NUMERICAL SIMULATION OF THE DEBRIS BEHAVIOR AFFECTED BY WAVE BREAKING

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INTRODUCTION

In the design and risk assessment of coastal structures against collision of tsunami debris, it is necessary to analyze the collision probability and set the appropriate collision speed of the debris. Given the pronounced influence of flow fields and structures on the collision probability and collision speed, it is desirable that the motion of debris moving with the tsunami be taken into account in these analyses and settings. If a tsunami causes wave breaking, implementing the setting of the collision probability based on a consideration of the effect of wave breaking on debris motion is necessary.

The presence or absence of wave breaking and the location of the wave-breaking zone affect the debris behavior (Oda et al., 2019). Kaida et al. (2023) showed the mechanism of the effect of the wave breaking on the debris motion by analyzing the results of hydraulic experiments.

To set the debris collision probability and the debris collision speed in practice, a numerical debris-tracking (nDT) model for analyzing the behavior of debris can be a useful tool. Therefore, confirming that the existing nDT model adequately reproduces the behavior of debris affected by wave breaking is necessary. In this study, the results of a reproduced numerical analysis of the experiment conducted by Kaida et al. (2023) are presented. Subsequently, based on the results of the numerical simulation, the applicability of the existing nDT model in evaluating the behavior of debris considering the effect of wave breaking is described.

DEBRIS-TRACKING SIMULATION MODEL

The nDT model (Kihara and Kaida, 2020), which calculates the debris trajectories by solving the equation of motion of the debris, was used to reproduce the experiments described below. In this model, the hydrodynamic force, collision force between debris, collision force between debris and walls of structures, and friction force on the bed were considered as external forces. The surface roller model introduced by Kihara et al. (2023) to solve the debris behavior driven by breaking waves was not applied in this study.

HYDRAULIC EXPERIMENT

Kaida et al. (2023) conducted hydraulic experiments in a wave flume (80 m long, 0.9 m wide, and 1.2 m high) under two different bottom slopes (1/50 and 1/150, Figure 1 (a)). Large and small pieces of debris (Figure 1(b)) were placed on the surface of the still water immediately before the experiment started, and then moved to the shore by the tsunami (Figure 1 (c)). The debris were initially placed at 1 m intervals in the interval from x = −8 m to −1 m. Water levels and vertical distribution of cross-shore directed flow speeds were measured with spatially dense resolution from x = −8 m to the shoreline. Debris trajectories were obtained by analyzing the images captured synchronously with the hydraulic measurements.

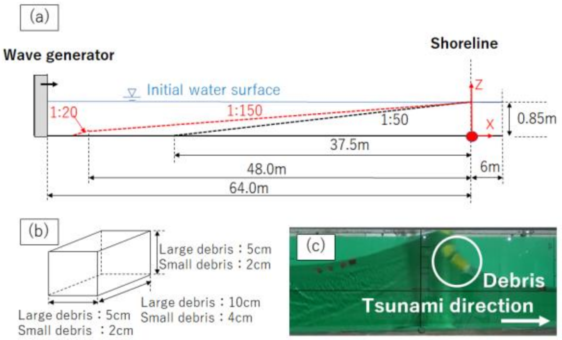

Figure 1 - Cross-sectional view of the experimental flume (a), specification of debris model (b) and a video snapshot taken from the side of the flume showing the movement of large debris caused by the tsunami (Case 50-1).

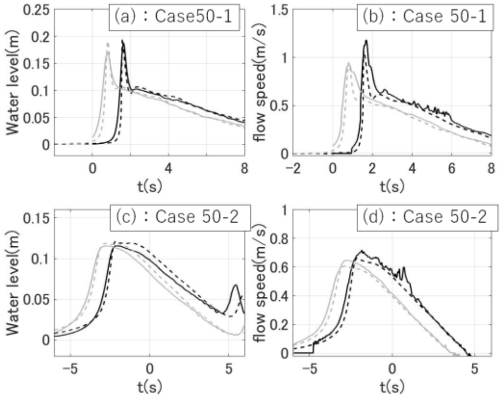

Figure 2 - Time histories of water level and shore-directed surface flow speed at x = −8m (gray) and −4m (black). Solid line: experimental, Dashed line: calculated results.

In this study, we focus on two types of waveforms on the bottom slope (1/50). One waveform is the one that causes the wave breaking between x = −4 m and −3.5 m (Case 50-1), and the other is the one that does not cause the wave breaking (Case 50-2) (Figure 2).

The temporal variations in the cross-shore distribution of the water level and debris trajectories are shown in Figure 3. The trajectory from the lower left to the upper right of the figure indicates that the debris moved toward the shoreline over time. The time when the color contour

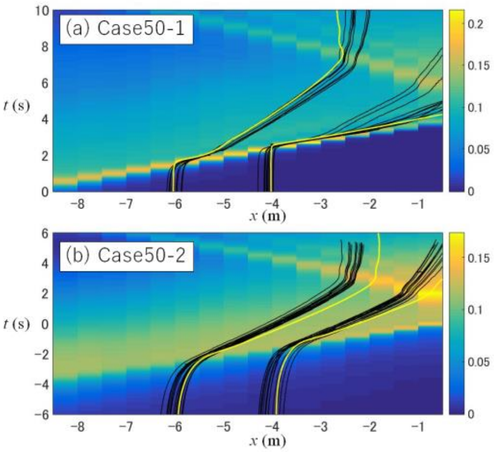

Figure 3 - Debris trajectory initially located at x = −6 m and x = −4 m. The black and yellow lines indicate the trajectories of debris obtained from experiments and numerical calculations, respectively. Color contour shows water level (m) obtained in the experiment.

changes from dark blue to yellow represents the rapid rise of the water level, that is, the arrival time of the tsunami tip. In Case 50-1 (Figure 3(a)) the debris initially placed around the wave-breaking zone (x = −4 m) moves toward the shoreline for several meters while maintaining the same inclination as that of the tsunami tip. This implied that the debris moved with the tsunami tip at a speed equivalent to that of the wave. On the other hand, the debris initially placed at x = −6 m offshore from the wave-breaking point in Case 50-1 and the debris in Case 50-2, which is a non-wave-breaking condition, do not exhibit these characteristics.

NUMERICAL SIMULATION AND APPLICABILITY OF THE nDT MODEL

The reproduction calculations were performed for Case 50-1 and Case 50-2. The open-source code SWASH (non-hydrostatic and non-linear shallow water equation) was used to calculate the two-dimensional flow field in the cross-section. The number of layers in the vertical direction was set to 1. The SWASH calculation results reproduced the experimental results well, including the effects of wave breaking. The nDT model described earlier was coupled 1-way with the flow field calculated using SWASH to calculate the time evolution of the position of the large debris (Figure-1(b)).

Trajectories of debris initially placed at x = −4 m and −6 m are shown in yellow in Figure 3. The effects of the presence or absence of wave breaking and the location of the wave-breaking zone on the behavior of floating debris were well reproduced by the numerical simulation. Figure 4 shows the numerically reproduced relationship between the free surface and position of the floating debris object. In Case 50-1, floating debris placed near the wave breaking area were trapped at the steep tsunami tip and transported to an area near the shoreline. This result reproduces the behavior of the floating debris objects in the experiment (Figure 1(c)). Kaida et al. (2023) pointed out that the driving mechanism behind debris movement associated with wave breaking is the convolution of the Froude-Krylov force, influenced by the sharp water surface gradient (Figure 4(a)) and the drag force due to the high flow speed (Figure 2(b)) near the surface. The obtained results supported the mechanism proposed by Kaida et al. (2023). The results of our numerical simulation show that with highly accurate calculations of the water surface profile and shore-directed surface flow speed, the existing nDT model can adequately reproduce the behavior of debris driven by wave breaking without introducing a surface roller model (Kihara et al, 2023).

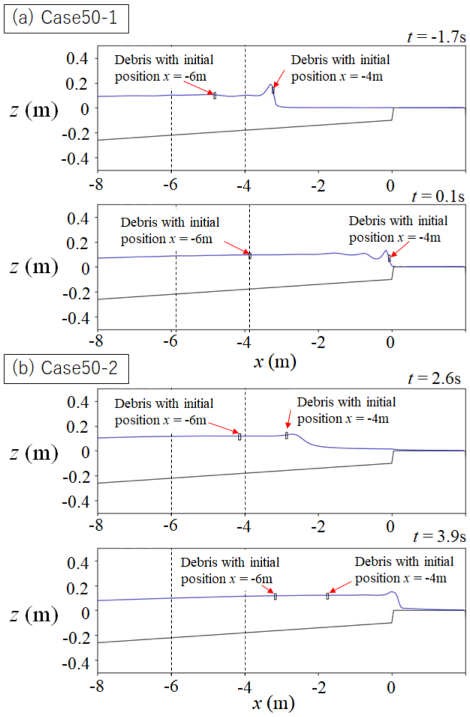

Figure 4 - Snapshots showing the relationship between free surface (blue line) and location of floating debris calculated by numerical simulations. The black line indicates the bottom slope.

REFERENCES

Kaida, H., Kihara, N., Niida, Y. and Tomita, T. (2023): Study on the drifting mechanism of the tsunami debris affected by the wave breaking, Journal of JSCE, Vol. 11, No. 2, SI (Coastal Engineering), accepted (in Japanese).

Oda, Y., Hashimoto, T. and Hashimoto, A. (2021): Evaluation of impact force acting on tsunami seawall due to water borne debris, Journal of JSCE, Ser.B2, Coastal engineering, Vol. 77, No. (2), pp. I_205-I_210.

Kihara, N. and Kaida, H. (2020)： Applicability of tracking simulations for probabilistic assessment of floating debris collision in tsunami inundation flow, Coastal Engineering Journal, Vol. 62, No. 1, pp. 69–84.

Kihara, N., Kaida, H. and Tsurudome, C. (2023): Modelling of debris motion driven by tsunami wave breaking, Coastal Engineering Proceedings, Vol. 37.