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Effect of Discharge Boundary Conditions on the Available Power of a Wave Energy Converter

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ABSTRACT

The Overtopping BReakwater for Energy Conversion (OBREC) is an innovative type of Wave Energy Converter (WEC) that integrates renewable energy generation within the structure of conventional rubble-mound breakwaters. In an OBREC system, incident waves are guided up a sloping ramp, allowing water to overtop into a reservoir positioned above mean sea level. The stored water is then released through low-head turbines to generate electricity, with energy production directly linked to the hydraulic head created by the overtopped flow. Traditionally, the discharged water from the OBREC flows toward the rear side of the structure, into a sheltered area of the sea that remains unaffected by incoming waves or sea level fluctuations. However, the present study numerically investigates a modified configuration in which the overtopped water is discharged seaward, exposing the system to dynamic wave pressures and potential sea level variations. Findings indicate that in the presence of waves and increased sea levels, the location of maximum mean energy shifts progressively toward the basin, resulting in a significant reduction of energy conversion up to approximately 90%. This new setup aims to assess how wave-induced pressures and hydrodynamic feedback from the open sea may influence the overtopping behaviour and overall energy conversion efficiency of the OBREC.

1. Introduction

In recent years, the exploitation of renewable energy from the marine environment, such as wave, tidal, and offshore wind energy, has gained growing attention. Among these sources, wave energy offers a promising opportunity for integration within coastal protection structures, leading to innovative hybrid solutions such as the Overtopping BReakwater for Energy Conversion (OBREC). However, under storm conditions, their efficiency may be reduced.

The available power in a flow depends on both its depth and velocity and can be estimated using Equation (1) and Equation (2).

$$P_f = \frac{1}{2}\rho A {v_{in}}^3 \qquad (1)$$

$$A = R^2 \arccos\left(1 - \frac{h}{R}\right) - (R - h)\sqrt{R^2 - (R - h)^2} \qquad (2)$$

Here, v_{in}, A, h and R represent the inflow velocities, filled area of the pipe, the flow depth, and the pipe radius, respectively.

2. Materials and Methods

The numerical model FLOW-3D (Flow Science 2023) was applied for the present work. A uniform cell size of 0.05 m was used in all directions, resulting in a total of 1,045,506 computational cells. Mesh refining has been used to choose the grid size to be used in overtopping calculations. The k–ε (RNG) turbulence model was applied to represent Reynolds stresses. The computational domain and boundary conditions are shown in Fig. 1. Cross-sections A, C, and F serve as reference points for calculating the available power throughout the system.

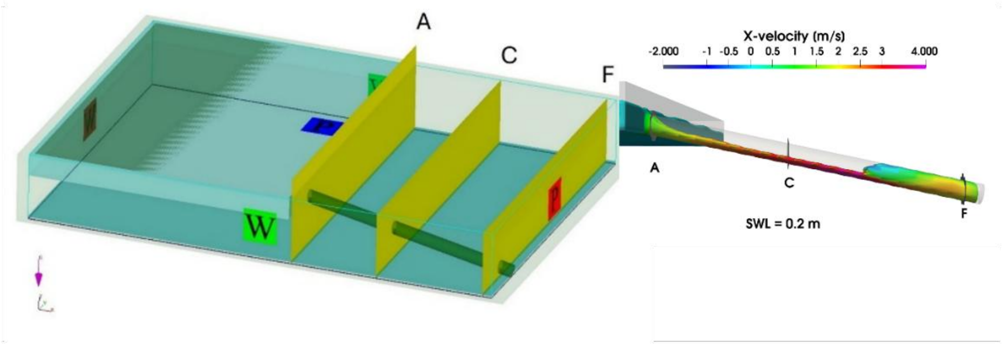

Fig. 1. Representative simulation results within the numerical domain, highlighting boundary conditions and the orientation of control cross-sections A, C, and F.

In this study, pressure boundary conditions were imposed to represent physics, corresponding to a 1.5 m head in the basin. To simplify the numerical setup, only the wave-induced pressure was considered at the other side of pipe, without any external flow into the outlet boundary.

$$p = -\rho g z + Dp \qquad (3)$$

In Equation (3), z denotes the depth at a selected location, and Dp represents the dynamic wave component, calculated following Dean and Dalrymple (1991) using Equation (4):

$$Dp = \rho g \eta \mathrm{K}p_{(z)} \, , \mathrm{K}p_{(z)} = \frac{\cosh k(h+z)}{\cosh kh} \qquad (4)$$

Here, η,k, and h represent the free surface elevation, the wave number, and the water depth, respectively.

3. Results and discussion

For the outlet boundary conditions, different scenarios were considered. Specifically, wave-induced pressure fluctuations, corresponding to at different sea levels, were applied. Values of 0, 0.2 and 0.3 m were selected to mimic storm surge occurrence. In Table 1, mean available power are shown for different scenarios at different cross sections.

Table 1. Mean kinetic power (W/s)

		With Waves		
	Cross Section	A	C	F
Still water level	0 m	103.25	422.74	686.71
	0.2 m	102.63	419.82	575.27
	0.3 m	102.82	420.33	482.44

4. Conclusion

The optimum installation location is expected to differ among conveyance systems and may shift toward the basin under storm surge or tidal conditions.

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