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Numerical Simulation of Wave Slamming on a Flap-Type Oscillating Wave Energy Device

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This paper presents the numerical investigations of an oscillating wave surge converter (OWSC) operating in extreme sea states leading to slamming. We use the open-source computational fluid dynamics (CFD) library OpenFOAM to carry out the two-dimensional numerical simulations. A preliminary study is done to verify the convergence of our results, while scalability tests confirm the high-performance computing capabilities of OpenFOAM and the possibility of extending this study to large three-dimensional configurations. The OWSC device is simulated with both incompressible and compressible solvers, and the results are compared against previous numerical and experimental results. It is shown that an incompressible solver can capture the dynamics and general behavior of the flap device. Nevertheless, the compressibility effects can be reproduced only with the aid of a compressible solver, which takes into account the density changes in the air and water phases. Those effects produce high-frequency, small oscillations on the seaward side of the flap but do not contribute to further increasing the peak pressure values characteristic of slamming.

INTRODUCTION

The use of renewable energies, such as wind and solar, has experienced a noticeable increase in recent years. However, other sources of renewable energies, such as the one extracted from ocean waves nearshore, still remain largely underexploited at present. Therefore, more experiments and accurate numerical simulations need to be carried out in this area with special focus on structure survival as a consequence of harsh ocean conditions.

This paper focuses on the Oyster oscillating wave surge converter (OWSC) (Whittaker and Folley, 2012), which consists of a flap device hinged on the seabed and driven back and forth by the action of waves. The energy taken from the waves is utilized to pump fresh water into a hydraulic plant inshore, where it is finally converted into electricity. OWSCs obtain their maximum efficiency in nearshore locations of shallow water depths, where they acquire larger motions from the waves. One of the current challenges of the OWSCs is their survivability in extreme sea states, e.g., winter sea storms (Kay, 2014), in which large and infrequent extreme waves may compromise their structural integrity and consequently lead to an increase in their maintenance costs. Furthermore, global warming and climate change are likely to increase the frequency as well as the intensity of storms and hurricanes, which may influence the design of future OWSCs.

Several experiments and simulations have already been conducted to measure the loads on OWSCs under harsh ocean conditions, typically low tidal levels and large amplitude waves. The experimental scale model tests performed under those conditions indicated the presence of discrete slamming events (Henry et al., 2014b), which were identified as significantly large pressure peaks below and above the ambient pressure on the seaward wall surface of the OWSC. On the other hand, Henry et al. (2014a) carried out two-dimensional numerical simulations of the same experiment using the incompressible commercial CFD software Ansys Fluent. Although the incompressible numerical simulations seemed to capture well the general behavior and dynamics of the flap device, the authors could not predict any slamming events. In their simulations, they attributed the absence of large peak pressures produced by slamming to the presence of air entrapment and associated compressibility effects (Henry et al., 2014a), which were ignored by the incompressibility assumptions.

During violent wave impacts and slamming events, the fluid compressibility can play a major role in the correct prediction of impact loadings (Lugni et al., 2010). Aeration effects may also become important in the presence of enclosed air bubbles and air pockets trapped in water bodies (Bullock et al., 2007). Furthermore, the effect of body rotation (Xu et al., 2010) is of special importance in the particular case of an oscillating device. Therefore, the commonly incompressible assumption of the fluid, i.e., the air and water mixture, retained in previous simulations of OWSCs may yield to a numerical underestimation of the maximum impact loadings on OWSCs (Henry et al., 2014a).

In this paper, a battery of simulations is conducted on the basis of two-dimensional experiments on the slamming of an OWSC. Firstly, we describe briefly the numerical methods of the incompressible and compressible models used. Secondly, we analyze the convergence of our numerical results. Then we perform scalability tests to assess the performance of these simulations in a High Performing Computing (HPC) environment. Finally, we carry out a new numerical simulation of the OWSC utilising a compressible Navier-Stokes solver and compare our results against the experiments and incompressible data in order to determine whether the compressibility effects become important during slamming. In this regard, power take-off systems of the OWSC were not considered.

NUMERICAL PROCEDURES

Incompressible and Compressible Navier-Stokes Solvers

The numerical procedures considered in this paper rely on a cell-centered, co-located, finite-volume method already implemented in the open-source CFD library OpenFOAM (Jasak,

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KEY WORDS: Wave energy, oscillating wave surge converter, compressibility, slamming, impact, HPC simulation.