Numerical and Hydraulic Experiments for Storm Surge Inundation by Wave Overtopping and Overflow

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ABSTRACT

Global warming is increasing the risk of storm surges such as inundation by seawater inflow. However, the evaluation method of seawater inflow under the condition where wave overtopping and surge overflow occur simultaneously has not been sufficiently studied and further examinations are needed. For example, the effects of sea waves and/or inundation depth on land area are generally not considered in the estimation of storm surge inundation. In this study, the evaluation method of storm surge inundation by overtopping-overflow was examined by numerical experiments using OpenFOAM and hydraulic experiments. It was shown that the average inundation level can exceed the average sea level and an estimation equation to calculate the inundation level was proposed and validated by the experiments.

KEY WORDS: wave overtopping; surge overflow; storm surge; global warming; hydraulic experiments; numerical experiments; Open FOAM

INTRODUCTION

Climate change due to global warming has a great impact especially in the coastal area, and the risk of storm surge is concerned to increase. When a strongly developed tropical cyclone causes storm surge and high waves, seawater may pass through the seawall due to wave overtopping and surge overflow, resulting in inundation of coastal area. Inundation risk evaluation is important to prepare for such disasters caused by storm surge, and it is necessary to consider not only wave overtopping but also combined wave overtopping and overflow.

There are three types of seawater inflow caused by storm surge and high waves. The first type is the condition where the average sea level is lower than the crown height of a levee, and seawater goes over the levee by wave overtopping. In the second type, the average sea level exceeds the crown height and seawater flows into the land area due to both wave overtopping and overflow. When the sea level rises much higher, seawater flows in only by overflow, disappearing the influence of waves, which is the third type of the inflow in storm surge. Wave overtopping has been studied for a long time, the method to calculate overtopping discharge has already been established. On the other hand, combined wave overtopping and overflow has been actively studied in recent years.

Hughes and Nadal (2009) conducted hydraulic experiments on combined wave overtopping and overflow and proposed the equation to calculate overtopping-overflow discharge from the wave height and the crown height of the levee. They mentioned that the effect of wave overtopping decreases when the crown height is lowered to some extent. Li et al. (2012) investigated discharge of combined wave overtopping and overflow by full scale experiments. Their experimental results were in good agreement with the Hughes and Nadal, but the difference was large in the case of small water depth. This suggests that the equation of Hughes and Nadal cannot be applied in the case of small water depth. Reeve et al. (2008) conducted numerical simulation of combined wave overtopping and overflow by the model based on the Reynolds-averaged Navier-Stokes equations. Discharge calculated by the simulation was large compared by other experimental results such as Schuttrumpf et al. (2001) and Hughes and Nadal (2009), and the validity of the calculation may have been insufficient. Mase et al. (2020) summarized these previous studies and examined a method that can seamlessly calculate the overtopping-overflow discharge under various conditions. In their study, the overtopping-overflow discharge is calculated as the total discharge of wave overtopping and overflow. By introducing the variable Ratio, it is expressed that the influence of wave overtopping depends on the type of seawater inflow. Mase et al. also conducted inundation simulation by combination of a coupled surge and wave model by Kim et al. (2008) and Kim et al. (2015) and the overtopping-overflow calculation model. This series of models need to be evaluated based on the actual observations for its accuracy.

Although many studies on wave overtopping and overflow have been conducted, it cannot be said that a method to calculate the overtopping-overflow discharge has been established, and further verifications of the applicability are required. For example, none of the models assume the probability that the inundation level may exceed the sea level when storm surge and waves continue for a certain time. In this study, the inundation level at the condition where wave overtopping and overflow occur