A numerical study on interaction of focused waves with fixed cylinder by a hybrid model coupling SPH and QALE-FEM

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ABSTRACT

Cylinder structures are the common types of installations in coastal and offshore engineering. Thus it is of high importance to study the wave interaction with moving cylinder structures. In this paper, a 3-D hybrid model based on the smoothed particle hydrodynamics (SPH) and the Quasi Arbitrary Langrangian-Eulerian Finite Element Method (QALE-FEM) is used to study the interaction of focused waves with fixed and moving cylinder. The hybrid model has advantages in simulating the focused waves and cylinder interactions in terms of accuracy and efficiency by making use of respective advantage of the above-mentioned two methods. In this hybrid model, the SPH method is used in the near-field interaction between the focused waves and cylinder and the QALE-FEM method is adopted for the wave generation at the SPH boundaries. In order to understand the true predictive capability of the numerical model, the simulation results are validated against with a set of experimental data, including the wavemaker motion, wave elevations near the cylinder and wave pressure on the cylinder.

KEY WORDS: hybrid model; SPH; QALE-FEM; interactions; cylinder structures; focused waves

INTRODUCTION

The nonlinear interactions between extreme waves and cylinder structures constitute an important practical problem in the design and operation of the offshore structures for the safety and survivability of the structures. A reliable prediction of such problems depends on the accurate simulation of incoming waves and the structural responses in such waves. In the extreme condition, the former normally requires a large computational domain allowing a completed development of the spectrum and associated nonlinearities; whereas near the structures, the wave breaking may occur and small-scale physics, e.g. the viscous/turbulent effects, may be important. This implies that a reliable numerical simulation of the wave-structure interaction (WSI) in an extreme sea shall be able to deal with both the large-scale wave propagation and the small-scale near-field physics simultaneously.

Fully nonlinear potential theory (FNPT) e.g. the quasi-arbitrary Lagrange Euler finite element method (QALE-FEM) (Ma and Yan, 2006; Yan and Ma, 2007; Ma and Yan, 2009) have been proven to be robust and highly efficient for modelling nonlinear waves and their interaction with structures without wave breaking. In the CCP-WSI Blind Test 1 (Ransley et al, 2019), the QALE-FEM is one of the most robust numerical method to simulate the wave run-up and wave impact on a fixed FPSO. However, potential flow solvers assume that the flow is inviscid and irrotational, and therefore, cannot be applicable to model breaking wave impact, slamming and other small-scale physics which are dominated by the viscous effect, although their computational efficiencies are relatively high.

Alternatively, the viscous flow theory (NS model), solving the Navier-Stokes equation and the continuity equation with appropriate boundary conditions, has capacity to resolve the viscous/turbulence effects and to deal with violent wave breaking. The methodologies and