

COMPOUND FLOODING OF WAVE OVERTOPPING AND STORM SURGE USING A FULLY COUPLED SURGE, WAVE AND TIDE MODEL

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INTRODUCTION

Typhoons accompanied by storm surges, high waves, and heavy rainfall cause severe compound flooding in coastal areas. Various flood factors in compound coastal flooding interact dynamically. As a result, flood damage in coastal areas is exacerbated. For example, Kansai Airport experienced heavy flooding due to Typhoon Jebi (2018). During this event, multiple flood factors included wave overtopping, rainfall, seawater reverse flow through sewer systems, and partial seawall collapse caused by wave overtopping. As in previous studies, estimating flooding caused by individual factors has limitations in accurately analyzing the complex physical processes and interactions between the factors, such as compound flooding events at Kansai Airport. This study conducted a series of numerical experiments at Kansai Airport to propose a method for estimating compound flooding in coastal areas.

METHOD

The fully coupled model for compound flooding developed by Jo et al. (2021) based on the coupled surge, wave and tide model (SuWAT) is used for the numerical experiments. The developed model can consider multiple flood factors such as storm surge, wave overtopping/runup, rainfall-runoff, and sewer reverse flow as shown in Fig. 1. In this model, the formula of wave overtopping and runup (IFORM, Yuhi et al., 2020) is implemented to estimate the volumes of wave overtopping and surge overflow through transient processes from the wave overtopping-dominant process to the surge overflow-dominant one and vice versa. This model can trace the non-breaking wave information using a method by Mase et al. (2016) because IFORM uses offshore wave information. Also, the reduction factor by wave direction is considered by implementing a way in EurOtop (2018). Rainfall runoff and sewer reverse flow can be estimated by integrating Storm Water Management Model (SWMM). Boundary conditions for calculating compound flooding in this model are shown in Fig. 2.

The seawall installation status for wave overtopping is shown as red and blue lines in Fig. 3. Moreover, the partial seawall collapse at the east side aggravated the flood damage at Kansai Airport (orange-colored small triangle section in Fig. 1). Therefore, the allowable condition of the wave overtopping rate for seawall collapse (see Table 1), empirically suggested by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) in 2018, was applied to the seawall collapse section as follows:

$$P_a = 10,828 Q_{over_a} \quad (\text{Eq. 1})$$

Where, P_a is the allowable pressure and Q_{over_a} is allowable overtopping discharge ($m^3/s/m$). When the overtopping amount calculated by Eq. 1 exceeds the

allowable conditions, the seawall height is assumed to be equal to 0 m for the top of the seawall, resulting in being similar to land heights.

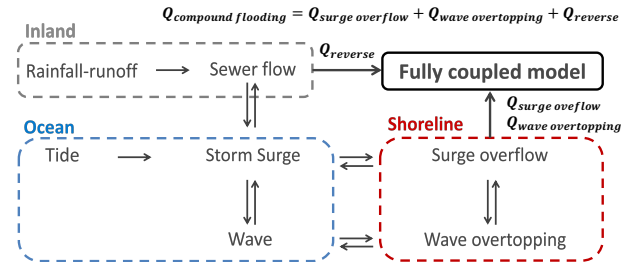


Figure 1 - A framework of the fully coupled model for compound flooding, taking into account surge, wave, tide, wave overtopping/runup, rainfall-runoff, and sewer flow.

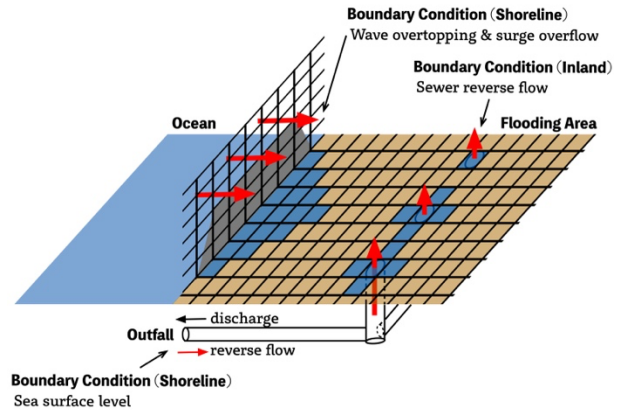


Figure 2 - Boundary conditions for compound flooding calculation in the fully coupled model.

Table 1 - Allowable conditions for structure failure due to wave overtopping discharges ($m^3/s/m$)

Covering	Q_{over_a}
Concrete three-side wrapping	0.05
Top surface paving · No backfill construction	0.02
No top surface paving	less than 0.005

The geophysical region for numerical experiments consists of seven domains downscaled from 7 km to 10 m grid sizes. Consequently, a detailed analysis of the flood depth at the innermost domain can be conducted. The calculated flood depth in this study is compared with the field survey flood depth at 14 points (marked with green circles in Fig. 3) to validate the fully coupled model developed.

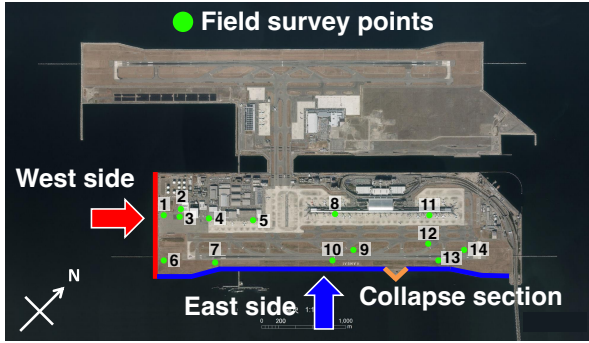


Figure 3 - Seawall installation status along the west (red line) and east (blue line with orange line for seawall collapse section) sides of Kansai Airport with 14 field survey points (green circle) for measuring the flood depth after the flood ended

RESULTS AND CONCLUSIONS

Figure 4 separately shows the wave overtopping discharge on the west and east sides. Significantly, the wave overtopping discharge along the east side without seawall collapse (blue bars and lines) and with seawall collapse (orange bars and lines) are presented to compare the effect of the seawall collapse. As a result, the seawall collapse led to a 4.98% increase in the peak wave overtopping discharge (from 0.027 to 0.029 m³/s per m) and a 7.38% increase in the accumulated discharge (from 73.71x10³ to 79.16x10³ m³ per m) along the east side. The wave overtopping discharge along the west side without seawall collapse is calculated by 0.054 m³/s per m in the peak discharge and 30.30x10³ m³ per m in the accumulated discharge.

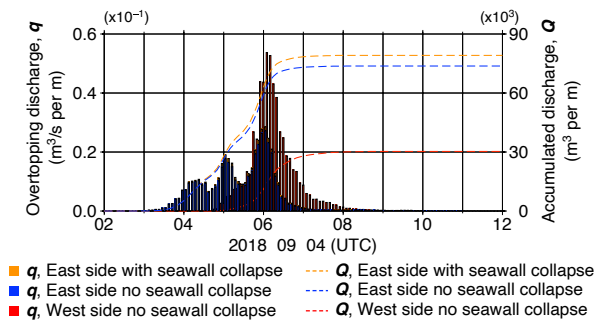


Figure 4 -Time series of the wave overtopping discharge along the west and the east sides considering seawall collapse

The maximum flood depth at Kansai Airport, considering all flood factors (i.e., wave overtopping, rainfall-runoff, sewer reverse flow, and seawall collapse), is shown in Fig. 5. Additionally, comparisons of the flood depths between the measurement and calculation at 14 survey points are presented in Fig. 6. The calculated flood depths revealed a similar height to the measured ones along the survey points. However, discrepancies in flood depth estimation were found at four survey points (e.g., 4, 5, 11, and 14). These discrepancies might be attributed to inaccuracies in the topographic data of the inland area. The topographic data used in this study were derived from a 5m-resolution Digital Elevation Model (DEM) provided by the Geospatial

Information Authority of Japan (GSI). Nevertheless, the DEM data is acquired through aerial observations and may not accurately reflect the evolving terrain due to ongoing erosion at Kansai Airport. Additionally, the observed data may also be affected by the imprecision in measurements, as they are taken after the flooding has completely ended.

Despite these limitations, this study effectively considered the complex interactions of various flood factors to estimate compound flooding. This result clearly demonstrates the proposed approach's applicability in assessing compound flooding with seawall collapse that can occur along the shoreline. However, the study area, Kansai Airport, is manufactured with multiple managed variables; therefore, further research is necessary to adapt this approach to actual coastal regions.

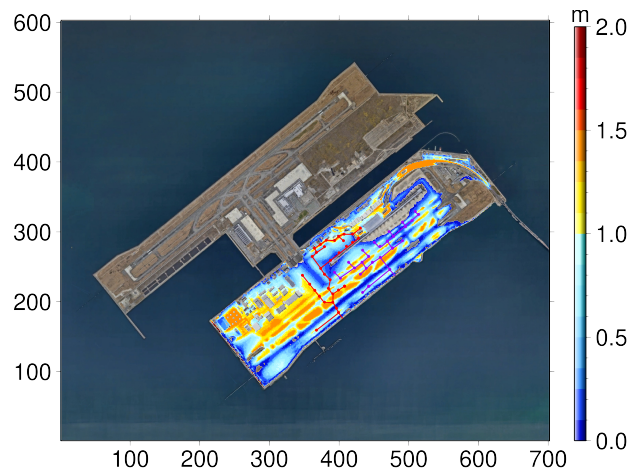


Figure 5 - A spatial distribution of the maximum flood depth at Kansai airport due to the multiple flood factors such as wave overtopping, rainfall-runoff, sewer reverse flow, and seawall collapse

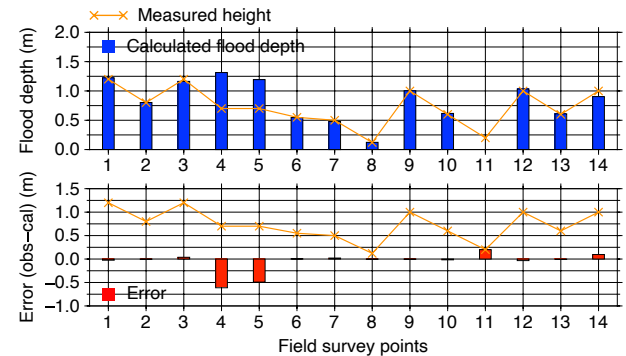


Figure 6 - Comparison of the maximum flood depth by calculations (blue bar) and the field survey (orange line with X symbols) with the error between both at 14 survey points

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Jo, Kim, Mase, Mori, Tsujimoto (2021): Development of a coupled coastal flood model of surge, wave, precipitation and sewer backflow for urban area. *Journal of JSCE, Ser. B2, Coastal Eng., 77(2)*, pp. 1_253-1_258.
 Yuhi, Mase, Kim, Umeda, Altomare (2020): Refinement of Integrated Formula of Wave Overtopping and Runup Modeling, *Ocean Engineering*, 220, 108350