# TSUNAMI RISK ASSESSMENT FOR BUILDING USING NUMERICAL MODEL AND FRAGILITY CURVES

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The 2004 Indian Ocean tsunami had already passed and many of risk assessment tools for the potential tsunami had proposed. This study demonstrates methods for assessing the tsunami risk using tsunami fragility curves. Nam Khem village in Thailand was selected for the study area because of its availability of the fragility curves and bathymetry/topography data. Tsunami propagation and inundation model was performed to obtain tsunami height or inundation depth. The fragility curves for different damage level and material type in Thailand were then applied. It was estimated that the maximum number of 600 out of 900 buildings might be heavily damaged or destroyed for the worst case scenario. The analysis also suggests that the propagation model was possible for a roughly estimation because it provided nearly the same results compared with the inundation model. However, it is necessary to consider the material type when the fragility curves are going to be used in a different country, i.e., reinforced concrete building in Thailand from the 2004 tsunami and wooden house in Japan from the 2011 East Japan tsunami.

***Keywords***: *Tsunami risk assessment, building damage, tsunami simulation, tsunami fragility curve*

## 1. INTRODUCTION

Many tsunami vulnerability functions have been proposed after tsunami events. Tsunami risk to building can be assessed using, i.e., fragility curves. The next challenge is then the potential damage from a future tsunami. This study selected one village in Thailand as to estimate a potential risk to building using tsunami propagation and inundation model and different types of fragility curves.

## 2. OBJECTIVES

Location of ruptures for catastrophic tsunami with a return period or earthquake magnitude will be determined. Satellite image of high resolution is used to locate each building location in the study area. Number of possible damage building is to be estimated applying the developed tsunami fragility curves. Building and population data can be established using the visual inspection via the high−resolution satellite image. A question arises whether the rough estimation from the propagation model and global population data has sufficient accuracy when comparing with the results from the inundation model and visual inspected data.

## 3. METHODS

### (1) Tsunami source model and scenario

Fault rupture that has high potential to cause a destructive damage to the study area in southern Thailand (**Fig. 1**) is suggested to be the rupture length that is longer than 300 km which originated from 5° – 6° N and 92° – 93° E (segment no. 5–6) for the Andaman coast. In this study, rupture length from 300 km ($M_w$ 8.5) to 800 km ($M_w$ 9.3) are considered for the potential tsunami with each 100 km segment. Earthquake return period of $M_w$ 8.5, 8.7, 8.9, 9.0, 9.2 and 9.3 equal 250, 325, 400, 440, 490 and 550 years respectively (Suppasri et al., 2011a). **Table 1** summarizes and shows number of population at risk for each segment and scenario. For example, the highest number of population of 36,265 is occurred when the $M_w$ 9.0 of a 600 km–length fault (6 segments) is generated starting from segment 4 to segment 9. For the rupture length that is longer than 600 km, it is determined that the fault might be extended to the south because it provides larger potential tsunami exposure. Other parameters are set to be fixed as depth = 10 km, dip = 15°, slip = 90° for the worst case and estimated segment size and slip is shown in **Table 2**.

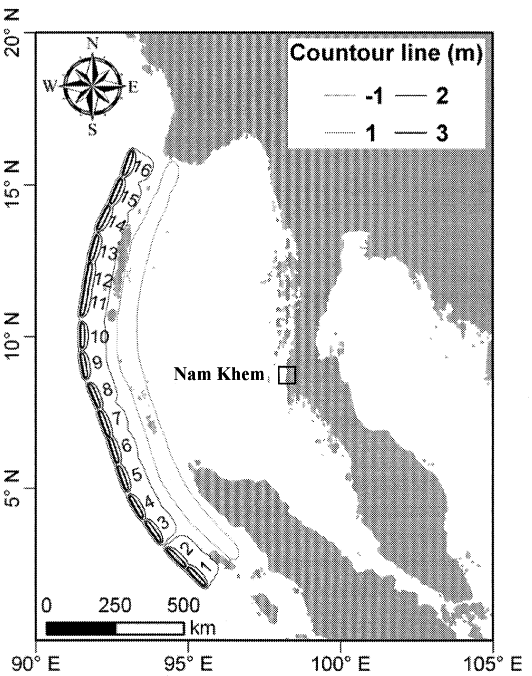


**Fig.1** Location and bottom deformation of the 16 segments.

**Table 1** Position of the 16 segments and potential tsunami exposure.

| No. | Location (bottom-left) | | | Potential Tsunami Exposure (No. of population) | |
|---|---|---|---|---|---|
| | Lat. | Lon. | Strike | 600 km (9.0 $M_w$) | 300 km (8.5$M_w$) |
| 16 | 15.30 | 92.87 | 18 | | |
| 15 | 14.38 | 92.45 | 22 | | |
| 14 | 13.51 | 92.01 | 25 | | 324 |
| 13 | 12.51 | 91.78 | 15 | | 313 |
| 12 | 11.56 | 91.63 | 10 | | 0 |
| 11 | 10.66 | 91.48 | 10 | 14,622 | 303 |
| 10 | 9.60 | 91.51 | 0 | 20,243 | 307 |
| 9 | 8.60 | 91.64 | 350 | 21,263 | 2,628 |
| 8 | 7.64 | 92.08 | 337 | 33,608 | 2,640 |
| 7 | 6.72 | 92.38 | 340 | 25,385 | 910 |
| 6 | 5.82 | 92.68 | 342 | 33,749 | 897 |
| 5 | 4.90 | 93.00 | 340 | 35,732 | 927 |
| 4 | 4.00 | 93.50 | 330 | 36,265 | 915 |
| 3 | 3.20 | 94.10 | 325 | 33,714 | 586 |
| 2 | 2.40 | 94.90 | 315 | 35,290 | 11 |
| 1 | 1.75 | 95.60 | 315 | 33,201 | 0 |

**Table 2** Estimating magnitude and size of each fault.

| Length (km) | Segment Number | Width (km) | Slip (m) |
|---|---|---|---|
| 800 ($M_w$ 9.3) | 2 – 9 | 175 | 14.01 |
| 700 ($M_w$ 9.2) | 3 – 9 | 160 | 11.99 |
| 600 ($M_w$ 9.0) | 4 – 9 | 150 | 9.98 |
| 500 ($M_w$ 8.9) | 5 – 9 | 135 | 8.12 |
| 400 ($M_w$ 8.7) | 5 – 8 | 120 | 6.23 |
| 300 ($M_w$ 8.5) | 7 – 9 | 100 | 4.57 |

### (2) Tsunami propagation and inundation model

There were two tsunami models that were applied in this study; propagation and inundation model (Suppasri et al., 2011a and 2011b). Propagation model of the linear wave theory was performed to simulate the maximum tsunami height at shoreline for a macro scale calculation. The global bathymetry data with the grid size of 1,855 m was obtained from General Bathymetric Chart of the Oceans (GEBCO) and global population data of 928 m mesh can be derived from Landscan. On the other hand, tsunami inundation model of the non–linear wave theory was then performed using the smallest 17 m bathymetry data of Nam Khem village and building data was obtained from visual inspection. Initial water level according to the sea floor deformation is shown in **Fig. 1**.

### (3) Tsunami fragility curves for building damage

The fragility curves were developed and demonstrated for different structural damage level **(Fig. 2)** and constructed building material (**Fig. 3**) (Suppasri et al., 2011b). The fragility curves are shown by separating the reinforced concrete (RC) buildings from mixed type buildings and wooden building. This was the first attempt in the tsunami fragility research field that the curves were split so that the damage assessment can be conducted for the different building material. At 2–3 m inundation depth, wooden building and mix type building starts damage with the probability as high as 0.90 and 0.60 respectively, where the RC building has only 0.20. RC building has high damage probability of 0.70 when the depth reaches 8 m, whereas the mix type building has almost already damage with the probability of 0.90.

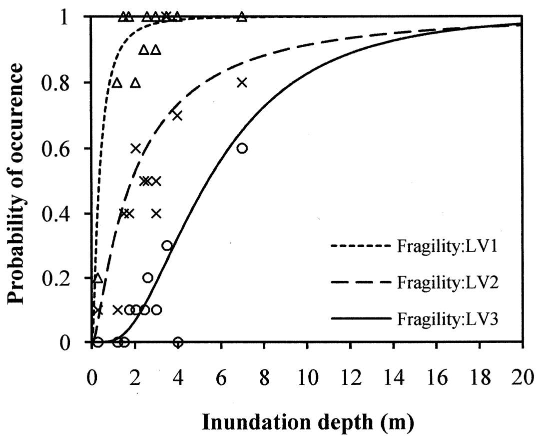


**Fig.2** Tsunami fragility curves of RC building for secondary member (LV1), primary member (LV2) and collapse (LV3).

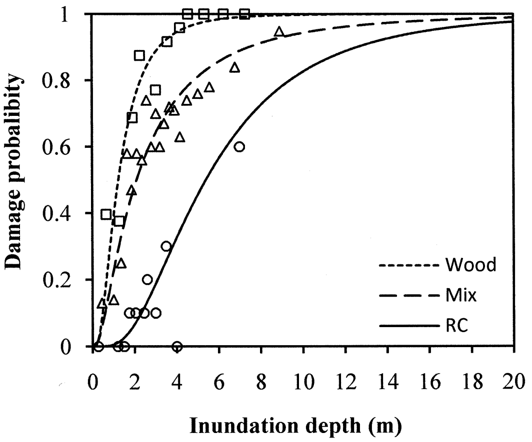


**Fig.3** Tsunami fragility curves of mix type building material and RC building in Thailand and wooden house in Okushiri, Japan.

## 4. RESULTS

In this section, results obtained from both macro scale estimation (Propagation model) and micro scale (Inundation model) conducted in Nam Khem village will be summarized. **Figure 4** depicts the building location derived by visual inspection from the satellite image (Google map). There are approximately 900 buildings that were visually inspected from the map as shown in black dots. **Figure 5** presents the number of population for each grid cell derived from the global population data (Landscan). There are totally 5 population cells located in the Nam Khem village but only 4 cells have value namely, 8, 56, 436 and 1,451. Thus, from the Landscan data, total number of population in Nam Khem village is the summation of those 4 cells which becomes 1,951. On one hand, the number of population for Nam Khem village reported by Department of Disaster Prevention and Mitigation (DDPM) (DDPM, 2007) is 1,994 with 403 households (About five members per one family). This implies that the number of population from Landscan is quite getting along well with the actual reported data from Thai government. However, this number is not including the number of non−registered population which considerable as large as twice as the local population. As we can see that the total reported household is 403 while 900 was counted via the satellite image and similar to book from Nam Khem village (2007).

Comparison of tsunami inundation depth can be seen by **Fig. 6** and **Fig. 7**. **Figure 6** shows the maximum tsunami height simulated by the propagation model of 1,855 m grid size. In this figure, the maximum height is 3.75 m where the land elevation derived from the global bathymetry data is 1 m. Hence, the roughly estimated tsunami inundation depth might be 3.75 subtract by 1 equal 2.75 m. On the other hand, the maximum tsunami inundation depth is shown in **Fig. 7**. Distribution of the depth can be seen with the 17 m resolution. The deep grey color of 2.75 m (Average for the whole village) in the **Fig. 6** is well represented in the distribution of the color in the **Fig. 7**. From the two figures, the rough estimation obtained from the propagation model can reasonable computed the average inundation depth as the comparison with the inundation depth distribution obtained from the inundation model.

Fragility curves developed in this study was also applied to see the different of the two calculations. First, if the maximum tsunami height and global population data were used, number of damage building might be $(1{,}951 / 5) \times 0.65 = 254$ buildings (Damage probability of 2.75 m tsunami is equal to 0.65). Second, if the maximum tsunami height and visual inspected building data is used, number of damage building might be $900 \times 0.65 = 585$ buildings. Lastly, if the maximum tsunami inundation depth and visual inspected building data (**Fig. 8**) is used; number of damage building becomes 593 buildings (**Table 3**). The results show that the estimated building numbers are quite different or about twice when comparing with the visually inspected building data. The main reason for the different number of building is because the global population and Thai government data are not including the exact number of non−registered population which causes smaller number of building in the village.

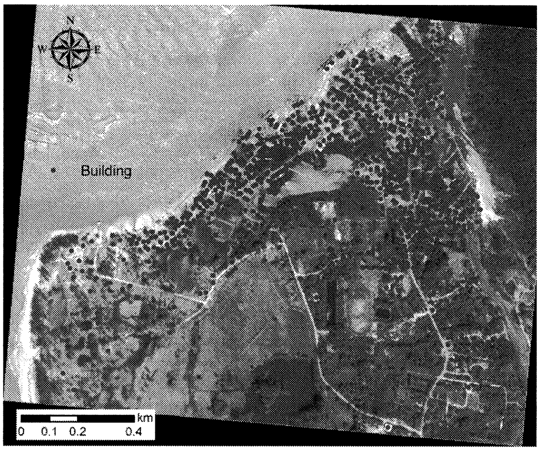


**Fig.4** Building location obtained from visual inspection.

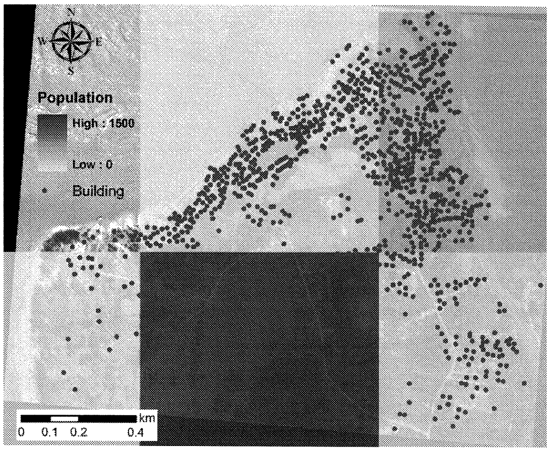


**Fig.5** Population data estimated by Landscan (Grid size: 928 m).

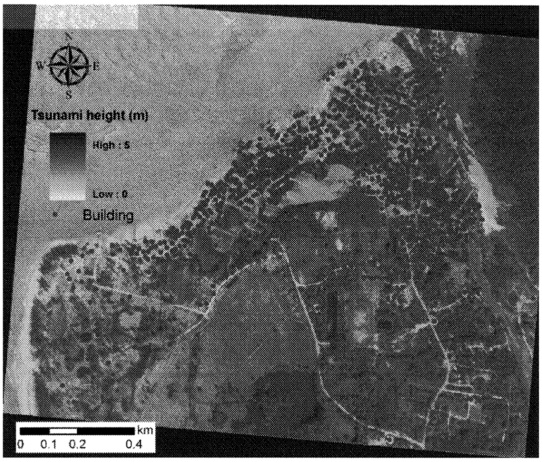


**Fig.6** Maximum tsunami heights (Grid size: 1,855 m).

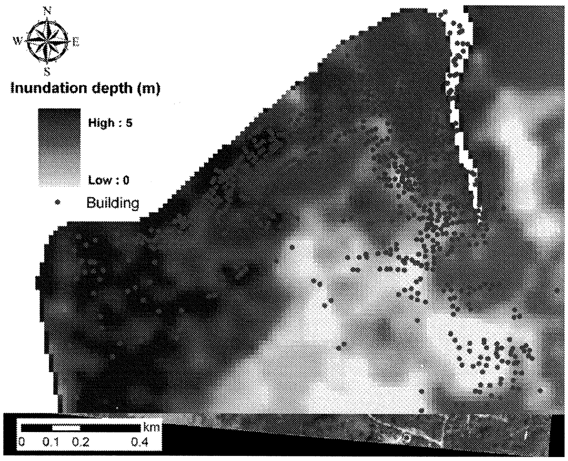


**Fig.7** Maximum inundation depths (Grid size: 17 m).

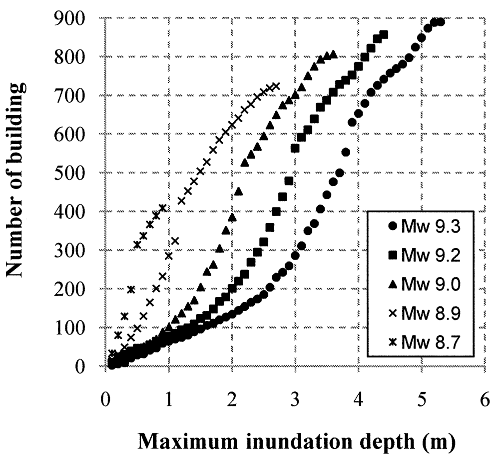


**Fig.8** Relationship between building at risk and maximum inundation depth in Nam Khem village.

**Table 3** Number of estimated damage building against the potential tsunamis.

| $M_w$ | Return period (year) | Number of building | | | |
|---|---|---|---|---|---|
| | | Damage Level 3 | Damage Level 2 | Damage Level 1 | Collapse |
| 9.3 | 550 | 216 | 395 | 212 | 593 |
| 9.2 | 490 | 139 | 382 | 264 | 502 |
| 9.0 | 440 | 68 | 344 | 323 | 387 |
| 8.9 | 400 | 18 | 230 | 353 | 213 |
| 8.7 | 325 | 0 | 85 | 248 | 58 |

## 5. DISCUSSIONS

There is an important point about the building structure that should be carefully considered before applying the fragility curves. **Figure 9 and 10** show examples of the damage on building wall in case of the 2004 Indian Ocean tsunami in Thailand and in case of the 2011 East Japan tsunami in Japan respectively. These two 2-story buildings can be classified at the same damage level from their appearance. However, the building structures are different and these features are not possible to be identified from the satellite image. **Figure 9** is a RC-frame building with brick wall whereas; **Fig. 10** is a wood-frame, steel column building with wooden wall. Building in **Fig. 10** might sound weaker but had the same performance even it was attacked by a larger tsunami. Brick wall which is commonly used in Thailand provide resistant force at some level. However, wooden wall which is commonly used in Japan because of its light weight for reducing damage from earthquake is easily to be destroyed and let tsunami flow through inside. Therefore, high pressure will suddenly accumulate at a whole brick wall projection area that is perpendicular to a tsunami direction causing more severe damage at the same tsunami size.

**Fig.9** Damaged building in case of the 2004 Indian Ocean tsunami at 3.7 m flow depth.

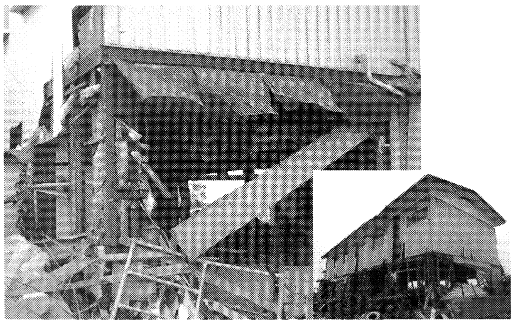

**Fig.10** Damaged building in case of the 2011 East Japan tsunami at 5.2 m flow depth.

## 6. CONCLUSIONS

Location of fault segment that has the highest potential risk to coastal community in Thailand was reconsidered and determined for designed recurrence scenario. The potential rupture area starts from 300 km ($M_w$ 8.2/250 years) to 800 km ($M_w$ 9.3/550 years). Tsunami inundation modeling was performed to obtain according to the fault parameter decided by the earthquake generated tsunami return period. Representative vulnerable location was selected, Nam Khem as it was large number of fatalities and damaged buildings reported in the 2004 tsunami. Results from the analysis show the number of coastal population and building against inundation depth for each tsunami return period. Number of coastal residence was estimate using data. Number of damage building at risk was estimated using tsunami fragility developed in the previous study. Two types of estimation were adopted including potential damage of RC building in 3 levels and damage of mix type building. The maximum number of about 600 buildings might be heavily damage or collapse in Nam Khem for the worst case scenario. Comparison of the tsunami simulation from different grid size (1,855 m and 17 m) shows that tsunami propagation model is somewhat reliable to simulate the average tsunami inundation depth of a location where a detailed bathymetry data is not available.

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