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Numerical Study of Interaction of Focused Waves with a Fixed Cylinder by a Hybrid Model Coupling SPH and QALE-FEM

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This paper presents a 3-D hybrid model that couples smoothed particle hydrodynamics (SPH) with the quasi-arbitrary Lagrangian–Eulerian finite element method (QALE-FEM) for modeling wave–structure interactions (WSIs), using the one-way domain decomposition strategy. SPH, which is relatively more time-consuming, is used in a small near-field zone around the structure, whereas QALE-FEM is adopted in a large domain, dealing with the wave generation. They are coupled through a coupling boundary at the SPH domain. The hybrid model has advantages in modeling highly nonlinear WSIs with high robustness by making use of the respective advantages of these two methods. The hybrid model is then employed to numerically simulate the interaction between focusing waves and a fixed cylinder, contributing to the numerical comparative study in ISOPE 2020. Good agreement is achieved.

INTRODUCTION

The nonlinear interactions between extreme waves and cylindrical structures constitute an important practical problem of safety and survivability in the design and operation of offshore structures. The reliable prediction of such problems depends on the accurate simulation of incoming waves and of the structural responses in such waves. In extreme conditions, the simulation of such waves normally requires a large computational domain that allows a sufficient spectrum evolution and completed development of the associated nonlinearities. Near structures, wave breaking may occur, and small-scale physics (e.g., viscous/turbulent effects) may be important, implying that a reliable numerical simulation of the wave–structure interaction (WSI) in an extreme sea relies on accurate modeling of both the large-scale wave propagation and the small-scale near-field physics simultaneously.

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Fully nonlinear potential theory (FNPT), e.g., quasi-arbitrary Lagrangian–Eulerian finite element method (QALE-FEM) (Ma and Yan, 2006; Yan and Ma, 2007; Ma and Yan, 2009), has been proven to be robust and highly efficient for modeling nonlinear waves and their interaction with structures without wave breaking and significant viscous effects. In the CCP-WSI Blind Test 1 (Ransley et al., 2019), the QALE-FEM was the most robust numerical method to simulate the wave runup and wave impact on a fixed Floating Production Storage and Offloading (FPSO) unit. However, potential theories assume that the flow is inviscid, incompressible, and irrotational and therefore cannot be applicable in modeling breaking wave impact, slamming, and other small-scale physics that are dominated by the viscous and turbulent effects, although their computational efficiencies are relatively high.

Alternatively, the viscous flow theory solving the Navier–Stokes equation and the continuity equation with appropriate boundary conditions (NS model) has the capacity to resolve the viscous/turbulent effects and to deal with the violent wave breaking. The methodologies and models of solving the NS model have been expanded in recent years. These methods include the classic mesh-based methods (e.g., the finite element method, the finite volume method, and the finite difference methods) and the mesh-free methods, among which the smoothed particle hydrodynamics (SPH) method is emerging as a potential tool for simulating fluid