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Numerical Simulation of Interaction Between Focusing Waves and Cylinder Using qaleFOAM

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This paper presents a numerical simulation of the interaction between focusing waves and a cylinder using a hybrid solver, qaleFOAM, which couples a fully nonlinear potential solver, QALE-FEM, with an incompressible two-phase Navier—Stokes (NS) solver, OpenFOAM, using the domain decomposition approach. In qaleFOAM, a wave is generated by using a piston wavemaker in a large domain governed by the QALE-FEM (fully nonlinear potential theory (FNPT) domain) and propagates into a small subdomain near the cylinder (NS domain), in which OpenFOAM is employed. The wave in the NS domain interacts with the cylinder, enters the downstream of the FNPT domain and is effectively absorbed by a self-adaptive wavemaker at its end. Both the wave elevations and the pressure on the cylinder surface are estimated and compared with the experimental data. Good agreement has been achieved. In addition, different numerical configurations have been attempted, in an effort to examine the effects of the cylinder surface boundary condition and turbulence modeling for such cases.

INTRODUCTION

For the survivability of marine, coastal, and offshore structures, the interaction between extreme waves and structures needs to be reliably assessed in engineering practices. The cylinder is a widely used, typical structure (e.g., as the foundation of oil/gas platforms and offshore wind turbines), while the focusing wave is widely accepted as a realistic representative of the extreme wave in experimental and numerical research. Recent research on the interaction between the cylinder and the focusing wave has attracted extensive interest (e.g., Hildebrandt et al., 2014; Ma et al., 2015). Considering the fact that extreme waves often involve significant nonlinearity, the linear and second-order wave theories, which are widely used in routine design, may not suffice for a reliable assessment. Therefore, fully nonlinear approaches (e.g., fully nonlinear potential theory (FNPT) and computational fluid dynamics (CFD) based on the Navier–Stokes (NS) models) are sought. The FNPT can be solved by the boundary element method (e.g., Ning et al., 2017), the finite element method (e.g., Wu and Hu, 2004), the quasi-arbitrary Lagrange–Euler finite element method (QALE-FEM) (Yan and Ma, 2007, 2010a; Ma and Yan, 2006, 2009), the spectral element method (Engsig-Karup et al., 2016), the high-order spectral method (Ducrozet et al., 2016), and the spectral boundary integral method (Wang and Ma, 2015; Wang et al., 2018). The numerical methods for solving the NS model exhibit a more significant diversity than the FNPT solvers. One may categorize them into the conventional mesh-based methods like the finite volume method (Hildebrandt and Sriram, 2014; Xie, 2012, 2013, 2015; Yang et al., 2017) and into the meshless (particle) methods, including smoothed particle hydrodynamics (SPH) (e.g., Lind et al., 2012; Zheng et al., 2014), the moving particle semi-implicit (MPS) method (e.g., Khayyer et al., 2019), and the meshless local Petrov–Galerkin method based on Rankine source solution (MLPG-R) (e.g., Rijas et al., 2019).

Generally speaking, the NS model is more time-consuming compared with the FNPT model, not only because the governing equations of the NS model are more complicated but also because solving NS models requires much higher mesh/particle resolutions to secure a convergent solution. This is confirmed by the first CCP-WSI Blind Test (Ransley et al., 2019; Yan et al., 2019) in which a fixed floating production storage and offloading (FPSO) unit subjected to extreme waves was considered. Ransley et al. (2019) concluded that, compared with the NS models, the FNPT models, such as QALE-FEM (Yan and Ma, 2007; Ma and Yan, 2009), have a similar degree of accuracy but require much less computational time (approximately 10%). However, the FNPT assumes that the fluid is inviscid, irrotational, and incompressible and therefore cannot implicitly deal with the viscous and turbulent effects that are significant in many scenarios, e.g.,

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KEY WORDS: Focusing wave, wave–structure interaction, numerical simulation, turbulence, qaleFOAM, FNPT, hybrid model.