Tsunami Evacuation Route Modeling (Study in Karang City and Karang Raya Village City)

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Abstract. Kota Karang Village and Kota Karang Raya Village are two urban villages located in the coastal city of Bandar Lampung and are vulnerable to tsunami threats. The tsunami threat comes from the possible subduction of the Indo Australia Plate and the Eurasian Plate as well as the volcanic activity of Mount Anak Krakatau. The two villages are inhabited by 16.726 people with a high density of 29.344 people per km2 and occupy an area of 0,57 km2 with an average height of 10 meters. The dense population and moderate contours left both villages potentially causing casualties in the event of a tsunami disaster. Therefore, a study on the optimization of the tsunami evacuation route in both urban villages is needed. The method used in this research is to conduct a review of the tsunami evacuation route through analysis of population data and topographic data which will then become evacuation simulation input using Evacuware software. The data included in the form of population data by sex and age and topographic data in the form of situation map and evacuation route map. The simulation is done with two scenarios, the first scenario uses two Temporary Evacuation Sites namely Mount Mastur and Dwipangga Park. The second scenario conducted by placing four additional vertical shelter using three reconstructed primary schools and one reconstructed community health center. Keywords: evacuation, tsunami, evacuware

1. Introduction

On December 26, 2004, the subduction of the Eurasian Plate and Indo-Australian Plate in a 1.000 km longitude trench led to an earthquake of 9.1 on the Richter Scale, generating a tsunami with run-up more than 20 meters along adjacent coastline, killing more than 240.000 people. From this point, the tsunami propagates outward and within 2 hours has killed 58.000 people in Thailand, Sri Lanka and India. Losses suffered by the population and the state include loss of life, psychological suffering, social disorder, loss of rare habitat and infrastructure damage. It takes a long time to rehabilitate the psychological condition of the community and the condition of infrastructure at the disaster site (NOAA, 2017). History records that the island of Sumatra had experienced a devastating disaster in the form of the eruption of Mount Krakatoa. Naryanto (2003) mentions that the massive explosion of Mount Krakatau on 27 August 1883 destroyed 295 towns and villages as well as 36.000 casualties. Throw material as much as 18 cubic km, smoke as high as 80 km and cause tsunami as high as 20 - 30 meters along Merak Beach Banten, South Lampung and Jakarta coast. This wave devastated Semangko Bay and Lampung Bay. As many as 2500 people died in Benewani Village, 327 people died in Tanjungan and Tanot Baringin and 244 in Beteong. A tidal wave of 13,6 meters also hit a lighthouse in Bengkulen made of concrete and killed 10 people at work. The eruption of Mount Krakatau in 1883 was heard in Teluk Betung at 10:00 am and tsunami waves reached the area at 11:03 am, five hundred people died in the area and surrounding areas. Berouw warships that are engaged in the area have been thrown by the tsunami waves up to the valley of the River Kuripan as far as 2 km from the coastline. Departing from the historical record of the eruption of Mount Krakatau and the possibility of a dislocation in the fracture along the western island of Sumatra to the island of Flores since the tsunami disaster in Aceh in 2004, a study of evacuation along the coastline of Lampung Bay is required. Bandar Lampung city is located at the peak of Lampung Bay arch and facing the threat of tsunami generated from two sources namely, dislocation of Parit Sunda fault and volcanic activity of

Mount Anak Krakatau. Along the coastal city of Bandar Lampung administratively there are four districts, West Teluk Betung District, South Teluk Betung District, Bumi Waras District and Panjang District. Kota Karang and Kota Karang Raya Village are part of the District of West Teluk Betung in Bandar Lampung City. Both urban villages are located 13,5 km south of the capital Bandar Lampung. Kota Karang and Kota Karang Raya Village has an area of 0,57 Km2 and an average height of sea level of about 10 m. This village is inhabited by 16.726 people with the sorting of 8.376 male and 8.350 female (Central Bureau of Statistics Bandar Lampung City, 2016).

Triatmadja et al. (2010) explains that the travel time of the tsunami differs depending on the distance of the source and the depth of water. Tsunami events are expected to be generated along the Sunda trench that lies between the boundaries of the Indoaustralia and Eurasian plates. Tsunami arrived along the coastline of Lampung Province at different times. The distance between the tsunami generating site to station 7 (Kota Agung) and station 12 (Bandar Lampung) is almost the same but the tsunami travel time to two stations differ significantly. The arrival time of the tsunami in Bandar Lampung is approximately 40 minutes longer than in Kota Agung. The tsunami travel time to Bandar Lampung is about 100 minutes after the dislocation incident in the plate. With a 20 minute break between the earthquake and official warning for residents to evacuate, there is only 80 minutes time left for residents to reach the temporary evacuation site. Regional Disaster Management Agency of Bandar Lampung City has installed evacuation signs and guidance to temporary evacuation site when a tsunami occurs but the condition of the infrastructure both the road and the temporary evacuation site conditions directed by the Government of Bandar Lampung has some constraints that may complicate evacuees when evacuating such as narrower road to temporary evacuation site and insufficient temporary evacuation site area to accommodate large numbers of evacuees. Temporary evacuation site Dwipangga Park has an adequate area to accommodate more than 2000 evacuees, but residents of Kota Karang and Kota Karang Raya have to run more than 2 km to the intended temporary evacuation site. Especially for the residents of the Pasaran Island that must travel a distance of up to 3 km in order to reach temporary evacuation site Dwipangga Park, a safe plains as high as about 20 m above mean sea level.

Figure. 1. Tsunami Threat Map in Coastal Lampung Province

Figure 2. Bandar Lampung City and Kota Karang and Kota Karang Raya Village Location

2. Description Of Research Location

Temporary Evacuation Site (TES) suggested by the Government of Bandar Lampung City through the recommendation from Regional Disaster Management Agency of Bandar Lampung City for Kota Karang and Kota Karang Raya Village is directed to Dwipangga Park (Lampung Province Regional Police Office) 2 km in distance and Mount Mastur 1.5 km in distance (Fig. 3) starts from the coastline of Kota Karang Village. While the population on the Pasaran Island has to travel even further to reach the temporary evacuation site. Regional Disaster Management Agency of Bandar Lampung City has installed evacuation signs and guidance to temporary evacuation site when a tsunami occurs but the condition of the infrastructure both the road and the temporary evacuation site

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Figure. 3. Two Evacuation Routes

Figure 4. Evacuation Route Modelin

Table 1. Population Data in Kota Karang and Kota Karang Raya Village

No.	Age Group	Male	Female	Total
1	0 - 4 Year	677	648	1325
2	5 - 6 Year	437	473	910
3	7 - 13 Year	959	927	1886
4	14 - 16 Year	691	746	1437
5	17 - 24 Year	1365	1394	2759
6	25 - 54 Year	3291	3136	6427
7	Over 55 Year	956	1026	1982
	Total	8376	8350	16.726

Table 2. Normal human running speed (not athletes) in some age and gender categories on sandy soil and asphalt for 100 meters distance.

Category	Speed on the Beach (m/sec)		Speed on Asphalt (m/sec)	
	Male	Female	Male	Female
Children	2	2	2,4	2,4
Adolescent	3,3	3,3	4,12	4,12
Adult	2,86	2,38	3,6 (6,15)	3,0 (5,5)
Elderly	1,67	1,67	1,84	1,84

People with different ages and genders have different abilities to run for evacuations. Table 2 categorize the population as children, adolescents, adults and the elderly. Each resident of different ages and genders has different running abilities. Running surface conditions also affect the speed in running.

3. Evacuware Modeling

Rahadianto (2016) in his research on tsunami evacuation simulation in Pasaran Island concluded that the distance between Pasaran Island and temporary evacuation site is too far. From the simulation result, it is known that with in 100 minutes evacuation time of tsunami which is reduced by 20 minutes from the generating time, 55% of the population of Pasaran Island became tsunami casualties for not reaching the temporary evacuation site. Therefore one of the subject Rahadianto suggested was an addition of shelters in areas that included the safety of evacuees. Based on this

consideration, the author will determine two simulation scenarios. The first simulation is conducted by following the evacuation route that has been determined by the Government of Bandar Lampung City. The first temporary evacuation site from Kota Karang and Kota Karang Raya Village are temporary evacuation site Dwipangga Park which approximately 2,5 km from the coast with a large shelter area, a height of about 20 m above mean sea level, and long enough distance. The second temporary evacuation site is Mount Mastur on Jalan Banten Perwata Village approximately 1,5 km from the coast, has closer range but the number of evacuees that can be accommodated is limited and its height is only 13 m above mean sea level. The second simulation is conducted by making additional vertical shelter at the location around Kota Karang Village or the nearest village which can still be reached by the evacuees. The vertical temporary evacuation site is determined by considering the range, capacity, cost of manufacture, construction method, and the construction design that is able to withstand the tsunami waves and the accompanying debris. The author will determine one or more locations of government buildings that can be reconstructed to have an initial function during normal situations and tsunami shelter functions in the event of a disaster (Figure 5).

Figure 5. Six suggested evacuation sites

Figure 6. First simulation scenario minute 0

Figure 6 explains the situation at the beginning of the first simulation, before the residents move within 20 minutes after the tsunami generation. There are ten rectangular shaped points that contain colored dots representing 16.726 residents spread from the Pasaran Island to some point in the urban village of Karang and Kota Karang Raya. The directed route has two alternatives to temporary evacuation site Mount Mastur which has closer range but limited capacity and maximum height only 13 m above mean sea level. The second gathering point is located in Dwipangga Polda Lampung Park, this point has a longer distance but has a very large capacity and a height of 20 m above mean sea level. The scenario will run with a span of 20 minutes to figure out how evacuees are moving toward temporary evacuation sites.

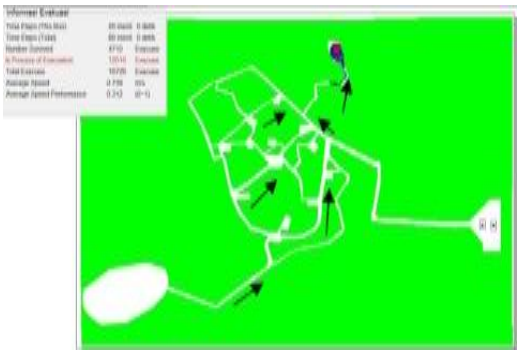

Figure 7. First simulation scenario minute 80

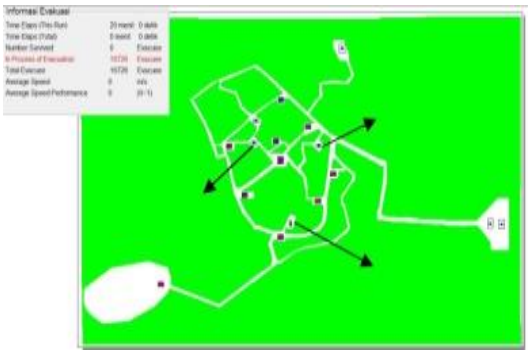

Figure 8. Second simulation scenario minute0

In the 80th minute more evacuees were seen gathering at the Mount Mastur temporary evacuation site (Figure 7). As many as 4.710 evacuees or 28,16% of total evacuees are already inside the shelter or temporary evacuation site area and are declared survive, while there are still 12.016 evacuees or 71,84% of total evacuees are still in the process of evacuating. At the beginning of the second

simulation Figure 8 explains the situation before the residents move that is within 20 minutes after the tsunami generation. There are ten rectangular shaped dots that contain colorful dots representing 16.726 people spread from the Pasaran Island to some point in the urban village of Kota Karang and Kota Karang Raya. The directed route has six alternatives of temporary evacuation sites such as Mount Mastur which has closer range but limited capacity and maximum height only 13 m above mean sea level. The second temporary evacuation site is located in Dwipangga Park, this point has a longer distance but has a very large capacity and height 20 m above mean sea level. Thethird temporary evacuation site is the Elementary School 01 Kota Karang vertical shelter, The fourth temporary evacuation site is the Elementary School 02 Kota Karang vertical shelter, the fifth temporary evacuation site is the Elementary School 04 Kota Karang vertical shelter and the sixth temporary evacuation site is the Kota Karang Community Health Center. The scenario will be conducted with a span of 20 minutes to figure out how evacuees are moving toward temporary evacuation sites.

Figure 9. Second simulation scenario minute 80

In the 80th minute evacuees increasingly crowded the four vertical shelter as shown in Figure 9. Especially in the vertical shelter of the Kota Karang Community Health Center. At this time 8.897 recorded evacuees or 53,19% of total evacuees are already in the four vertical shelter and declared survive, while there are still 7.829 evacuees or 46.81% of total evacuees are still in the process of evacuating.

4. Discussion And Conclusion

Table 3. Result from the first simulation

No	Minute	Survivor	Percentage	On Progress	Increasing Survivor
1	0	0	0.00%	16726	0.00%
2	20	2545	15.22%	14181	15.22%
3	40	3630	21.70%	13096	6.49%
4	60	4328	25.88%	12398	4.17%
5	80	4710	28.16%	12016	2.28%
6	100	4710	28.16%	12016	0.00%
7	120	4710	28.16%	12016	0.00%
8	140	4710	28.16%	12016	0.00%
9	160	4710	28.16%	12016	0.00%

From both conducted simulations, there are considerable differences in the results between the two scenarios. In the first scenario all evacuees move towards Mount Mastur temporary evacuation site and none move towards Dwipangga Park temporary evacuation site, in the first 20 minutes 2.545 evacuees or 15,22% of the total evacuees are declared survive and as time goes on until it reaches the 80th minute the number of evacuees survived to stop at 4.710 evacuees or 28,16% of the total evacuees and did not increase until the 160th minute. The number of survived evacuees which stopped indicates that the shelter area has reached it's maximum capacity.

Table. 4. Result from the second simulation

No	Minute	Survivor	Percentage	On Progress	Increasing Survivor
1	0	0	0.00%	16726	0.00%
2	20	6407	38.31%	10319	38.31%
3	40	8373	50.06%	8353	11.75%
4	60	8782	52.51%	7944	2.45%
5	80	8897	53.19%	7829	0.69%
6	100	8954	53.53%	7772	0.34%
7	120	8991	53.75%	7735	0.22%
8	140	9024	53.95%	7702	0.20%
9	160	9053	54.13%	7673	0.17%

In the second simulation all evacuees move toward the four vertical shelter and no one moves towards Mount Mastur temporary evacuation site and Dwipangga Park temporary evacuation site. In the first 20 minutes 6.407 evacuees declared survived or 38,31% of the total evacuees. From here the number of additional survivor per 20 minutes decreased gradually and in the 160th minutes recorded 9.053 evacuees who survived or 54,13% of the total evacuees. There was an increase in the number of evacuees who survived in the first simulatioin with the number of survived evacuees from 4.710 evacuees to 9.053 evacuees in the second simulation or the number of survived evacuees increased by 4.343 residents. Increased from 28,16% of evacuees survived to 54,13% of evacuees survived. The correlation between number of evacuees surviving with time (Figure 10) in the two simulations show that the decrease of the rising arch occurs after the 80th minute. This is due to the fulfillment of the capacity of the shelter area so that it can no longer accommodate the evacuees. In the first simulation there was a stagnation in the number of evacuees survived in the 80th minute because the shelter area has reached its optimum capacity. The simulation picture explains that in fact most of the evacuees managed to reach Mount Mastur temporary evacuation site but only about a third of it can be accommodated by shelter. The results of this simulation can be considered as a suggestion for evacuware software to have an additional evacuation direction command for evacuees in order to provide effective and efficient division of evacuation routes.

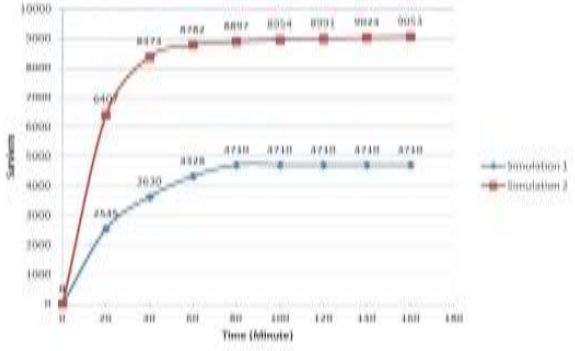

Figure 10. The correlation between the number of survivor with time

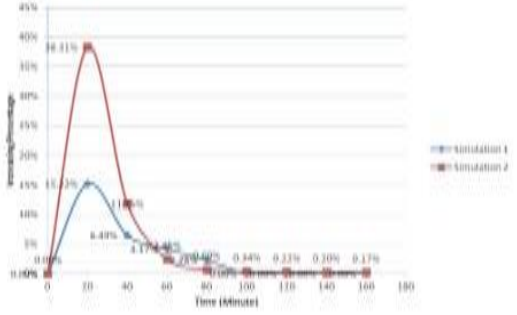

Figure 11. The correlation between the increase in the percentage of evacuees survived with time

Fig.11. shows an increase in the percentage of evacuee survivors per 20 minutes of time unit. Both simulations experienced the largest number of survivors in the first 20 minutes. As many as 15.22% survivors in the first simulation and 38,31% survivors in the second simulation. In the second 20 minutes the percentage of the number of survivors continues to decrease. This indicates that the first 20 minutes of evacuation was the most decisive moment against the accumulated number of evacuees surviving the tsunami disaster. In the first tsunami evacuation simulation, all evacuees in the two villages simultaneously moves only to Mount Mastur temporary evacuation site. None of the

evacuees are moving towards the Dwipangga Park temporary evacuation site, evacuees are concentrated in one temporary evacuation site and not all shelter areas are covered, while in the second tsunami evacuation simulation, all evacuees in two villages moves toward four vertical shelters. None of the evacuees are moving towards Mount Mastur temporary evacuation site and Dwipangga Park temporary evacuation site. Both simulations use the direction of running evacuees according to the best and closest path, because this method of running direction gives the best effect for the accumulation number of survivor compared with choosing randomly moving directions in the direction of 45 degrees and -45 degrees to the best path method. After both simulations run for 80 minutes, in the first simulation only 4.710 evacuees managed to survive or only 28,16% of the total evacuees, while in the second simulation recorded 8.897 evacuees survived or 53,19% survivors of the total number of evacuees. There was an increase of 4.187 survivors or an increase of 88,90% survivors from the first simulation. There is a stacking of evacuees on a temporary evacuation site or a certain vertical shelter because of the shelter area reaching maximum capacity and no longer able to accommodate the evacuees who have already reached the temporary evacuation site area, and also can be concluded the first 20 minute span is the most decisive moment against the accumulated number of evacuees surviving in both simulations. The number of survivors can be optimized by giving additional command on the Evacuware software that serves to direct the evacuees to move in accordance with the order. This additional commad expected to avoid concentrating evacuees only in one temporary evacuation site. In the second scenario simulation, if some evacuees in the northern part of urban village move to Mount Mastur temporary evacuation site, it is possible to increase the number of survivor. Another additional parameter required in the Evacuware software is a command to determine the area of a shelter so that the boundaries of shelters can be clearly defined, 500 m2 vertical shelter can accommodate a total of 2.000 evacuees so that in the second simulation with a total of 500 x 4 dots or equal to 2000 m2 area, it can accommodate 8.897 evacuees and the remain 7.829 evacuees are declared as casualties or not accommodated by shelters. This figure can be used as a basis if all residents in the two villages are planned to survive and accommodated in the four additional shelters, the vertical shelter area should be increased to approximately 5.000 m2 to accommodate 16.726 evacuees. Procurement of tsunami early warning facilities is required, at least by installing sirens at some point in every village along the coast of Bandar Lampung City. Temporary evacuation site on Mount Mastur needs to be expanded and leveled to accommodate more evacuees.

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