Escape hill development as a strategy to improve urban safety after earthquake and tsunami Aceh 2004 based on regional planning and geotechnical aspect

M Munirwansyah1, H Munirwan2* M Irsyam3 and R P Munirwan1

1 Department Civil Engineering, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia
2 Department Urban and Regional Planning, Institut Teknologi Sumatera, South Lampung, 35365, Indonesia
3 Geotechnical Engineering Research Group, Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Jalan Ganesa 10, Bandung 40132, Indonesia
* E-mail: hafi.munirwan@pwk.itera.ac.id

Abstract. This paper examines urban safety of coastal zone in Banda Aceh city, based on multidisciplinary aspect. Firstly, from the perspective of geophysics aspect, the disasters are affected by the imbalance of the law of action-reaction, that material experiences repeated recurring collapse in return-period. Secondly, geotechnical considerations are a required to ensure the safety aspect in term of construction of escape hill. Lastly, from regional planning aspect, this research finds that the increasing of immigrating population to the high-risk coastal zone has not been followed by the development of evacuation facilities, amongst are escape hills. One consideration in escape hill development is the influence of freeboard and run up level, to obtain a safe embankment height and soil bearing capacity. Based on the soil properties $c=0.03$ kN/m$^2$ and $\phi=32.5^\circ$ was able to build escape hill up to a height of $8.00$ m in stable with safety factor SF=2.6. Material sets with these variations can be proposed to establish the term of reference and detail engineering design in carrying out the escape hill construction at this location. This research finds that it is needed to build 12 more evacuation sites to improve urban safety in Banda Aceh City.

Keywords: Escape hill, Strategy urban safety, High risk disaster, Coastal zone aspect.

1. Introduction
This research was conducted in the coastal zone of Banda Aceh city. This location is considered as a zone that has the most influential index of vulnerability of disaster area, which cover: open coastal zone, the area that has tsunami hit experience, increased population concentration which is very significant because land prices are cheap and its strategic location [5]. Beside of that, Banda Aceh is located directly on the path of two big earth plates namely the Indo-Australia and Eurasia plates. These plates are the main cause of the strong earthquake which magnitude 9.3 SR. which may trigger the tsunami [1].

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. Which caused the strong vibrations that propagate from the Andaman
to the Banda Aceh [2]. Referring to the data taken from BNPB (National Disaster Management Agency), the tsunami disaster caused 173,741 people were died, 116,368 people were declared missing [3]. 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 tsunami threat. Such as the earthquake that caused the tsunami. Hence, it is necessary to prepare and build a rescue site, one of it is an escape hill.

The escape hill study location of this research is located in within the short distance near the resident area, so it can be accessible for the resident during the tsunami wave struck. Figure 1. Shows the study location of this research. Beside of that, the study area is considered as green open space area that can be elevated since its soil profile has sufficient soil carrying capacity to hold the required embankment height [4]. However, the established space for evacuation hills must have the capacity to accommodate not only local resident, but also non-local resident that are located near the escape hill when tsunami wave early warning ring.

![Escape hill coverage zone and residential area in the study location](image)

**Figure 1.** Escape hill coverage zone and residential area in the study location

Rescue sites or temporary evacuation sites (TES) must be built according to the travel time needed to escape from the residential area to escape hill or another TES. The radius of the rescue zone will be formed according to the radius of the running distance of the community with a shorter period of time than the tsunami is expected to emerge after the BMKG announces the potential of the tsunami through both the media and sirens. Factors of age and ability to run, run alone and run by carrying items or carrying a weak family also have different speeds for each person so that the achievement radius is different as shown in the yellow radius, trunk and red that need to be considered in preparing the TES.

This research finds that the city plan for disaster prevention plan has not been effectively and efficiently implemented because the increasing of immigrating population to this area has not been followed by the development of evacuation facilities, such as; temporary evacuation roads and sites [5]. Furthermore, this study also discusses an alternative development strategy of escape hill (artificial hill) as a temporary evacuation place to accommodate the evacuation sites, which is reviewed from geotechnical aspect and soil bearing capacity.
One consideration in escape hill development is the influence of freeboard and run up level. To obtain a safe embankment height and safety factor on the carrying capacity of local soil (soil bearing capacity). It must be understood that the earthquake did not cause human death but the collapse of buildings that might caused casualties [6].

2. Data and Methods
Tsunami is one of the natural disasters that threaten coastal residents who are located in opposite or in within the influence with the source of meeting two subduction plates. Even though huge earthquake does not happen every day, the accumulation of energy due to the collision of the Indian ocean plate that slides in shifts down the continental Asia plate (Sumatra Island), giving rise to energy shear which, if the shear field is released, causes considerable destruction.

Earthquake historical data in Aceh-Indonesia Province is quite dominant, even above magnitude 5 SR. Figure 2 shows the historical data of Aceh earthquake with magnitude higher than 5.0 SR. These earthquakes are mostly centered on the bottom of the Indian Ocean along subduction lines (subduction). One of the examples is the earthquake in December, 2014, that have caused tsunami waves in the Aceh region.

![Figure 2. Historical data of Aceh earthquake with Magnitude 5 - 9.3 SR](image)

2.1. Magnitude and epicentre distance
To calculate the distance of the earthquake source to the location of the escape hill development, two coordinate points, respectively from the earthquake source and the study location area are being recorded. The coordinates of the earthquake source determined by the latitude and longitude coordinates of the earthquake map, while the coordinates of the escape hill location are determined using GPS (global positioning system).
3. Calculation of Tsunami Flood Scenarios and Geotechnic Aspect

3.1. Travel time to escape hill

To find out the travel time needed to escape hill and to find out the horizontal distance (R), we need to measure the epicenter (ΦE) longitude and latitude coordinates epicentre (LE), as well as the longitude coordinates of the escape hill construction location (ΦS) and the latitude coordinates of the escape hill (LE) construction site in the planned disaster zone, as in equation (1). Tsunami wave strike time from source f (t) of the Andaman earthquake location December 26, 2004 with magnitude 9.3 to reach the escape hill location and time to escape for the people who live in a safe radius by estimating various human conditions to run fast like parents, or still able to run, humans running with human carriers or items can be calculated using equation (2). Figure 3. illustrates the calculation method to identify the travel time to escape hill.

\[
\cos ES (R) = \sin \Phi E \sin \Phi S + \cos \Phi E \cos \Phi S \cos (LE-LS) \tag{1}
\]

\[
f[t] = \frac{(\sin \Phi E \sin \Phi S + \cos \Phi E \cos \Phi S \cos (LE-LS)/\cos ES}{f(v)} \tag{2}
\]

![Figure 3. Calculation distance of focus earthquake, hypocentre to escape hill](image)

3.2. Escape hill proximity radius

From the estimated tsunami wave speed to the location of the disaster zone, it can be determined the farthest distance radius (R) for local residents to choose a safe place to escape from the hill escape zone or escape the building so that people are not carried away by tsunami when evacuating. The distance radius in this zone is different for each behavior and ability of the community to reach the TES target, as shown in Figure 4.
3.3. Tsunami wave propagation and embankment height

To set the height of the embankment to make off the hill so that the tsunami platform is protected from the brunt of the tsunami wave, accurate data from the height of the tsunami run-up is needed, namely tsunami wave propagation and high embankment data, as shown in Figure 6. The requested (Hcrit) formula can be used (3), where Cu is a non-drained cohesion, Nc is the carrying capacity factor and \( \gamma \) is the weight of the soil subgrade volume. The hill off the high embankment must be controlled lower than the Hcrit value which can be calculated using equation (3).

\[
H_{\text{crit}} = \frac{C_u \cdot N_c}{\gamma} \tag{3}
\]

The embankment height is planned 1.2-1.5 times the height of the run-up height level tsunami (Hrup) as cited by [7], sketch of the escape hill height image with consideration of the above is illustrated in Figure 5. Hcrit is not included in the thick stripping top soil must be clearing and grubbing to a depth of 50 cm, which is then backfilled as subgrade preparation with selected embankment material so that collapse and lateral motion effects of the soil can be avoided.
The tsunami risk assessment which was applied to a case study in Banda Aceh coastal zone Indonesia, the step of study follow the methodology was development to evaluate the effectiveness of risk-reducing system against such hazards [8]. Than a new approach to probabilistic earthquake induced tsunami risk assessment. The risk is evaluated in a probabilistic framework for a full set of hazard events including all uncertainties [9]. This approach is applied to the probabilistic tsunami risk assessment for public housing and schools in Banda Aceh coastal zone [10].

The study plan for recovery and tsunami mitigation strategies, which are required to be implemented in the future, was required in the first stage [11]. Disaster infrastructure development must be prepared formally after the December 26, 2004 tsunami disaster. At present there are only 5 escape buildings built, while according to quantitative data 19 temporary evacuation sites that have not yet been built are needed. Tsunami is a rapid onset natural hazard that can be considered as one of the extremely destructive hazards. Based on the origin of the Tsunami, there can be limited time available to evacuate people to safe places and make appropriate responses decisions in timely manner. Therefore, its imperative to increase the inherent capacity of a city to respond to this type of natural hazard [12].

3.4. Geotechnical engineering aspect
Infrastructure planning is very dependent on the analysis of the geotechnical aspects that last a long time, so that when it is built in receiving earthquake or tsunami loads, the Earthquake Catastrophe in Pidie Jaya Aceh Indonesia has damage to the city of Meureudu, Base on preliminary report for infrastructure, the geotechnical engineering aspects damages related are presented, 2,474 house need units to be rebuilt, almost 10 km of roads and 50 bridges need to be reconstructed, [13]. The following is a study in the field of geotechnic aspect which needs to be considered to obtain the stability and effective carrying capacity of the subgrade that is feasible in escape hill development, evaluation of deformation of embankments that occur and safety factor.

4. Result and Conclusion
Indonesia as an archipelagic country is geographically vulnerable to tsunami natural disasters. Banda Aceh is among the cities affected by the tsunami on December 26, 2004 with the strength of the 9.3 SR earthquake. Referring to data from BNPB (National Disaster Management Agency), as a result of the disaster 173,741 people died, 116,368 people were declared missing, resulting in thousands of homes and buildings being damaged, and causing nearly 500,000 to become refugees. Judging from the
mortality rate, it can be influenced by the lack of temporary evacuation sites in the field, there is still a lack of effort by the local government that is not optimal to provide temporary evacuation sites in the face of various future earthquakes that cause tsunamis. Therefore, in areas that have affected the tsunami it is necessary to build local rescue sites such as the escape hill. until now there are only 5 rescue buildings, namely 4 in Banda Aceh City and 1 in Peukan Bada District. Aceh Besar. From the results of qualitative and quantitative analysis, 19 TESs in the form of escape building or escape hill are needed.

4.1. Calculation result on the tsunami wave distance and travel time to escape hill
Based on the data of the December 26, 2004 tsunami earthquake, it was found that the epicenter's distance to the escape hill location was 619.17 km with a tsunami wave speed of 700 Km/H. Table 1 illustrates the calculation result of tsunami arrival time to the escape hill location.

| No | Distance of the epicenter (andaman) to the location (Tibang City Park) (s) (km) | Tsunami wave speed (v) (km/hour) | Tsunami arrival time to location (t) (hour) | Tsunami arrival time to location (t) (minute) |
|----|-----------------------------------------------------------------|----------------------------------|------------------------------------------|------------------------------------------|
| 2  | 682.87                                                          | 700                              | 0.98                                     | 58.53                                    |

From the calculation of the distance and time of the tsunami to the escape hill location, the distance and travel time of residents to escape to escape hill can be calculated, the population calculated is the population around escape hill namely Tibang Village, Jeulingke Village, Lamgugob Village and Gampong Alue Naga. Table 2 shows the calculation result of safe distance counts to travel to the escape hill, compared with the tsunami arrival time.

| No | Village Name | Distance (s) (km) | Travel time by running to Escape Hill (minute) | Tsunami arrival time (59 minutes) |
|----|--------------|-------------------|-----------------------------------------------|----------------------------------|
| 1  | Tibang       | 0.40              | 24.00                                         | Safe                             |
| 2  | Jeulingke    | 0.63              | 37.80                                         | Safe                             |
| 3  | Lamgugob     | 1.49              | 89.40                                         | Not safe                         |
| 4  | Alue Naga    | 1.63              | 97.80                                         | Not safe                         |

4.2. Conclusion
From the results of quantitative and qualitative studies and analyzes, It can be concluded that at least 19 temporary tsunami evacuation sites (TES) are needed in Banda Aceh city, improve urban safety from tsunami. Table 3 shows the proposed coordinate escape building locations. The spatial distribution of the proposed TES location can be seen from Figure 7.
### Tabel 3. Calculation Results of Distance from the Coast to the Location of the Temporary Tsunami Evacuation Place

| No | Village Name                      | Distance from coast (km) | Latitude (N)       | Longitude (E)       |
|----|-----------------------------------|--------------------------|--------------------|---------------------|
| 1  | Escape Hill R – Tibang            | 2.19                     | 5°58'33.91"       | 95°35'06.37"       |
| 2  | Escape Building R 1 - Alue Naga    | 0.55                     | 5°59'86.68"       | 95°34'15.40"       |
| 3  | Escape Building R 2 – Lamgugob     | 3.09                     | 5°57'60.59"       | 95°35'25.18"       |
| 4  | Escape Building R 3 – Lamgugob     | 3.90                     | 5°56'97.15"       | 95°35'53.42"       |
| 5  | Escape Building R 4 – Jeulingke    | 2.88                     | 5°57'43.01"       | 95°34'57.06"       |
| 6  | Escape Building R 5 - Lambaro skep | 2.40                     | 5°57'41.46"       | 95°33'34.45"       |
| 7  | Escape Building R 6 – Lampulo      | 1.43                     | 5°57'84.98"       | 95°32'69.46"       |
| 8  | Escape Building R 7 - Gp. Jawa     | 1.43                     | 5°57'04.94"       | 95°31'97.40"       |
| 9  | Escape Building R 8 - Keuramat     | 2.54                     | 5°56'72.90"       | 95°32'55.49"       |
| 10 | Escape Building R 9 - Lampaseh Kota| 1.78                     | 5°56'13.89"       | 95°31'32.92"       |
| 11 | Escape Building R 10 - Kp. Baru    | 2.63                     | 5°55'12.74"       | 95°31'32.35"       |
| 12 | Escape Building R 11 - Lamjabat    | 1.68                     | 5°54'59.01"       | 95°29'43.87"       |
| 13 | Escape Building R 12 - Lamjamee    | 1.36                     | 5°53'71.22"       | 95°28'38.40"       |
| 14 | Escape Building R 13 - Lampoh Daya | 2.38                     | 5°53'48.42"       | 95°28'80.98"       |
| 15 | Escape Hill R - Alue Deah Teungoh | 0.50                     | 5°56'26.80"       | 95°29'73.03"       |
| 16 | Escape Building Alue Deah Tengoh  | 0.83                     | 5°56'38.87"       | 95°30'31.46"       |
| 17 | Escape Building Deah Glumpang      | 0.54                     | 5°55'96.25"       | 95°29'35.23"       |
| 18 | Escape Building Lambung            | 1.78                     | 5°55'19.84"       | 95°30'27.35"       |
| 19 | Escape Building Ulelhe             | 0.38                     | 5°55'36.90"       | 95°28'58.01"       |

From the calculation, it is obtained that the population achievement area that is safe reaches the escape hill research location, namely Tibang Village and Jeulingke Village. While the need for temporary evacuation sites for the tsunami needed is still very poor, weighing the disaster zone Banda Aceh City is not only Tibang Village but also other coastal areas.

From the results of qualitative and quantitative analysis, 12 more evacuation sites are still needed. The temporary evacuation site can be in the form of escape building, escape hill, multi-storey buildings located in zones and empowered mosque mosques are built into high-rise and assisted by the provision of facilities to meet disabelitas principles such as by providing ramp lanes (ramps).
Figure 7. The number of temporary evacuation sites (TES) results from quantitative and qualitative analysis for the coastal areas of the city of Banda Aceh.

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