EFFECT OF WATER LEVEL CHANGE ON WAVE OVERTOPPING VOLUME BASED ON EXPERIMENT SIMULTANEOUS OCCURRENCE OF STORM SURGES AND WAVES

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INTRODUCTION

Typhoon Jebi hit Osaka Bay, Japan in 2018, causing significant damage to coastal areas due to storm surges and high waves. Although the water level due to the storm surge was lower than the seawalls, the super-imposed storm surge caused inundation damage in some areas in the hinterland, such as Kansai Airport due to wave overtopping. Inundation damage in inner bay areas was enhanced by the simultaneous occurrence of storm surges and high waves. Therefore, it is necessary to reexamine the transition state of water level rise caused by storm surges and the effects of the simultaneous occurrence of storm surges and high waves.

In this study, changes in wave overtopping and overflow were measured experimentally under conditions of transitional rise in water level due to storm surge and a series of phenomena from a state in which only wave overtopping occurs to a state in which wave overtopping and overflow occur simultaneously were reproduced by hydraulic experiment. Furthermore, the results were compared with the wave overtopping to surge transition model developed by Mase et al. (2020), and the accuracy of the existing models was examined.

HYDRAULIC EXPERIMENT

The experiment was conducted in a tsunami simulation tank (45 m long, 4 m wide, and 2 m high) of the DPRI, Kyoto University. The tank has a flow generator (pump) and a piston-type wave generator, which can be operated simultaneously. A sub-tank, 25 m long, 4 m wide, and 2 m high, connected by a large-diameter pipe, can be used to circulate the water with a pump. The pump was used to measure the tidal change of the storm surge for 6 minutes, and the wave generator was used to act on the irregular waves for 8 minutes simultaneously. A 0.8 m high horizontal bed connected to a 1/10 slope seafloor was installed in the tank, and a 0.25 m high model of a vertical seawall was installed. The initial water depth is 0.89 m, and the crown height becomes 0.16 m. A water sampling box was installed behind the seawall to measure wave overtopping and overflow volume. The model scale by Froude's law was set as 1/25. Experimental conditions of storm surges and waves are shown in Table 1.

Figure 1 shows the water level change in front of the seawall when the pump inflow Q is varied from 0.03 to 0.12 m^3/s in 0.01 m^3/s increments. Not only the rise of the water level due to storm surge but also the fall of the water level can be reproduced. When Q is more than 0.10 m^3/s, the peak water level exceeds the crown height h_c = 0.16 m, resulting in overflow.

EXPERIMENTAL RESULTS AND DISCUSSION

One of the effects of the simultaneous occurrence of storm surges and waves is the change in water level. Figure 2 shows the 30 s moving-averaged water level change during simultaneous storm surge and waves, and the water level change only during storm surge under the conditions of H_0' = 0.225 m and $T_{1/3}$ = 2.0 s. When the pump inflow is small, Fig.2(a), the water level at the simultaneous occurrence of storm surge and waves (red line) is shown to be higher than that of the storm surge only (blue line). This is presumably due to the setup effect of wave breaking. On the other hand, when the inflow is large, Fig.2(b), the water level at the time of simultaneous occurrence of storm surge and waves is lower than the water level only by storm surge. This is because the water level rises due to the storm surges, and waves do not break.

Next, time variations of wave overtopping and overflow were analyzed as shown in Figure 3. The blue line shows that the overflow began at 230 s which means only the overtopping is active before it. Comparing the results of the simultaneous wave and storm surge experiment (red line) and the only wave experiment (yellow line), the results of

Table 1 - Experimental conditions of storm surges and waves

Q (m^3/s)	H_0' (m)	$T_{1/3}$ (s)	L_0 (m)	H_0'/L_0
0, 0.03 to 0.12 (every0.01)	0.068	1.6	3.99	0.017
	0.106	2.0	6.24	
	0.153	2.4	8.99	
	0.081	1.2	2.25	0.036
	0.144	1.6	3.99	
	0.225	2.0	6.24	

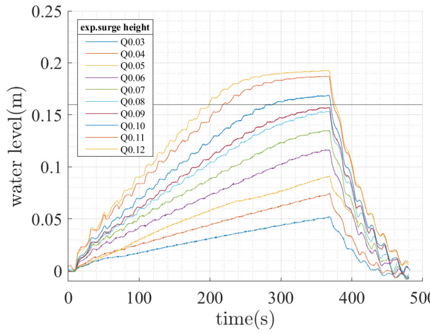
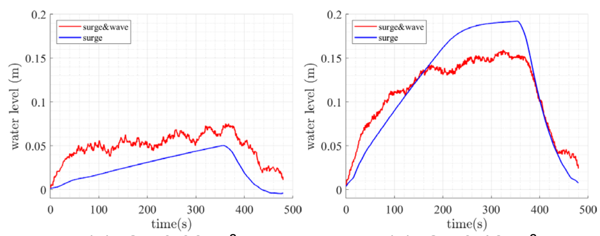


Figure 1 - Time series of water level change in front of seawall for each pump inflow condition without waves.



(a) Q = 0.03 m^3/s (b) Q = 0.12 m^3/s

Figure 2 - The 30 s moving-averaged water level change during simultaneous storm surge and waves (red line) and only during storm surge (blue line).

the simultaneous experiment are larger. Therefore, the amount of wave overtopping associated with a rise in water level is larger than that at a constant water level. The experimental results obtained by adding the wave overtopping and storm surge by individual measurement become a quarter of the wave and storm surge and wave overtopping discharge, which occur at the same time. This indicates that treating wave overtopping and storm surge overflow separately to evaluate the transition process is an underestimation.

Figure 4 shows the same analysis as Fig.3 but for all cases. For all experimental conditions, it was found that evaluating the transition process of wave overtopping and overflow individually underestimates the total discharge of wave overtopping and overflow. Therefore, it was confirmed from the experiments that it is highly important to consider the transition processes of wave overtopping and overflow due to the simultaneous occurrence of storm surge and waves.

EVALUATION OF EMPIRICAL MODEL

The wave overtopping to surge transition model is proposed by Mase et al. (2020), which is based on IFORM (Integrated Formula of wave Overtopping and Runup Modeling) by Mase et al. (2013) and Yuhi et al. (2021) and was extended based on the experimental results of Hughes and Nadal (2008).

Figure 5 shows the overtopping/overflow discharge q (m^3/s/m) calculated from the 1-min averaged value by wave overtopping to surge transition model on the vertical axis and the 1-min averaged value by experiment on the horizontal axis. Since the discharge was measured for 8 minutes, 480 points are plotted in total (8 min x 60 cases). Comparing all experimental results, we found the following three points: First, the calculated value of IFORM is overestimated compared to the experimental results. Second, the wave overtopping and overflow increase as the wave steepness increases. Third, IFORM can estimate the experimental values in the case of large storm surges compared to the case of small storm surges.

To improve the accuracy, the coefficient C in IFORM equation was varied (C = 0.01, 0.05, 0.1 to 0.5), and the estimated values were compared with the experimental results. Figure 6 shows the same conditions as shown in Figure 5, but with the coefficient C changed to 0.1. Figure 6 shows that the accuracy of IFORM estimation is significantly improved when the coefficient C is set to 0.1.

REFERENCES

Mase H. et al. (2020): Combined Wave Overtopping and Overflow Modelling in Wave-Surge Coupling Simulation Model, Journal of JSCE, Ser. B2 (Coastal Engineering), Vol.76, No.1, pp.7-19 (in Japanese).

Mase H. et al. (2013): Wave runup and overtopping at seawalls built on land and in very shallow water, Journal of Waterway, Port, Coastal and Ocean Engineering, ASCE, Vol. 139, No.5, pp.346-357.

Yuhi, M. et al. (2021): Refinement of integrated formula of wave overtopping and runup modeling, Ocean Engineering, 220.

Hughes, S.A., N.C. Nadal (2008): Laboratory study of combined wave overtopping and storm surge overflow of a levee, Coastal Engineering, 56, 3, pp.244-259.

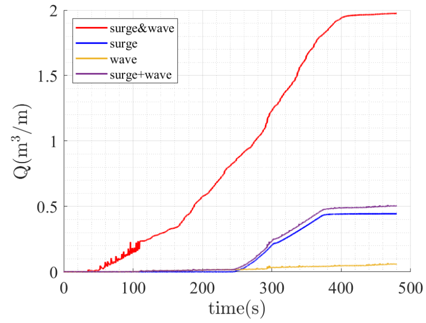


Figure 3 - Time variations of wave overtopping and overflow. Red: storm surge and wave, blue: only surge, yellow: only wave, purple: adding surge plus wave.

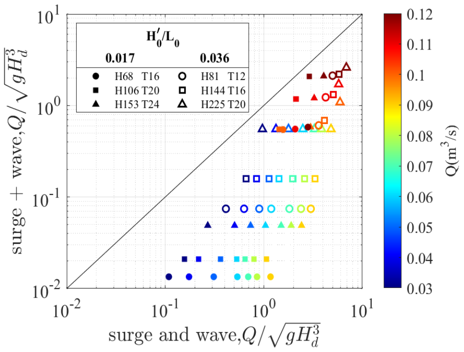


Figure 4 - Comparison of the wave overtopping discharge between the simultaneous occurrence of storm surge and waves and the addition of the overtopping discharge of storm surge and waves, respectively.

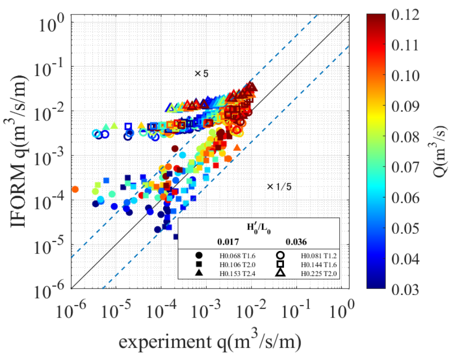


Figure 5 - Comparison of overtopping discharge estimation model IFORM with experimental results.

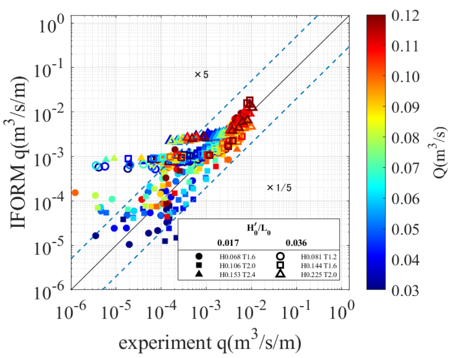


Figure 6 - Comparison results same as Figure 5 when the value of IFROM's coefficient C is changed to 0.1.