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Numerical Study of Focused Wave Interactions with a Single-Point Moored Hemispherical-Bottomed Buoy

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In this work, our computational fluid dynamics (CFD) solver naoe-FOAM-SJTU is adopted to simulate the interaction between focused waves and a moored hemispherical-bottomed buoy. This solver adopts a two-phase Navier–Stokes model and a spring mooring system. Three crest-focused wave groups, based on NewWave theory, are generated and validated against the experimental measurements from the Collaborative Computational Project in Wave–Structure Interaction (CCP-WSI) working group. Numerical results for the buoy's heave and surge displacement, pitch angle, and mooring load are compared against corresponding physical data. The effects of wave steepness on the behavior and mooring loads are discussed.

INTRODUCTION

Under extreme wave conditions, strong nonlinear impact phenomena such as severe wave runup, relative motion, and green water may occur, which will cause a large local impact load on wave energy converters (WECs). Exploring the interaction between extreme waves and WECs has great importance for the design and protection of these kinds of structures. As an extreme wave is highly nonlinear and can arise as a highly transient event within a multifrequency sea state, a focused wave group is typically adopted to model an extreme wave in physical or numerical modeling. The focused wave group where many wave components in a spectrum focus simultaneously at a position in space can represent an extreme wave profile with a specified wave energy spectrum. Thus, a focused wave can play the role for extreme wave conditions. The accurate prediction of the motion of a WEC under extreme wave conditions can be viewed as that under the focusing wave.

Previously, Savin et al. (2012) experimentally measured lateral force acting on the funnel under two sea states. Two measurements were taken by two separate measuring systems with slightly different timing. The development of the method could be used for evaluation of the forces from waves acting on the WEC. Azimuth-inclination angles and snatch load on a tight mooring system are mainly discussed in their work. Hann et al. (2015) considered experimental measurements of the interaction of a taut moored floating body, representing a WEC in survivability mode, with extreme waves. They discussed the influence of wave steepness effect on model response and mooring load using focused wave groups. Goteman et al. (2015) considered the survivability of a 1:20 scale point-absorbing WEC model in extreme wave tests with focused waves embedded in regular waves and irregular waves. Mai et al. (2016) performed experiments to examine wave–structure interactions for a series of simplified floating production storage and offloading (FPSO)-shaped bodies.

Besides experimental investigation of wave interaction with floating structures, numerical methods have also been widely used in dealing with this problem. Wolgamot and Fitzgerald (2015) reviewed efforts that have been made to analyze the behavior and performance of WECs using nonlinear hydrodynamics methods. They affirmed the potential advantages of solving the wave–structure interaction problems by computational fluid dynamics (CFD) methods. Sykes et al. (2009) provided a preliminary assessment of the validity of employing a boundary element method (BEM) code to predict the displacement and associated hydrodynamic forces of a simple floating oscillating water column (OWC). Bredmose and Jacobsen (2010) computed breaking wave loads on a monopile foundation within a three-dimensional CFD model. The wave impacts were obtained by application of focused wave groups to the amplitudes of a Joint North Sea Wave Project (JONSWAP) spectrum. The CFD results were compared to load estimations obtained from the Morison equation. Westphalen (2011) applied two commercial Navier–Stokes solvers to solve wave–wave and wave–structure interaction problems for the final application of simulating a single float of the WEC. Li and Lin (2012) studied fully nonlinear wave–body interactions for a stationary floating structure under regular and irregular waves for different water depths, wave heights, and periods in a two-dimensional numerical wave tank. Palm et al. (2013) used open-source code OpenFOAM to simulate the dynamics of a floating WEC coupled to a high-order finite element solver for cable dynamics. Their results illustrated that the coupled model is able to capture the complicated force propagation in the mooring cables. They numerically simulated a moored floating vertical cylinder in six degrees of freedom (6DoF) based on OpenFOAM (Palm et al., 2016). Then, Palm et al. (2018) analyzed the nonlinear forces on a moored point-absorbing WEC in resonance at prototype scale and at model scale. They recommended that both Reynolds-averaged Navier–Stokes (RANS) equations and Euler simulations could be used during numerical validation against experimental model scale tests in order to separate the viscous drag influence from the induced drag. Consequently, this approach could be used to quantify the effects of scale on WECs. Ransley (2015) used a numerical tool based on OpenFOAM to simulate focused wave impacts on generic WEC hull forms. Two floating

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KEY WORDS: Wave–structure interactions, naoe-FOAM-SJTU solver, focused wave, 6DoF motion, mooring loads.