# Numerical investigation of the survivability of a wave energy converter

**Haoyu Ding**[*], **Jun Zang**
Centre for Infrastructure, Geotechnical and Water Engineering, Department of Architecture and
Civil Engineering, University of Bath, BA2 7AY, U.K.
[*]E-mail: hd484@bath.ac.uk

## HIGHLIGHTS

The survivability of a wave energy converter (WEC) buoy is investigated numerically in this research. Various wave conditions with varying wave heights and wave steepness, including regular waves and focussed waves are considered. Both laminar flow and turbulence flow solvers are used to examine the performance, efficiency and accuracy in computing motion responses of and forces on the wave energy devices. Surge decay of the WEC buoy and results of different regular waves interacting with the WEC buoy are presented. A focused wave is generated by OpenFOAM as an extreme wave condition aiming to conduct further survival investigation on the WEC system.

## 1 INTRODUCTION

The research on wave energy convertors (WECs) has attracted great interests, however, there are still many challenges remaining in the development of effective, reliable and economically viable WECs. Because WECs are always exposed to the harsh marine environments, survivability under extreme marine environments that cause extreme loads and large responses is one of the challenges that are needed to be addressed. To assess and analyse the survivability of WECs, identifying survival conditions, quantifying loadings and responses of WECs and characterising the pressure and velocity field of WECs under survival conditions are required. Numerical modelling is an efficient and feasible option to meet these requirements and carry out a series of test cases for WEC systems with different incident wave conditions. In addition, the numerical modelling tools for analysing WEC survivability should have the capability of dealing with breaking waves, large free surface deformations and large motion responses. OpenFOAM® has been proved to be an accurate and mature viscous flow model for simulating wave-structure interactions even under violent waves [1]. This research aims to apply OpenFOAM® to investigate the survivability of a WEC system as part of a joint EPSRC project.

## 2 NUMERICAL METHOD

For this survival study, large motion responses of floating WEC buoy may occur in extreme wave conditions. Thus, the application of an overset mesh can enhance the capability of OpenFOAM models for simulating large amplitude motions. The solver, *overInterDyMFoam*, is employed for dynamic mesh to simulate the interactions between fluid and floating structure on overset mesh. Waves are generated and dissipated by using the relaxation-based wave generation toolbox *waves2Foam* proposed in [2]. The Navier-Stokes equations, which is introduced below, are utilised for *interFOAM* to describe the two-phase flow. These equations are written as a mass conservation equation and momentum equation by Newton's second law, which are showed below respectively:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0 \tag{1}$$

$$\frac{\partial \rho \mathbf{u}}{\partial t} + \nabla \cdot (\rho \mathbf{u}\mathbf{u}^T) = -\nabla P - (\mathbf{g} \cdot \mathbf{x})\nabla \rho + \nabla \cdot (\mu \nabla \mathbf{u}) + \sigma_t k_\gamma \nabla \gamma \tag{2}$$

where $\mathbf{u} = (u, v, w)$ is the flow velocity vector, $\rho$ is the density of fluid, $\mathbf{x} = (x, y, z)$ is the Cartesian coordinate vector, $P$ is the pressure in excess of the hydrostatic part, $\mathbf{g}$ is the acceleration due to gravity, $\mu$ refers to the dynamic viscosity, $\sigma_t$ and $k_\gamma$ are the surface tension coefficient and the surface curvature, respectively. When water waves are simulated, both water and air are solved simultaneously by Eq. 1 and 2.

To track the shape and position of the free surface, the volume of fluid (VOF) method has been employed in OpenFOAM®. The transport equation of the VOF field can be yielded as:

$$\frac{\partial \gamma}{\partial t} + \nabla \cdot \left(\vec{U}\gamma\right) = 0 \tag{3}$$

Where, $\gamma$ is the volume fraction. $\gamma = 0$ is for air, 1 is for water and intermedia value is for the mixture of two fluids at the interface. This equation shows the relationship between the velocity field and $\gamma$ in each cell. While, in order to keep tracking accurate free surface, an additional convective is included in the transport equation to provide a sharper interface resolution. The velocity field is modelled by corresponding gas and liquid velocities denoted by $\vec{U}_{\mathrm{g}}$ and $\vec{U}_{\mathrm{l}}$, respectively. The velocity field can be yielded by weighed averages as $\vec{U} = \gamma\vec{U}_{\mathrm{l}} + (1-\gamma)\vec{U}_{\mathrm{g}}$. According to this equation for velocity field, the new transport equation of VOF can be written as:

$$\frac{\partial \gamma}{\partial t} + \nabla \cdot \left(\vec{U}\gamma\right) + \nabla\left[\vec{U}_r\gamma(1-\gamma)\right] = 0 \tag{4}$$

Where $\vec{U}_r = \vec{U}_{\mathrm{l}} - \vec{U}_{\mathrm{g}}$. In the simulation of OpenFOAM®, two immiscible fluids are considered as one effective fluid throughout the flow domain. The physical properties, including density and dynamic viscosity, can be denoted as weighed averages by using of volume fraction $\gamma$.

$$\phi = \gamma\phi_{water} + (1-\gamma)\phi_{air} \tag{5}$$

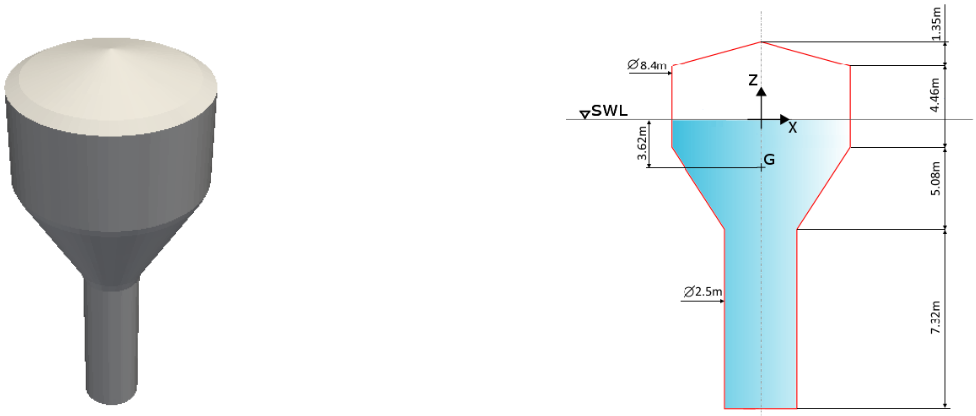
Based on this method, these physical properties can be equal to the properties of each fluid in their corresponding occupied regions and varying only across the interface.

## 3 NUMERICAL SETUP

A WEC structure under development by the Swedish company CorPower Ocean has been investigated in [3] by a series of tank tests. The WEC buoy is selected in this research as part of an EPSRC joint project for the numerical investigations on the survivability of WEC structures. Figure 1 shows the buoy shape and the dimension of the WEC buoy in a full scale. A laboratory model scale of 1:16 was chosen in [3]. To compare with the experimental results directly, the numerical model scale used in this research is also selected to be 1:16.

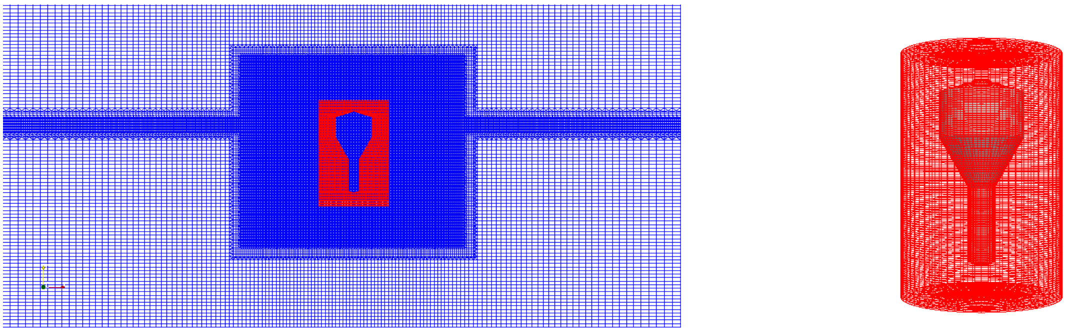
In the numerical wave tank, water depth is 3.125 m, which follows the setup in the experiments. The WEC buoy is restrained by a vertical mooring line which is attached to the bottom of the WEC buoy and connected to a fixed point at the depth of 3.09 m. A pretensioned force of the mooring line in the vertical direction (the direction of z-axis in Figure 1(b)) is applied on the WEC buoy, and the pretensioned force equals to 515 N at the equilibrium position of the WEC buoy. The total mass of the buoy is 19.1 kg. The axial stiffness of the mooring line is set to 202 N/m.

A cross-section of the numerical wave tank from side view is shown in Figure 2(a). The mesh around free surface boundary and around the WEC buoy are refined from the background mesh, where overset mesh is applied in this research. Figure 2(b) shows the cylindrical overset mesh domain around the WEC buoy, which will have the same movement as the floating buoy during the numerical simulations. And the background mesh shown in Figure 2(a) is static mesh, which will be kept fixed during the simulations. The data information is transferred between the background mesh and the overset mesh. In this way, the deformation of mesh in traditional dynamic mesh can be avoided and the capacity of numerical wave tank to large amplitude motions can be enhanced.



(a) (b)

Figure 1: (a) illustration of a WEC buoy shape and (b) dimension of the WEC buoy in real scale.



(a) (b)

Figure 2: (a) one cross-section of the numerical wave tank in OpenFOAM from side view to show the mesh around the WEC buoy, (b) overset mesh around the WEC buoy.

## 3 RESULTS

Surge decay of the WEC buoy with a mooring line restraint are simulated first and compared with experimental results to validate the numerical prediction of motion responses. The axial stiffness of mooring line is 202 N/m in the experimental scale in [3]. In the surge decay test, the initial position of the WEC buoy is 0.1 m away from the equilibrium potion in the horizontal direction and the mooring line gives a restoring force in surge. Figure 3 shows the comparison of the surge decay between numerical results and experimental results, which shows an agreement. Both numerical model and physical experiment have predicted the resonance period of ~ 4 s for surge in this setup. The mooring line simulated in our numerical model is considered as a linear spring, there may be differences between the linear spring in the numerical model and the physical experiment. Thus, the buoy simulated by the numerical model decays slightly faster than that in the experiment. While the differences of the surge decay amplitudes in Figure 3 between numerical results and experimental results are minor. In general, the numerical model shows a good performance on representing the motion of this WEC buoy.

Some test cases with regular waves interacting with the WEC buoy are carried out, and the surge and heave response are presented in Figure 4(a). Figure 4(a) shows the surge and heave response amplitude operator (RAO) as a function of *kh*, where RAO = amplitude of response / incident wave amplitude, *k* is wave number, *h* is water depth and *kh* is employed to denote different incident wave conditions. The heave RAO at *kh* = 2.52 is larger than the values of *kh* = 1.53 and 5.59. While the surge RAO in this wave condition keeps increasing with the decrease of *kh*, and the surge RAO of *kh* from 2.52 to 1.53 increases significantly faster than that of *kh* from 5.59 to 1.53. It is obvious that the response of the WEC buoy is sensitive to the changes of incident wave conditions. To assess the survivability of the WEC buoy further, extreme wave conditions are also generated in the numerical model to simulate the interactions between the WEC buoy and extreme waves. The focused waves are applied for the short-term survival investigations in [1]. This research also utilises the focused waves for further survival investigations on this WEC buoy. Figure 4(b) shows a focused wave generated in the numerical model by New Wave theory and based on JONSWAP spectrum. The significant wave height ($H_s$) is 0.55 m, the peak period ($T_p$) is 2.75 s and the peak-enhancement factor ($\gamma$) is 5 in Figure 4(b).

Further results on the WEC buoy interacting with this extreme wave condition and a range of varying wave conditions will be presented during the workshop.

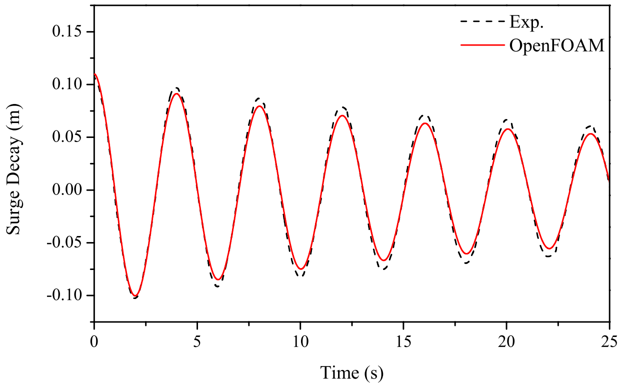
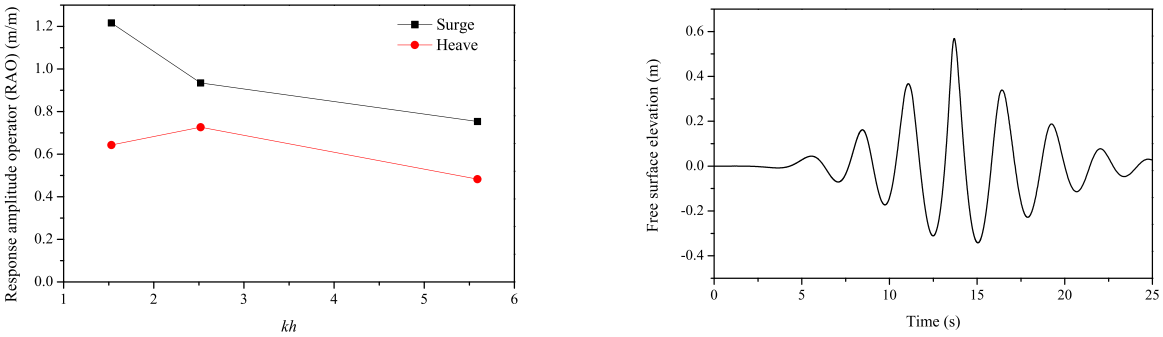


Figure 3: comparisons between OpenFOAM results and experimental results of surge decay of the WEC buoy in time histories.



(a) (b)

Figure 4: (a) Surge and heave response amplitude operator as a function of dimensionless wave number, *kh*, (b) free surface elevations of a focused wave generated in OpenFOAM numerical wave tank in time histories.

## REFERENCES

[1] Ransley, E.J., Greaves, D., Raby, A., Simmonds, D., Hann, M., 2017. *Survivability of wave energy converters using CFD*. Renewable Energy, 109, 235-247.
[2] Jacobsen, N.G., Fuhrman, D.R., Fredsøe, J., 2012. *A wave generation toolbox for the opensource CFD library: OpenFoam®*. International Journal of Numerical Method Fluids, 70, 1073-1088.
[3] Todalshaug, J.H., Ásgeirsson, G.S., Hjálmarsson, E., Maillet, J., Möller, P., Pires, P., Guérinel, M., Lopes, M., 2016. *Tank testing of an inherently phase-controlled wave energy converter*. International Journal of Marine Energy, 15, 68-84.