing soil parameters.

According to [9] the tsunami run up in Deah Baro area was up to 7.0 m. It was recorded from [9] that several Tsunami Height Memorial Poles were constructed along Banda Aceh and Aceh Besar to remember the height of tsunami wave of Aceh tsunami 26 December 2004. The poles constructed for future generations to remember the rare event of tsunami disaster.

| No. | Soil Parameter | 1.6 m Soil Sample Taken | 3.0 m Soil Sample Taken | Unit |
|-----|----------------|-------------------------|-------------------------|------|
| 1.  | Material Model | MC                      | MC                      |      |
| 2.  | Type of Soil Taken | Undrained              | Undrained              |      |
| 3.  | Dry Soil Weight (\(\gamma_{\text{dry}}\)) | 10.3                   | 9.7                     | kN/m³|
| 4.  | Wet Soil Weight (\(\gamma_{\text{wet}}\)) | 13.9                   | 13.9                    | kN/m³|
| 5.  | Horizontal Permeability (k_x) | 8.64E-01               | 8.64E-01               | m/day|
| 6.  | Vertical Permeability (k_y)  | 8.64E-01               | 8.64E-01               | m/day|
| 7.  | Young’s Modulus (E_{ref})  | 10000                  | 19610                  | kN/m²|
| 8.  | Poisson’s Ratio (v)        | 0.3                    | 0.3                    |      |
| 9.  | Cohesion (c)               | 10.7                   | 0.4                    | kN/m²|
| 10. | Friction Angle (\(\phi\)) | 32.3                   | 37.6                   | o    |
| 11. | Dilatancy Angle (\(\psi\)) | 0                      | 0                      | o    |

The coastal land use after 2004 tsunami along the research area were already studied by [10] [11] and [12]. Land use if Ulee Lheue bay in 2015 mostly for paddy field, fishponds and coastal forest [10]. It shows an indication that people tend to avoid shore line for residential area in order to avoid upcoming tsunami disaster. Majority of resident tend to change their livelihood activity for adaptation with post disaster condition. Moreover, the designing of escape hill as green structure design in research area are suit with the recent land use. [12] studied about how to lead Banda Aceh to green city especially along tsunami 2004 affected area.
2. Material and Method

There were eight hills modelling have been conducted by using Plaxis software. The finite element and limit equilibrium methods are the most common numerical methods nowadays among the engineers. Material set of escape hill modelling with variating the value of soil cohesion and soil shear angle parameters had been considered. Deah Baro Village of Meuraxa district was chosen as an escape hill design location because this location was one of most destructive area after tsunami 2004. Furthermore, according to the existing Tsunami Height Memorial Poles in this village, the maximum run up of 2004 tsunami wave almost 7.0 m which is highest among Meuraxa district. Several undisturbed soil samples were taken within this village for obtaining the existing soil parameters.

![Figure 1. The designing cross section geometry of escape hill](image)

The soil data obtained from this research are from experimental works in Soil Mechanics Laboratory of Syiah Kuala University Indonesia. Existing soil in Deah Baro Village as a subgrade were collected and tested for physical and mechanical soil parameter in order to analysis the base soil stability of escape hill. The slope soil data used was based on natural subgrade as existing soil and natural embankment of sand. The existing soil parameter can be seen in Table 1. The natural soil as subgrade with soil classification of A-1-b as AASHTO method and SW for USCS. The cross-section geometry of escape hill design is shown in Figure 1. The slope angle designing in 23° with the width and height of escape hill are 35.0 m and 12.0 m respectively. The degree of 23° was considered after several trial and error of safest slope angel. As already mention before, height of 12 m chosen because the design escape hill must be higher the maximum run up tsunami 2004 which is 7 m [9].

As the form of escape hill in Figure 1, due to 23° of the design must be analyses in terms of slope stability, underneath soil bearing capacity and also the effect of ground water or pore water pressure to the escape hills. Previous slope stability analysis were conducted by [13], [14] and [15]. In this research embankment installation with 2 m interval was considered as proposed by [13] for spatially variable soils. In spite of the analysis was based on an assumption of all embankment soil and subgrade soils are homogenous and isotropic, in the reality it is very hard to be applied [15]. This article purpose is to design an escape hill with the rule of geotechnical engineering aspect namely bearing capacity of soil below the escape hill and slope soil stability for the designing escape hill. [16] and [17] were also studied a comparison between mechanical soil parameter modelling.

3. Results and Discussion

The analysis was based on natural subgrade and natural embankment parameter. The embankment soil type used is sand. The embankment installation procedure was modelled with an interval of 2 m. embankment up to 12 m. Eight model of soil parameters were tried with the variation of cohesion and
shear angle parameter. The first model was by using the existing soil conditions and combining the value of cohesion and soil shear angle to established the safest model condition. The result from this model were settlement of 9.117 cm with safety factor of 1.577. After increasing 25% of cohesion parameter for second model, the settlement and safety factor change to 9.112 cm and 1.598 respectively. Moreover, the third model was increasing the cohesion to 50% and get the result of settlement of 9.112 cm and safety factor of 1.621 as in Table 2.

Table 2. Result of Cohesion and Shear Angle Modelling for Safety Factor

| Slope Model | Cohesion (kg/cm²) | Shear Angle (°) | $U_{tot}$ (m) | Safety Factor |
|-------------|------------------|----------------|---------------|--------------|
| 1           | C                | 0.04           | φ             | 30.92        | 91.17E-03    | 1.507        |
| 2           | $c + 25\%$      | 0.05           | φ             | 30.92        | 91.12E-03    | 1.598        |
| 3           | $c + 50\%$      | 0.06           | φ             | 30.92        | 91.12E-03    | 1.621        |
| 4           | $c + 100\%$     | 0.08           | φ             | 30.92        | 91.12E-03    | 1.660        |
| 5           | C                | 0.04           | φ + 10%       | 34.02        | 91.12E-03    | 1.646        |
| 6           | C                | 0.04           | φ + 20%       | 38.02        | 91.12E-03    | 1.747        |
| 7           | C                | 0.04           | φ + 30%       | 40.20        | 91.12E-03    | 1.771        |
| 8           | $C + 100\%$     | 0.08           | φ + 30%       | 40.20        | 91.12E-03    | 1.850        |

The forth model was added 100% the value of cohesion and obtained settlement for 9.112 cm and safety factor of 1.66. The fifth model was used the original cohesion value but increasing the soil shear angle for 10%, the result shows that settlement of soil for 9.112 cm and safety factor of the slope model was 1.646. When adding the shear angle value for 20% in sixth model, the settlement remain 9.112 cm and safety factor was 1.747. 30% of soil shear angle was added for 7th model. The outcome displays that settlement of soil still remain 9.112 cm and safety factor of 1.771. The last model was using the most effective combination within cohesion and soil shear angle which was ($c_{nature} + 100\%$) and ($\phi_{nature} + 30\%$). The settlement of hill was 9.112 and safety factor was 1.850. The compilation result of different parameter influence can be seen in Table 2.

The study of comparison was completed in order to examines the application of finite element method and limit equilibrium method in calculating the effective design of the slope in terms of safety factor and critical failure of surface. From Plaxis analysis of the deformation procedure it had been noted that the extreme scenario of slope movement as deformation mesh element, total displacement of the escape hills is $91.17 \times 10^{-3}$ m as shown in Figure 2 and Figure 3. The safety factor for the slope obtained as 1.507. The displacements effect to natural subgrade is still acceptable for design purposes. Figure 4 explained about the possibility of slope natural embankment to slip. Moreover, it also explained that there is an influence from embankment load distribution above to natural subgrade lied below the escape hill. As a result, the analysis of natural soil must be considered in escape hill design.
The total stresses of escape hill design recorded for 234.7 kN/m as in Figure 5. Homogenous soil height of the slope has a significant effect on safety factor for designing escape hill resting on existing soil layers.

**Figure 4.** Escape hill total load distribution

**Figure 5.** Total Stresses of Escape Hill

The factor of safety from Table 2 were above the required safety factor which is 1.5. Results obtained increases with increasing soil friction angle and soil cohesion. These results are realistic and as predicted.

4. Conclusions

The use of green design of disaster mitigation construction must be considered by local government for future spatial plan. Escape hill can be chosen as one of the solutions for environmentally friendly structures for tsunami evacuation building. However, the design of escape hill must follow several aspects including geotechnical engineering aspects. Based on the slope stability result from Plaxis software and by using natural soil as subgrade with soil classification of A-1-b as AASHTO method and SW for USCS, the settlement value of final model dimension was 9.117 cm with safety factor of 1.507. The safety factor is still acceptable because of still larger that 1.5 as a standard value for slope safety factor. Escape hill geometry dimension is 12 m high which is larger than tsunami run up wave with soil pressure was calculate per layers of 2 m. The deformation of slope stability and safety factor were the output of this article. The safety factor obtained is acceptable since it is larger than the required safety factor larger than 1.5.

5. References

[1] Raby A, Macabuag J, Pomonis A, Wilkinson S and Rossetto T 2015 Implications of the 2011 Great East Japan Tsunami on sea defence design *Int. J. Disaster Risk Reduct.* 14 332–46

[2] Munirwansyah M, Munirwan R P and Yunita H 2018 Geotechnical Engineering Aspect Related to Pidie Jaya–Aceh Earthquake Disaster and Mitigation *Int. J. Adv. Sci. Eng. Inf. Technol.* 8 870

[3] Irsyam M, Dangkua D T, Hendriyawan, Hoedajanto D, Hutapea B M, Kertapati E K, Boen T and Petersen M D 2008 Proposed seismic hazard maps of Sumatra and Java islands and microzonation study of Jakarta city, Indonesia *J. Earth Syst. Sci.* 117 865–78

[4] Fachhurrzaizi, Syamsidik, Al’ala M and Mahardi W 2017 Numerical simulations of tsunami waves impacts on Ulee Lheue Harbour in Banda Aceh-Indonesia *IOP Conf. Ser. Earth Environ. Sci.* 56 012015

[5] Schmidtlein M C and Wood N J 2015 Sensitivity of tsunami evacuation modeling to direction and land cover assumptions *Appl. Geogr.* 56 154–63

[6] Løvholt F, Setiadi N J, Birkmann J, Harbitz C B, Bach C, Fernando N, Kaiser G and Nadim F 2014 Tsunami risk reduction - are we better prepared today than in 2004? *Int. J. Disaster Risk Reduct.* 10 127–42
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