An Approach to Design Evacuation Route through Developing Tsunami Casualty Model

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

1. Introduction

Generally, the tsunami hazard map content the information about the flow depth and the predicted tsunami arrival time can be used to briefly determine the potential evacuation route. However, in narrow roads that is surrounded by the buildings, sometimes the wave height as well as its velocity is amplified, so it is creating a more dangerous situation for those who cannot escape before tsunami comes. On highly populated areas, the tsunami evacuation sometimes is not conducted properly. The use of cars and motor cycle are potentially generated the bottle neck in the road junctions. In this case, once the bottle neck occurred in the road where the tsunami flow parameters such as flow depth and velocity is high, then it can be predict that the tsunami casualties will be increased. This situation enforces a careful analysis of tsunami impact especially to human in order to design the appropriate evacuation route.

2. Objectives

Present study is aimed to improve the previous human casualty model based on hydrodynamic force acts on human body. Previous model of human casualty that was already applied on flood, storm and tsunami field is enhanced to get better understanding about the distribution of hydrodynamic force on separate parts of human body. The model is assimilated to the already developed tsunami inundation model to assess which road should be taken and which road should be avoided, when the tsunami evacuation route is determined.

Previously, Takahashi et al., 1992 conducted an experiment to study about the wave force impact to human body and provide several threshold to show the relationship between inundation depth, flow velocity and the human balance (stand or fall). However, it is difficult to apply their result on practical purposes especially for tsunami mitigation.

Koshimura et al., 2006 developed the first human casualty model for tsunami impact assessment. However, only slipping type of human fall due to the wave force is considered, and there was no verification of the model.

Yeh H, 2010, provide a more complex model with accommodates various type of human body that is represented by age and gender. This model accommodates two type of human fall (slipping and toppling). However, the approximation of the human body on his model seems too simple and still there was no verification of the resulted threshold from his model.

In the present research, we firstly revise the previous model from Koshimura et al., 2006 according to the agreement with the experimental data from Takahashi et al., 1992. The next step is developing the new routine to accommodate the toppling type of human fall, so both of routine (slipping and toppling case) can be assimilated to tsunami inundation model. The calculation results are used to generate the Tsunami Casualty Index (TCI) on the study area.

3. Methodology

The real human body shape is approximated by a set of cylinder content two cylinders as the legs, one cylinder as the body, and two cylinders as the hands. The head is not consider as a part of the calculation because if the water is higher than the neck perhaps the buoyancy force is more influence rather than hydrodynamic, which is not consider in the present model. However, the head's mass is including for total mass calculation of human body model.

The relationship between hydrodynamic force acting on the human body model as it gives by Takahashi et al., 1992, consist of two types; first, the condition where the friction force on the evacuee sole feet is less than the hydrodynamic force acting on body model, this will led to the slipping fall type (Eq. 1). The second is when the moment in the bottom back of heel due to the hydrodynamic force is bigger than resistance moment due to body weight, than it will led to a toppling fall type (Eq. 2).

The hydrodynamic force incorporating the tsunami flow is expressed by Morrison equation, the relationship between first and second condition is derived from Takahashi et al., 1992 as it is described as below,

$$\left(\int \frac{1}{2}\rho C_D u^2 dS + \int \rho C_M \frac{\partial u}{\partial t} dV\right) \geq \mu_s \left(W_0 - W\right) \qquad (1)$$

$$\left(\int \frac{1}{2}\rho C_D u^2 dS + \int \rho C_M \frac{\partial u}{\partial t} dV\right) h_G \geq \left(W_0 - W\right) I_G \qquad (2)$$

In the human casualty model, F_H denotes the hydrodynamic force using the Morrison equation; μ is the friction coefficient; W_0 is the body weight; W is the buoyancy; h_G is the height of the central gravity as a function of flow depth, and I_G is the moment arm.

The schematic of human body is given below,

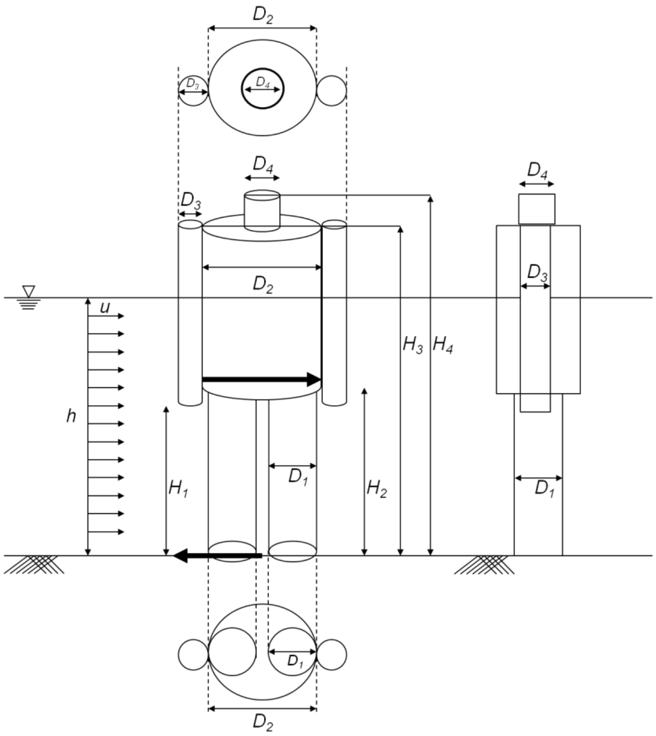

Figure1. Schematic description of human body

The verification of present model to the experimental data from Takahashi et al., 1992 is given by the Figure2.

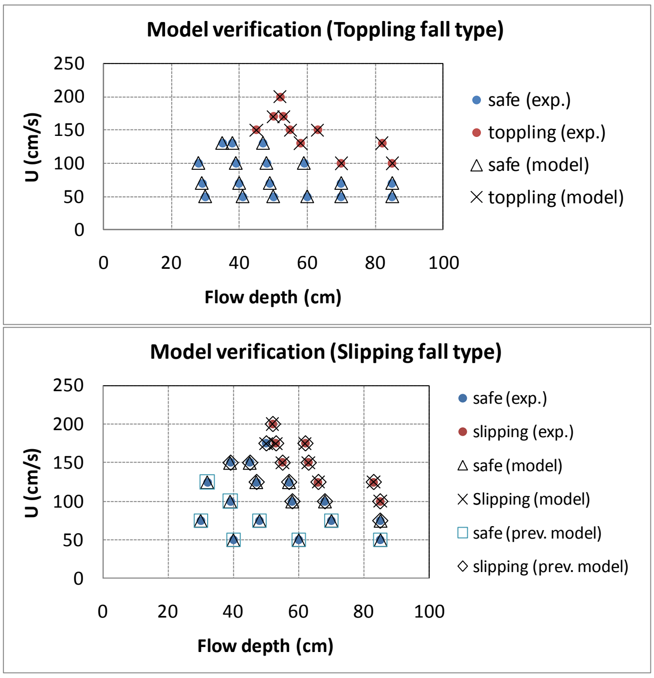

Figure2. Verification of the present model with the experimental data

4. Model Application

We applied the present model in Padang city, Indonesia. This city is predicted will be hit by a 6 m tsunami wave and arrives within 20 min after the earthquake (Muhari et al., 2010). The tsunami will inundate at least 10 km2 in the central city of Padang where almost 130.000 people are lies within the inundation area.

The tsunami inundation model includes the building features (topographic model), so the tsunami will inundate only the road that will be use in case of evacuation and the building with height less than tsunami flow depth. The result of the calculation will be overlaid with the road network, so identification of potential tsunami evacuation route become easier.

To approximates the various body height, we use the anthropometry data of Indonesian people (Chuan et al., 2010) and divides the condition into adult male, adult female, children 15 years old, 10 years old, and 6 years old. The anthropometry data for the categories is given by Table 1. The numerical calculation is directed to develop the TCI for each category. The TCI is defined as the ratio between the times of tsunami inundation parameter that is satisfied the eq. 1 and 2 with the total time of tsunami inundation. The results of the calculation are showing by the Figure3.

5. Conclusions

The human casualty model is developed and applied in Padang city based on specific anthropometry data in the respective region.

The numerical calculation shows that in all categories, the area within 500 m from the maximum inundation line is safe for all categories. In contrary, the area within 500 m from coastline is dangerous especially for the children with 10 and 5 years old.

Mostly, the dangerous roads for evacuation are lies near the river where the tsunami not only inundate from the sea side, but also overtop from the riverbank.

Furthermore, the result suggests that for the facility such as school in the area within 500 m from the coastline should try to conduct the evacuation drill to check whether they can reach the safe area before tsunami comes (<20 min). Otherwise, it will be difficult for the children to survive from the tsunami.

Acknowledgement

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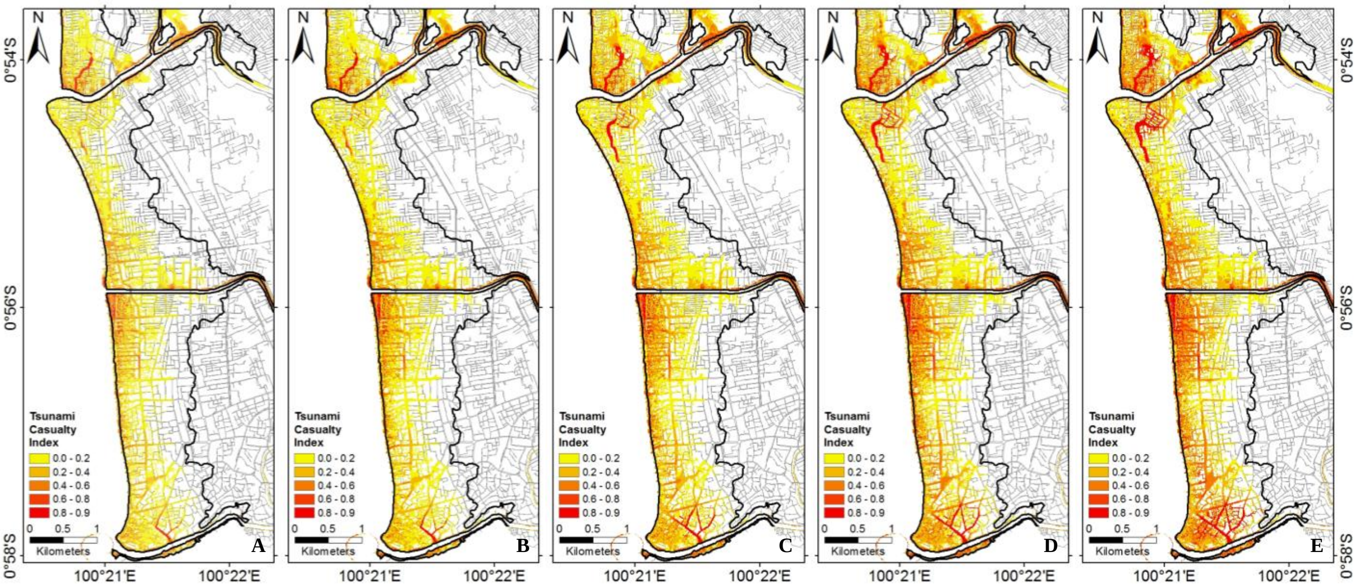

Figure3. Spatial distribution of TCI for the category adult male (A), adult female (B), children 15 years old (C), children 10 years old (D), and children 5 years old (E). Solid line is the inundation line.