Is using of maximum flow depth from tsunami fragility functions overestimates wooden housing damage?

ANAWAT SUPPASRI[1], KWANCHAI PAKOKSUNG[1], PANON LATCHAROTE[2], NORIYUKI TAKAHASHI[3], FUMIHIKO IMAMURA[1]

[1]*International Research Institute of Disaster Science (IRIDeS), Tohoku University, Japan*
Faculty of Science and Technology, Thammasat University, Thailand
Department of Architecture and Building Science, Graduate School of Engineering, Tohoku University, Japan

1. Introduction: Maximum flow depth is widely used in developing tsunami fragility functions as the maximum flow depth is the only parameter that can be directly measured after tsunami events. However, tsunami lateral load represented by hydrodynamic force is largely controlled by flow velocity. Therefore, housing damage can occur before reaching the maximum flow depth and using of the maximum values (flow depth and flow velocity) might underestimate building damage. Therefore, this study aimed to investigate how large the previously proposed tsunami fragility functions overestimates housing damage when using the maximum flow depth.

2. Data and method:

2.1 Study area: This study selected city area of Ishinomaki City, Miyagi Prefecture because of the following reasons.

(a) Less impact from wave amplification: The city is in a plain area where wave amplification is small compared to the Sanriku Ria coast (Suppasri et al., 2013).

(b) Less impact from wave directions: Factors from wave direction are minor as most of the buildings were lined facing along the shoreline and the wave attacking direction is perpendicular to the buildings front.

(c) Less impact from floating objects: The populated areas of the city is far from fishing ports and storages that became floating objects.

(d) The largest sample size: Among the cities along the plain area, the populated areas of Ishinomaki City had the largest numbers of damaged buildings that can be used as samples of this study (Suppasri et al., 2013).

2.2 Building damage data and lateral resistance force: Detailed building damage data was obtained from Ministry of Land, Infrastructure and Transportation and Tourism (MLIT, 2012). The data contains building size, numbers of stories, construction materials and interpolated measured maximum flow depth. As a pioneer study, this study only used wooden residential houses in the analysis because of the largest numbers of sample. In addition, only damage level 5 (collapse: non-repairable) and 6 (collapse: wash away) were considered since this damage level can be easily analyzed as the damage definition is clearer compared to other damage levels (minor, moderate or major damage). Lateral force was the main cause of the collapsed wooden houses. Lateral resistance to building and wind forces for each wooden house was calculated following *Article 46 Enforcement Ordinance of Building Standard Law* using the standard lateral strength of the bearing wall of Japanese housing which equal to 1.96 kN/m. The lateral resistance was then calculated depended on the necessary wall length at each floor. The necessary wall length can be calculated based on the building floor area and its design coefficient for earthquake and the vertical projection area which is an area of the building width or length multiply by floor height above 1.35 m for wind. The design lateral resistance was then determined as the maximum required resistance against earthquake and wind loads.

2.3 Tsunami numerical simulation: Tsunami numerical simulation was performed to reproduced the 2011 Great East Japan tsunami in Ishinomaki City. The numerical used a set of nonlinear shallow water equations that were discretized using the Staggered Leap-frog finite difference scheme (TUNAMI model) with bottom friction in the form of Manning's formula which varied by land use types (Suppasri et al., 2011). Six computational domains from Tohoku region down to City area of Ishinomaki City were used as a nesting grid system of 1,215 m (Region 1), 405 m (Region 2), 135 m (Region 3), 45 m (Region 4), 15 m (Region 5) and 5 m (Region 6). Time series of flow depth, flow velocity and hydrodynamic force were calculated for each housing from the total of about 20,000 wooden housings. After model verification with the interpolated measured maximum flow depth, simulation results give good Aida's K and κ as 1.04 and 1.32. The calculated hydrodynamic force and lateral resistance were used as wooden housing damage (collapse) criteria for further assessment.

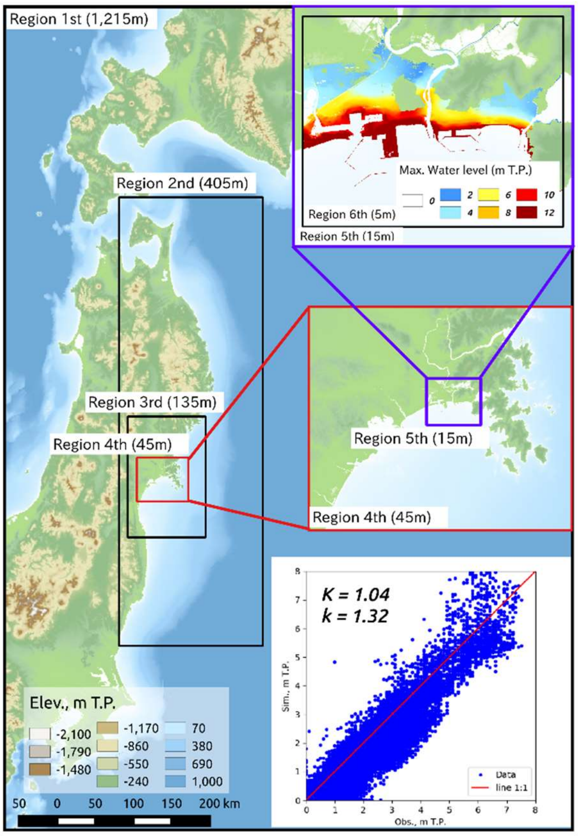

Fig. 1 Study area, simulation results and model verification

3. Results and discussions:

3.1 Reproduction of the collapsed wooden housing: It is assumed that the housing damage (collapse) occurs when the hydrodynamic force is larger than the lateral resistance force. The results show that more than 99% of the collapsed wooden houses were classified under this assumption. However, there is only 58% accuracy as there are still many of collapsed wooden houses in a case that the hydrodynamic force is less than the lateral resistance force. The main reason is that the additional force from floating debris (increasing of water density) from the damaged or collapsed houses was not included in the simulation.

3.2 Developing fragility functions: For further discussion, critical flow depth (*Dc*) at the time that hydrodynamic force (*Fc*) is larger than lateral resistance force, the maximum hydrodynamic force (*Fm*) and the maximum flow depth (*Dm*) were used. The building damage probabilities for each damage level were calculated and shown against a median value of the mentioned parameters (*Dc*, *Dm*, Fc and *Fm*) within a range of 2,000 buildings. Linear regression analysis was then performed to develop the fragility functions. Detailed descriptions of this method are explained in Suppasri et al. (2011 and 2013). Parameters related to the developed fragility functions are shown in Table 1.

Table 1 Summary of parameters for drawing the fragility functions

X for fragility function P(x)	Mean	Standard deviation	R^2
Dc: Level 6	2.857 (μ)	1.4351 (σ)	0.94
Dc: Level 5+6	0.9584 (μ)	0.5143 (σ)	0.99
Dm: Level 6	3.7559 (μ)	1.0302 (σ)	0.97
Dm: Level 5+6	1.3711 (μ)	0.5958 (σ)	0.98
Fc: Level 6	1.0093 (μ')	1.1620 (σ')	0.94
Fc: Level 5+6	3.7007 (μ')	1.5260 (σ')	0.98
Fm: Level 6	1.0498 (μ')	1.2106 (σ')	0.94
Fm: Level 5+6	3.8329 (μ')	1.5443 (σ')	0.98

The developed fragility functions using *Fc* and *Fm* as explanatory parameters (Fig. 2) show exactly the same results because hydrodynamic force is a combination of flow depth and flow velocity. Quantitative assessment of the developed fragility functions can be done when using *Dc* and *Dm* as explanatory parameters (Fig. 3).

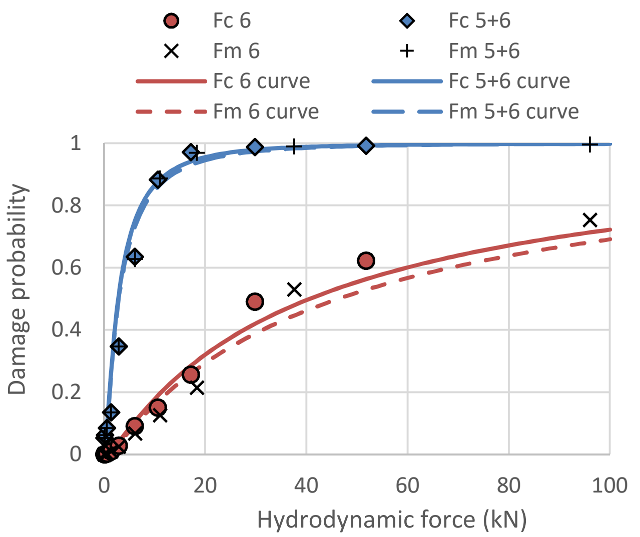

Fig. 2 Fragility functions (*Fc* and *Fm* as explanatory parameters)

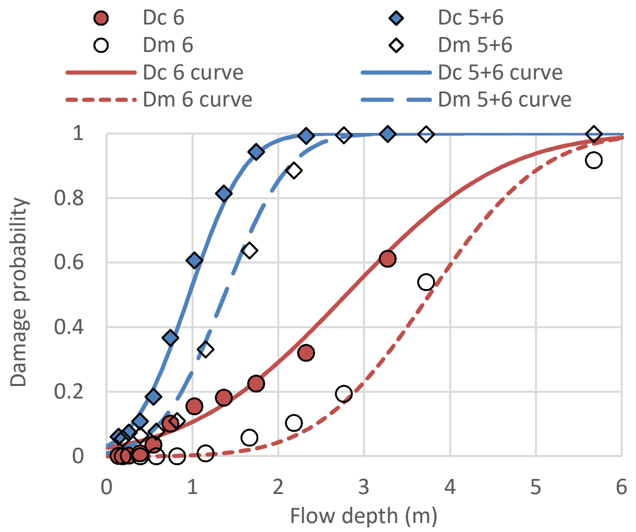

Fig. 3 Fragility functions (*Dc* and *Dm* as explanatory parameters)

For damage level 6, it can be seen that *Dm* overestimates the damage probability by roughly 0.5 to 1.0 m during the damage probability of 0.1 to 0.9. For example, at 0.3 damage probability, *Dm* is 3.2 m even though *Dc* is only 2.0 m. Similarly, for the combined damage levels 5 and 6, it can be seen that *Dm* overestimates the damage probability by 0.5 during the damage probability of 0.1 to 0.9. In other words, using the maximum flow depth overestimates the flow depth at the same damage probability which gives higher flow depth value when considering the same damage probability.

4. Conclusions and recommendations: This study demonstrates that building damage assessment using hydrodynamic force and lateral resistance force could have explained the collapsed wooden houses. However, this method still underestimated the additional force caused by the floating collapsed or damaged buildings. The developed fragility functions show that the maximum flow depth overestimates the performance of wooden housing. Therefore, larger damage is expected at the same flow depth when using the maximum flow depth. Nevertheless, using hydrodynamic forces give similar results.

Acknowledgements: This study was funded by JSPS Grant-in-Aid for Young Scientists (B) (no. 16K16371), the Willis Research Network and the Tokio Marine & Nichido Fire Insurance Co., Ltd., through IRIDeS, Tohoku University.

References:

Ministry of Land, Infrastructure, Transportation and Tourism (MLIT): Survey of tsunami damage condition: http://www.mlit.go.jp/toshi/toshi-hukkou-arkaibu.html (accessed 4 July 2012)

Suppasri, A., S. Koshimura and F. Imamura (2011) Developing tsunami fragility curves based on the satellite remote sensing and the numerical modeling of the 2004 Indian Ocean tsunami in Thailand, Natural Hazards and Earth System Science, 11, 173-189.

Suppasri, A., Mas, E., Charvet, I., Gunasekera, R., Imai, K., Fukutani, Y., Abe, Y. and Imamura, F. (2013) Building damage characteristics based on surveyed data and fragility curves of the 2011 Great East Japan tsunami, Natural Hazards, 66 (2), 319-341.