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Numerical Simulation of Fixed and Moving Cylinders in Focusing Wave by a Hybrid Method

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Based on the open source tool OpenFOAM, a self-developed solver qaleFOAM is applied to generate a focusing wave and simulate the interaction between the focusing wave and fixed/moving cylinder. With qaleFOAM, the focusing wave is generated by the external wave tank based on fully nonlinear potential theory (FNPT) and quasi-arbitrary Lagrangian-Eulerian finite element method (QALE-FEM), and a relaxation zone is used for the wave propagation between the external wave tank and the internal Navier–Stokes domain. In this paper, the generation and propagation of focusing wave is tested first, and the wave elevation at different wave gauges is monitored to show the accuracy of focusing wave generation. Then, a cylinder fixed/moving in the incident focusing wave is simulated by qaleFOAM, the wave elevation near and away from the cylinder is monitored, and the pressure distribution on the cylinder surface is probed. The computed result is compared with the experimental result to validate the numerical method.

INTRODUCTION

The focusing wave is a kind of steep wave, which usually occurs in severe sea conditions and is harmful for ships and offshore structures. When some maritime accidents happen, the occurrence of focusing wave is usually monitored and observed, and the focusing wave is of large steepness and disappears quickly (Nikolkina and Didenkulova, 2011). As a kind of simple shape, the cylinder is widely applied to the design and construction of offshore structures, such as ocean platform legs and the foundation of offshore wind turbines, and the investigation into the hydrodynamic characteristics and flow around a cylindrical structure has attracted the attention of many researchers (Mo et al., 2013; Bihs et al., 2016). For the design and hydrodynamic optimization of the offshore structures, it is necessary to take the interaction between the structure and focusing wave into account (Liu and Pino, 2004), which is related to the extreme loads of the offshore structures.

In recent years, both experimental and numerical investigations into the focusing wave has been widely carried out. Li and Cheng (2009) studied the characteristics of extreme wave by tank test, where the wave is generated by the wavemaker of the tank. Bai and Taylor (2009) applied the fully nonlinear method to simulate the focusing wave. Li et al. (2013) studied the generation of focusing wave by the wavemaker in a real wave tank, and the rule of wavemaker movement was discussed. Vyzikas et al. (2014) used the open source CFD tool OpenFOAM and the free library waves2Foam for the numerical simulation of focusing wave, and the accuracy of the numerical method is tested by comparison with the experimental result. Bai et al. (2018) carried out the numerical simulation of focused wave in the circulating channel by transient water theory, where the dynamic grid and volume of fluid method are applied to simulate the motion of the wavemaker and the free surface, respectively. Yoo et al. (2019) numerically studied the interaction between the focusing wave and the fixed cylinder. Ha et al. (2019a, 2019b) carried out the numerical study on the interaction between a truncated cylinder and the focused wave.

In this paper, the generation and propagation of the focusing wave is simulated by the external potential wave tank, which is based on the fully nonlinear potential theory (FNPT) and the quasi-arbitrary Lagrangian-Eulerian finite element method (QALE-FEM) (Ma and Yan, 2009; Yan and Ma, 2010, 2017). In the internal domain, the wave propagation and interaction with a fixed/moving cylinder is simulated by the viscous flow method. Based on OpenFOAM and the self-developed solver qaleFOAM (Li et al., 2018), the external potential wave tank is connected with the internal viscous flow method through a transition zone. With qaleFOAM, the accuracy of the wave generation and transition between the internal and external domain is tested and validated, and the convergence test about the mesh is carried out. Then, the interaction between the incident focusing wave and the fixed/moving cylinder is simulated by qaleFOAM, and the computed results of the wave elevation and the pressure on the cylinder are compared with the experimental result.

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KEY WORDS: Focusing wave, moving cylinder, FNPT, Navier—Stokes (NS), hybrid method.