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Assessing Building Vulnerability to Tsunami Hazard in Padang

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Graphical abstract

Abstract

It may be necessary to carry out a study about risk analysis of building vulnerability to tsunami hazard in order to identify and develop potential tsunami risk in a coastal community. The objective of this study is to develop a risk analysis of building vulnerability to tsunami hazard in Parupuk Tabing, Padang. The study aims to: (1) identify and develop the building vulnerability of various building types to tsunami hazard; (2) simulate the tsunami propagation; and (3) develop risk analysis of building vulnerability to tsunami hazard in Padang. Risk level is determined by relative vulnerabilty index score of each building to a tsunami. The buildings were classified in five classes (very low risk, low, medium, high and very high). The method used to analize pattern of various types of building and tsunami inundation is by applying formulas in the field and simulating an earthquake with TUNAMI N3 Imamura method respectively. Clearly, the relative vulnerability index ranges of the building samples in Parupuk Tabing are from 3 to 5 (medium, high and very high risk). This study shows that risk components for building protection are around 30 to 40%, whereas water inundation is 33.33%, followed by building vulnerability of 22.67-33.67%. It can be estimated that, the condition can be very vulnerable, if the level of water is more than 2 m around a building and the vulnerability of water is around 33%. The results of this study contribute to the development of risk management strategies in designing of building and construction standards as well as plan for vertical evacuation and land use zones in order to mitigate the impact of tsunami disaster in coastal communities of Padang.

Keywords: Building vulnerability; tsunami hazard; risk analysis

■1.0 INTRODUCTION

Many countries lie in a tectonic active region. The coasts of these countries have very high risk of tsunamis. Problems and issues related to tsunami hazard are becoming global problems. For example, in this decade, a 9.3 Richter Scale reading of earthquake agitated the region of Aceh and caused the tsunami and ruptured the 1000 km of major fault lines ocean on December 26, 2004 [1]. The impact of this 2004 Indian Ocean Tsunami caused serious damages on infrastructures along the coast. Japan struggled through cascading disasters at 9.0 magnitude of earthquke on March 11, 2011 that triggered a 30-foot tsunami, wreaking havoc on a swath of the country's infrastructures and raising fears of a major radioactive release from a series of damaged nuclear power breakdown of reactors [2].

Tsunami forces can cause serious damage and failure of structures because tsunami waves in deep oceans can reach shorelines within several minutes and subside until several kilometers from the coasts and sweep away more infrastructures including the buildings of community [3]. Due to these phenomena, it is important that major cities located along the coastal areas are arranged to absorb the impact of tsunamis.

Based on historical records of seismicity beneath Mentawai islands in Indonesia, the last giant earthquake occurred in 1833. The earthquake caused tsunami wave with run up of 3 to 4 m which flooded several hundred meters into the mainland. This tsunami had caused many houses to lose walls and roofs as well as collapse. Danny Hilman studied that Mentawai earthquakes in Sumatra subduction zone which occur on average every 200 years and generate tsunamis [4]. To reduce the effects of a tsunami which may impact the coast of Padang, we need to assess and conduct a study on tsunami risk along the coast.

Although tsunamis are relatively rare events, tsunami waves are the most terrifying and complex physical phenomena, damaging almost all the regions in coastal areas. Many reports stated that there are many factors that influence the building vulnerability to tsunami hazard. Stefan Reese observed that residential timber structures were more fragile than masonry residential building [5]. Design and type of structures are important components for considering an effect of tsunami hazard.

Christopher Koutitas proposed an equation for computing the tsunami forces on structures by tsunami overland flow assuming that seaward face of the buildings will be loaded by a hydrostatic pressure based on an inundation depth, with no load on the landward face of the structures [6]. Primary tsunami hazard emerges from waves that come unexpectedly though buildings near the shores. Buildings can be damaged by tsunami waves depend on building vulnerability parameters. In order to identify and develop all the potential risks in a coastal community, it may be necessary to carry out a study about risk analysis of building vulnerability to tsunami hazard.

Generally, buildings most at risk of tsunamis are near the shorelines. It is important to develop strategies to assess risk in the context of building vulnerability to tsunami hazard. As a concept and process, risk, initially used in social sciences, has been applied in other disciplines.

According to International Strategy for Disaster Reduction (2004), when addressing the risks associated with natural hazard, vulnerability is determined by physical, social, economic and environmental factors or processes, which can cause the rise of the susceptibility of a community due to the impact of hazards [7]. Coburn states that vulnerability is propensity to injury or damage from hazard [8]. In practical terms, a hazard is often associated with an uncontrolled condition that can result damages. In this study, risk can be defined as the combination of hazard and vulnerability.

In the context of tsunami risk on buildings, the interaction of hazard that poses a level of treat and building vulnerability can be used to create risk levels. Sandra Eckert divided tsunami risk on buildings into 5 levels, namely very low, low, medium, high and very high [9]. Furthermore, hazard and building vulnerability are significant components that should be analyzed as probability levels that should be identified for each hazard and vulnerability event.

■2.0 FIELD STUDY AND MODEL DEVELOPMENT

2.1 Characteristics of Study Area

Parupuk Tabing, as study area, is located between 0.8758 S – 0.8825 S latitudes and 100.3375 E and 100.3491 E longitudes. The type of this coastal zone is low–lying area with sandy beach and dense population and different house types along the shoreline. The maximum tsunami inundation usually occurs on sandy shore type [10].

2.2 Risk, Vulnerability and Hazard Model

The objective of this research is to develop a risk analysis of building vulnerability against tsunami hazard. The research is developed by modeling every type and pattern of a building towards a tsunami. The identification and collection of data were developed based on the weightage of factors and vulnerability assessment of buildings due to a tsunami. In a study of building vulnerability assessment method for tsunami hazard, stated that the risk levels of each building is estimated as a weighted sum of three different components: (1) building vulnerability; (2) building protection; and 3) water vulnerability [11].

The value of an existing building vulnerability due to tsunami hazard involves various components of risk by developing the International Strategy for Disaster Reduction (ISDR, 2004) formula as follow:

$$R = V \times H \quad (1)$$

where R is risk level; V is vulnerability level and H is hazard level.

The formula is used to simplify the logic of risk calculation, where, if hazard and vulnerability exist, risk would emerge. In the context of Relative Vulnerability Index (RVI) as a measure of risk level, the score of every building is calculated by using the following formula:

$$\text{Risk level} = (1/3) \times \text{building vulnerability} + (1/3) \times \text{building protection} + (1/3) \times \text{water vulnerability} \quad (2)$$

The model of tsunami propagation is developed by modeling tsunami waves generated from Mentawai trench to arrive at Parupuk Tabing coastal area based on a magnitude of 9.0 to 10 km depth. Using this approach, the risk levels of each building can be obtained. Tables 1(a), (b) and (c) are indicators for the building vulnerability due to tsunami hazard.

Table 1 (a, b & c**)** Components for building vulnerability to tsunami hazard (modified from Dall'Osso *et al*. 2009)

a. Building vulnerability components

No	Component	Weight (%)	Very high risk	Score	High risk	Score	Medium risk	Score	Low risk	Score	Very low risk	Score
1	Material	30	wood	5	wood+concrete	4	traditional brick with RC-column	3	RC with brick infill walls	2	concrete + steel	1
2	Number of stories	15	1 story	5	2 stories	4	3 stories	3	4 stories	2	>5 stories	1
3	Soil condition	20	impermeable soil	5		4	medium soil	3		2	permeable soil	1
4	Basement	5	no	5		4		3		2	Yes	1
5	GF const. & found.	5	> 40 years	5		4	20-40 years	3		2	0-20 years	1
6	Preservation condition	5	very poor	5	poor	4	average	3	good	2	very good	1
7	Ground floor	5	not open plan	5	not open plan but many windows	4	50% open plan	3	open plan & windows	2	open plan	1
8	Orientation of building	15	long sides parallel to the shoreline	5	long side forming angle > 30 shoreline	4	long side angel <60 and > 30 shoreline	3	long side forming angle > 60 shoreline	2	long sides perpendicular the shoreline	1
	Total weight	100										

b. Protection of building components

No	Component	Weight (%)	Very high risk	Score	High risk	Score	Medium risk	Score	Low risk	Score	Very low risk	Score
1	Movable objects	5	extreme	5	high	4	average	3	moderate	2	minimum	1
2	Building row	15	0	5	1-2 row	4	3-4-5 row	3	6-7-8-9 row	2	>9 row	1
3	Height of concrete fence	15	0-20%	5	20-40%	4	40-60%	3	60-80%	2	80-100%	1
4	Natural barrier	10	no protection	5	moderate	4	average	3	high	2	very high protection	1
5	Distance from shoreline	25	0-200 m	5	200-500 m	4	500-1000 m	3	1000- 1500 m	2	>1500 m	1
6	Distance from river	15	0-100 m	5	100-200 m	4	200-300 m	3	300-500 m	2	>500 m	1
7	Island of obstacle	5	big	5		4	small	3		2	no	1
8	Gap between buildings	10	close	5	1/4 house	4	1/2 house	3	3/4 house	2	a house	1
	Total weight	100										

c. Water inundation component

No	Component	Weight (%)	Very high risk	Score	High risk	Score	Medium risk	Score	Low risk	Score	Very low risk	Score
1	Inundation	100	$h > 2$	5	$1.5 < h < 2$	4	$1 < h < 1.5$	3	$0.5 < h < 1$	2	$h < 0.5$	1
	Total weight	100										

2.3 Tsunami Model

Tsunami simulation in this research can be considered as a scenario of water vulnerability. The scenario was derived for return periods of 200 years and generated for this study using the Tohoku University's numerical analysis model for Investigation Near-field Tsunami no. 3 (TUNAMI-N3). This model was developed by Prof. Fumihiko Imamura of Japan to predict the tsunami propagation. TUNAMI-N3, with 2D non-linear shallow water equation, is a numerical simulation program based on the depth of water and run-up of tsunami on land [12]. This method used varying domains and grids. Tsunami source, bathymetrical and topographical data were used to foretell the run-up and travel times of tsunami waves for different parts of the coastal area. Bathymetrical data, as input of this model, was derived from General Bathymetric Chart of the Oceans (GEBCO), whereas topographical data was obtained from Shuttle Radar Topography Mission (SRTM). This model results the inundation and elevation of tsunami around a house.

This research was divided into three stages. The first was the pre-processing within the study itself to create files of bathymetrical and topographical data. Because this method used nested grids, the domain of the study area was divided into four areas (grids) with 2430 m grid spacing (domain A), 810 m grid spacing (domain B), 270 m grid spacing (domain C) and 90 m grid spacing (domain D). Bathymetrical and topographical files were interpolated by kriging method to produce numerical data of domains. These data were graphically displayed in degrees using the Universal Transverse Mercator (UTM) coordinate systems.

The second stage was processing the running program of TUNAMI-N3 which needed the numerical parameters such as epicenter, time steps, number of domains, grid spacings, simuation times, hypocenter, epicenter, magnitude, dislocation, fault length and wide, strike, dip, slip and tsunami elevation point.

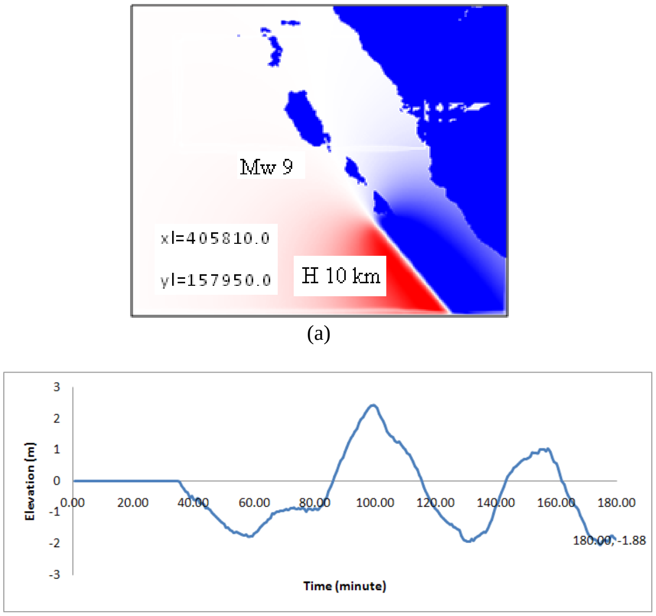
The third stage of this model was the post processing stage that cultivates the results of modeling in order to be informative and communicative. The results of this step are graph generation, elevations, and run-ups of a tsunami at 9 magnitude that was generated from the Mentawai trench.

3.0 RESULTS AND DISCUSSION

Figure 1 depicts the building samples in the area of study. It can be seen that in general the observed building types are made from wood, semi-permanent wooden houses, traditional brick with reinforced concrete columns, concrete mixed wood and reinforced concrete frame with brick infill walls. Most of the buildings are one-storey high and oriented parallel to the shoreline. Building distribution is located in the shoreline and closed to the two rivers because the majority of the communities are fishermen. In addition, the buildings in the area around 600 m from the shoreline are generally new and two-stories high and made from reinforced concrete frame with brick infill walls. Figure 1 shows the house types as building samples.

Figure 1 House types in this study area

Figure 2 describes the vertical deformation model of earthquake scenario at moment magnitude 9.0, with 10 km depth of hypocenter located at Southeastern Pagai in Mentawai islands. Based on the modeling result of TUNAMI-N3, the highest tsunami elevation of sea level at Mean Sea Level (MSL) is 4.35 m as shown in Figure 2(b). Tsunami arrival time at MSL area may be come at 35 minutes after an earthquake and the highest inundation occurred is 2.40 m (Figure 3), whereas topography around shoreline is from 0.02 to 3.00 m. It can be concluded that the area is most vulnerable to tsunami waves. Inundation distribution for every building can be seen in Figure 3.



(b)

Figure 2 (a) Earthquake model of a tsunami source; (b) Water elevation along coastal area in Parupuk Tabing

Based on the susceptibility of houses against tsunamis along the coast, the relative vulnerability index ranges of some samples of buildings are from 3 to 5 (from medium to very high risk) as shown in Table 2. The values imply extreme vulnerability to tsunami and unsafe. Along the coast there is only one vertical evacuation structure (picture H6) which is not enough to accommodate the nearby residents. This requires a follow-up study from the government about mitigation of tsunami disaster in the area of study.

Table 2 Relative vulnerability index model of buildings in Parupuk Tabing, Padang

Vulnerability Index	Type of house
1	
2	
3	H13, H14, H15, H16
4	H7, H10, H11, H12
5	H1, H2, H3, H4, H5, H8, H9

4.0 CONCLUSIONS

n order to assess and develop risk analysis of building vulnerability to tsunami hazard, various relative vulnerability indexs of buildings in this study area were obtained. Using identification and development of relative vulnerability index of buildings (see Table 2), the results show that the relative vulnerability index ranges of the building samples are from 3 to 5 (low, medium and high risk of tsunami hazard). In this case study, the values indicate that 30-40% of three components of risk is building protection. The next two components for risk of building vulnerability to tsunami hazard are water inundation (33.33%), followed by building vulnerability (from 22.67 to 33.67%). The results show quite clearly that if the water level is more than 2 m around a house and water vulnerability is approximately 33%, these conditions will be very vulnerable.

The application of this study contribute to the ongoing development of risk management strategies, design of building and construction standards, plan for vertical evacuations and land-use zoning in order to mitigate the effect of tsunamis in Padang coastal communities. It may be concluded that this research play important roles in preparation for the tsunami impact.

Figure 3 Map of tsunami inundation against the buildings in Parupuk Tabing

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