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Numerical Study on Interaction Between Focusing Waves with Fixed Cylinder

Bo Han, Weiwen Zhao* and Decheng Wan*†
Computational Marine Hydrodynamics Lab (CMHL), School of Naval Architecture, Ocean and Civil Engineering
Shanghai Jiao Tong University, Shanghai, China

Wave focusing is one of the mechanisms that results in the generation of extreme waves. The accurate numerical simulation of the interaction between the focusing wave with a fixed vertical cylinder is presented in this paper, and the simulation is conducted using the naoe-FOAM-SJTU solver, an in-house CFD solver for marine hydrodynamics. The generation of focusing wave is realized by the provided movement of the wavemaker, and the propagation of the wave is validated in advance. The wave elevations and the pressures around the cylinder are provided and compared with the experiment.

INTRODUCTION

For the design of coastal and offshore structures, safety is always a crucial issue. Generally, accidents in coastal and offshore structures can hardly be afforded. So from the view of design, the structures should be able to survive in the harshest sea conditions as demanded. Therefore, accurate prediction of hydrodynamic performance under extreme sea conditions is of great significance to safety.

The freak wave is dangerous for structure design. Longuet-Higgins (1974) pointed out that the freak wave could be regarded as the combination of a series of monochromatic waves with their crest focusing at a single point simultaneously, which we called focusing wave. The free surface of the focusing-wave case has drastic changes around the focusing point, which is impacted seriously with the viscosity, especially when it comes to problems of interaction between the focusing wave and offshore structures near the focusing point. Though the method of potential flow can quickly solve cases like this, the influence of viscosity can hardly be taken into consideration. In some experiments, the Keulegan-Carpenter number (1958) is out of the range that the influence of drag force can be neglected. Besides, the existence of the tank bottom also increases the influence of drag force to some degree. Hence, there remains the necessity to use a computational fluid dynamics (CFD) solver, which contains the calculation of viscosity through Navier–Stokes equations.

With the rapid development of parallel computing software and hardware, CFD has been more and more noticed and put into application in the field of ocean and coastal engineering in recent years. The approach to studying and simulating a freak wave is also a challenge for CFD. Higuera et al. (2013) and Hu et al. (2016) realized the irregular wave and even extreme wave generation with separated components in the OpenFOAM. DX Wang et al. (2019) realized wave generation with the piston-type wavemaker in the numerical wave tank.

In the area of offshore hydrodynamics, the interaction between wave and fixed vertical cylinder is a hotspot issue and basic work of great significance. A clear vision of the interaction wave elevation and loads of waves around the vertical cylinder is an important issue (Faltinsen et al., 2014). Bredmose et al. (2010) and Hildebrandt et al. (2013) simulated the interaction of breaking focusing wave and fixed structures. Westphalen et al. (2012) picked up and analyzed the nonlinear effect of interaction between the wave and vertical cylinder in the CFD numerical simulation. Chen et al. (2020) compared the wave runup of different directions around the cylinder in the experiment and the numerical simulation of the interaction between focusing waves and a vertical cylinder. Yan et al. (2015) compared the experimental and numerical results of the interaction between the focusing wave and the moving cylinder.

A CFD solver aiming to solve the problems of ship and marine engineering, naoe-FOAM-SJTU (Shen and Wan, 2016), was established based on the open-source platform OpenFOAM in modules, which can realize the functions of wave generation and absorption, 6 DOF motion of rigid body, arrangement of overset grid, etc. (JH Wang et al., 2019). Zhang et al. (2019) discussed the applications of naoe-FOAM-SJTU in the coupling hydrodynamic problems in ship and ocean engineering, including the interaction between waves and structures. In this paper, naoe-FOAM-SJTU is applied in the numerical simulation of the interaction between a focusing wave and a fixed cylinder, as a basic study on the monopile structure, which is among the most common types of installations in the area of coastal and offshore applications. This solver, but not the interFoam or interDyMFoam in OpenFOAM, is chosen because the focusing waves are expected to be the same as the experiment referred, and the given data are the position history curve of the wavemaker. These data can be directly used in the naoe-FOAM-SJTU to generate the focusing wave, while for interFoam or interDyMFoam, new boundary conditions or other wave generation method still must be coded. The free surface elevation and pressure data in certain locations are compared with experiment data.

NUMERICAL METHODS

Governing Equation

The simulation is conducted with the CFD solver naoe-FOAM-SJTU, which is based on the incompressible fluid assumption and takes viscosity into consideration. Thus, the governing equations should be written as follows:

$$\nabla \cdot \mathbf{U} = 0 \tag{1}$$

*ISOPE Member; †Corresponding author.

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KEY WORDS: Focusing wave, numerical simulation, fixed cylinder, CFD.