

# Impact of Outlet Boundary Conditions on the Extractable Power of a Wave Energy Converter

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## Abstract

The Overtopping BReakwater for Energy Conversion (OBREC) is an innovative Wave Energy Converter (WEC) that incorporates renewable energy production into conventional rubble-mound breakwater structures. In an OBREC system, incoming waves travel up a sloped ramp, causing water to overtop into a reservoir located above the mean sea level. The accumulated water is subsequently discharged through low-head turbines to produce electricity, with the generated power directly dependent on the hydraulic head produced by the overtopping process. Conventionally, the discharged water flows toward the rear of the structure, entering a sheltered sea area that is not influenced by incident waves or sea level variations. In contrast, the present study numerically examines a modified configuration in which the overtopped water is released toward the open sea, subjecting the system to wave-induced pressures and possible sea level changes. This configuration is investigated to evaluate the effects of wave-related pressures and hydrodynamic interactions with the open sea on the overtopping process and the overall energy conversion efficiency of the OBREC.

## Introduction

In recent years, the use of renewable energy from the marine environment, including wave, tidal, and offshore wind resources, has attracted increasing interest. Among these options, wave energy presents a significant potential for integration into coastal protection structures, giving rise to hybrid solutions such as the Overtopping BReakwater for Energy Conversion (OBREC). However, their performance may decrease under storm conditions.

The power available in a flow is governed by both flow depth and velocity and can be evaluated using Equation (1) and Equation (2).

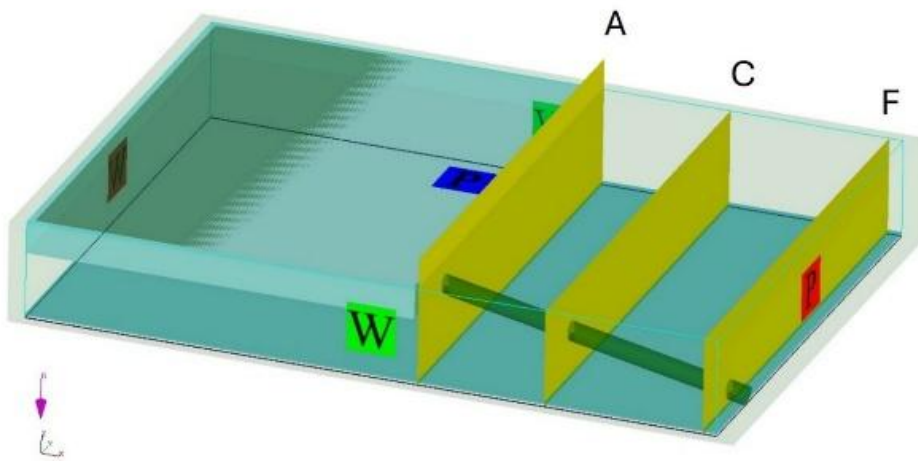
$$P_f = \frac{1}{2} \rho A v_{in}^3 \quad (1)$$

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

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

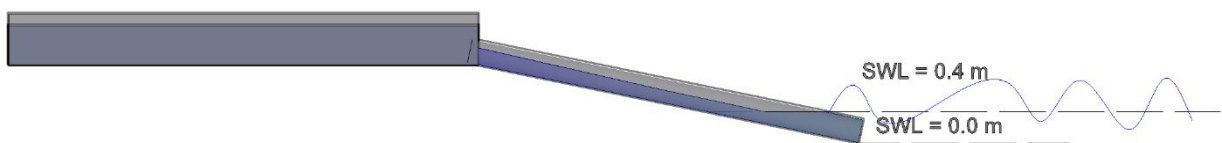
### Materials and Methods

The numerical simulations were carried out using the FLOW-3D model. A uniform grid resolution of 0.05 m was adopted in all spatial directions, resulting in a total of 1,045,506 computational cells. Turbulence effects were modelled using the RNG  $k-\epsilon$  formulation to account for Reynolds stresses. The computational domain and the applied boundary conditions are shown in Fig. 1.



**Fig. 1.** Numerical domain with boundary conditions and identification of the control cross-sections A, C and F.

A schematic illustration of the basin and conveyance system is provided to highlight the influence of wave-induced water-level variations at the outlet (Fig. 2).



**Fig. 2.** Sketch of the basin and conveyance system illustrating the influence of wave action at the outlet.

A basin water level elevated by 1.5 m was prescribed, resulting in the corresponding hydrostatic pressure distribution. To simplify the numerical setup, only wave-induced pressure was applied at the downstream side of the pipe, with no external flow imposed at the outlet boundary.

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

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):

$$Dp = \rho g \eta Kp_{(z)}, Kp_{(z)} = \frac{\cosh k(h+z)}{\cosh kh} \quad (4)$$

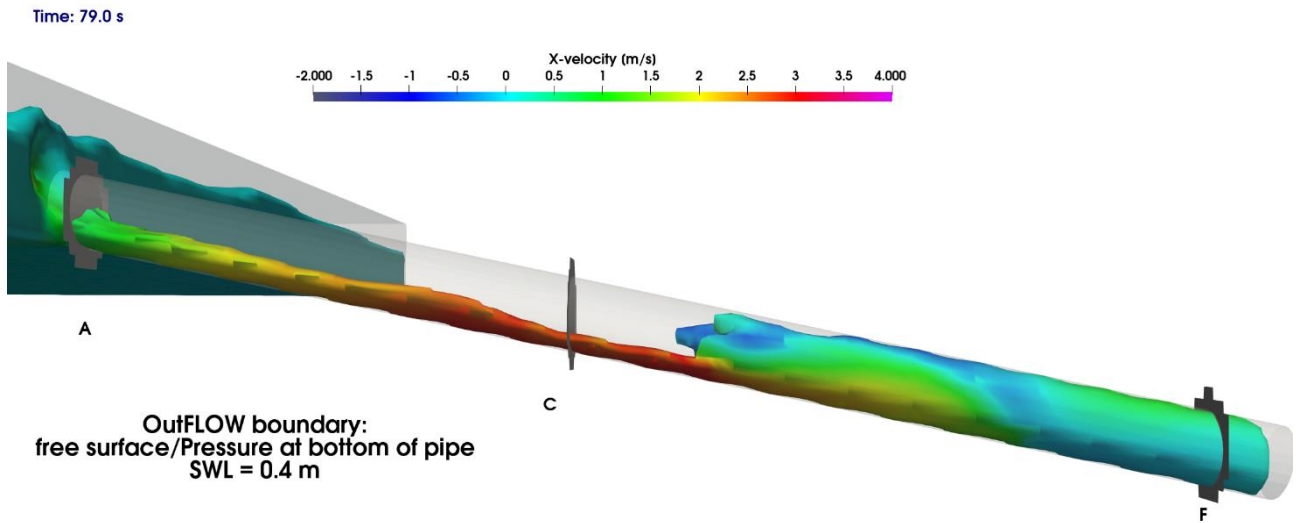
Here,  $\eta$ ,  $k$ , and  $h$  represent the free surface elevation, the wave number, and the water depth, respectively. Above the mean water level, hydrostatic pressure alone provides an acceptable approximation and is therefore adopted in this study.

## Results and discussion

For the outlet boundary conditions, different scenarios were considered. Specifically, wave-induced pressure fluctuations corresponding to different sea levels were applied. Water level variations of 0, 0.1, and 0.4 m were selected to represent storm surge conditions. **Table 1** presents the mean available power for the different scenarios at various cross sections. In Fig. 3, results for one scenario are shown, illustrating how the outlet pressure influences the flow within the pipe.

**Table 1.** Mean kinetic power (W)

		With Waves			
		Cross Section	A	C	F
water	0 m	65.09	357.94	543.27	
	0.1 m	63.7	344.69	466.4	
Still level	0.4 m	14.89	75.22	39.88	



**Fig. 3.** Velocity fields in the x-direction within the pipe at  $t = 79$  s for waves with SWL equal to 0.4 m.

## Conclusion

In this study, numerical analysis and mathematical tools were employed to evaluate wave-induced flow conditions within the WEC system. The findings provide a basis for identifying the optimal location for turbine installation inside the pipe, while reducing uncertainty in the analysis of complex WEC systems. The optimal installation location is expected to vary among different conveyance configurations and may shift toward the basin under storm surge or tidal conditions.

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## References

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