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The Aesthetic Man-made Hill: An Alternative Tsunami Vertical Evacuation for Padang City, West Sumatera, Indonesia

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***Abstract*— Geologists have been a long time warned that Padang, a city of more than nine hundred thousand peoples, could one day be probability destroyed by an earthquake and tsunami because of its location, i.e. flat terrain and close to the offshore thrust-fault seismic hazard. About half of the city's population live close to the coast and within a five-meter elevation above the sea level. Padang peoples have been amply demonstrated in previous West Sumatra earthquakes that most of the panic' peoples, the exodus to the higher-level area by using cars and motorbikes. As the results, a chaos and traffic jams at several points on the evacuation road and prevented peoples to reach the safe area.This situation suggests that Padang city requires the vertical evacuation facilities to overcome the circumstance mentioned above. Indeed, several multistory buildings are located on the coastal area of the Padang city, enabled to be used as the tsunami evacuation shelters when tsunami run into the city. Unfortunately, especially on the northern part of the city, due to dense population whom living close to the coast area and limitation of the number of the multistory buildings make them still in high-risk to tsunami hazard. In this paper, a nine-meter high of an aesthetic man-made hill is proposed as an alternative vertical evacuation place in it dense population area. A man-made hill is designed to accommodate more than 10,000 evacuees. The site's functional, the detail of engineering construction and the evacuation scenario are briefly discussed in this paper.In between tsunamis, it may be accessed by the community at any time as the public facilities such as recreation park and sports facility in around and on the top of the hill.**

***Keywords*— natural disaster; earthquake; tsunami; vertical evacuation; man-made hill.**

I. Introduction

The horrific impact of the great Aceh M 9.1 earthquake and followed by tsunami occurred on the western coast of Aceh in 2004 has evoked widespread concern about similarly devastating tsunamis on other densely populated coasts. One of the most plausible localities for a tsunami of disastrous proportions in the near future is the section of the coast of West-Sumatra and Bengkulu provinces. Millions of peoples live along this length of coast including in smaller cities and villages along the coasts of the mainland and the Mentawai islands [1,2,3]. As reported by Hayes et. al. [4], since great earthquake Aceh 2004, much of the Sunda megathrust between the northern Andaman Islands and Enggano island, a distance of more than 2,000 kilometers, has ruptured in a series of large subduction zone earthquakes. These events include the great M 9.1 earthquake of December 26, 2004; the M 8.6 Nias island earthquake of March 28, 2005; and two earthquakes on September 12, 2007, of M 8.5 and M 7.9. On October 25, 2010, the M 7.8 on the shallow portion of the megathrust to the west of the Mentawai islands caused the substantial tsunami on the west coast of those islands and the M 8.4 and M 7.9 occurred near Bengkulu on September 12 and 13, 2007, respectively. However, unfortunately, a relatively small segment of approximately twohundredkilometers length apparently still holds and have not been ruptured yet. The segment seats right on between the two large ruptures caused by Nias and Bengkulu earthquakes and the location of the segment is exactly in front of Padang city as is shown as a red-square box in Figure 1 [5]. Since Padang city is situated on directly facing to the Mentawai segment of the zone of Sunda subduction, therefore there is a potential impact of the future tsunami may have significant risk in this area. In addition, with the flat terrain topographic in Padang city, the probability of large inundated areas and large inundation depths has been also predicted high [1,6].

After a successive earthquake struck the west coast of Sumatra island post-earthquake Aceh 2004, many of the researchers have devoted their attention to the possibility of disaster in the Padang city. Their research has been focused on various aspects covering of damaged of civil infra-structures and earthquake and tsunami hazards as well, such as Maidiawati [7], Pribadi [8] have conducted the post-earthquake investigation to observe the damaged on the structure of the reinforced concrete buildings caused by Bengkulu earthquake 2007. While other researchers, such as Harukawa [9] and Kanamori [10], have been concentrated for studying of the probabilistic and histories of the earthquakes along the Sumatra island, especially near the Padang city.

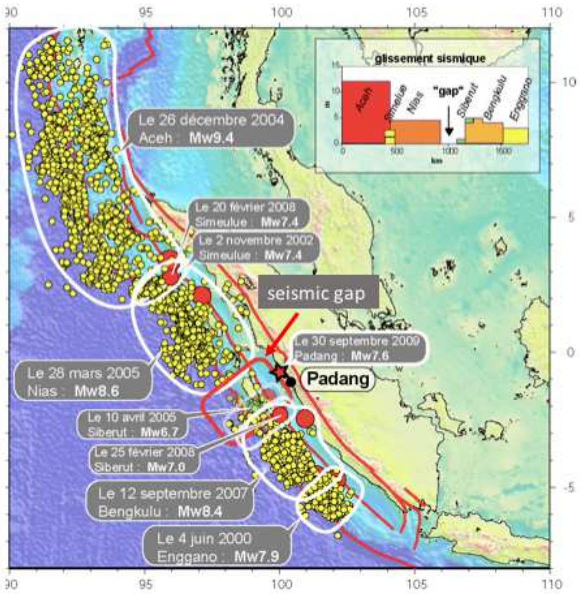


Fig. 1 The Sumatran Seismic Crisis [5]

M 7.6 West Sumatra earthquake on September 30, 2009, is one of the last major earthquakes that struck the western coast of West-Sumatra province [5]. The epicenter of this earthquake is marked in a red-star in Figure 1 and located on the coast of the Indian Ocean between the Sumatra fault and the Sunda trench fault and about 60kilometers west-norther of Padang city. The EERI [11] has reported that the 2009 West-Sumatra earthquake caused more than a thousand of deaths and significant damage to about 140,000 houses and 4,000 other buildings. The casualties, i.e. 383 deaths and 431 serious injuries, in Padang city were mostly due to building damage and collapse. Fortunately, there was no tsunami at that time.

The event of the 2009 West Sumatra earthquake has motivated many researchers to study in more intense about the earthquake and tsunami disaster that might hit the Padang city in near-future. A final goal of their studies is mostly for developing such mitigation of the tsunami preparedness against the future catastrophic events.

II. Material and Method

Padang city is the homeland of more than nine hundred thousand peoples. As the capital city, this city is known as one of the most urbanized cities in West-Sumatra Province. In Figure 2 is shown the location and topography feature of the Padang city. Located on the west coast of the Sumatra island, south of the equator. The topography is low-lying plains along the coastline. One of the picturesque aerial views of Padang city is shown by a photograph in Figure 3 [12].

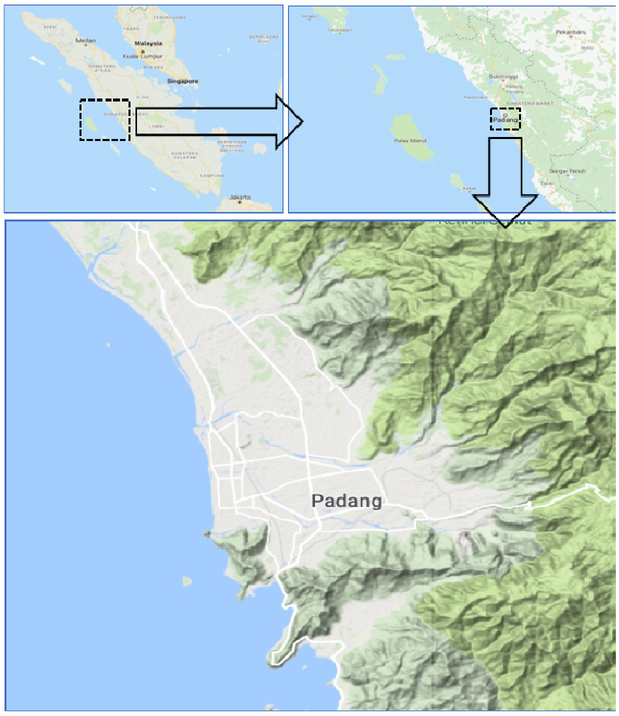


Fig. 2 Topography Feature of Padang City (Source: Google Maps)

Table I shows the list of the population for eleven sub-districts in Padang city for the year of 2016 [13]. Most of these sub-districts area outspread on the coastline, i.e. most of Teluk Kabung sub-district, partially of Lubuk Begalung sub-district, Padang Selatan sub-district, Padang Barat sub-district, Padang Utara sub-district and partially of Koto Tangah sub-district. By this such condition makes about half of the city's population have to live close to the coast and within a five-meter elevation above the sea level. It should be noted that when school and office are in sessions, the population who have activity in near coastal area will increase to more than half of city's population.

Fig. 3 Aerial View of Padang City [12]

As it is mentioned above that the geologists have warned that one day the Padang city may be destroyed by the great earthquake followed by the tsunami. The tsunami wave triggered by the Mentawai earthquake on October 25, 2010, as is studied by Lay [14] and Newman [15] has been believed as a series of great earthquakes that caused and may cause the tsunamis on the west coast of the Sumatra island. More specific, by using numerical approach, Barrero [1] and Ario [6] have simulated the tsunami inundation in the western part of Sumatra island, particularly Padang city. Barrero [1] used the method of splitting tsunami and 1797 Padang earthquake as the tsunami scenarios; concluding that flow depth along the eightkilometers length of the coast of Padang city, ranging from 1.5 meters to 4 meters and inundation distance about 600 meters to one kilometer to inland area. Meanwhile, Ario [6] applied the stochastic tsunami simulation method to estimate the tsunami hazard level in Padang city due to several artificial earthquake scenarios. His study results have concluded that for the M 9.0 earthquake scenario, the tsunami inundation areas in Padang city may be covering more than 19 square kilometers with a maximum inundation depth may reach about 10 meters. Peoples who live close to coastline area require about 60 minutes to evacuate to the safe zone in the inland high area. Based on the conclusions of these studies suggest that the resistant vertical evacuation structures have to be designed and constructed in the populated areas such as in along the coastline of Padang city.

TABLE I
POPULATION DISTRIBUTION BY SUB-DISTRICT IN PADANG CITY

Sub District	Area km2	Population	Density People/km2
Bungus Teluk Kabung	100.78	25,132	249
Lubuk Kilangan	85.99	53,621	624
Lubuk Begalung	30.91	116,826	3780
Padang Selatan	10.03	63,355	6317
Padang Timur	8.15	85,473	10487
Padang Barat	7.00	49,812	7116
Padang Utara	8.08	75,869	9390
Nanggalo	8.07	62,868	7790
Kuranji	57.41	139,105	2423
Pauh	146.26	64,999	444
Koto Tangah	232.26	177,908	766

Fig. 4 Study Area (Source: Google Maps)

As has been well known that an advanced evacuation plan in tsunami-prone areas consists of horizontal and vertical evacuation. The horizontal evacuation is not recommended for children and the elderly. Ario [6] and Anshar [16] have identified the existing buildings that can be used as tsunami evacuation shelters. These buildings include hotels, mosques, government office buildings, school buildings university buildings and other multistory buildings. Unfortunately, these buildings are not eventually distributed in the populated area near the coastline. For instance, only one tsunami evacuation shelter exists in the populated area near the coastline in Koto Tangah sub-district area.

In Figure 4, the area covered by the red-line indicates the administrative area of the Koto Tangah sub-district in the northern part of Padang city. Even though the Koto Tangah sub-district has the largest area in Padang city, but the population is mostly concentrated near the coastline. It seems that the density of the population near the coastline for Koto Tangah and Padang Utara sub-districts are almost the same, i.e. about 9,000 peoples per square kilometer, as is shown in Table I.

A prediction of tsunami inundation depth in Padang Utara and partly of Koto Tangah sub-districts is shown in Figure 5 [17]. In the coastline area, the depth of inundation varying from 5 meters to 9 meters. For these areas, the required time for horizontal evacuation to the safe zone has been estimated more than 60 minutes. On the other hand, the tsunami has been predicted to hit the coastline about 20-30 minutes after the earthquake [1].

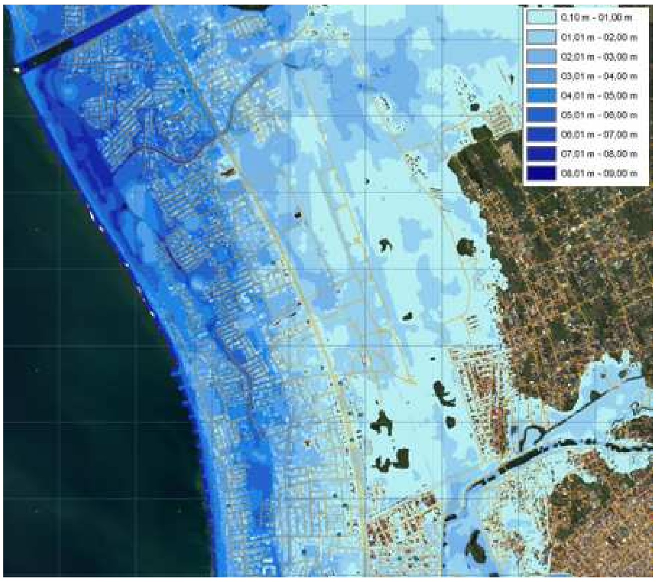


Fig. 5 Tsunami Inundation Area
(Source: https://gempapadang.wordpress.com)

Table II is the tabulation of the population of children and elderly for each sub-district in Padang city; i.e. peoples with age less than 9 years old and great than 60 years old, respectively. At least about 14,000 population of children and elderly people in Padang Utara sub-district. It is considered that almost the same population living in the coastline of Kota Tengah sub-district. The evacuation time will increase as increasing number of these children and elderly peoples as evacuees because the speed of evacuation will significantly reduce. Therefore, the vertical evacuation scheme is the best option to save them from the tsunami hazard.

TABLE II
DISTRIBUTION OF CHILDREN AND ELDER POPULATION IN PADANG CITY

Sub District	Population		
	< 9 yo	> 60 yo	Total
Bungus Teluk Kabung	5,512	1,654	7,166
Lubuk Kilangan	10,967	2,983	13,950
Lubuk Begalung	21,977	6,863	28,840
Padang Selatan	11,819	4,493	16,312
Padang Timur	13,557	6,228	19,785
Padang Barat	7,287	4,667	11,954
Padang Utara	9,690	5,146	14,836
Nanggalo	10,238	4,919	15,157
Kuranji	25,486	8,347	33,833
Pauh	11,368	3,604	14,972
Koto Tangah	33,374	11,010	44,384

III. RESULTS AND DISCUSSION

Due to this tsunami-prone condition, in this study, thus establish the man-made hills is proposed for populated areas mentioned above. The man-made hills are expected can be as one of the solutions to reduce the probability of casualties when the tsunami run into these areas. A 3-D image of the current proposed man-made hill is shown as rendering-model in Figure 6. The hill has three leveling, i.e. 3 meters, 6 meters and 9 meters from the ground level, respectively. The level of 9 meters is allocated for evacuation area. The 9 meters of the top level of the hill was defined based on the depth of tsunami inundation in Figure 5. FEMA F-646 [18] recommend a minimum safe high of the vertical evacuation for tsunami should at least 1.3 of the depth of predicted tsunami inundationat shelter location and additionalone meter for free space. The locations of the current proposed man-made hills are given in Figure 8. The estimated of the depth of tsunami inundation at these areas about 5 meters.

Fig. 6 The 3-D Image of Proposed Man-made Hill

The site's functional of this proposed man-made hill is schematically drawn in Figure 7. The man-made hill has been designed with good sense aesthetics such that comfortable and convenient to be accessed any time by the communities as public facilities, city recreation park and sports arena. The sports arena is located on the top and around the hill.

As a tsunami evacuation shelter, this man-made hill may accommodate more than 10,000 evacuees on the top of the hill. Certainly, the main priority of utilization of the hill as tsunami evacuation shelter is for the evacuees of the children and elderly. The evacuees' capacity estimation of this hill was estimated based on FEMA standard [18], i.e. the area of existing evacuation divided by the space needed per person. The area of evacuation area on the top of the hill almost 10,000 square meters, while the space needed per person is 0.93 square meter.

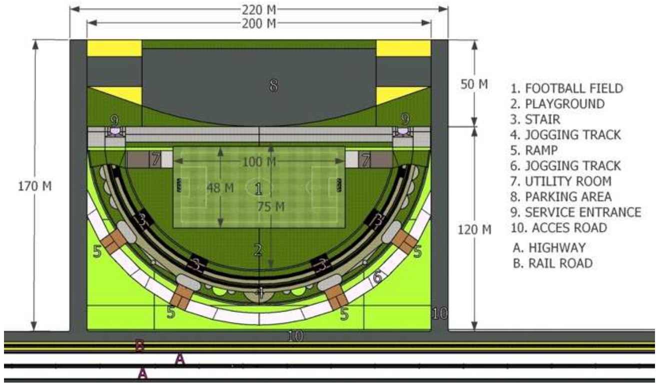


Fig. 7 Site’s Functional of Proposed Man-made Hill

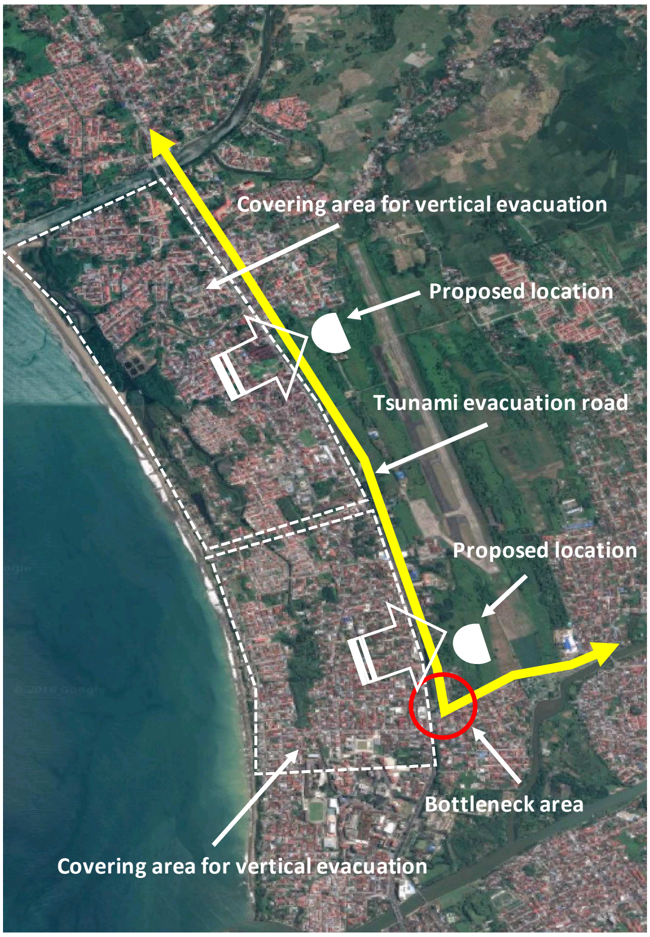
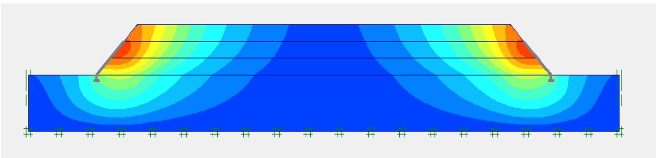


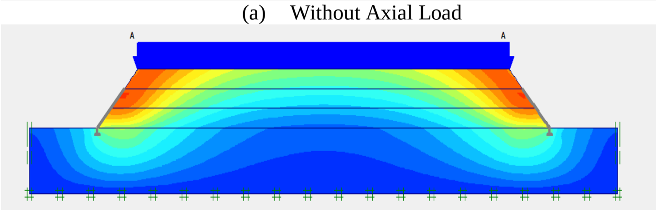
Fig. 8 Proposed Location of the Man-made Hills

The horizontal evacuation route to the safe area is marked in arrowed yellow-line in Figure 8. This route has been known as a very crowded road, especially in morning and afternoon, i.e. in school and office are in sessions. The bottleneck location in this lane is marked in a red-circle in the figure. The situation mentioned above is the hazardous situation if the tsunami occurred today. The evacuees may be stuck at the bottleneck area.

The proposed locations for the place of the man-made hills are also shown in Figure 8. These locations have been selected due to their positions close to dense-populated coastline areas, i.e. Padang Utara and partly Koto Tangah sub-districts, respectively. The white dash-line box in Figure 8 indicates the estimation covered area for the priority area whom able to use the closest man-made hills when the tsunami hits these areas. By the existence of this man-made hill is expected will make the chaos and traffic jam during earthquake and tsunami became much reduced.



(a) Without Axial Load



(b) With Axial Load

Fig. 9 Numerical Results of Slope Stability Analysis

The man-made hill is constructed by compacted soils on the coarse and medium sands, to achieve the maximum dry density in the range of 1,3 ton-f/m^3 to 1,7 ton-f/m^3, cohesion in the range of 1 ton-f/m^2 to 2 ton-f/m^2 and internal friction angle in the range 30^0 to 35^0. The sand-clay and silk-clay are used as compacted soils. The construction of the man-made hill has been evaluated for the slope stability, the bearing capacity, the consolidation and the possibility of liquefaction beneath the construction. The computer program based on nonlinear finite element analysis has been used for this purpose. Figure 9 shows the numerical results of the slope stability analysis for the cases without and with axial loads. The axial load due to evacuee activities and the required equipment. The axial load in 2,5 ton-f/m^2 was applied in this study. The numerical analysis was optimized to obtain the safety factor at least 1,20.

In order to define the bearing capacity, the consolidation and the possibility of liquefaction beneath the construction, the soil investigation work on site and in the laboratory, have been conducted based on the soils taken from the site where the construction is planned to build. Analysis by using standard calculation for defining the bearing capacity results in the good bearing capacity of the soils on site as is indicated by the safety factor of 2,2. Furthermore, the consolidation analysis estimates the construction will consolidate about in maximum of 80 centimeters. The possibility of the liquefaction in the soil beneath of the construction was evaluated based the acceleration ground motion of the M 7.6 West Sumatra earthquake on September 30, 2009, where the maximum acceleration of it ground motion about 300 gals. Evaluate all the soils' samples to potential liquefaction, conclude that the soils beneath of the construction are safe from the possibility of liquefaction.

The cost for constructing is estimated at about USD 3 million. It cost includes the man-made hill construction, the recreation, and the sports facilities. The cost is also covering facilities needed when evacuation such as electrical and the drinking water treatments.

IV. Conclusions

The 9meters of the aesthetic man-made hill for tsunami evacuation shelter has been proposed and discussed in this paper. The evacuation area on the top of the hill is approximately about 10,000 square meter and may accommodate more than 10,000 evacuees. The hill constructed by the compacted soils with estimated construction costs of about USD 3 million. The construction of this man-made hill is relatively cheap compared to the multistory reinforced concrete building, i.e. only less than USD 300 per evacuees. The construction cost for multistory reinforced concrete building for tsunami evacuation shelter is approximately around USD 600-800 per evacuees. Besides, the maintained cost of the hill construction is also estimated lower compare to the reinforced concrete building. The excellent feature of the hill is the communities may access the hill for recreation and sports activities or other communities' activities. Since the hill has been designed in the good aesthetic point of view, this man-made hill may be established as a new landmark for the Padang city.

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