TSUNAMI-DECK: A NEW CONCEPT OF TSUNAMI VERTICAL EVACUATION SYSTEM

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A new type of tsunami vertical evacuation structure is proposed to be applied in densely populated area. The proposal is a combination utility of pedestrian bridge and tsunami tower, which is then installed at intersection. This simple structure does not require a specific place and land occupancy for its development. Also, the easiness on the construction and maintenance makes it applicable in developing countries. However, limitation of this idea in practical is found in the design of the height, especially in area where the predicted tsunami height is more or less similar to the height of pedestrian bridge. In order to keep the existing height of pedestrian bridge to be used in tsunami-deck, placement criteria are needed to ensure the safety of evacuee. Starts from the concept of sudden expansion phenomena, a set of numerical exercise is conducted to parameterized hydraulic condition that will allow the sudden drop of water level due to the building configuration at intersection. Preliminary results indicate that if the sudden expansion ratio (D) > 1.5, and the ratio between the widths of road to the residential blocks (β) < 0.1, the sudden expansion will occur at intersection with hydraulic gradient depends on the Froude number (Fr). In this condition, a tsunami-deck can be installed by adjusting the deck's design according to the characteristic of surface elevation at intersection.

Key Words: *Tsunami-deck, pedestrian bridge, sudden expansion, hydraulic gradient*

1. INTRODUCTION

In pre-disaster condition, difficulty to find space for vertical evacuation structure is a common problem in densely populated areas. Utilizing the existing tall buildings especially in developing countries is sometimes risky because the structural quality is not adequate against the earthquake. As an implication, repeatedly seen congestion that occur along the roads used for evacuation due to the dependence on horizontal evacuation system and the in-avoided tendency to use cars for evacuation.

To overcome the above situation, a new type of vertical evacuation structure is proposed. Tsunami-deck is a combination of pedestrian bridge and tsunami tower to put at an intersection (**Fig.1**). It has several advantages on the applicability in densely populated area ,as it has a multipurpose on daily basis i.e. as pedestrian bridge, easy to construct and easy to maintain, and the most important thing is that the structure solves the congestion during the evacuation period directly where it occurs.

Since the idea is based on the extended function of pedestrian bridge, the limitation of the function may come from the design height. The existing height of pedestrian bridge in Japan is around 4.5–5m. Open structure higher than this height for evacuation shelter might not be appropriate for the elderly. Therefore, placement criteria according to the tsunami flow characteristic at intersection are necessary.

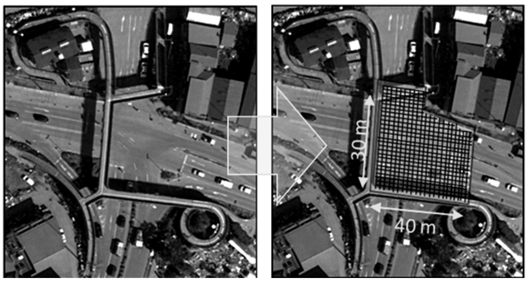

Fig.1 Conception of tsunami-deck

The objective of this paper is to introduce the concept, and numerically models the placement criteria for for constructing tsunami-deck. Started from the concept of sudden expansion phenomena (e.g. Goto and Shuto, 1983), a set of numerical exercise is performed to set parameters of hydraulic condition that will allow the sudden drop of tsunami flow depth due to the building configuration at intersection.

2. METHODOLOGY

A hypothetical town is set as shown in **Fig 2**. Residential block prior the intersection occupied all areas, while the second is not. This design allows the flux at the intersection to spread out in different direction, and minimizing the unnecessary reflecting flows from the side walls. In reality, this design can only represent areas where the width of residential blocks is much bigger than the width of roads among them. The numerical simulations were conducted in several scenarios as shown in **Table1**. Initial of tsunami wave is represented by sin wave with various amplitudes.

A set of non-linear shallow water equation in Imamura (1996) is used to model the tsunami propagation and inundation. Reliability of the 2D Shallow Water Equation (SWE) approach to model tsunami flow passes through obstacles had been validated by Goto and Shuto (1983), and Tsudaka et al. (2011). They obtained result of fairly good agreement with experimental data. However, one should note that this approach has limitation on reproducing flood water behind single building (Tsudaka et al. 2011). Also the absence of diffusion term in the momentum equation might yield inaccuracy of the modeled water level at intersection.

Referring to **Fig.2**, the influence of expansion ratio (*D*) was assessed by increasing d_2 while d_1 keeps remain. The effect of road parallel to the coast is analyzed by increasing l_2, while l_1 keeps constant. The effect the potential building damage prior the intersection and their effect on the hydraulic gradient at intersection is analyzed by reducing the l_1 while the l_2 remains. Lastly, we estimate the effect of the ratio between road widths to the width of residential blocks –symbolized as (β)– on influencing the hydraulic gradient. The above mentioned numerical scenarios were applied into

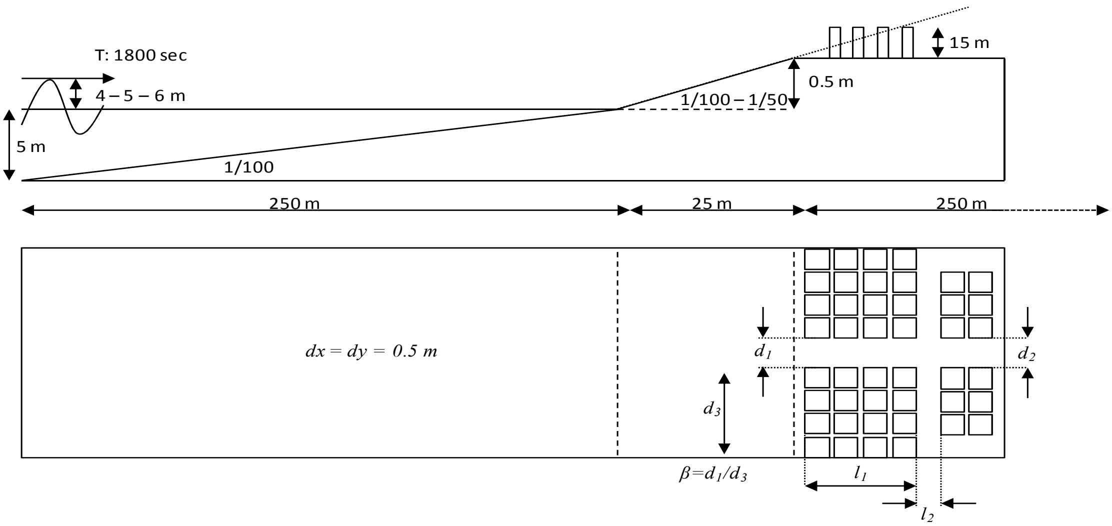

Fig.2 Design of hypothetical town for numerical simulation of tsunami at intersection

Table1. Scenarios for numerical simulation of tsunami at intersection

Case	Slope 0					Slope 1/50		Slope 1/100	
	d_2/d_1 (D)	l_1/l_2	l_2/l_1	β	Amplitude (A) (meter)	d_2/d_1 (D)	Amplitude (A) (meter)	d_2/d_1 (D)	Amplitude (A) (meter)
Case 1	1.20	5.9	0.17	0.11	2, 3, 4, 5, 6	1.20	5.00	1.20	5.00
Case 2	1.40	4.7	0.22	0.16	2, 3, 4, 5, 6	1.40	5.00	1.40	5.00
Case 3	1.60	3.5	0.27	0.21	2, 3, 4, 5, 6	1.60	5.00	1.60	5.00
Case 4	1.80	2.3	0.32	0.24	2, 3, 4, 5, 6	1.80	5.00	1.80	5.00
Case 5	2.00	-	-	0.28	2, 3, 4, 5, 6	2.00	5.00	2.00	5.00
Case 6	2.20	-	-	-	2, 3, 4, 5, 6	2.20	5.00	2.20	5.00

flat and sloping (1/100 and 1/50) topography with 0.5 m cell size. Selection of the grid size is according to an empirical relation of $dx/(gh_{max})^{1/2}$ T $< 3\times10^{-3}$ to obtain 0.5 < predicted value/measured value < 2 as proposed by Fujima (2012). The wave period of 0.5 hours is selected for the sin wave as initial. This period is similar to the average observed period of first wave during the 2011 Tohoku tsunami at Sendai buoys.

From the results of each scenario, a cross section in the middle of the road perpendicular to the shoreline is extracted to be analyzed as given the following section.

3. RESULTS AND DISCUSSIONS

We first analyzed the influence of expansion ratio (D) as given in **Fig. 3**. If $d_1 \approx d_2$, hydraulic gradient will not be observed at intersection. It will start to be visible if the expansion ratio (D) 1.4, and saturated when $D \geq 2$. Thus, it can be said that in the similar range of Froude number examined in this study, higher expansion ratio (> 2) will not give higher hydraulic gradient (tg α) at intersections.

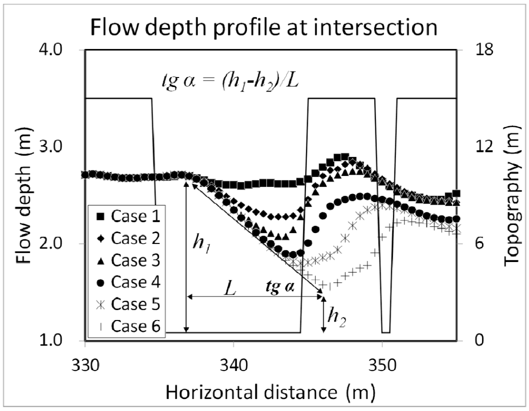

Fig.3 Pattern of the tsunami flow depth depending on the expansion ratio at intersection

The next analyses is taking into account the change of road width parallel to the coastline, and the effect of road length prior the intersection on influencing the hydraulic gradient. The numerical results show that no significant effect from these factors. It means: first, the water mass that goes to roads parallel to the coastline will not significantly influence the hydraulic gradient at intersection. It just creates a small different on the initial position of hydraulic jump after the expansion, which is not consider in this study (**Fig. 4**). The second, the length road prior to intersection is not influencing the hydraulic gradient. Their effect is limited only to slightly reduce the flow depth depending on the road length (**Fig. 5**). The latter was explained by Goto and Shuto (1983) as the energy loss when flow passing through lined obstacle only caused by friction due to roughened walls which are considered as neglect able. Nevertheless, the important thing to note is that even if some of houses along the road prior to the intersection are damaged by tsunami, the sudden expansion phenomena will still occur as long as the expansion ratio at the intersection meets the requirement as discussed previously.

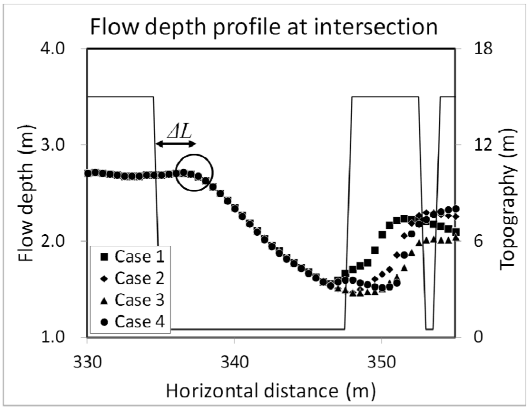

Fig.4 Pattern of the tsunami flow depth by the change of road width l_2

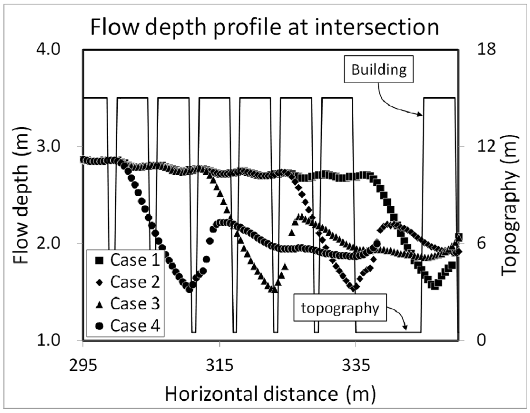

Fig.5 Pattern of the tsunami flow depth by the change of road width l_1

Considering the influence of Froude number (Fr), the numerical experiments were conducted using Froude number above its critical condition. This is because bore usually observed under supercritical flow (Fr > 1). The results confirmed that higher Froude number yields to larger hydraulic gradient at the intersection as shown in the correlation between hydraulic gradient and expansion ratio with Fr ranges from 1.13 to 1.34 (**Fig. 6**).

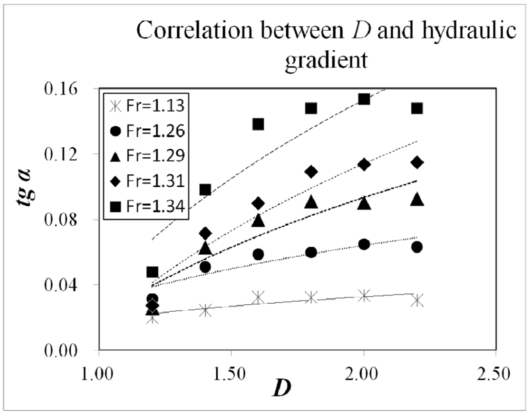

Fig.6 Correlation between expansion ration (D) with the hydraulic gradient (tg α)

The influence of (β) affects to the initial point of the decline of water level after the rearmost part of the residential block (ΔL, see definition in **Fig. 4**). If d_3 is not significantly larger than the d_1, the hydraulic gradients were not observed at the intersection. On that condition, ΔL is larger than l_2 (**Fig. 7**). To simplify the correlation, a graph between β and the non-dimensional number of $\Delta L/l_2$ is drawn in **Fig.8**.

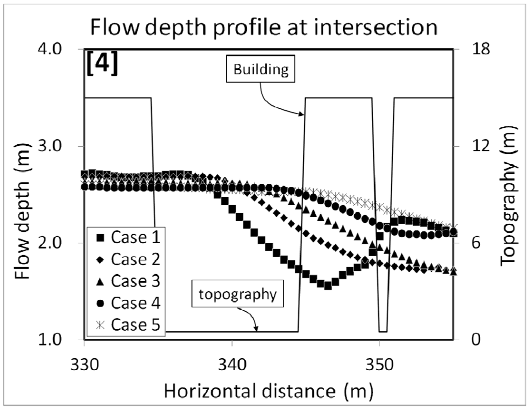

Fig.7 The influence of β on determining the head loss at intersection

The ($\Delta L/l_2$) indicates the ratio between initial points of hydraulic gradient relative from the rearmost cell of road prior to intersection, with the width of road parallel to the shoreline (l_2). Here, 'A' denotes the amplitude of modeled waves. It can be seen that ΔL will overlap l_2 if $\beta > 0.25$ because the flow depth starts to decline when tsunami front already passed the intersection. In the other words, there will be no hydraulic gradient at intersection on this condition even if the condition of expansion ratio allows the sudden expansion to occur.

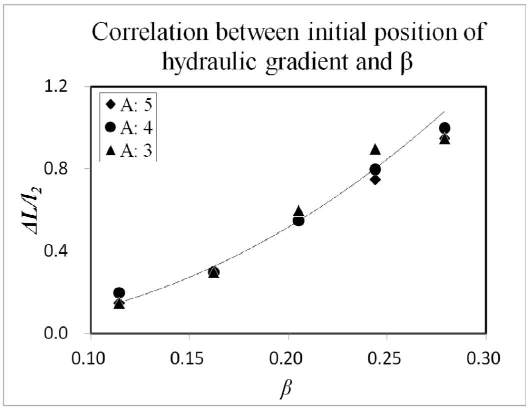

Fig. 8 Correlation between β with the non-dimensional parameter $\Delta L/l_2$

The above discussed phenomena only observed in scenario of flat topography. We did not obtained similar results from sloping topography (1/100 and 1/50). Therefore, this becomes another limitation of the developed criteria that it is only applicable if the surrounding topography is relatively flat.

The practical implications of the above discussion; first, the tsunami-deck is applicable only if the predicted tsunami flow depth is lower than their height. Second, if the predicted flow depth is comparable to the deck's height, than (1) it should be placed at intersection with geometric configuration of buildings allows the sudden expansion to occur. (2) An adjustment should be made on the deck's design to ensure the flow passing through beneath the structure according the ΔL (**Fig.9**).

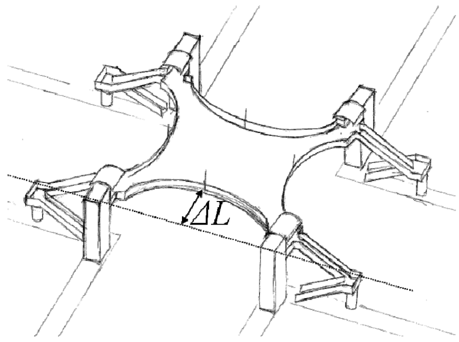

Fig.9 Adjustment on the deck shape to accommodate ΔL

4. CONCLUSIONS

A new type of tsunami vertical evacuation structure is proposed to be applied in densely populated areas, particularly in developing countries. The easiness/feasibility of their construction as well as the maintenance, and the flexibility on their placement (at intersection) are combined with the large space available on the deck creating an 'easy to find' evacuation shelter. Thus, this structure can be a solution for the congestion problem during evacuation.

Limitation due to the existing height is solved by determining criteria for their placement. Utilizing the sudden expansion phenomenon at the intersection, the tsunami-deck can be installed in the area with predicted flow depth less than the deck's height. Moreover, adjustment on the deck's shape is necessary according to the ΔL at intersection with geometric configuration of (D) > 1.5 and (β) < 0.15.

The present study described only the hydrodynamic part for the introduction of tsunami-deck concept. It is highly acknowledged that the structural analysis and the potential of solid debris impact should be taking into account for the further study which is now currently on going.

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