Development of a Fully Coupled Compound Flooding Model for Coastal Urban Areas: Application to Typhoon Jebi at Kansai Airport

〇Junbeom JO, Sooyoul KIM, Nobuhito MORI

Introduction

Storm surges caused by typhoons and localized heavy rainfall are major drivers of compound flooding in coastal cities. Conventional approaches to flood risk estimation, which utilize decoupled models, have limitations in accurately predicting compound flooding because they ignore the complex interactions among multiple drivers. Therefore, it is essential to propose a reliable method to integrate various flooding drivers. In the present study, a fully coupled compound flooding model is developed based on the model by Jo et al. (2024), taking into account coastal and pluvial flooding drivers.

Method

The flooding analysis model proposed by Jo et al. (2024) calculates coastal and surface flows using depth-integrated 2D nonlinear shallow water equations. However, the sewer flow is calculated separately using 1D shallow water equations. Therefore, the fully coupled compound flooding model presented in this study implements a two-way coupling process between the surface and sewer system, as shown in Figure 1. The developed model is applied to the compound flooding event by Typhoon Jebi (2019) at the Kansai Airport.

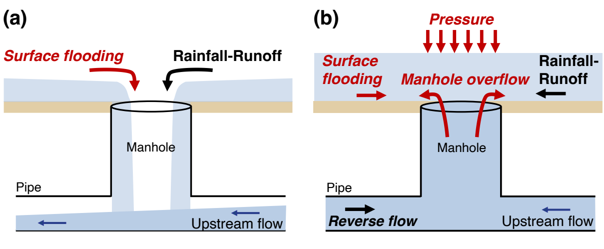

Fig 1. Interaction between surface and sewer flow

Results and Discussion

Figure 2 illustrates the 10-minute rainfall intensity (Fig. 2(a)) accompanied by Typhoon Jebi and the surface water depth along a profile line. The profile line is a straight line extending 240 m inland from the seawall, crossing three manholes. The surface water depth along this line showed minimal differences between the one-way and two-way coupling cases during the peak storm surge at 6:00 (Fig. 2(c)). However, at 4:00 (Fig. 2(b)) and 8:00 (Fig. 2(d)), before and after the passage of typhoon, the surface water depth above the manhole closest to the outlet was significantly reduced in the two-way coupling case.

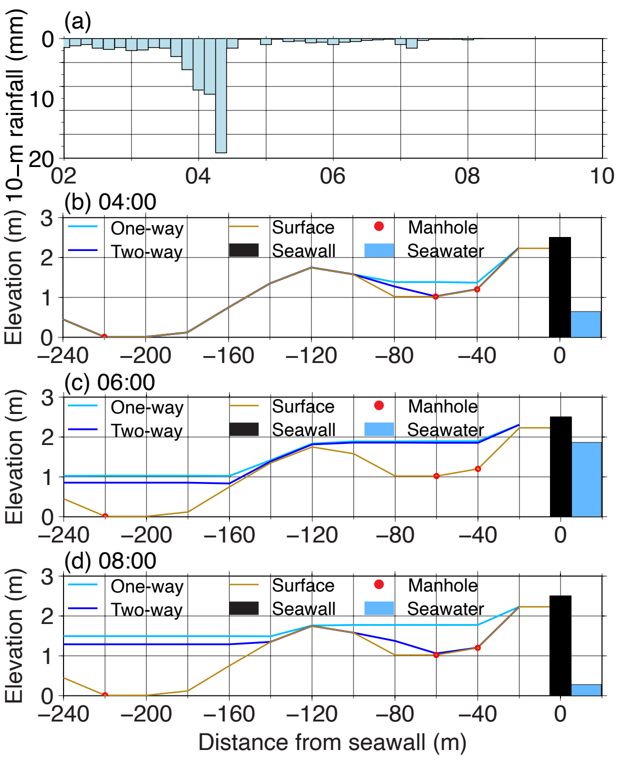

Fig 2. Time series of 10-minutes rainfall intensity (a) and flood depth variation along profile line ((b)-(d)).

To evaluate the impact of the two-way coupling, the spatial distribution of flood depth at 4:30 was compared (Figure 3). In the one-way case, surface flooding was concentrated near the outer edges close to the seawall, as the surface flooding could not be intercepted. On the other hand, in the two-way case, surface flooding caused by wave overtopping was intercepted by the manholes. As a result, the range of flooding near the seawall was reduced. However, this intercepted flow also led to significant overflow through manholes at upstream locations. This indicates that the intercepted wave overtopping, which could not be discharged through the outlet, influenced the sewer flow.

Figure 4 compares the maximum flood depths calculated at 14 observation points at Kansai Airport. The two-way coupling case demonstrated that the interaction between the surface and sewer flow resulted in a generally reduced maximum flood depth. This result indicates that the two-way coupling process can alter the compound flooding patterns in coastal cities.

Conclusion

This study developed a fully coupled compound flooding model for coastal urban areas by integrating a surge-tide-wave model with an urban flooding model. The applicability of the model was evaluated by reproducing Jebi-induced Kansai Airport flooding as follows:

1. The model considers the physical phenomena of intercepting surface flooding and discharging overflow, both occurring through the manhole.
2. Surface flooding conditions caused by wave overtopping affect the sewer system, resulting in flooding distributions and timing changes.

The developed model accurately estimates the characteristics of compound flooding by fully integrating various physical processes. These results demonstrate that the developed model might be useful for enhancing flood risk prediction.

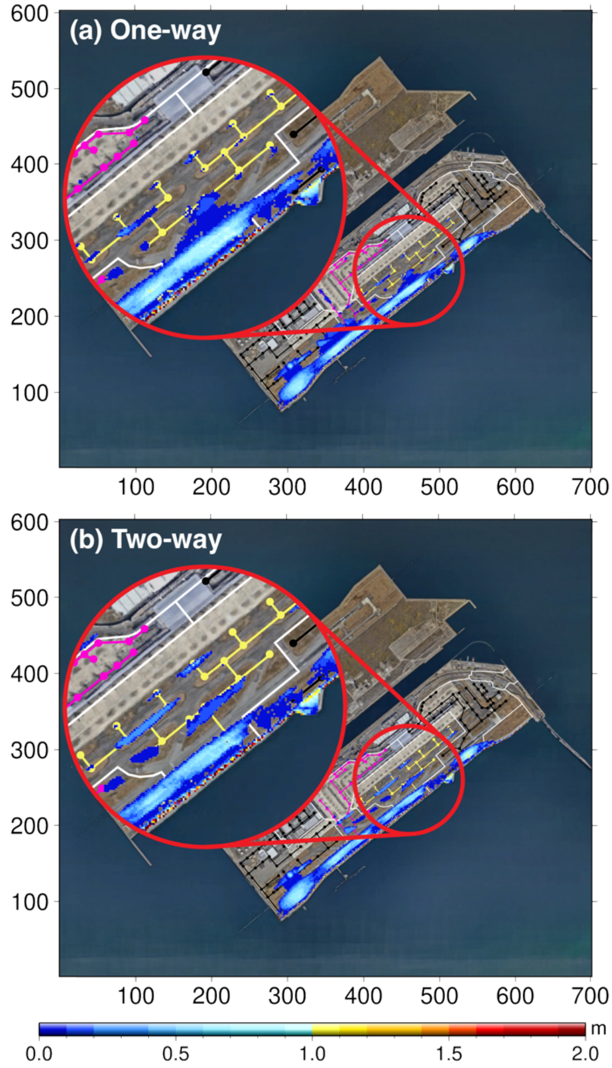

Fig 3. Spatial distributions of flood depth at 4:30 with One-way (a) and Two-way (b) coupling processes.

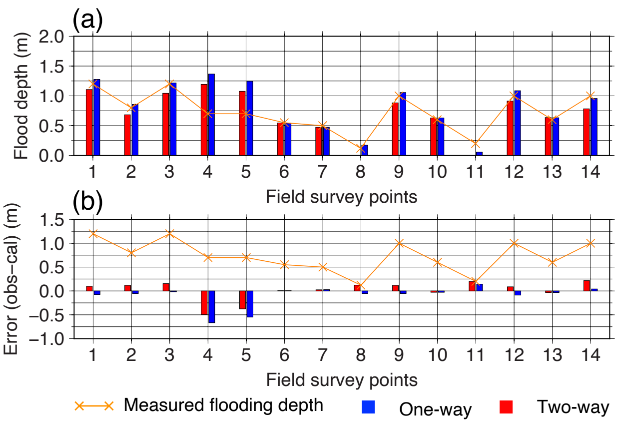

Fig 4. Comparisons of the maximum flood depths at 14 field survey points: (a) maximum flood depths and (b) differences between measurement and the calculations.