International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 30, No. 1, March 2020, pp. 43–52; https://doi.org/10.17736/ijope.2020.jc781

http://www.isope.org/publications/publications.htm

# CCP-WSI Blind Test Using qaleFOAM with an Improved Passive Wave Absorber

Shiqiang Yan*, Jinghua Wang, Junxian Wang and Qingwei Ma*
School of Mathematics, Computer Science and Engineering, City University of London
London, United Kingdom

Zhihua Xie*
School of Engineering, Cardiff University
Cardiff, United Kingdom

**The paper presents the contribution to the CCP-WSI Blind Test, in which the responses of wave energy converters subjected to extreme waves are considered, by a hybrid model, qaleFOAM, coupling a two-phase Navier–Stokes (NS) model and the fully nonlinear potential theory (FNPT) using the spatially hierarchical approach. The former governs a limited computational domain (NS domain) around the structures and is solved by the OpenFOAM/InterDyMFoam. The latter covers the rest of the domain (FNPT domain) and is solved by using the quasi Lagrangian-Eulerian finite element method. Two numerical techniques have been developed to tackle the challenges and maximizing the computational efficiency of the qaleFOAM, including a modified solver for the six-degree-of-freedom motions of rigid bodies in the NS model and an improved passive wave absorber imposed at the outlet of the NS domain. With these developments, the accuracy and the computational efficiency of the qaleFOAM are analyzed for the cases considered in the blind test.**

## INTRODUCTION

A reliable prediction of the responses of the offshore structures in a realistic extreme sea plays a fundamental role in the safe and cost-effective design of such structures. Numerous numerical models and software have been developed based on wide ranges of theoretical models, including the Navier–Stokes (NS) models and the fully nonlinear potential theory (FNPT), which assumes that the flow is incompressible, inviscid, and irrotational.

Aiming to quantify the accuracies, efficiencies, and reliabilities of different models in practical applications, a CCP-WSI blind test using cases with a fixed floating production storage and offloading (FPSO) unit subjected to extreme waves were carried out by Ransley et al. (2019a). In the blind test, the experimental data were released after the participators submitted their numerical predictions. This minimizes the possibility of numerical calibrations or tuning, and therefore, the performances of the participated numerical models can largely reflect their reliabilities in practices. One conclusion of the blind test is that the accuracy of the FNPT models, such as the quasi Lagrangian-Eulerian finite element method (QALE-FEM; Ma and Yan, 2006, 2009; Yan and Ma, 2007), is at a similar level as the NS models (Ransley et al., 2019a; Yan, Xie, et al., 2019). This may be because the size of the FPSO model is relatively large with reference to the significant wave length, and therefore, the viscous effect is insignificant.

The viscous effects become important in certain conditions—for example, the relative size of the structure is small (e.g., $< 0.2$ wavelength) (Ma and Patel, 2001); the motion of the structure is significant (e.g., Yan and Ma, 2007); or the structure is subjected to breaking wave impact (e.g., Rijas et al., 2019), the action of the current (e.g., Li et al., 2018), or a gap resonance (e.g., Saitoh et al., 2003; Lu and Chen, 2012). For such problems, the NS models are necessary to resolve small-scale physics associated with the viscosity and the turbulence. Consequently, the FNPT may not be suitable unless an appropriate artificial viscosity is applied following a systematic numerical calibration to quantify the artificial viscosity (e.g., Yan and Ma, 2007; Lu and Chen, 2012). Nevertheless, the NS model is more time-consuming compared with the FNPT models, as evidenced by Ransley et al. (2019a), not only because of its complexity of the governing equations but also because a much finer mesh and smaller time step size are required to achieve convergent results. To model the wave-structure interaction (WSI) using the NS model, two critical issues, associated with correctly reproducing the wave field, need to be carefully addressed to secure a satisfactory robustness.

The first issue is the wave generation in the NS domain. One may use a wavemaker to generate the wave, as the physical experiments. However, the NS domain needs to be sufficiently large so that the evanescent waves associated with the wavemaker motion do not influence the motion of the structures. Alternatively, one may specify the inlet boundary conditions, including the wave elevation, velocity, and pressure, to generate the wave in the NS domain. Tool kits are available (e.g., Jacobsen et al., 2011) for such a purpose using different wave theories such as, for example, the linear wave theory, Stokes wave theory, stream functions, and high-order spectrum method (e.g., OceanWave3D). However, for WSIs in an extreme condition, which is essential for evaluating the reliability and survivability of the structure, the linear or weakly nonlinear wave theories may be insufficient, and thus, an FNPT model may be necessary to specify such wave inlet conditions. The hybrid model coupling the FNPT and the NS models (e.g., Yan and Ma, 2010, 2017; Sriram et al., 2014; Fourtakas et al., 2018; Li et al., 2018) have been developed to tackle the challenges. Both one-way and two-way coupling have been considered. Detailed reviews can be found in Sriram et al. (2014) and Li et al. (2018). These models are shown to be more efficient than NS models for modelling extreme waves and their interaction with structures.

*ISOPE Member.

Received August 26, 2019; updated and further revised manuscript received by the editors November 20, 2019. The original version (prior to the final updated and revised manuscript) was presented at the Twenty-ninth International Ocean and Polar Engineering Conference (ISOPE-2019), Honolulu, Hawaii, June 16–21, 2019.

KEY WORDS: Hybrid model, qaleFOAM, NS, FNPT, wave absorber, blind test.