

NUMERICAL SIMULATION OF A SINGLE FLOATING POINT ABSORBER WAVE ENERGY CONVERTER USING OPENFOAM®

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1. INTRODUCTION

Wave energy from ocean waves is captured by Wave Energy Converters (WECs) and converted into electrical power. In this study, WECs of the floating point absorber (FPA) type are selected. Their geometry is represented by a cylindrical buoy with a spherical end. The focus of this study is limited to a free decay test of a single WEC.

2. NUMERICAL MODELLING

CFD-modelling is performed to study the behaviour of a single WEC in a wave field using OpenFOAM. Simulations of the two-phase flow field are performed by solving the incompressible RANS-equations. Wave generation and absorption at the boundaries of the numerical wave tank are implemented in the IHFOAM toolbox. The CFD-fluid solver is coupled to a motion solver in order to simulate rigid body motions. Only the governing motion of the WEC's behaviour is considered, the heave motion.

Important parameters of the WEC, such as the damping ratio ζ_d , natural angular frequency ω_n and damped angular frequency ω_d , are obtained from a free decay test. During such a free decay test, the body is placed out of equilibrium with an initial displacement. A damped oscillatory motion is started after releasing the WEC until all the forces acting on that WEC are in equilibrium. In order to validate the numerical model, experiments in a wave flume were conducted to measure the WEC's heave motion. Therefore, a steel shaft was installed through a vertical shaft bearing over the whole height of the WEC (see Figure 1a). Because of the complexity of meshing the shaft bearing inside the WEC, another methodology is formulated to obtain a grid around the WEC without that vertical shaft (see Figure 1b).

Firstly, the shaft inside the physical WEC reduces the water-plane area A_w and changes the natural frequency ω_n . Moreover, the natural frequency is dependent on the mass m and added mass m_a . Therefore a WEC without shaft but with a modified mass m_{num} is implemented in OpenFOAM. This is done to obtain the same natural frequency as the physical WEC, assuming that the damping ratio ζ_d and added mass m_a are identical in both experimental and numerical models, see eq. (1). The modified-mass method can be derived starting from the expression in eq. (1). Subsequently, the damped frequency ω_d in both numerical and experimental models are rewritten by using eq. (2) and (3). Finally, this procedure returns eq. (4) which calculates the modified mass m_{num} needed in the numerical model to satisfy eq. (1).

$$\omega_{d,num} = \omega_{d,exp} \quad (1)$$

$$\omega_d = \omega_n \cdot \sqrt{1 - \zeta_d^2} \quad (2)$$

$$\omega_n = \sqrt{\frac{\rho g A_w}{m + m_a}} \quad (3)$$

$$m_{num} = m_{exp} \left[\left(1 + \frac{m_a}{m_{exp}} \right) \frac{A_{w,num}}{A_{w,exp}} - \frac{m_a}{m_{exp}} \right] \quad (4)$$

Secondly, there is a motion of a viscous fluid, water, in the underwater space between the steel shaft and the shaft bearing. This flow can be simplified as a Couette flow between two parallel plates of which one is moving relative to the other. This Couette flow is responsible for a viscous force acting parallel to the motion of the moving plate (shaft bearing inside the WEC). This force is dependent on the viscosity of water, the space between the plates and the velocity. However, a simplified model is assumed by only including the velocity v explicitly using a linear damper ($F = -c \cdot v$) in which c is the damping coefficient. As expressed in eq. (5), the WEC's damping ratio ζ_d is equal to the

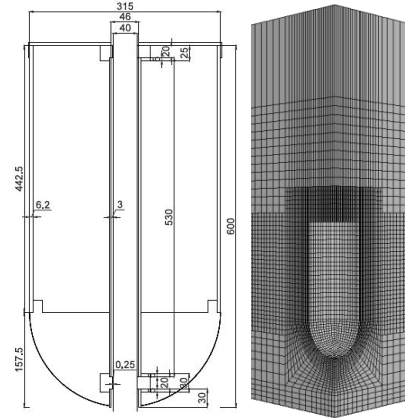


Figure 1. (a) Cross-section of the physical WEC [1]. (b) 3D grid around the WEC.

ratio of the damping coefficient b_d and the critical damping coefficient b_c . The target damping coefficient $b_{d,target}$ is calculated by eq. (5) using the experimental damping ratio and the WEC's modified mass. Subsequently, the numerical damping coefficient $b_{d,num}$ is determined following the same eq. (5) but now using the numerical damping ratio. This numerical damping ratio is obtained from a CFD simulation without linear damper, so the Couette flow is neglected. Thereafter, the difference between both damping coefficients is used as the damping coefficient c of the linear damper inside the motion solver to account for the Couette flow, see eq. (6).

$$\zeta_d = \frac{b_d}{b_c} = \frac{b_d}{2 \cdot \omega_n \cdot (m + m_a)} \quad (5)$$

$$c = \Delta b_d = b_{d,target} - b_{d,num} \quad (6)$$

3. RESULTS

The numerical model described in the previous paragraph is used to simulate a free decay test using the structured grid shown in Figure 1b consisting of solely hexahedral cells. Only the lowest and highest row of cells are distorted to prevent undesirable mesh deformation around the air-water-interface. Figure 2 presents the WEC's heave motion with respect to its equilibrium position. The continuous blue line represents the numerical result while the dashed red line shows the experimental data from the wave flume. The dashed-dotted black line depicts the analytical envelope [1]. In general, the figure proves that this numerical result is extremely close to the experimental decaying motion. After 13 s, some small discrepancies in the phase of the signal are observed between CFD and the experiment due to the different absorption methodology between IHFOAM and the physical wave flume. Moreover, the motion of the WEC generates radiated waves, which are shown at five locations (Figure 3a) for both numerical and experimental results in Figure 3b. Although these small-amplitude waves (< 1 cm), both results are very similar in the first 10 seconds of the signals. Thereafter, some deviations between both results are observed. Numerical results obtained from simulations using a smaller time step or a denser grid are converging towards a time- and grid-independent solution. All these observations show that OpenFOAM/IHFOAM is a robust and suitable toolbox to research wave-structure interaction.

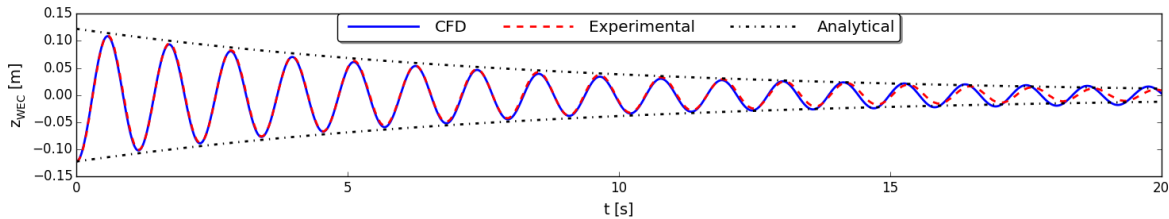


Figure 2: The WEC's vertical position during a free decay obtained with CFD (continuous blue line, $\Delta t = 0.001$ s, $\Delta z = 0.02$ m) compared to the experimental decaying motion (dashed red line) and the analytical envelope (dashed-dotted black line).

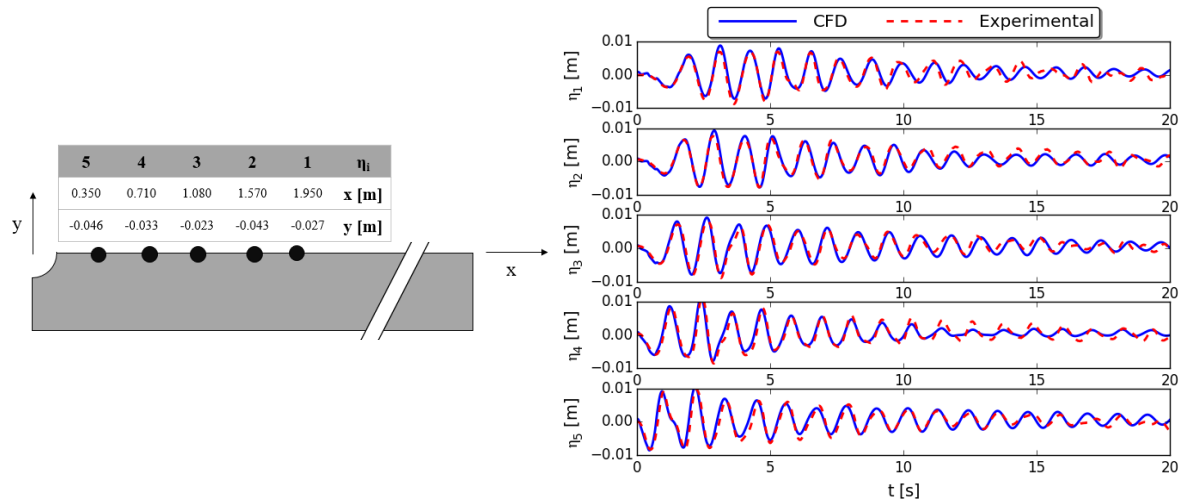


Figure 3: (a) Plan view of the five wave gauges inside the numerical wave flume. The WEC's centre ($x = 0$ m ; $y = 0$ m) is located at the upper left corner while the absorbing wave boundary condition is located at the right side of the domain ($x = 4.95$ m). (b) The radiated wave field represented by the surface elevation η_i in function of time t ($\Delta t = 0.001$ s, $\Delta z = 0.02$ m).

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