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Comparative Numerical Study on Focusing Wave Interaction with FPSO-like Structure

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Evaluating the interactions between offshore structures and extreme waves plays an essential role for securing the survivability of the structures. For this purpose, various numerical tools—for example, the fully nonlinear potential theory (FNPT), the Navier–Stokes (NS) models, and hybrid approaches combining different numerical models—have been developed and employed. However, there is still great uncertainty over the required level of model fidelity when being applied to a wide range of wave-structure interaction problems. This paper aims to shed some light on this issue with a specific focus on the overall error sourced from wave generation/absorbing techniques and resolving the viscous and turbulent effects, by comparing the performances of three different models, including the quasi-arbitrary Lagrangian Eulerian finite element method (QALE-FEM) based on the FNPT, an in-house two-phase NS model with large-eddy simulation and a hybrid model coupling the QALE-FEM with the OpenFOAM/InterDymFoam, in the cases with a fixed FPSO-like structure under extreme focusing waves. The relative errors of numerical models are defined against the experimental data, which are released after the numerical works have been completed (i.e., a blind test), in terms of the pressure and wave elevations. This paper provides a practical reference for not only choosing an appropriate model in practices but also on developing/optimizing numerical tools for more reliable and robust predications.

INTRODUCTION

Understanding the characteristics of the interaction between extreme waves and structures, as well as a reliable prediction of the behavior of the structures in a realistic extreme sea, plays a fundamental role in the safe and cost-effective design of coastal and offshore structures and of marine renewable devices. Such assessments and predictions can always be performed in a laboratory environment or in a numerical wave tank, where the extreme waves are often modeled by using a focusing wave based on the spatial-temporal focusing mechanism (Ma et al., 2015) or the NewWave theory (Tromans et al., 1991).

In design practices, classical approaches in frequency domain are employed, such as linear and second-order theories, which, however, are shown to be insufficient when higher-order nonlinear effects are pronounced. Such higher-order nonlinearities have been pointed out to play important roles in the interaction between extreme waves and structures (Zang et al., 2010). To overcome this drawback, approaches in the time domain considering sufficient nonlinearities have been developed. These include the fully nonlinear potential theory (FNPT) and the general viscous flow theory, which is formulated by the Navier–Stokes (NS) equations. The FNPT model, which assumes that the flow is inviscid and irrotational, has been solved by different numerical methods, such as the boundary element method (e.g., Longuet-Higgins and Cokelet, 1976; Grilli et al., 2001), finite element method (e.g., Wu and Eatock-Taylor, 2003; Yan and Ma, 2007; Ma and Yan, 2009), and spectral element method (e.g., Engsig-Karup et al., 2016). The NS model does not have the assumptions of the FNPT model. However, in the real application of the NS model to the wave-structure interactions, certain degrees of simplification might be applied, resulting in different forms of the NS models with the main diversities including (1) one-phase (Ma, 2005; Zhou and Ma, 2010; Lind et al., 2012; Zheng et al., 2014) or two-phase (Xie, 2012; Chen et al., 2014; Hildebrandt and Sriram, 2014; Ferrer et al., 2016; Hu et al., 2016) models and (2) compressible (Yang et al., 2016) or incompressible (Yang et al., 2017) models. The significant diversities also exist in terms of numerical approaches on (1) how to solve the governing equation, for which both the conventional mesh-based methods such as, for example, the finite volume method (Chen et al., 2014; Hildebrandt and Sriram, 2014; Xie, 2015; Yang et al., 2017), or meshless methods such as, for example, the smoothed particle hydrodynamics (e.g., Lind et al., 2012; Zheng et al., 2014) and the meshless local Petrov–Galerkin method (Ma, 2005; Zhou and Ma, 2010; Sriram and Ma, 2012), have been attempted; (2) how to track or capture the free surface—for example, the volume of fluid (VOF; e.g., Xie, 2012; Hu et al., 2016) and level set method (Zhang et al.,

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KEY WORDS: Wave-structure interaction, comparative study, blind test, FNPT, NS models, LES.