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Numerical Study of Focused Waves Acting on a Fixed FPSO-Shaped Body

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This paper applies our in-house solver, naoe-FOAM-SJTU to study focused waves acting on a fixed FPSO-shaped body. This benchmark test follows the settings of experiments conducted in the Ocean Basin at Plymouth University's COAST Laboratory. The different headings and different wave steepness are considered to figure out how the focused waves act on the fixed model. The values of wave height in different positions of the empty wave tank are obtained through computations and verified by experimental results. The scattered wave height and impact pressure on the hull are provided. The results of the wave and the corresponding pressure on the hull are compared with CCP-WSI Blind Test Workshop to ensure the accuracy of the calculation. The influence factor of incident wave angle and wave steepness is discussed.

INTRODUCTION

For offshore structures, it is essential to study the hydrodynamic loads on those structures operating in the hostile environment. On the one hand, the designation and operation need to avoid structure damage and loss on work stoppage, thus the severe sea states must be considered. Dangerous extreme waves like focused waves may impact marine architectures that are dispatched to a particular place for a long-term production operation. Under these conditions, the FPSO may suffer damage on ship bow. On the other hand, the wave—wave interaction may transfer high-frequency energy to the structure. Those wave-induced high frequencies may cause nonlinear structure behaviors. Therefore, it is necessary to investigate offshore structures in hostile sea states.

It is known that the focused wave has significant characteristics of randomness. Thus, the real sea state statistics can hardly be recorded. One striking case is the "New Year Wave," which happened in the central North Sea at Statoil Draupner Platform on Jan 1st, 1995. The peak crest elevation reached 18.5 m, while the significant wave height there is 12 m (Bihs et al., 2017). Because focused waves only rarely appear in nature currently, the main approaches to study its generation and hydrodynamic properties are experimental and numerical methods. As the potential method cannot solve the extreme sea states with strong nonlinear phenomenon, the advantages of computational fluid dynamics (CFD) method arouse widespread concern in shipbuilding engineering. However, the range of model fidelity still remains considerably uncertain when simulating the interaction of waves with offshore structures when using numerical methods. To deeply understand these issues, the wave—structure interaction and the wave evolution of the focused waves are studied in this paper.

Experiments are usually carried out in water flumes using wave paddles to generate focused waves. By adopting a focused wave group, many irregular wave components in a spectrum will focus at the designated time and place simultaneously. Previous methods included frequency focusing method (Chaplin, 1996) and modified phase and amplitude wave maker control signal to make optimized focused waves (Schmittner et al., 2009). Nevertheless, the effectiveness of their linear wave theory decreased when the wave groups were high nonlinearity. Stagonas et al. (2014) implemented an empirical iterative methodology which can generate focused waves at designated time and space with any height. By controlling the frequency spectrum and phase of the wave components, the extreme wave profile can be formed in a short time and focused at the designated time and location, this making the physical experiments and numerical simulation more efficient. Several experiments have been done to investigate the focus waves and the interaction between wave and structure. Ning et al. (2009) conducted experimental and numerical studies on a series of steep focused wave groups in a water flume. By using high order boundary element method, their calculation results fitted the experimental results well, even for the waves near to breaking. As for high-order boundary element method, a domain decomposition technique is implemented by Bai and Taylor (2007) to make this method more efficient. To investigate the wave—structure interaction, a simplified FPSO model was set in the Ocean Basin at Plymouth University's COAST Laboratory (Mai et al., 2016). This experiment took the model length, and focused wave steepness and incident wave angles into account. Results were given and analyzed with a general phase-based harmonic separation method. In addition, based on the experiment of COAST laboratory, several numerical methods are used for further research. Based on the fully nonlinear potential theory (FNPT), Ma et al. (2015) used the Quasi Arbitrary Lagrangian Eulerian Finite Element Method (QALE-FEM) combined with modified time domain self-correction technique. The results are in good agreement with the experimental results. Hu, Greaves, and Raby (2016) and Hu, Mai, et al. (2016) then took advantage of the computational fluid dynamics to do corresponding numerical simulations using open source code OpenFOAM. The comparison of calculation results shows OpenFOAM is reliable to solve the hydrodynamic problems of wave—structure interaction. Yan et al. (2015) applied unidirectional focusing waves and a cylinder based on QALE-FEM with FNPT and OpenFOAM coupled with potential theory. They compared those two methods when simulating the focusing waves and the cylinder.

In the present studies, CFD method based on Navier-Stokes equations is used to solve high nonlinear free surface focused

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KEY WORDS: Focused wave, FPSO, benchmark test, naoe-FOAM-SJTU solver.