Development of Estimation Method on Drift and Collision Behaviors of Debris Caused by Tsunamis

by

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ABSTRACT

In order to reduce tsunami damage, it is necessary to appropriately estimate the potential damage caused by the collision of tsunami debris such as maritime cargo containers, small boats or timbers, drifting out to sea or onto land. This paper reports on the development of a simple method for estimating the drift and collision behavior of tsunami debris. The method combines the flow field modeled using a horizontal two-dimensional simulation of a tsunami, with floating debris modeled using the distinct element method. The applicability of this estimation method is further discussed using the results of model experiments on the drift behavior of maritime cargo containers.

KEYWORDS: Debris, Drift and Collision Behavior, Maritime Cargo Container, Tsunami Disaster Mitigation

1. INTRODUCTION

Japan is prone to the threat of interplate earthquakes and large-scale tsunamis caused by these earthquakes. A tsunami could cause flood damage along the Japanese coastal regions, notably in harbor areas where there are many cargo containers, large quantities of stored lumber, and moored boats and ships that could be set adrift. The potential damage that facilities and infrastructures, such as buildings and seawalls along the coast, could sustain from collision with such debris must be considered. Monetary loss of drifting objects is not the only concern. Greater damage could be caused by the collision of debris with seawalls and other costal structures, harbor structures, houses behind the harbors, and the outflow of hazardous material from dangerous goods storage. When waterways and anchorages are littered with drifting and submerged debris, navigation must be halted and the harbor may cease functioning until the debris is removed and the safety of navigation is confirmed. Damage from a tsunami could have such far-reaching effects.

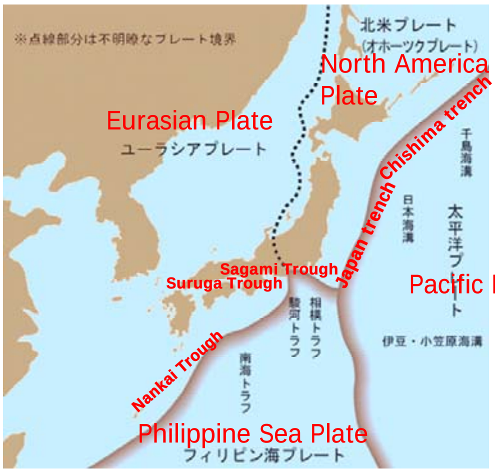

Fig. 1 Earthquakes In and Around Japan

To reduce potential damage, structural measures such as installing fences to prevent drifting, and non-structural measures such as planning the layout of the cargo storage area and consolidating the mooring sites for small boats, must be implemented. This requires an understanding of the drift and collision behavior of cargo containers, lumber and small boats. It is also necessary to develop a relatively simple method for estimating and assessing the potential collision damage. Therefore, in this research, a model was developed for simulating the drift behavior, when subject to external forces from the flow, and reproducing the collision of debris with fixed structures. This was achieved using data on the flow field in water and on land that was obtained from an

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often-used tsunami inundation simulation model based on the nonlinear long-wave theory. The debris, the shape of which was reproduced according to the distinct element method (DEM), is placed in this flow field. The applicability of this model was further studied using the results from a separate experiment on the drift and collision behavior of cargo containers conducted by Nagoya University and MLIT.

2. EXPECTED DAMAGE CAUSED BY TSUNAMI DEBRIS IN JAPAN

2.1 Risk of Tsunami from Large-Scale Earthquakes

Many plates collide around the Japanese Islands. It is known that earthquakes occur where plates meet. So, many earthquakes and tsunamis attack Japan periodically. Fig. 1 shows that the plates; the Pacific Plate, Philippine Plate, North American Plate and Eurasian Plate all meet at the sea off Japan, making this country prone to large-scale interplate earthquakes. In the past century, there have been seven tsunamis with more than a hundred fatalities. Six of these tsunamis occurred in the adjacent seas, and one was from the 1960 Great Chilean Earthquake. The earthquake occurrence probability in various regions of Japan is assessed and publicized by a government organization, the Headquarters for Earthquake Research Promotion. The hypocentral regions, occurrence probability and expected magnitude of earthquakes such as trench earthquakes with subsequent tsunami are shown in Fig. 2. Notably, the Pacific Coast region is at high risk of sustaining damage from large-scale tsunamis, and there are concerns over large-scale distant tsunamis such as those that followed the Cascadia earthquake and the next Chilean earthquake.

2.2 Distribution of Potential Tsunami Debris throughout the Country

Population and industry in Japan are destined to be concentrated on the alluvial plains and along the coast because only about 10% of the total area is suitable for such uses. These may be dangerous regions, but the cities are highly developed with meticulous use of available land,

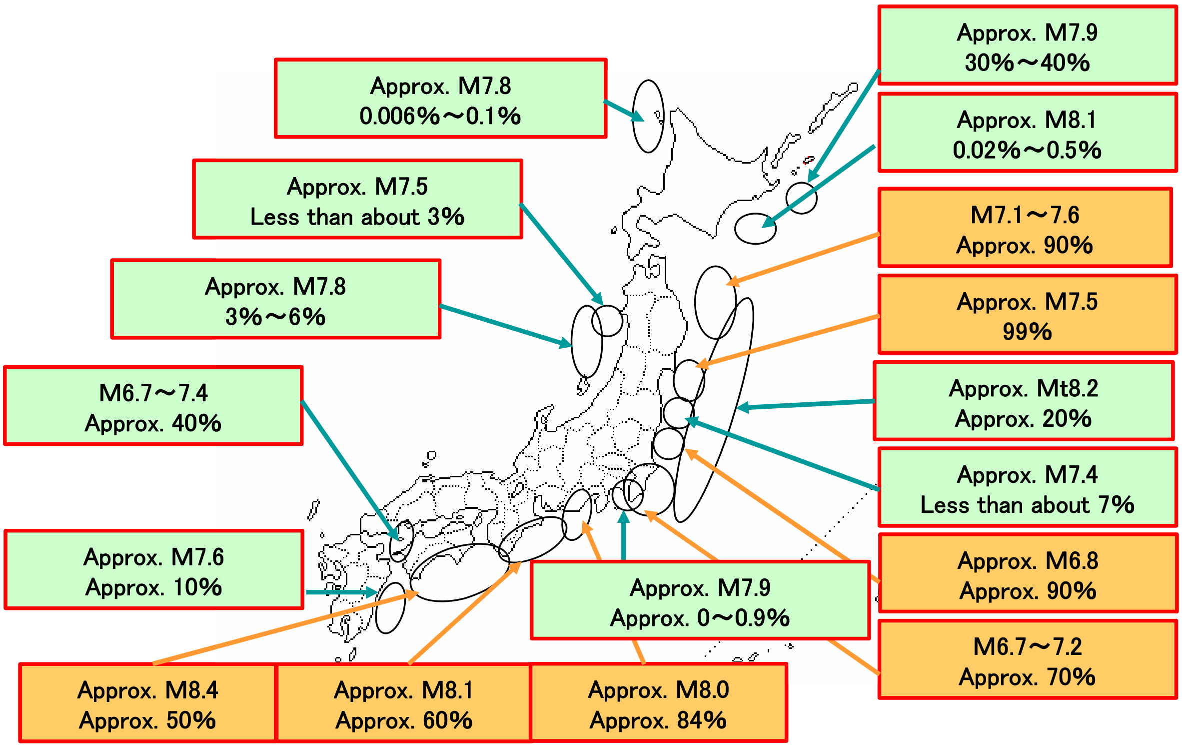


Fig.2 Probability of Major Earthquakes in Japan

such as the vertical development of underground space. Just as the land is intensively utilized, the city waterfront is highly developed mainly as ports. With their functional requirements, ports must be located outside the tsunami defense line, and are consequently at risk of inundation damage from tsunamis. Furthermore, many cargoes in these ports such as cargo containers, lumber, and small boats are highly prone to be set adrift in a tsunami and could cause damage. Fig. 3 shows the location of major ports handling maritime cargo containers and lumber. About 30 ports handle cargo containers and 35 ports handle more than ten thousand tons of lumber in 2004. The major part of these ports that handle cargo containers and lumber are located in regions where tsunami damages concern. Together with these cargoes, small boats could also be set adrift in a tsunami. Notably, many small boats are illegally moored without proper registration and with their owners unidentified. Since they are not properly overseen and often inadequately moored, these boats are prone to drift, but taking immediate action to prevent this is difficult. There are approximately 134,000 small boats illegally moored throughout the country.

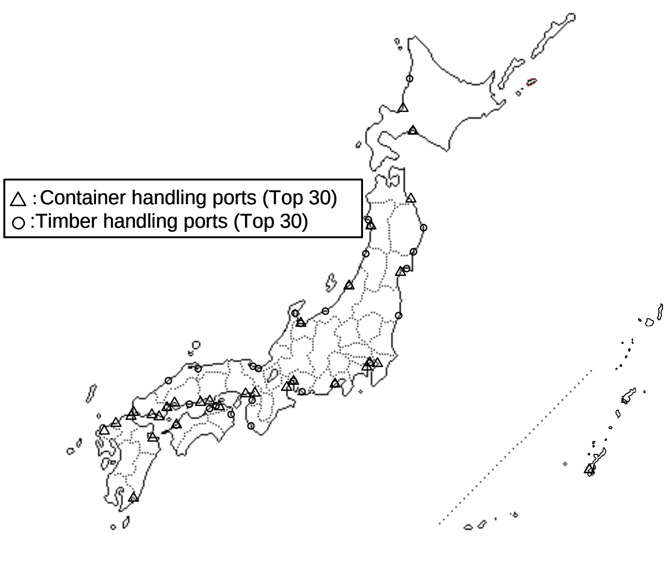


Fig.3 Location of Major Ports Handling Maritime Cargo Container and Timber

3. MODELING THE DRIFT AND COLLISION BEHAVIOR OF CARGO CONTAINERS

3.1 Simulation Method

The method for tracing the drift behavior of debris such as cargo containers by assuming a particle without mass was already established. However, a simple and practical model for estimating drift and collision behavior that considers the mass and size of the debris and the acting hydrodynamics was yet to be developed. Therefore, in this research, a model was developed for reproducing the drift and collision behavior. The debris was modeled according to the distinct element method, using the water level and horizontal distribution of flow velocity from the calculation for estimating a tsunami at sea and calculating the run-up based on the nonlinear long-wave theory. Inertial force and drag force are also assumed to act on the debris. Fig. 4 shows the calculation procedure using this model. Fig. 5 shows the schematic illustration of the cargo container that was modeled according to DEM. For this model, in order to drift as a single structure and reproduce the drift and collision behavior, the debris has to be elastoplastic rather than rigid. As shown in Fig. 6, the distinct element method applied the model where each element consists of connected elements such as springs, dashpots, and link element [1].

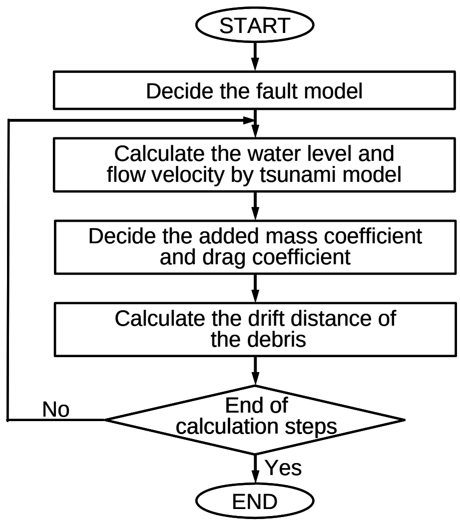


Fig.4 Calculation Procedure for the Drift Model

Fig.5 Schematic Illustration of Container Modeled Using DEM

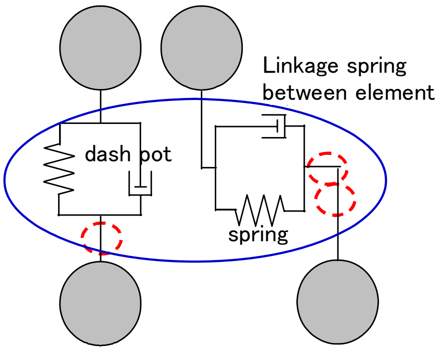


Fig.6 DEM Model

The hydrodynamic force (in the x-direction) from the fluid acting on the debris is according to the Morison's formula as shown below:

$$F_x = C_M \rho V \frac{\partial u}{\partial t} + C_D \frac{\rho u^2}{2} A_x$$

Where,

ρ is the water density; V is the volume of the portion in water; u is the flow velocity in the x-direction; A_x is the projected area (cross section) in the flow direction; C_M and C_D indicate the added mass coefficient (inertia coefficient) and drag coefficient.

3.2 Calculating the Drift and Collision Behavior According To the Modeled Topography

The simulation of container drift and collision behavior with other structures was performed by first calculating the water level and flow velocity in the modeled topography that assumes a harbor.

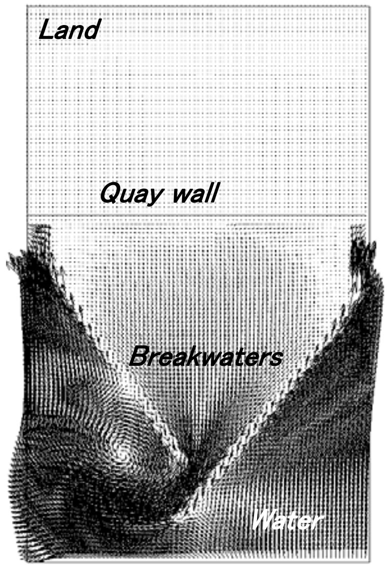


Fig.7 Example of Calculated Flow Field (Velocity)

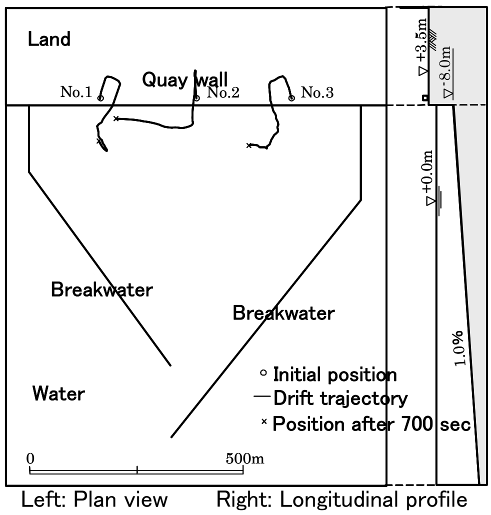


Fig.8 Drift Trajectory of Containers (Calculated Example)

Fig. 7 shows the flow velocity vector at the moment of tsunami beginning to run-up onto land. With this drift model, the added mass coefficient and drag coefficient, which changes according to factors such as the relative angle of the debris to the flow, must be precisely determined. These were decided by considering previous research [2]. Fig. 8 shows an example of the calculated drift trajectory for the center point of the container. This reproduced, to a certain level, the phenomenon where the container drifts in the container yard, collides with the wall, and then drifts out to sea with the reversed flow. To assess the impact force, damage behavior, and other factors affecting land structures, a more precise study should be conducted through verification and improvement of the model utilizing the results of large scale experiments.

4. VERIFYING THE APPLICABILITY OF THE ESTIMATION MODEL WITH THE MODEL EXPERIMNT ON CONTAINER DRIFT

4.1 Calculated Reproduction of the Model Experiment

At Shimizu Port, which is located along the Pacific Coast, there are concerns over potential large-scale tsunami damage. The Ministry of Land, Infrastructure and Transport, and Nagoya University have jointly performed experiments on tsunami-based drifting of a container from the container terminal of this port [2], [3]. The scale of the test model was 1/150. The topographical conditions were: two cases with collapsed breakwaters, assuming the collapse of the breakwaters from the earthquake; and three cases with the breakwaters intact, assuming the breakwaters were not affected by the earthquake. The wave conditions were: periodic waves and solitary waves.

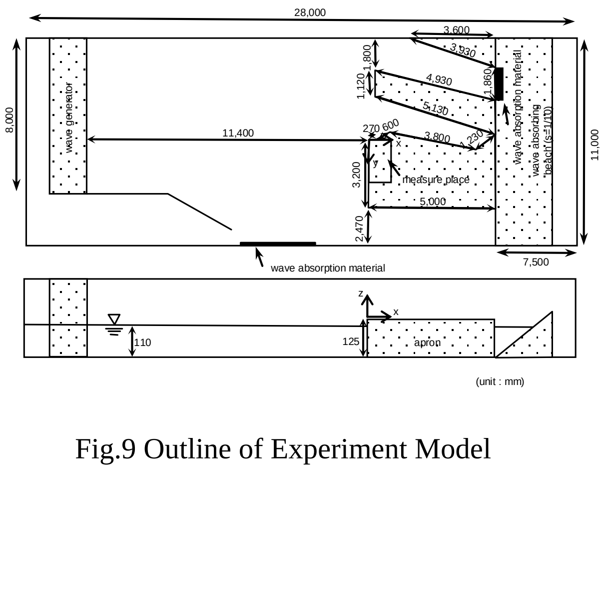


Fig.9 Outline of Experiment Model

As shown in Fig. 9, two cases are used to study the applicability of the estimation model by assuming that the seawalls have completely collapsed from the earthquake, and therefore, have no effect on tsunami propagation. The wave conditions are solitary waves with different periods. A nonlinear dispersive wave model was used for the water, and a nonlinear long-wave model was used for land, and then the measured water level and waveform were used as boundary conditions. One of the cases is shown in Figs. 10 and 11, and changing tsunami heights with time over the apron were obtained from the experiments and the calculation.

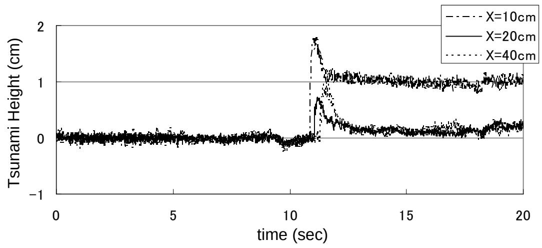


Fig.10 Tsunami Height (Observed)

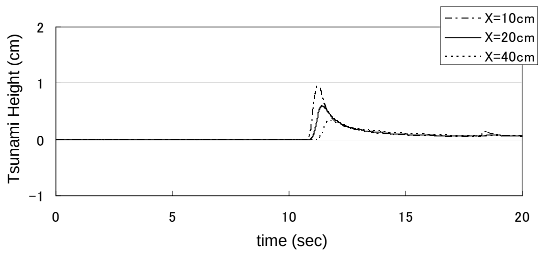


Fig.11 Tsunami Height (Calculated)

In the calculated results, the peak in run-up water level over the apron was slightly less than that of the results of the experiments, but it is believed that changes in the run-up water level with time were successfully reproduced to a certain level. On the other hand, the calculated Froude number over the apron (x = 10 cm) was a maximum of about 2.0. Since this was estimated to be similar in the experiment results, it is believed that flow velocity over the apron could be reproduced to a certain level with the calculation as well.

4.2 Verification of Container Drift Behavior

The drift calculation for the container was performed according to the tsunami wave forces acting on the container and calculated with the Morison's formula. The drag coefficient and inertia coefficient were decided by referring to the experiment by Mizutani, et al. (2005) [2]. There are two types of containers lengths: 20 ft and 40 ft; and two types of weight: half-loaded and fully loaded. Fig. 12 shows the drift trajectory from the model test when the 20-ft container was either half or fully loaded.
Fig. 13 shows the calculated position of drifting container in x-direction (drift distance) when the 20-ft container was either half or fully loaded. The calculated result, when the container was half-loaded, was a drift of about 25 cm in the x-direction and about 1 cm in the y-direction. When the container was fully loaded, the drift was about 20 cm in the x-direction, which was smaller than when the container was half-loaded, and about 1 cm in the y-direction. The calculated drift distance was rather small compared to the test results, but this was successful in reproducing the trend where the drift of the container over the apron showed a large movement in the x-direction, while being affected by the flow in the y-direction.

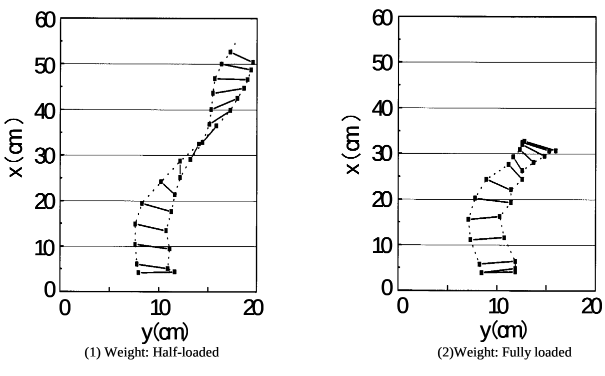


Fig.12 Drift Trajectory of the Container (Observed, 20-ft Container)

With the 40-ft container, the drift distance in the x-direction showed a similar trend as shown in Fig. 14. In the calculation, the container floated (the z-value became positive) and drifted, and then stopped when the bottom dragged. This is believed to be reproducing the behavior where the container started to drift with the increase in water depth at the apron. Then the drifting stopped with the decrease in water depth that caused friction between the bottom of the container and the surface of the apron.

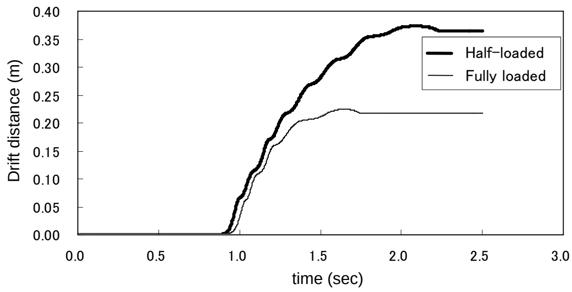


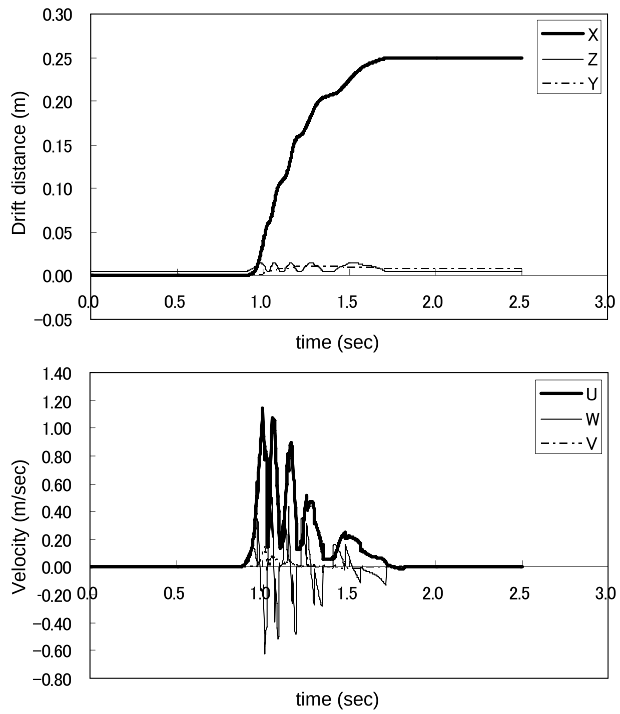
Fig.13 Drift Distance in the x-Direction (Calculated, 20-ft Container)

5. SUMMARY OF RESULTS

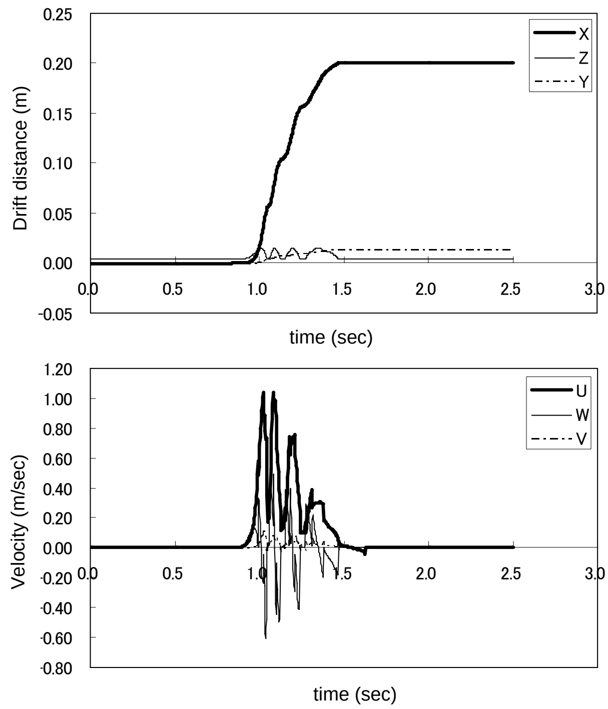
1) Simulation of drift and collision behavior of cargo containers and other debris, in model topography that assumes a harbor, was performed by establishing a drift model of the container considering factors such as the mass and size of the debris, and the hydrodynamics that will be acting on it from the tsunami. The results showed that this could be successfully reproduced to a certain level.
2) The friction at the container bottom and the drift behavior including rotation were modeled by comparing the calculated results from the estimation model and the results from the model test of the container. The established model reproduced the behavior where the container started to drift with the increase in water depth at the apron, and although the drift distance was rather small, it reproduced the trend according to differences in weight and length of the container.

6. CONCLUSION AND FUTURE ISSUES

With the use of this proposed method, estimating the drift and collision behavior of tsunami debris became possible with relative ease and low cost. The use of this method is anticipated in planning and designing structures



(1) Weight: Half-loaded



(2)Weight: Fully loaded

Fig.14 Drift Distance and Velocity of Container (Calculated, 40-ft Container)

such as debris protective barriers, as well as in estimating potential damage to buildings and other social infrastructures. Furthermore, this could be used in studying measures that do not rely on protective structures such as cargo storage that considers the effects from tsunami debris, and planning the layout of mooring sites and storage for small boats.

On the other hand, this method has limited ability for reproducing the behavior of large debris such as ordinary cargo ships, because the interaction between the flow field and debris is not considered. It is necessary to clarify how far this method could be used with large debris through comparisons with model experiments and other methods that could reproduce the phenomenon more logically and precisely. Furthermore, this requires verification through large-scale experiments to reproduce the collision more accurately. The National Institute for Land and Infrastructure Management will be actively involved in further research of these issues.

7. REFERENCES

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