Performance of Coastal Building in case of the 2004 Indian Ocean Tsunami

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1. Introduction: Recently, the need of risk assessment tools for the potential tsunami became important. Tsunami fragility curves were developed using visual inspection from a high resolution satellite images of pre and post event and the numerical simulation. The developed fragility curves reflect the structural performance of the buildings. For example, the developed tsunami fragility in Thailand (Suppasri et al., 2011) show that the damage probability of wooden house is as high as 0.8 at 2 m inundation depth, where only 0.5 and 0.1 for mix type and reinforced concrete (RC) building.

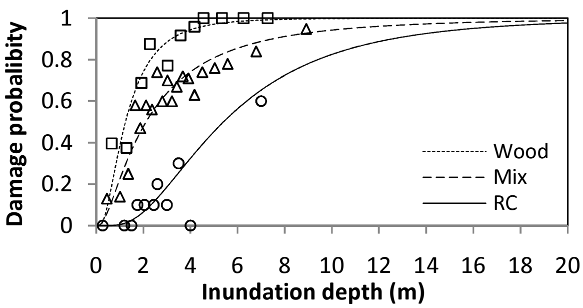

Figure 1. Fragility curves for different type of building materials

2. Objectives: It is known that the hydrodynamic force is the most directly related to the structural performance but more difficult to measure in a field than the inundation depth. To solve the question "which tsunami feature would be selected to represent the structural performance?", the structural performance obtained from the full scale experiments on building and column will be evaluated and use to validate the developed fragility curves.

3. Methodology: This study applies analytical method to estimate the structural performance against the 2004 tsunami of RC column and building. The maximum lateral load resistance force was obtained from the full scale experiment on RC column at laboratory as shown in Fig. 2 (Foytong, 2007) and RC building at tsunami inundated area in southern Thailand as shown in Fig. 3 (Lukkunaprasit et al., 2010).

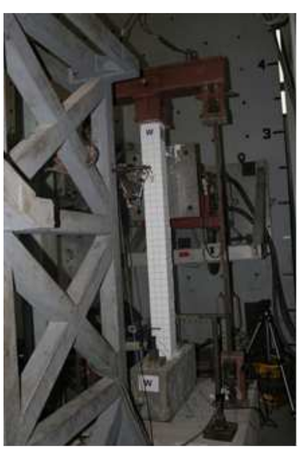

Figure 2. Experiment set up for the lateral load on RC column

Figure 3. Experiment set up for the lateral load on RC building

Consequently, corresponding maximum current velocity and inundation depth will be estimated using a design equation for tsunami wave force and current velocity (Okada et al., 2006). Finally, the obtained tsunami features (inundation depth, current velocity and hydrodynamic force) will be presented on the developed tsunami fragility curves in Thailand (Suppasri et al., 2011).

4. Results and discussion:

4.1 Structural performance of RC column

Full scale experiment (Fig. 2) was conducted to find the performance of the RC column that is used to construct and commonly found in the tsunami affected area in the southern Thailand (Foytong, 2007). The column has 0.15 by 0.15 m^2 cross section area with longitudinal RB12 reinforcement at four sides and RB6 tie bar at 0.2 m spacing for the lateral reinforcement. The experiment set up is shown in Fig. 8. Lateral load was given to the RC column, and plotted against the lateral displacement ratio. The maximum lateral resistance force of the RC column is 8.61 kN (Adjusted using impact factor of 1.5 suggested by Yeh, 2007). Therefore, the maximum force acting on 0.15 m width column is 8.61 / 0.15 = 57.4 kN/m or let says 60 kN/m. The maximum inundation depth and current velocity can be computed using the equations proposed by Okada et al., 2006. Equation 1 is the equation for computing lateral force of tsunami with makes use of the relationship from the Froude number, F_r.

$$F_{HD} = \frac{C_D F_r^2}{2}\rho g \eta_{max}^2 B_h \tag{1}$$

Where, F_{HD} is the horizontal force of tsunami, C_D is a drag coefficient, F_r is a Froude number, ρ is the density of water, g is the gravitational acceleration, η_{max} is the maximum inundation depth and B_h is a width of the inundation part of structure. Equation for the Froude number is express in Eq. 2.

$$u = F_r\sqrt{g\eta_{max}} \tag{2}$$

Where, u is the current velocity. Assuming C_D = 1.0 (for cubic shape) and F_r = 0.7 for a rough surface, the maximum inundation depth of 4.83 m is calculated from Eq. 5.17. Finally, the maximum current velocity of 4.82 m/s is obtained using Eq. (2).

4.2 Structural performance of RC building

Field load test at a survived weather monitoring building of the Meteorological station in Phang Nga was conducted by Lukkunaprasit et al., 2010. The single story reinforced concrete (RC) building which supported by shallow foundations was survived at the 4.4 m inundation depth (above the ground) with minor structural. Lateral loads were applied to the RC building (Fig. 3), and plotted against the lateral displacement. The maximum lateral resistance force of the RC building (Adjusted using impact factor of 1.5 suggested by Yeh, 2007) is 617 kN. Therefore, the maximum force acting on 10 m–span building becomes 617/10 = 61.7 kN/m which is consistence with the maximum force obtained from the experiment on the survived RC building of 57.4 kN/m. The maximum inundation depth and current velocity can be computed using the equations proposed by Okada et al., 2006 as shown in the Eq. (1) and (2) previously.

Using the information that the RC building still survived even the inundation depth was as high as 4.4 m, corresponding velocity that occur when the inundation depth is 4.4 m and the total force is 61.7 kN/m can be calculated at different condition of C_D and F_r using Eq. (1) and (2). For example, assuming C_D = 1.0 (for cubic shape), the inundation depth of 4.4 m was obtained when F_r = 0.8 and current velocity of 5.2 m/s was calculated. According to the condition above, this building might be collapsed when the inundation depth exceed 4.4 m. For instance, When C_D = 1.0 (for cubic shape) and F_r = 0.7, inundation depth and current velocity becomes 5.0 m and 4.9 m/s respectively. FFEMA 55 also suggests value of 2.0 for C_D, consequently, the inundation depth of 5.0 m is obtained when F_r = 0.5 and current velocity of 3.5 m/s can be calculated.

4.3 Structural performance of RC column and building

The selected RC building survived at inundation depth of 4.4 m and the maximum force on building from the experiment was calculated to be 61.7 kN/m. Therefore, this force might occur when the inundation depth exceed 4.4 m. From this point, the selected RC building performance is quite weak. Two examples show that when the inundation depth equal 5.0 m, the equivalent velocity would be 4.9 m/s (C_D = 1.0 and F_r = 0.7) and 3.5 m/s (C_D = 2.0 and F_r = 0.5). Performance of the RC column and building against the three tsunami features can be virtualized in the developed tsunami fragility curves. In spite of the different tsunami features (Inundation depth = 5 m, current velocity = 5 m/s and hydrodynamic force = 60 kN/m), consistence of the damage probabilities can be seen as similar as 0.85 for all of them (Fig. 4).

5. Conclusion: The maximum inundation depth that the RC column and building can resist is 5.0 m, 5.0 m/s for the current velocity and 60 kN/m for the hydrodynamic force. In spite of the different tsunami features, the damage probabilities obtained from the fragility curves still almost the same as it is about 0.85 for all of them. Most of the building type in this area is mostly non−engineering wood or brick and some RC building for hotel and resort. The fragility curves for Banda Aceh, Indonesia and Okushiri Island, Japan were compared. Because of the building type in both areas is mostly non−engineering wood or brick, the damage probabilities for most tsunami features are as high as 0.90 – 1.00.

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References:

Foytong, P. 2007. Fragility of buildings damaged in the 26 December 2004 tsunami, master thesis, Chulalongkorn University: 228p.

Lukkunaprasit, P., A. Ruangrassame, B. Stitmannaithum, C. Chintanapakdee and N. Thanasisathit (2010), Calibration of tsunami loading on a damaged building, *Journal of Earthquake and Tsunami*, 4 (2), 105–114.

Okada, T., T. Sugano, T. Ishikawa, S. Takai and T. Tateno (2006), Tsunami Loads and Structural Design of Tsunami Refuge Buildings, Building Technology Research Institute, The Building Center of Japan.

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.

Yeh, H. (2007), Design Tsunami Forces for Onshore Structures, *Journal of Disaster Research*, 2(6), pp. 531-536.

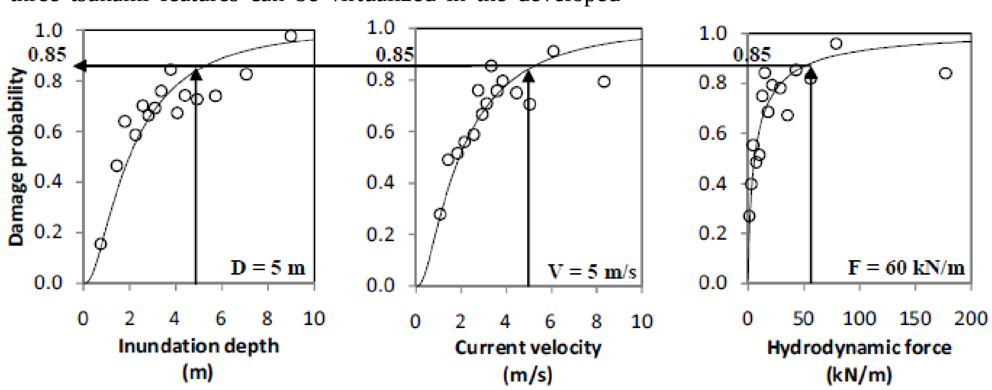

Figure 4. Tsunami fragility curves in Thailand and performance of RC structure