SPH NUMERICAL MODELLING OF A U-OWC WAVE ENERGY CONVERTER

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INTRODUCTION

This paper presents numerical simulations of a U-Oscillating Water Column (U-OWC) wave energy converter excited by regular sea waves. This device is an OWC (oscillating water column) converter comprising a U-duct at the seafront. As for the OWC device, it exploits the water column oscillations for compressing and expanding the air chamber above the water column with the purpose of producing an air flow through the turbine connected to the air chamber. However, the U-OWC comprises also a U-duct at the seafront that allows the converter to reach resonance conditions with the sea waves. The device was proposed by Boccotti (2003) and tested at the Natural Ocean Engineering Laboratory (NOEL) in Reggio Calabria, Italy. Those experimental activities showed that the U-duct allows achieving, thanks to the resonance condition, better energy-wise performances compared to a similar OWC exposed to identical sea states conditions. A U-OWC prototype was installed in the Civitavecchia harbor (Arena, et al. 2013).

Herein, to model the U-OWC wave energy converter, Smoothing Particle Hydrodynamics (SPH) has been adopted and implemented through the DualSPHysics software (Dominguez et al., 2022).

NUMERICAL METHOD

SPH is a Lagrangian method that numerically solves the Navier-Stokes equations. It is based on interpolants, so that a variable F in position $\boldsymbol{r_i}$ is expressed through the values that the same variable has in a neighborhood of $\boldsymbol{r_i}$:

$$F(\boldsymbol{r_i}) = \sum_{j=1}^{N} F(\boldsymbol{r_j}) W(|\boldsymbol{r_i} - \boldsymbol{r_j}|, 2h) \frac{m_j}{\rho_j}, \qquad (1)$$

where $W(|\boldsymbol{r_i} - \boldsymbol{r_j}|, 2h)$ is the kernel, a smoothing function that is maximal at $\boldsymbol{r_i}$ and decreases symmetrically moving away from it.

Such an approach allows recasting the momentum and continuity equations as:

$$\frac{d\boldsymbol{v_i}}{dt} = -\sum_j m_j \left(\frac{P_i + P_j}{\rho_i \rho_j} + \Pi_{ij} \right) \nabla_i W_{ij} + \boldsymbol{g}, \qquad (2)$$

and

$$\frac{d\rho_i}{dt} = \sum_j m_j (\boldsymbol{v_i} - \boldsymbol{v_j}) \nabla_i W_{ij} + \delta h c_i \sum_j \psi_{ij} \nabla_i W_{ij} \frac{m_j}{\rho_j}, \qquad (3)$$

with m mass, v velocity, P pressure, ρ density and $\boldsymbol{g}$ gravity acceleration. The term Π_{ij} in eq. (2) is the artificial viscosity, which is used for stabilizing and regularizing the numerical simulations (Monaghan, 1992). The second term on the right-hand side of eq. (3) is the density diffusion term, which is a numerical noise filter smoothing the pressure and density fields (Fourtakas et al., 2019).

Since the fluid is weakly compressible, pressure can be computed as a function of density through the Tait’s equation of state:

$$P_i = \frac{c_s^2 \rho_0}{\gamma} \left[\left(\frac{\rho_i}{\rho_0} \right)^{\gamma} - 1 \right], \qquad (4)$$

where ρ_0 is the initial density, c_s is the speed of sound and γ is the polytropic constant.

The DualSPHysics software is used to perform SPH simulations. It can be executed both on the CPU and the GPU, and can be coupled with other models like Chrono (Martínez-Estévez et al., 2023).

CASE STUDY

In this work, the simulations have been performed by referring to the small-scale tests conducted by Vyzikas et al. (2017) on a U-OWC in Froude similarity with the one tested at the NOEL site.

The experimental tests were performed in a wave flume equipped with a mechanical wave-maker. The U-OWC small-scale model comprised 3 symmetrical chambers as shown in Figure 1. The water depth was 0.75 m, the device had a duct 0.143 m wide and 0.447 m long, while the chamber was 0.286 m wide. The U-duct opening was placed 0.196 m below the mean water level.

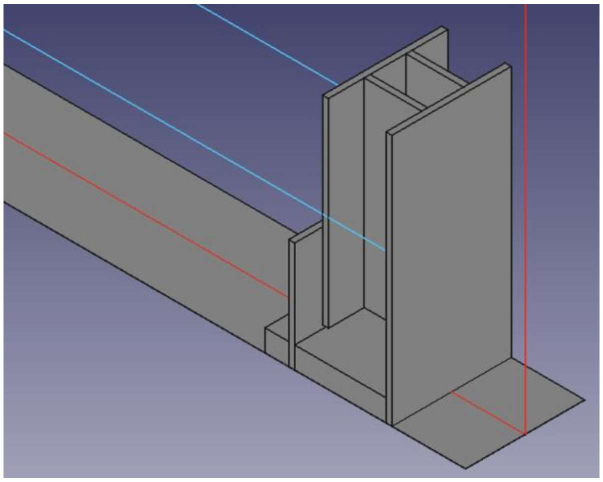

Figure 1 - 3D geometry of the U-OWC converter model.

RESULTS

The study examined the simulation conditions of a U-OWC, which features a water column that is constantly exposed to atmospheric pressure: this was achieved by keeping the air chambers open. This experimental set-up allowed testing the numerical model without the additional complexity associated with the mathematical description of the pneumatic chamber and of the associated thermodynamic process.

The simulation is performed in a two-dimensional framework. Specifically, the red lines shown in Figure 1 are the edges of the two-dimensional domain.

The numerical piston generates second-order regular waves and is equipped with an Active Wave Absorption System (AWAS) (Altomare et al., 2017).

Time series of 100 seconds have been simulated. Waves with four different periods – heights pairs are generated as shown in Table 1.

	H (m)	ω (Hz)
1	0.122	0.570
2	0.096	0.510
3	0.088	0.465
4	0.159	0.385

Table 1 – Wave frequencies (ω) – heights (H) pairs.

The induced water column oscillation pertaining to each numerical run is measured inside the central chamber. Next, it is divided by the associated incident wave amplitude for obtaining the Response Amplitude Operator (RAO). RAO values given by the SPH simulations are validated against those measured in the experiment of Vyzikas et al. (2017).

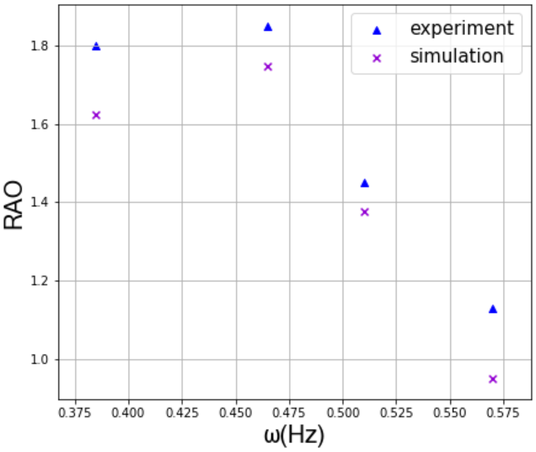

Figure 2 – RAO comparison between experimental data (blue triangles) and SPH simulations (purple crosses).

Figure 2 shows the RAOs obtained by the proposed SPH model and by the experimental data. The results are in rather good agreement. The key features of the RAO are captured over the whole frequency domain. In particular, the frequency associated with the largest water column oscillations is identified properly. Overall, the simulation results show a general underestimation of the absolute RAO values, and this can be due to the choice of the boundary conditions and other simulation parameters (such as artificial viscosity, interparticle distance, smoothing length, etc.), for which an even more detailed optimization study is intended to be carried out.

CONCLUSIONS

This article has proposed SPH simulations implemented with DualSPHysics solver to model a U-OWC device and compare with small-scale experimental tests. The numerical modelling has provided rather good results vis-à-vis experimental data obtained in a wave flume.

The next step is to introduce the pneumatic chamber into the SPH model with the long-term objective of validating a 3D simulation against data collected at NOEL site.

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