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CCP-WSI Blind Test Series 3: CFD-Based Numerical Wave Tank Experiments Employing an Impulse Source Wave Maker

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During the development and optimisation of wave energy converters, numerical wave tanks are useful tools, providing detailed insight into the hydrodynamic performance of devices. Specifically, computational fluid dynamics (CFD)-based numerical wave tanks (CNWTs) can deliver high-fidelity, high-resolution results for a wide range of test conditions. However, CNWTs come at significant computational cost and require more man-hours during model setup, compared to lower-fidelity, frequency domain-based models. The computational costs can only be significantly decreased by improving the numerical solvers or by increasing expenditure on computational power. The required man-hours for the model setup, however, can be reduced by streamlining the setup of CNWTs. To this end, the formulation of best-practice guidelines can expedite this streamlining. A step toward such best-practice guidelines is blind tests. This paper presents the CNWT used for the authors' contribution to the Collaborative Computational Project in Wave–Structure Interaction (CCP-WSI) Blind Test Series 3. In the employed numerical wave tanks, a self-calibrating impulse source wave maker is implemented for wave generation. In addition to the numerical results, and the comparison with the recently disclosed experimental data, the paper presents the spatial and temporal convergence studies, as well as results for the numerical wave maker calibration. The numerical results show average deviations with the experimental data of less than 10%. Furthermore, a correlation between the accuracy of the numerical replication of the wave and the agreement between numerical and experimental device motion is highlighted.

INTRODUCTION

In recent years, growing concerns of human-induced global warming have fueled the R&D of novel technologies to harness renewable energy resources. Among these resources, marine renewable energies (MREs), and specifically ocean wave energy, show significant potential to contribute to the global energy supply (Falcão, 2010). The harsh ocean environment, in which wave energy converters (WECs) are deployed, poses challenges to the R&D of these devices. Although the energy resource is free, to be commercially viable, the price of the produced energy from a WEC, stemming from capital, operational, and maintenance costs, must be minimised.

To drive down the cost of the produced energy, optimisation of the WEC devices is required, for which numerical wave tanks (NWTs) are a valuable tool. Depending on the implemented equations for the solution of the wave–structure interaction (WSI) problem, different levels of fidelity, at different levels of computational cost, can be achieved (Penalba et al., 2017). Lower-fidelity models, implementing methods based on the Laplace equation and, thus, assuming inviscid and irrotational fluids, are associated with minimal computational cost and are valuable tools for parametric studies or optimisation algorithms. However, due to the required linearisation of the hydrodynamic equations, lower-fidelity models are only valid when considering linear conditions, i.e., small amplitude waves and device motions. Still assuming irrotational and inviscid fluid, non-linear free-surface deformations can be captured in fully non-linear potential flow solvers, such as OceanWave3D (Engsig-Karup et al., 2009). Furthermore, linear models can be extended to capture non-linear effects, such as viscous drag (Morison et al., 1950) or non-linear Froude–Krylov forces (Babarit et al., 2010).

Higher-fidelity NWTs, such as CFD-based numerical wave tanks (CNWTs), are inherently able to capture all relevant hydrodynamic non-linearities (viscous and rotational fluids, turbulent effects, non-linear free-surface deformation, etc.), by numerically solving the Reynolds-averaged Navier–Stokes (RANS) equations. Thus, CNWTs are valid over a wide range of test conditions and are particularly valuable when modelling WECs under controlled conditions (Davidson et al., 2019), where an energy-maximising controller drives the WEC into resonance with the incident wave, resulting in enhanced device motion, beyond the limit of linear hydrodynamic model validity.

Although high-fidelity hydrodynamic models, such as CNWTs, are essential when modelling non-linear WSI for which linear hydrodynamic models are relatively inaccurate, CNWT models are not yet widely used in the MRE field, due to relatively long

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KEY WORDS: Wave energy, CCP-WSI Blind Test, impulse wave maker, CFD, numerical wave tank, OpenFOAM, RANS.