Tsunami-Deck; an introduction concept for a new type of tsunami vertical evacuation shelter

ABDUL MUHARI, SHUNICHI KOSHIMURA, FUMIHIKO IMAMURA
Disaster Control Research Center, TOHOKU University, Japan

1. Introduction

The 2011 East Japan tsunami reveals lot of important lessons. The number of casualties suggests some improvements should be made in order to minimize problems during evacuation in particular, and the whole countermeasures strategy in general.

In places where high ground relatively near to the populated area, problems during evacuation might not be as difficult as it faced in relatively flat areas. For instance, in Sendai plain: under estimated tsunami inundation area yield to limited vertical evacuation sites available in areas which was not predicted to be inundated by tsunami. Therefore, it was observed that the used of cars for evacuation in this area cannot be avoided. Here, if more people using cars means higher possibility for congestion occurred along the road, and caused the delay evacuation. As an overview from 870 survivor in Miyagi, Fukushima and Iwate, 55.7% respondents using cars for evacuation*, and 34% of them were trapped on traffic jam*.

Based on above data, we identify the basic problems we used as foundation to propose a new type of tsunami vertical evacuation shelter. We focus on solving the congestion problem so the unique solution called 'Tsunami-deck' can be applied even in highly populated areas, and provide more distributed vertical evacuation places in the relatively flat areas.

2. Objectives

Present study is aimed to propose a new type of vertical evacuation shelter applied in highly populated areas. Southworth (1991) stated that most of traffic delays during evacuation occur at intersection. Based on experiences during the 2011 tsunami, it was very difficult to avoid cars for evacuation due to complex physiological reasons in addition to flat topographic conditions. Therefore, the proposed solution should be able to solve the problem of delay evacuation due to congestion even if the tendency to use cars cannot be reduced.

The basic concept we propose is based on structure that can be found worldwide, which is the pedestrian bridge. Figure 1 shows the basic idea of an extended function of pedestrian bridge by putting a 'deck' to store more evacuees during the tsunami.

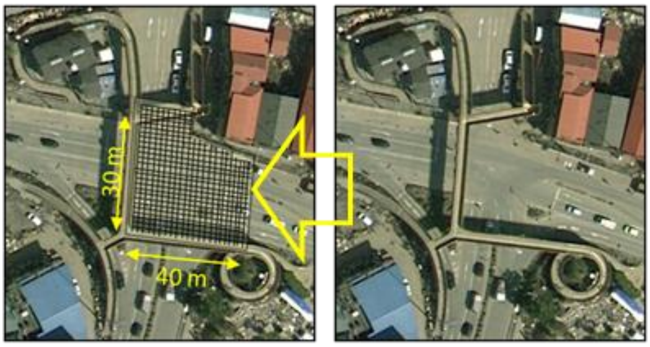

Figure 1. Basic idea of Tsunami-Deck

* http://www.yomiuri.co.jp/dy/national/T110817006318.htm

By expanding the space available in pedestrian bridges; even if the people use cars for evacuation and even if they were trapped by traffic jam at the intersection, they can just left the cars and climb up the pedestrian bridge (Tsunami-deck). Also, it requires less space occupation except for the columns of the bridge. The latter is crucial since in a develop city there are not so many open spaces available. So the option of large evacuation structures may be not suitable.

3. Methodology

We first study about the performance of pedestrian bridge during the 2011 Japan tsunami. It is acknowledged that mechanism of flow-structure interaction between ordinary pedestrian bridge and the tsunami-deck is different. However, the conception of tsunami-deck requires the deck should always be higher than the maximum predicted tsunami flow depth. On that sense, the force incorporating tsunami flow will only works on its columns, which is same situation to the ordinary pedestrian bridge.

We observed the condition of around 68 pedestrian bridges in tsunami affected area in Hokkaido, Aomori, Iwate, Miyagi, Fukushima and Ibaraki Prefectures. From that amount, 21 of them were the pedestrian bridges in train station (T. Bridge) as shown in Table1

Table1. Number of observed pedestrian bridges in East Japan

No	Prefecture	P. Bridge	T. Bridge	Total
1	Hokkaido	4	0	4
2	Aomori	0	1	1
3	Iwate	11	2	13
4	Miyagi	22	8	30
5	Fukushima	10	2	12
6	Ibaraki	0	8	8
	Total			68

Most of pedestrian bridges were observed through the satellite image and the oblique photograph provided by the Geographic Survey Institute of Japan (GSI) in addition to several bridges that were observed through the field survey.

We use the lognormal distribution function to determine the cumulative damage probability as it gives by Shoji and Moriyama (2007) when analyzing the damage of bridge during the 2004 tsunami in Sumatra, Indonesia, and Sri Lanka. The equations are given below,

$$P_c^i = \int_0^z \frac{1}{\sqrt{2\pi}.\sigma_Y.z} exp\left\{-\frac{1}{2}\left(\frac{\ln z - \mu_Y}{\sigma_Y}\right)^2\right\} dz$$

$$\mu_Y = \ln m_z$$

$$\sigma_Y^2 = \ln(1 + V_z^2)$$

$$\Phi_{\text{fit}}^{-1}(P_c^i) = \frac{\ln z - \mu_Y}{\sigma_Y}$$

Here, P_c^i is the cumulative damage probability (i: damage classification), μ_y and σ_y is the mean and standard deviation of Y (Y is $ln\ z$), z is the tsunami flow depth, m_z is the median values of z, v_z is the coefficient of variation (σ/μ), and Φ^{-1}_{fit} is the standard normal distribution function. The tsunami flow depth data was taken from field survey results provided by Japan Society of Civil Engineer (JSCE, 2011). One should note that the observed flow depth points are not always close to the bridges, so the uncertainty of the exact flow depth around the bridge is quite high. We expect to reduce this uncertainty by performing detailed numerical model in the future.

Based on above available datasets, a damage probability curve for pedestrian bridge is developed (Fig. 2). The curves shows that generally the bridge will totally damage (with more than 100% probability) if the tsunami flow depth is more than 7.5 m. It the other words, if the flow depth is more than the height of the deck (5 m), then at least 50% probability of that bridge will damaged by tsunami.

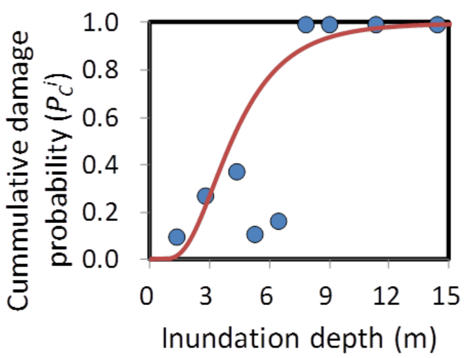

Figure 2. Damage probability curve of pedestrian bridge during the 2011 tsunami

The result brings consequences, if the pedestrian bridge will use for evacuation, than the height of the deck should be higher than the maximum predicted tsunami flow depth. FEMA 646 (FEMA, 2008) suggests that the design height for vertical evacuation building/structures should be $1.5h_{max} + 3$ m, h_{max} denotes the maximum predicted tsunami flow depth, and 3 m was chosen as safety factor. If assumed in some areas, the predicted flow depth is similar to the height of the deck, then the bridge's height should be increased up to 10.5 m. This height of course will not be appropriate especially for the elderly.

To overcome this situation, Goto and Shuto (1982) said that when flow passing through lined obstacles, energy loss in the rearmost region expressed by sudden expansion phenomenon that decreases the flow depth. This phenomenon should also occur at the intersection. Therefore, to describe clearer, we choose a case study for numerical experiment to show the sudden expansion phenomena and how does it affect on designing the height of tsunami-deck. The selected area is Padang city, Indonesia where the next mega-thrust earthquake generated tsunami is predicted to occur within next decades.

4. Case study in Padang City, Indonesia

We extract the Numerical simulation of future tsunami in Padang conducted in Muhari et al. (2011) in Fig. 3. Along the road perpendicular to the shoreline, sudden expansion was observed in cross section number 1, 2, 3 and 5. If tsunami deck put in these intersections, the deck's height is not necessarily so much higher than tsunami flow depth prior the intersection. Sudden expansion phenomena decrease the tsunami up to 1 m within 20-25 m horizontal distance depending on the width of road after the intersection. Here, as long as no potential of large tsunami debris in front of Tsunami-deck, the maximum flow depth after the intersection plus safety factor can be said as enough for the design height of tsunami deck.

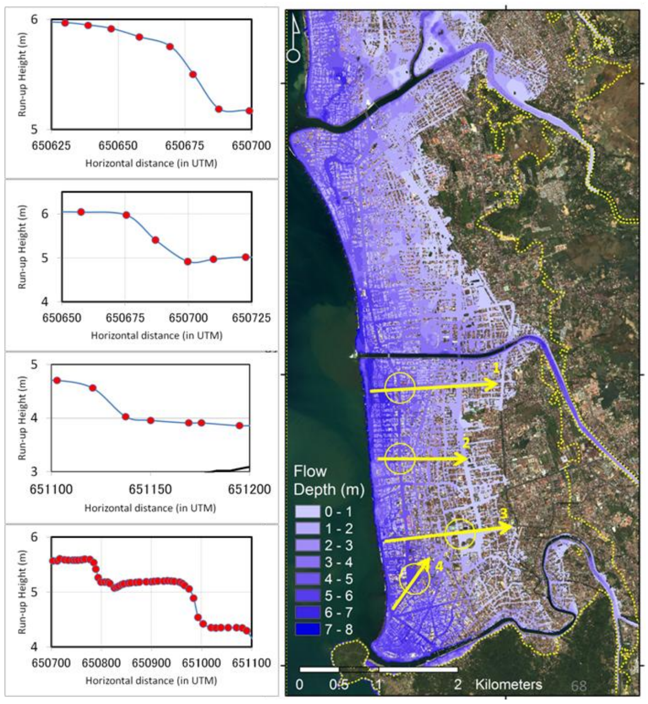

Figure 3 Numerical simulation of tsunami in Padang City, Indonesia and the cross section profile of flow depths where sudden expansion occur

5. Remarks and way ahead

A new type of vertical evacuation is proposed based on evacuation experience and preliminary assessment of pedestrian bridge during the 2011 Japan tsunami. The tsunami-deck has several advantages such as applicable on highly populated areas, solving the congestion problem directly where it occurs; provide more distributed evacuation sites, no large space required, and most important that it is not depend on how people come to tsunami-deck. This study still needs further hydraulic assessment on tsunami behavior at the intersection and flow-structure interaction. Also, further research for collateral damage due to tsunami debris is needed to be assessed.

Acknowledgement

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