Numerical Study on Breaking Waves Interaction with Vertical Wall attached with Recurved Parapet

Songtao Chen1, Qingjie Meng2, Decheng Wan1*

1 Computational Marine Hydrodynamics Lab (CMHL), School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University, Shanghai, China
2 Wuhan Second Ship Design and Research Institute, Wuhan, China
*Corresponding author

ABSTRACT

This paper numerically investigates breaking waves interaction with a vertical wall attached with a recurved parapet in 1:8 model scale. The in-house CFD solver naoe-FOAM-SJTU based on the open source platform OpenFOAM is used to perform the simulation. For wave generation, a novel generating-absorbing boundary condition (GABC) is adopted to replace the time-consuming moving boundary wavemaker. A geometric volume-of-fluid (VOF) method based on piecewise-linear interface calculation (PLIC) is incorporated in the present numerical model to capture the sharp interface and improve the accuracy of the predicted impact pressure. The time histories of the wave elevation and pressure at each probe are presented as well as the frequency analysis. In addition, the evolutions of free surface and pressure distribution are further provided to achieve a better understanding of this complex wave-structure interaction issue.

KEY WORDS: breaking waves; recurved parapet; naoe-FOAM-SJTU; generating-absorbing boundary condition (GABC); geometric VOF method

INTRODUCTION

Vertical breakwaters are typical coastal structures intended to reduce the effects of incoming waves, especially in extreme sea conditions. In practical design, wave overtopping has been a significant issue of sustained concern for decades. Among the various solutions, a parapet fixed on the top of the vertical wall has been proven effective by deflecting back the up-rushing water seawards. However, according to the previous studies, the shape and parameters of the parapet will significantly influence the impact force and pressure compared with the original vertical wall. In order to provide guidelines to predict the wave impact and wave loading, it is necessary to systematically investigate the variations under different wave conditions, including non-breaking and broken waves.

As a representative shape, the recurved parapet has gradually attracted more attention recently. Kortenhaus et al. (2002, 2003) highlighted the effectiveness of the recurves and parapets in wave overtopping through abundant experimental data collected in the wave flume of the Leichtweiss-Institute. Nevertheless, they pointed out that their existences may increase the wave loadings on the vertical wall. Ravindar et al. (2019) conducted large-scale (1:1) experiments to characterize the impact pressure under different wave breaking conditions at the Coastal Research Centre (FZK), Germany. According to their classification, it can be divided into three conditions: slightly breaking waves (SBW), breaking waves with small air trap (BWSAT), and breaking waves with large air trap (BWLAT). In addition, they reported the significant effect of the entrained air on the impact pressure. On this basis, Ravindar et al. (2021a, b) carried out small-scale (1:8) experiments in the Department of Ocean Engineering at the Indian Institute of Technology Madras, Chennai, Tamil Nadu, India. They analyzed the scale effects and proposed a combined Cuomo-Froude method for scaling up the impact pressure of small-scale results. Besides, they also discussed the impact pressure and forces of different types of parapets under the above-classified wave breaking conditions.

Considering the scale effect and the possible entrained air pocket, more and more scholars have adopted various numerical approaches to investigate the detailed behaviors of this problem. Castellino et al. (2018a, b) used the single-phase solver IH2VOF and the two-phase solver IHFOAM to conduct a series of two-dimensional simulations of a vertical breakwater with a recurved parapet under non-breaking waves. They identified an impulsive phenomenon referred to as “confined-crest impact” and further performed a sensitivity study on the parameters of the recurved parapet. Liu et al. (2019) used a two-phase compressible CFD solver with the Ghost Fluid Method (GFM) and a free surface turbulence model to explore the violent breaking wave impacts on a vertical wall. In their solver, the air compressibility was taken into account, thus being more physical under wave breaking conditions. Among four considered breaking conditions, they observed the maximum wave forces appear in the “flip-through” and “large air pocket” cases. Molines et al. (2020) numerically investigated the influence of parapets on crown walls of mound breakwaters with parapets based on OpenFOAM. Consistent with the previous studies, the dimensionless