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

Vol. 31, No. 1, March 2021, pp. 53–60; https://doi.org/10.17736/ijope.2021.jc818

http://www.isope.org/publications

CFD Study for Steep Focused Wave Interactions with Fixed and Moving Cylinders

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To share the state-of-the-art numerical analysis capability on the interaction between extreme waves and a structure that is either fixed or with a forward speed, a comparative study was suggested at the ISOPE-2020 conference. Therefore, we have performed a computational fluid dynamics simulation for the wave interaction with a cylinder, where a focused wave is approaching the cylinder and then strong wave impact pressure occurs on the surface of the cylinder. The numerical simulations were performed using the commercial software STAR-CCM+. The measured stroke data of the wavemaker in the experiments were directly used as input to the inlet boundary of the numerical simulation, and movement of the cylinder was directly simulated in conjunction with an overset grid method. The numerical simulation results were directly compared with the experimental results. It was observed that the numerical simulation results are in fairly good agreement with overall physical phenomena and wave impact pressures from the experiments.

INTRODUCTION

The wave impact load is of great importance in that it should be considered in the design of ships and offshore structures. Regarding wave impact loads, there have been noticeable studies using analytic, numerical, and experimental methods. von Kármán (1929) and Wagner (1932) suggested analytical methods for slamming impact load. The analytical methods are useful, but they are only limited to simple structures. Therefore, more practical studies are needed to estimate the wave impact load. Many researchers carried out experimental studies on wave impact problems. To measure the wave impact load, most of these researchers used pressure and force sensors. Kapsenberg et al. (2002), Hermundstad and Moan (2005), Kapsenberg and Thornhull (2010), and Voogt and Buchner (2004) measured the wave impact loads using pressure sensors. Kim et al. (2014, 2019), Huang et al. (2015), and Ha et al. (2018) used force sensors to measure the wave impact loads. Recently, not only the model tests but also computational fluid dynamics (CFD) have been widely adopted to estimate the wave impact loads. To accurately estimate the wave impact loads using CFD, good-quality waves should be generated. Hino et al. (1983) calculated nonlinear shallow-water wave problems using the marker and cell. Zelt (1991) simulated a breaking wave on a beach condition using the Lagrangian finite-element Boussinesq wave model, and the numerical results were compared with the experimental data. Lin and Liu (1998) studied the wave-breaking processes in two-dimensional simulations by the volume-of-fluid (VOF) model, and they showed that mean vorticity and turbulence intensity were very weak on the breaking wave front. Chen et al. (1999) generated a plunging breaker including splash-up, and the results showed strong vorticities in breaking waves. Gotoh (2009) computed the wave-breaking process and runup by the moving particle semi-implicit (MPS) method, and the computed results showed that highly nonlinear wave behavior can be captured. Ghosh et al. (2007) performed the CFD simulations and experiments. Characteristics of the breaking waves were measured using particle image velocimetry (PIV), and the CFD results obtained by the level-set method were directly compared with the PIV results. Liu et al. (1999) studied the wave interaction problem with a porous structure by using CFD. The CFD results were compared with the model test results. Bredmose and Jacobsen (2010) measured wave impact forces on a fixed monopole using the OpenFOAM program, and the results showed some variations of load on the fixed monopole according to the focusing locations. Khayyer and Gotoh (2009) performed the numerical simulations using a modified MPS method. They estimated the wave impact loads on a vertical wall. Chen et al. (2019) performed numerical simulations for the interaction between a focused wave group and a sheared current with a vertical piercing cylinder. They used two approaches: the general CFD method and a novel Lagrangian model. From the results, a more efficient method using the Lagrangian model was suggested. Chen et al. (2017) calculated for the interaction between solitary waves and vertical circular cylinders, and they used parallel particle-in-cell-based incompressible flow. The numerical calculation results for a single cylinder were compared with experimental data, and the comparison results showed good agreement with each other. They also investigated the solitary wave interaction with a group of 11 vertical cylinders. Mo et al. (2013) performed large-eddy simulations, and the results showed the abnormal flow pattern and interaction between a breaking wave and a cylinder. Ha et al. (2018) carried out the CFD study to estimate the wave impact loads on a truncated vertical cylinder. They simulated a steep wave, spilling wave, and plunging wave, and they showed the possibility for accurate estimation of the wave impact loads. Hong et al. (2018) performed the comparative study for CFD study at the ISOPE conference. The main topic was the wave impact loads on a truncated circular cylinder. Some of participants used various CFD tools and showed reasonable simulated results. The CFD will be continuously applied and expected to give accurate values in the future. In this paper, the numerical simulations were performed as part of comparative studies. Three focused waves were generated using measured stroke data. The wave impact loads on fixed and moving cylinders as well as the wave elevations were estimated from the numerical simulations. The results were directly compared with the provided experimental results, and the interaction between the incoming waves and cylinder is investigated.

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Received September 18, 2020; updated and further revised manuscript received by the editors December 23, 2020. The original version (prior to the final updated and revised manuscript) was presented at the Thirtieth International Ocean and Polar Engineering Conference (ISOPE-2020), Shanghai, China, October 11–16, 2020.
KEY WORDS: Computational fluid dynamics (CFD), overset grid, focused wave, wave impact, wave elevation.