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Study on Reflection Characteristic of a Curved Wing-like Submerged Structure Before a Vertical Wall

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A wave dissipating and defending system consisting of a submerged curved wing-like structure and a vertical wall is proposed. The interactions between the wave and the systems with a submerged rectangular structure and a submerged curved wing-like structure before a vertical wall are comparatively studied using a numerical wave flume based on OpenFOAM. The wave reflection coefficients of the two systems are calculated under different wave periods. The distributions of the flow field and vortex viscosity field are analyzed, and the main mechanism of wave dissipation is discussed. The numerical results indicate that the wave dissipating performance of the wave dissipating and defending system with a curved wing-like submerged structure is better than that of the system with a rectangular submerged structure.

INTRODUCTION

In waters where water area is limited, the vertical walls and vertical revetments are a common marine engineering structure to protect coastal regions. Severe wave force and high-amplitude waves have a large impact on the vertical structure; therefore, it is common to place a submerged obstacle in front of a vertical wall to reduce wave forces acting on the wall and to lower the wave elevation before the wall. Examples of such obstacles include horizontal plates (Wu et al., 1998; Hu et al., 2002), vertical plates (Kaligatla et al., 2015), and a rectangular obstacle (Koutandos and Prinos, 2011). The setup consisting of these structures on the water surface before a vertical wall is similar to a perforated caisson in hydrodynamic properties (Jarlan, 1961; Zhu and Zhu, 2010; Lee and Shin, 2014).

In an effort to reduce wave amplitudes or/and lengths, a few studies have been carried out in recent decades in terms of the structure with submerged obstacles in front of a seawall. Yueh and Kuo (1993) investigated the reflection of waves when a submerged fixed horizontal plate was placed before the vertical wall numerically and experimentally and found that the reflection coefficient can be reduced to a minimum when submergence depth is suitable. However, it is disappointing that wave breaking and viscosity were not taken into account in the study, and the wave height above the plate must be controlled to avoid touching the plate, which would result in wave breaking. Jeng et al. (2005) studied the waveform changes and the wave dissipating performance of the system with a submerged obstacle before a vertical wall. Kaligatla et al. (2015) developed a new wave dissipating structure, a vertical submerged flexible porous plate located near a vertical rigid wall, and analyzed the wave dissipating performance of the structure.

Of course, the idea of using submerged horizontal plates as breakwaters in the absence of a vertical wall is not new and has been studied extensively in the literature on wave reflection characteristics. Siew and Hurley (1977), Patarapanich (1984), Patarapanich and Cheong (1989), and Yu (1995) studied the wave reflection of submerged plate structures of negligible thickness. Liu et al. (2009) and Verduzco-Zapataa et al. (2017) studied the wave reflection characteristic of submerged plates considering the plate thickness, and the plate structure can be studied as a rectangular structure when the thickness of the plate is given. Ren et al. (2019) studied the dimension influence of a rectangular submerged structure on wave characteristics using the consistent particle method, including the detailed physics of the wave breaking process, the vortex generation and evolution, and the water particle trajectories. The influence of the shape of a submerged structure on the wave reflection characteristics has attracted more and more attention in recent years. Chen et al. (2015), Medina-Rodríguez, Bautista, and Méndez (2016), Medina-Rodríguez, Bautista, Méndez, and Bautista (2016), and Yueh et al. (2016, 2018) studied the wave reflection characteristics of submerged structures with different shapes. However, the wave reflection performance of the above wave dissipating structure will change significantly when the horizontal plates are utilized in cooperation with the vertical wall.

After building the submerged structure before a vertical wall, the movement and hydrodynamic characteristics of the water before the vertical wall will change fundamentally. On the one hand, the wave will be first blocked by submerged structures in the process of propagation, and the wave will deform or break in advance as a result of the boundary of submerged structure. Parts of the waves are reflected, and the remaining waves continue to spread forward until interacting with the vertical wall. On the other hand, the wave will generate total reflection or part of reflection after waves interact with the vertical wall, and the multiple wave reflection will occur between the submerged structure and the vertical wall. In this zone, the flow field is extremely complex, and the wave energy dissipation induced by the strong turbulent motion is large. The boundary shape of submerged structure directly affects the wave deformation, the turbulent intensity of flow field, and the multiple reflections between the submerged structure and straight wall. Therefore, the multiple wave reflections between the submerged structure and the vertical wall and the repeated rises and falls of water before the vertical wall are crucial for wave energy dissipation, so the boundary shape of the submerged obstacle should be paid more attention to because of its great influence on wave reflection and wave energy dissipation. Moreover, the effective frequency range of the wave dissipating structure whose effective frequency range is narrow can be broadened by the more matched structure shape to some extent.

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