

Developing fragility curves based on surveyed data of the 2011 Great East Japan tsunami in Ishinomaki city

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1. Introduction: The 2011 Great East Japan tsunami damaged and destroyed large number of building especially along the Tohoku coast in the east coast of Japan. The Tohoku coast comprises of two coastal topography types namely, Sanriku coast and Sendai and Ishinomaki plain coast. Difference in the coastal topography type leads to difference in tsunami and their building damage characteristics (Suppasri et al., 2013). Ishinomaki city was the only one city among affected areas that was damaged by the 2011 tsunami in both ria and plain coasts (Fig. 1). More than 400,000 buildings damaged or destroyed by the 2011 tsunami were report (National Police Agency, 2011). The Ministry of Land, Infrastructure and Transportation (MLIT) provides their survey results of 251,301 buildings (MLIT, 2012) which more than 25% of them (63,605 buildings) belong to the damaged building data in Ishinomaki city. This is a good chance to develop the tsunami fragility curves based on the mentioned different tsunami characteristics due to coastal topography.

wall clean up. In addition, very small number of buildings was classified as no damage which means buildings located outside tsunami inundation areas; recorded inundation depth is 0.0 m. Therefore, damage probability can only be calculated for damage level 2-6.

Table 1 Classifications and descriptions of building damage

Class	Description
Minor damage	There is no significant structural or non-structural damage, possibly only minor flooding.
Moderate damage	Slight damages to non-structural components.
Major damage	Heavy damages to some walls but no damages in columns
Complete damage	Heavy damages to several walls and some columns
Collapsed	Destructive damage to walls and several columns
Washed away	Washed away, only foundation remained, total overturned

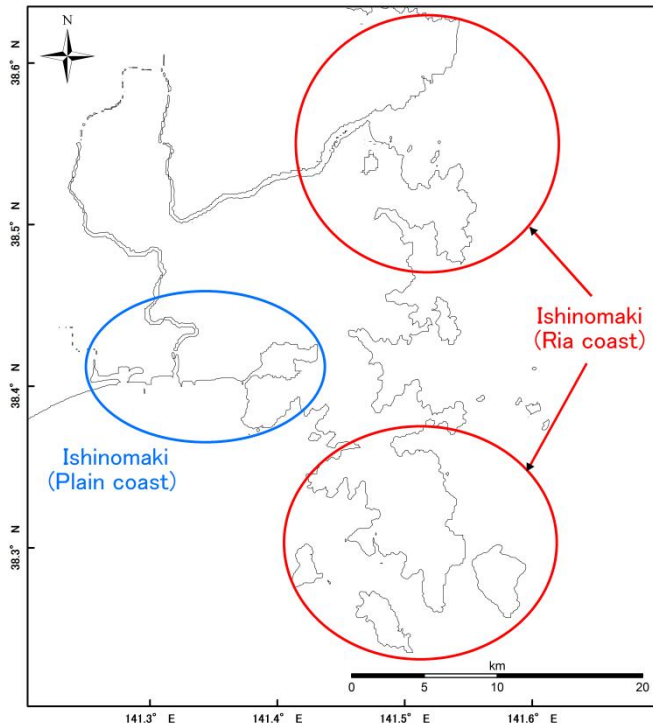


Fig. 1 Area map of Ishinomaki city

2. Data and method:

2.1 Damaged building data: Detailed building damage data and tsunami inundation depth surveyed by MLIT was obtained from Ishinomaki city. The data comprise of totally 63,605 damaged buildings which details of damage are provided for each building. In this data, damage level is classified into six levels as shown in Table 1 (level 1: minor damage, level 2: moderate damage, level 3: major damage, level 4: complete damage, level 5: collapsed and level 6: washed away) similar to Suppasri et al. (2013). Description of damage level 1-minor damage is actually minor flooding and possible to be use immediately after minor floor and

2.2 Developing tsunami fragility curve

The building damage probabilities for each damage level were calculated and shown against a median value within a range of the same number of building varying from 10 to 2,000 buildings based on the total number of building for each condition. Linear regression analysis was performed to develop the fragility function. The cumulative probability P of occurrence of damage is given either by Eq. (1) or by (2):

$$P(x) = \Phi[(x-\mu)/\sigma] \quad (1)$$

$$P(x) = \Phi[(\ln x - \mu')/\sigma'] \quad (2)$$

where, Φ represents the standardized normal distribution function, x stands for the hydrodynamic feature of tsunami used as demand parameter (e.g., inundation depth, current velocity or hydrodynamic force), and μ and σ (μ' and σ') represents the mean and standard deviation of x ($\ln x$) respectively. Two statistical parameters of fragility function, μ and σ (μ' and σ'), are obtained by plotting x ($\ln x$) against the inverse of Φ on normal or lognormal probability papers, and performing least-square fitting of this plot. Consequently, two parameters are obtained by taking the intercept ($= \mu$ or μ') and the angular coefficient ($= \sigma$ or σ') in Eq. (3) or (4):

$$x = \sigma\Phi^{-1} + \mu \quad (3)$$

$$\ln x = \sigma'\Phi^{-1} + \mu' \quad (4)$$

Throughout the regression analysis, the parameters are determined to obtain the best fit (in the least squares sense) of fragility curves with respect to the inundation depth.

3. Results and discussions:

From the total 63,605 buildings, 10,390 buildings and 53,215 buildings were used to develop the fragility curves for the ria coast and the plain coast as shown in Fig 2 and 3

respectively. The ria coast has a mean inundation depth value as high as 12 m whereas 7 m in the plain coast. In general, damage probability in the ria coast increase rapidly from the beginning and reach 0.80 when the inundation depth is 1 m (for level 2 and 3), 2 m (for level 4 and 5) and 6 m (for level 6) respectively. On the other hand, damage levels 4-6 in the plain coast are not observed until the inundation depth is greater than 1 m but most of them will have approximately the same damage probability when the inundation depth reach 3 m (for level 4-5) and 6 m (for level 6) respectively. This characteristic is similar to a fragility curves for major damage and greater of wooden house that developed using data from flood in Niigata prefecture in 2004 (Suzuki et al., 2005) as shown in dashed line of Fig. 3.

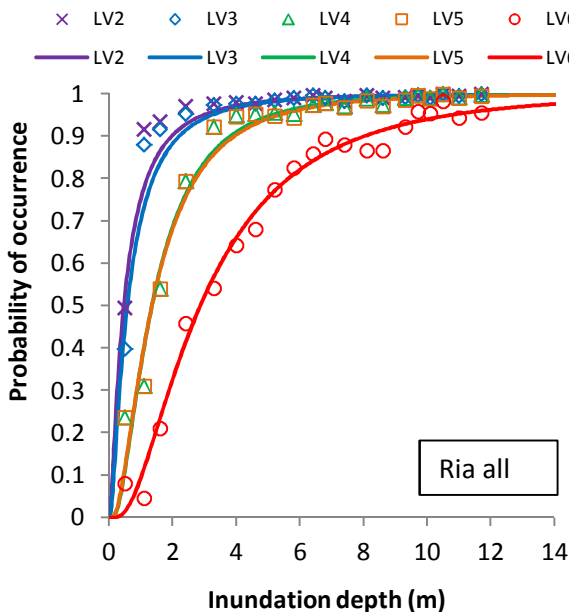


Fig. 2 Tsunami fragility curves for the ria coast

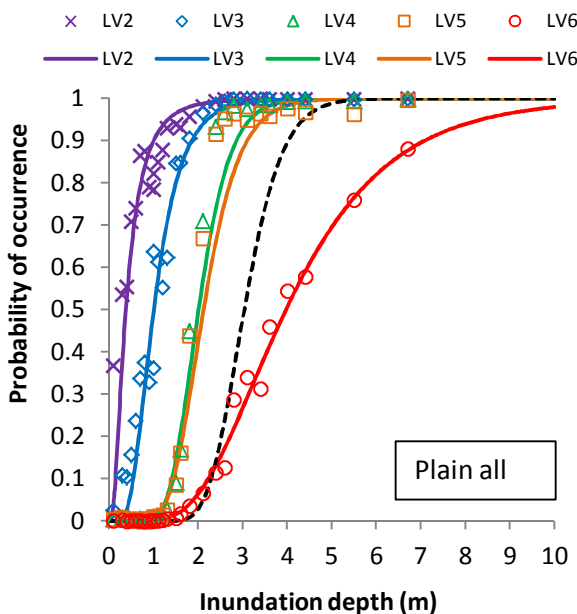


Fig. 3 Tsunami fragility curves for the plain coast

4. Conclusions and recommendations:

This study developed tsunami fragility curves based on different conditions of the surveyed 63,605 buildings in Ishinomaki city. The related parameters are shown in Table 2. At the same inundation depth, higher damage probability is found in ria coast due to higher flow velocity. For washed

away buildings, probability of occurrence in the ria coast is gradually increase from very low inundation depth but finally equal to the plain coast when the depth reach 6 m. Characteristic of building damage due to tsunami in the plain area is similar to flood in Japan.

Table 2 Summary of parameters for drawing the fragility curves

X for fragility function P(x)	μ'	σ'	R ²
Ria: level 2	-0.7753	1.1314	0.75
Ria: level 3	-0.5634	1.0555	0.79
Ria: level 4	0.2935	0.8141	0.90
Ria: level 5	0.2959	0.8383	0.89
Ria: level 6	1.0529	0.8032	0.93
Plain: level 2	-0.9814	0.7645	0.85
Plain: level 3	0.001	0.4799	0.93
Plain: level 4	0.6964	0.2757	0.93
Plain: level 5	0.7504	0.2969	0.91
Plain: level 6	1.3786	0.4514	0.98
Flood	0.2200	1.1100	0.86

Acknowledgements: The building damage data belong to the damage field survey of the 2011 Tohoku tsunami conducted by the Ministry of Land, Infrastructure and Transport (MLIT) provided by Ishinomaki city office. This research was partly funded by the Tokio Marine & Nichido Fire Insurance Co., Ltd. through the International Research Institute of Disaster Science (IRIDeS) at Tohoku University, the Willis Research Network (WRN) under the Pan-Asian/Oceanian tsunami risk modeling and mapping project and the Ministry of Education, Culture, Sports, Science and Technology (MEXT).

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