

# Simultaneous Simulations of Flood and Walking Evacuation -A Case Study in Kashima city, Japan



## Engineering

**KEYWORDS :** flood simulation, evacuation simulation, evacuation route

**T.Morita**

Department of Civil Engineering and Architecture, Saga University

**K.Ohgushi**

Department of Civil Engineering and Architecture, Saga University

### ABSTRACT

*A safety of walking the evacuation is studied in the case of flood and inundation in Kashima City, Japan using flood and evacuation simulations. The result has become different from the official hazard map. In addition, it is found that shelters of the city are not always safe. In the evacuation simulation, the residents are modeled to go through the roads and to go toward the shelters of the city by a network model. This simulation gives not only the required time for the residents to evacuate to the shelters but also the ranges of the residents' movement for the evacuation. In some evacuation cases, some residents cannot reach to the present shelters in the city because many roads are inundated. The safety on the route is confirmed based on the result of flood and evacuation simulations. The location of the necessary shelter is groped each time during the simulations.*

### INTRODUCTION

Damages caused by flood and high tide exceeding capability have occurred frequently like the northern Kyushu heavy rain in July 2012. Not only the structural measures but also non-structural measures are necessary to reduce the damages by the gigantic natural hazards. As the example of the non-structural measures against the flood disaster, distribution of hazard maps, rapid disaster communication about states of water level of the rivers and evacuation, strengthening disaster prevention awareness by the disaster prevention education and evacuation training for residents. Especially, well understanding of the hazard map by the residents can reduce the damage. The hazard map is one of the most familiar tools for the residents in the case disaster.

However, the hazard map has still the problem. Ushiyama showed that the residents' satisfaction about the hazard map was low (Ushiyama et al. 2004). One of the causes is the difference between the actual flood and the hazard map. This reason is why the hazard map refers the results of the most reliable things. The hazard map cannot cope with floods that have not been predicted.

As countermeasures to these problems, this study predicts some inundations which are not taken into consideration by the existing hazard map. Then, a refugee model is made and used for the evacuation simulations. Finally, it is discussed how humans damage by water disaster is reduced.

### A STUDIED AREA

The studied area is Hama district of Kashima City, Japan. This area is sandwiched by Hama River and Ishikizu River, and has a mild slope to the Ariake Sea as shown in Fig.1. JR Nagasaki Line Railway intersects Hama River at 200m upstream from the river mouth. A height of the railway bank is about 2m. This area is separated to low and high areas by this railway bank. The lowland area is suffering from storm surge, while the highland area has flood and inundation risks.



Fig.1 Studied Area, Hama district Kashima City, Japan

This area is suffered from inundation damages caused by overflow from Hama River by large flood in 1962 and 1972. Fig.2 shows the hyetograph in 1962, and Fig.3 shows flood area in 1962. Hama River's overflow started in 5:30 A.M. according to the Kashima disaster historic. Kashima flood warning hazard map is created by Kashima City Hall as shown in Fig.4. This hazard map shows that locations of shelters, water levels in the river and inundation areas expected once every 50 years by the flood. However, Hama River is not subject to inundation predicted in the hazard map because of the fact that the river is widen after the two floods. The area surrounded by Ishikizu River and railway bank is considered to be more dangerous.

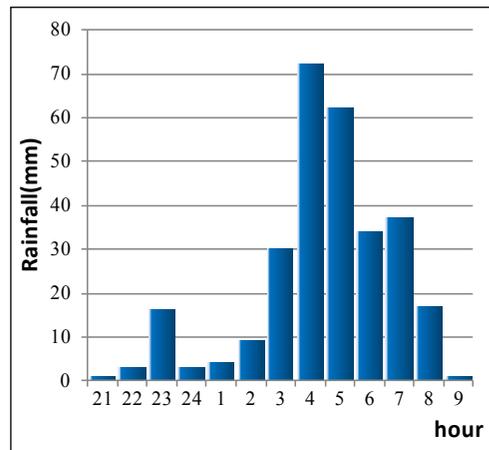


Fig.2 Hyetograph of 7 ~ 8 July 1962 heavy rain (the Kashima disaster historic)

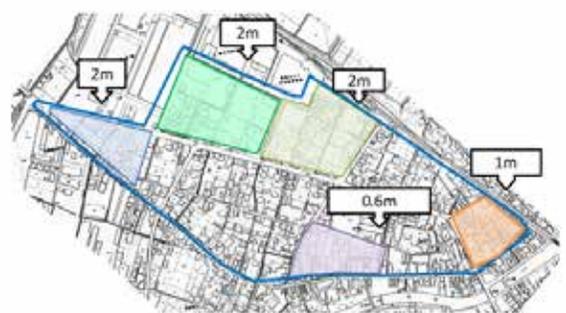


Fig.3 Depth distribution during the inundation in Hama district 1962 FLOOD SIMULATION



Fig.4 A part of hazard map in Kashima City

Various methods have been devised as methods of flood inundation analysis, but it is necessary to understand flow regime in such open spaces and roads because they can be used for evacuation route. Quasi three-dimensional equations are calculated using unstructured grids mesh by many triangles using MIKE series software that develop by DHI. Elevations are measured by airborne laser profiler. Maximum area of triangle mesh is about 10m<sup>2</sup>. So elevation data are created between almost all buildings. Basic equations of the simulation are continuity equation and motion equations,

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = S \tag{1}$$

$$\frac{\partial u}{\partial t} + \frac{\partial u^2}{\partial x} + \frac{\partial vu}{\partial y} + \frac{\partial wu}{\partial z} = -g \frac{\partial \eta}{\partial x} + F_x + \frac{\partial}{\partial z} \left( \nu_t \frac{\partial u}{\partial z} \right) \tag{2}$$

$$\frac{\partial v}{\partial t} + \frac{\partial vu}{\partial x} + \frac{\partial v^2}{\partial y} + \frac{\partial wv}{\partial z} = -g \frac{\partial \eta}{\partial y} + F_y + \frac{\partial}{\partial z} \left( \nu_t \frac{\partial v}{\partial z} \right) \tag{3}$$

where  $t$  is time;  $x$ ,  $y$  and  $z$  are spatial Cartesian coordinates;  $\eta$  is surface elevation;  $d$  is still water depth;  $h$  is total water depth;  $u$ ,  $v$  and  $w$  are velocity components in the  $x$ ,  $y$  and  $z$  directions;  $S$  is magnitude of discharge due to point source;  $g$  is gravity acceleration;  $\nu_t$  is vertical turbulent viscosity;  $F_x$  and  $F_y$  are horizontal stress terms. The horizontal stress terms are described using a gradients-stress relation, which is simplified to

$$F_x = \frac{\partial}{\partial x} \left( 2A \frac{\partial u}{\partial x} \right) + \frac{\partial}{\partial y} \left( A \left( \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right) \right) \tag{4}$$

$$F_y = \frac{\partial}{\partial x} \left( A \left( \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right) \right) + \frac{\partial}{\partial y} \left( 2A \frac{\partial v}{\partial y} \right) \tag{5}$$

where  $A$  is the horizontal eddy viscosity.

**(1) Flood simulation**

The simulation area was selected to 1.5km upstream side from the river mouth. This area is sandwiched by two rivers in Hama River and Ishikizu River. A laser profiler data with approximately 10cm accuracy was used for elevation data. Roughness is about 1cm and maximum area size is 50m<sup>2</sup>. In the road, more detail numerical mesh was adopted. A time step was 5 seconds, and simulation time was 4 hours from the start of flooding. Precipitation data referred to rain of 1962.

**(2) Simulation's conditions**

In this study, four cases are simulated. CASE1 reproduces 1961's flood using overflow depth from Hama River. In CASE2, flood into the area from near the shelter. CASE3 is a case of flood into the area from Ishikizu River. Those flood volume and flooding time are same due to the comparison of those flooding area. CASE4 is flood and tide simulation at the Ariake Sea (Torry, 2012). (3)

**Calculation result**

In Fig.5, the result of four cases simulation is shown. In CASE1, flooding area is the widest, because water passes many wide roads. A flood area is similar to 1962's flood. In this case, evacuee in west area can't go to shelter. Therefore, they need to select other shelters or high point. In CASE2, almost water move to north area. Paths connecting north area and south area is limited. Water passes a tunnel under the railway. Therefore, north areas evacuee should select other routes. In CASE3, water stays along Ishikizu River. In some areas water depth becomes very deep. A flooding area is similar to hazard map. However the roads around shelters are dangerous like other cases. In CASE4, water depth of almost north area is very deep. Residents must evacuate early from north area during high tide of the Ariake sea. Railway and bank defend south area from storm surge (Torry 2012).

In all cases, north area is comparatively dangerous because of low elevation. However water passes evacuation route that connect north and south area. This area should be mostextremely taken care.

In CASE1, 2 and 3, the wide road between two shelters is vulnerable against inundation. Selection of evacuation route should be cautious.

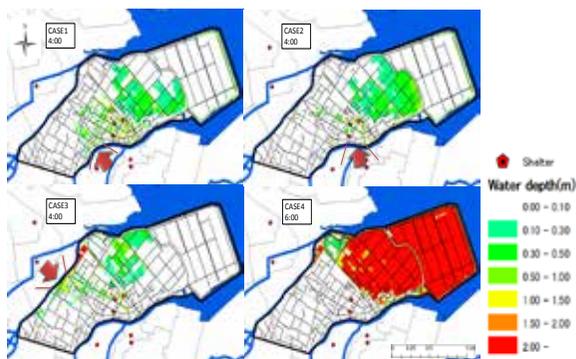


Fig.5 Result of inundation simulation in Hama

**EVACUATION SIMULATION MODEL**

Evacuee's movement paths are obtained by minimizing the pathway to the destination using the road and the vacant lot as the migratory pathway.

**(1) Set of evacuation routes**

The Branch-Node model based on the graph theory is used in the evacuation simulation. Firstly, All road capable of evacuees walking is validated by city planning map and field investigations. Those roads become the branch model. Then, each node was set as an entrance of the building, intersection of branch and a place higher than the surroundings. These nodes give the states such as shelters, high elevation place etc. Water surface elevation and discharge are given in each node by the result of the flood simulation. And water conditions at branch are interpolated between the nodes.

(2) Set of residents At first, 400 residents was classified to young people, adult people and old people, referring to the Kashima data book by Kashima City. A parson of each generation has individual parameter for walking speeds and body height.

When the residents evacuate with other residents, their evacuation depends on the slowest residents or small ones.

**(3) Reduction in a walking rate**

Walking speeds of residents are reduced by walking in water or walking distance. In this study, the discount by fatigue and water depth is employed (Akita *et al* 2007).

**a) Discount by Fatigue**

A following equation is used as a discount rate of walking speed due to fatigue at the time of elapsed time *t* from the walking start time.

$$T^t = \frac{1.0}{0.982 + \exp(1.12t - 4.0)} \quad (6)$$

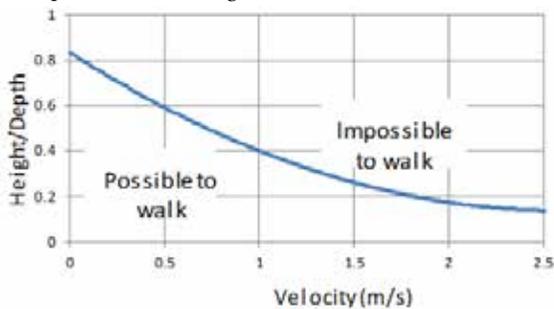
**b) Discount by water depth**

A following equation is used as the discount rate when the evacuees height *h<sub>i</sub>* to perform underwater walking of water depth *d*;

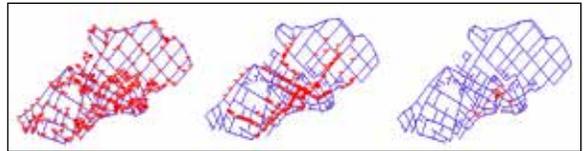
$$W_i = -\frac{1.0}{h_i}d + 1.0 \quad (7)$$

*h<sub>i</sub>* is water depth limit available for a walk obtained from the experiment by Suga (Suga *et al* 1995). As Fig.6, water velocity and evacuees height effect limit water depth. Furthermore, to considering the fatigue by walking in the water, the route length which real length divided by *W<sub>i</sub>* is used in evacuation simulation.

(4) A setup of an evacuation law In this study, the Dijkstra method (Ravindra *et al* 1993) is used for decision of the shortest path. This method is known as a tool to solving shortest path problem starting from single-point. Any point set as initial position, and calculates the distance and shortest path to all points from it. When it becomes impossible for evacuees to go to the initial destination, evacuees can change the destination to another shelter or high place instantly. The successful condition is to arrive at the shelter or the high place. The evacuation failure condition is that an evacuee stands in a deep place so that they cannot walk. Fig.6 is used to judge whether the residents can walk or not in the water with respect to the water depth and flow velocity. In particular water depth is important in the places of lower elevations. The flow rate is important in high places. The ratio of velocity and water depth is used for a border of walking in the water. This ratio was found by Suga (Suga *et al* 1995) in the experiments of walking in the water.



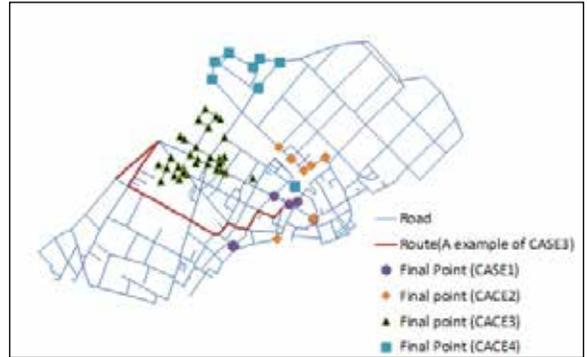
**Fig.6 Availability of waking evacuation on foot in water based on water depth-height ratio and velocity (Suga *et al* 1995)**



**Fig.7 Results of evacuation analysis**

**EVACUATION ANALYSIS**

In this simulation, evacuees start to evacuate from all node. Start time of evacuation is the time when the flood or storm surge intrudes into the area. The result is evacuation route or final point of evacuee who failed in evacuation.



**Fig.8 final point of evacuee who failed in evacuation**

**(1) Results of evacuation analysis**

Fig.7 is the result of CASE1 in which the surrounding of the shelter is inundated at fast. Lines are branches. And triangle is evacuees. As a result of the analysis, some of evacuees failed to evacuation at the east of shelter. Therefore, group should choose another route, because the shortest route was inundated.

Fig.8 shows final point of evacuee who failed in evacuation in all case. In CASE3, many evacuees failed. The point is along to Isikizu River. In those areas, the residents should evacuate with big margin of time. In the same manner, the residents in north area need early evacuation because of the risk of storm surge.

On the other hand, residents in the east area need prudent selection of route. Because east area is lower than south area. Therefore, the conditions of depth and flow velocity are severe for evacuation. Depending on the situation, high elevation route should be selected not only short route.

**CONCLUSIONS**

This study shows that inundation area have big difference by the location of the flooding. Safety route might be dangerous at real flood. For safer evacuation system, dangerous route should be found by multiple inundation and evacuation analysis. In addition, Conditions for evacuation by predicting the failure of evacuation can be considered. It is effective to take the flood simulation with evacuation analysis.

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