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Tsunami risk assessment of the 2004 Indian Ocean tsunami in Kamala beach Phuket

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Abstract

The December 26th, 2004 Indian Ocean tsunami caused damage to many buildings and killed many people in Indian Ocean countries. Regarding the 2011 Tohoku Japan tsunami, the devastating tsunami ravaged the eastern coast of Japan. It is important to mitigate the damage by tsunamis in the future. These events emphasize the need of tsunami risk assessment for evacuation planning, estimation of loss and estimating residential damage from tsunami hazard. The residential damage in Kamala Beach, Phuket is evaluated by the proposed tsunami fragility curves. The proposed tsunami fragility curves are considered only reinforced-concrete buildings and classified into two types: one-story buildings and buildings taller than one story. Building inventory is surveyed and classified into 5 zones. The tsunami inundation heights in each zone are averaged from the observed damage data. The results of evaluated buildings damage are compared with actual observed damage. Most one-story buildings are damaged in primary members and for buildings taller than one story are damaged in secondary members only. The damage probability for observed buildings of each area agrees well with the evaluated damage of buildings.

Keywords: Tsunami risk assessment, Fragility curves, Reinforced-concrete building

1. Introduction

The 26 December 2004 Indian Ocean tsunami caused serious damage to a large number of buildings and killed many people in the Indian Ocean countries including the western coastal regions of Southern Thailand. Regarding the 2011 Tohoku Japan tsunami, an unexpected earthquake with a magnitude of 9.0 occurred near the eastern coast of Honshu, Japan on March 11, 2011. This devastating tsunami ravaged the eastern coast of Japan. Approximately 20,000 people were killed and 830,000 construction buildings were damaged. To prevent and reduce structural damage in the future, there is a need to understand the behaviors of buildings under tsunami loading. The damage from these events emphasize the need of tsunami risk assessment for evacuation planning, estimation of loss and estimating residential damage from tsunami hazard. The primary components in risk assessment are hazard, fragility curves and structural inventory. This study evaluates the residential damage in Kamala Beach, Phuket, Thailand in the December 26th, 2004 Indian Ocean tsunami. The residential damage is evaluated by the proposed tsunami fragility curves [1]. Finally, the results of evaluated damage of buildings are compared with actual observed damage.

2. Damage of buildings at Kamala beach, Phuket, Thailand

From the observed database [2], the December 26th, 2004 tsunami caused the inundation height of about 3 m. which caused damage to many buildings in Kamala beach Phuket, Thailand as shown in Figure 1. Building damage data is distinguished into 5 zones. Zones are branched following the local road. Table 1 shows the number of damaged buildings in each zone for one-story buildings and buildings taller than one story. There are 62 observed damaged buildings in this area. 9 buildings suffered no damage, 31 buildings were damaged in secondary members, 19 buildings were damaged in primary members and 3 buildings collapsed. The distribution of 4 damage levels in this area for reinforced-concrete buildings is shown as Figure 2. From the observed damaged buildings, the average inundation heights and the probability of damage levels 0, 1, 2 and 3, which are average overall damage of buildings, of each zone for one-story buildings and buildings taller than one story are shown in Table 2. Most damage for one-story buildings is the damage level 2 and most damage for buildings taller than one story is the damage level 1. For zones 4 and 5, the probability of damage for one-story buildings is 100% because there are a small number of buildings in these zones.

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Table 1 The number of damaged in each zone

Zone	The number of one-story buildings	The number of buildings taller than one story
1	10	10
2	5	9
3	9	8
4	2	3
5	1	5

Table 2 The probability of damage from observation

Zone	Average inundation height (m)	Probability damage of one-story buildings (%)				Probability damage of buildings taller than one story (%)			
		DL0	DL1	DL2	DL3	DL0	DL1	DL2	DL3
1	1.68	10.9	45.5	43.6	0.0	21.7	75.9	2.4	0.0
2	2.73	0.0	11.2	39.2	49.6	1.2	94.4	4.4	0.0
3	2.62	0.0	22.0	65.5	12.5	0.0	90.1	9.9	0.0
4	3.38	0.0	0.0	100.0	0.0	0.0	89.2	10.8	0.0
5	0.38	100.0	0.0	0.0	0.0	85.2	14.8	0.0	0.0

(a) The inundation height was about 3 m

(b) Damage of residences and shops

Figure 1 Damaged at Kamala Beach, Phuket due to the December 26th, 2004 tsunami (Courtesy of Mr. Paisan Pongnaritson)

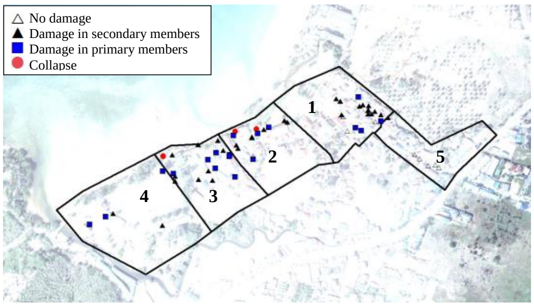
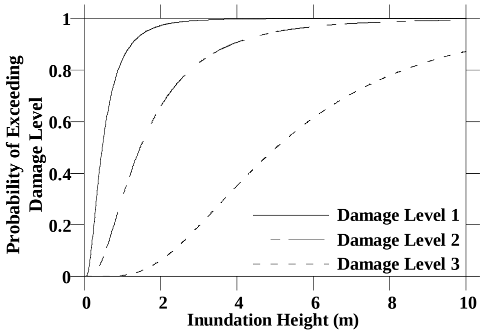


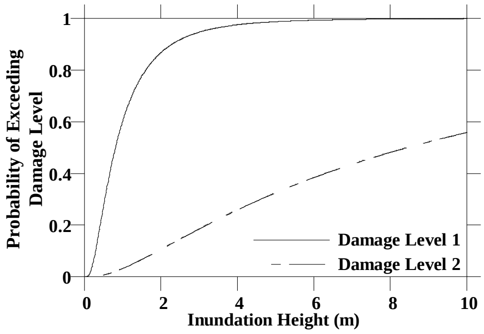
Figure 2 The location of observed buildings damaged by the December 26th, 2004 tsunami (Courtesy of Ministry of Natural Resources and Environment)

3. Fragility curve

The proposed tsunami fragility curves, which are used to evaluate the residential damage, are established from the building damage database in the December 26th, 2004 Indian Ocean tsunami [1]. The proposed tsunami fragility curves are considered only reinforced-concrete buildings. The fragility curves are developed using a maximum likelihood method and describe the damage probability corresponding to a specific damage level for different inundation heights. The damage levels are classified into 4 damage levels ranging from no damage to collapse; 1) no damage (DL0), 2) damage in secondary members only (DL1), 3) damage in primary members (DL2) and 4) collapse (DL3). The tsunami fragility curves for reinforced-concrete buildings are classified into two types: one-story buildings and buildings taller than one story as shown in Figure 3(a) and Figure 3(b), respectively.



(a) One-story buildings



(b) Building taller than one-story

Figure 3 Tsunami fragility curves of reinforced-concrete buildings [1]

4. Inventory of buildings

Building inventory was developed with building information consisting of structural types, the number of stories and building functions. 162 reinforced-concrete buildings were surveyed in Kamala Beach, Phuket in 2008. There are 58 one-story buildings and 104 buildings taller than one story. Surveyed buildings are classified into 5 zones to evaluate damage of buildings as shown in Figure 4. Table 3 shows the number of surveyed buildings for one-story buildings and buildings taller than one story. Zone 1 has the largest number of buildings with 17 one-story buildings and 31 buildings taller than one story.

Figure 4 Location of surveyed buildings and zones (Courtesy of Ministry of Natural Resources and Environment)

5. Evaluation of building damage

To evaluated building damage, the average inundation height from observed data of each zone is shown in Table 2. The probability of exceeding each damage level is known from the proposed fragility curves [1] and the average inundation heights. Then, the probabilities of each damage level are calculated by Eq. (1) [3].

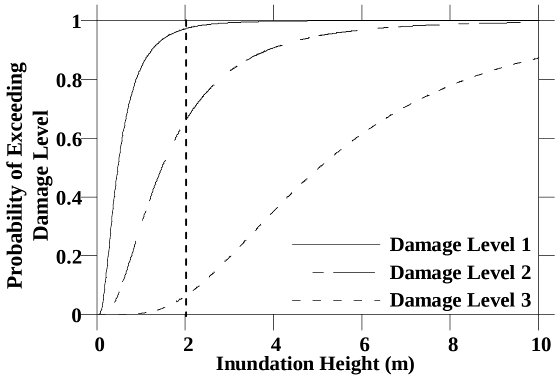
$$P = \frac{\sum_{i}^{n} \left(p_i \cdot a_i \right)}{A} \times 100 \quad (1)$$

where

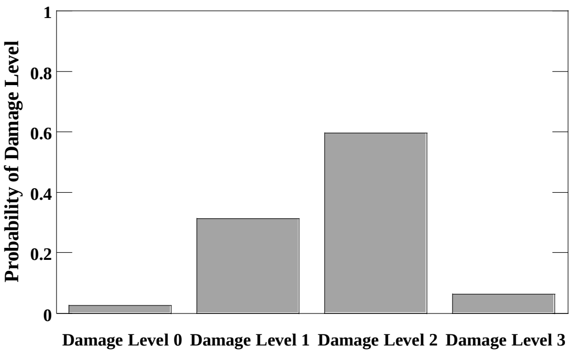
P = the probability of the specified damage level of a zone
p_i = the probability of the specified damage level of a building
a_i = the footprint area of a building
A = the total footprint area of all buildings in a zone

As an example, Figure 5 shows the probabilities of each damage level for one-story buildings at an inundation height of 2 m. Probabilities are 0.03, 0.31, 0.60 and 0.06 for damage levels 0, 1, 2 and 3, respectively. Table 4 shows the probability of damage levels 0, 1, 2 and 3 for one-story buildings and buildings taller than one story of each zone from tsunami risk assessment. The damage probabilities of one-story buildings and buildings taller than one story are shown in Figure 6 and Figure 7, respectively.

Zones along the shoreline have higher damage than zone 5. It can be seen that zone 5 has probability of the damage levels 0 and 1 higher than zones along the shoreline. For the damage levels 2 and 3, zones along the shoreline have higher probability than zone 5 which is far from the shoreline. Most damage for one-story buildings is the damage level 2 and most damage for buildings taller than one story is the damage level 1. The results of evaluated damage of buildings are compared with actual observed damage. The highest probability of damage for observed buildings of each zone agrees well with the evaluated damage of buildings.



(a) The probability of exceeding damage levels



(b) Probability of damage levels

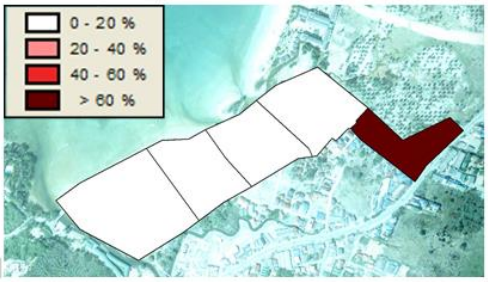
Figure 5 The probability of exceeding damage levels and probability of damage levels of one-story buildings at inundation height of 2 m

Table 3 The number of surveyed buildings in each zone

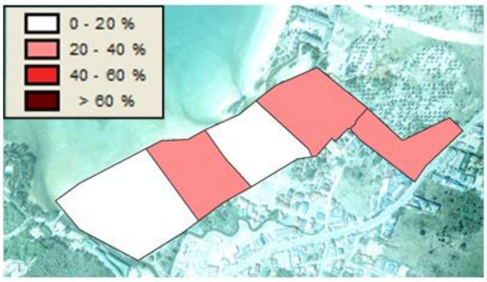
Zone	The number of one-story buildings	The number of buildings taller than one story
1	17	31
2	13	23
3	12	23
4	8	7
5	8	20

Table 4 The probability of damage for one-story buildings and buildings taller than one story from tsunami risk assessment

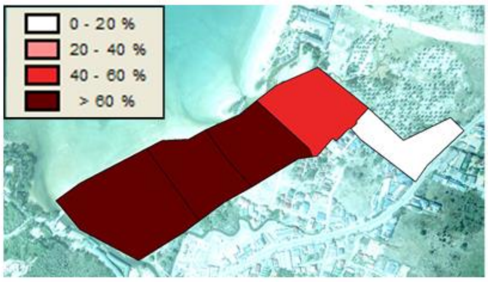
Zone	Probability damage of one-story buildings (%)				Probability damage of buildings taller than one story (%)			
	DL0	**DL1**	**DL2**	**DL3**	**DL0**	**DL1**	**DL2**	**DL3**
1	4.5	38.1	53.9	3.5	18.1	73.7	8.2	0.0
2	1.0	19.6	63.9	15.5	6.7	76.9	16.4	0.0
3	1.1	21.0	63.9	14.0	7.3	77.1	15.6	0.0
4	0.4	13.1	61.1	25.4	3.9	74.7	21.4	0.0
5	61.2	35.2	3.6	0.0	82.5	17.2	0.3	0.0



(a) Damage level 0



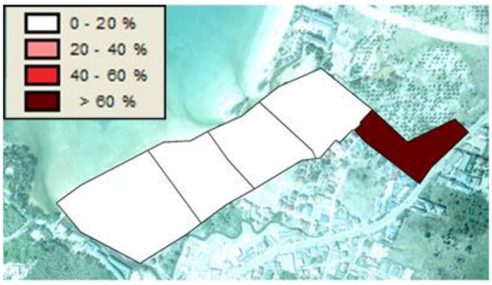
(b) Damage level 1



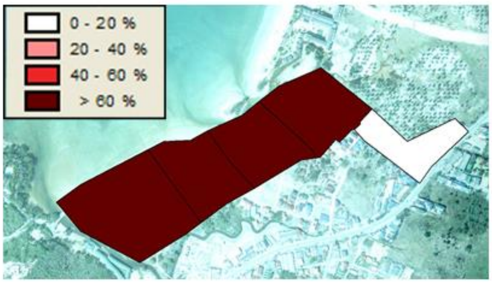
(c) Damage level 2

(d) Damage levels 3

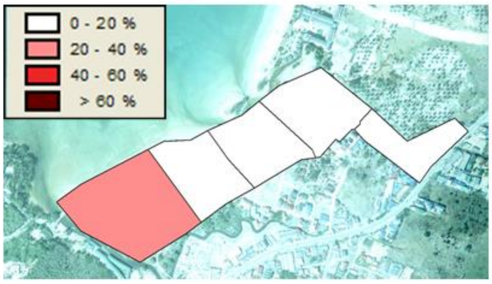
Figure 6 Probability of damage for one-story buildings



(a) Damage level 0



(b) Damage level 1



(c) Damage level 2

Figure 7 Probability of damage for buildings taller than one story

6. Conclusions

This study evaluates the residential damage in Kamala Beach, Phuket, Thailand in the December 26th, 2004 Indian Ocean tsunami. The residential damage is evaluated by the proposed tsunami fragility curves. The proposed fragility curves of reinforced-concrete buildings are classified for one-story buildings and buildings taller than one story. Building inventory is surveyed and classified into 5 zones to evaluate damage of buildings. The tsunami inundation heights in each zone are averaged from the observed damage data. From the evaluated results, zones along the shoreline have higher probability of damage than the zone that is far from the shoreline. Most damage for one-story buildings is damage in primary member of the structure (DL2). Buildings taller than one story are damaged in secondary members only (DL1). The highest probability of damage for observed buildings of each zone agrees well with the evaluated damage of buildings.

7. References

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