Experimental Analysis of a Dual-function Slotted Breakwater with an Oscillating Water Column

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A new dual-function design of a slotted breakwater with an Oscillating Water Column (OWC) is proposed for shallow and deep-water applications.

For the deep-water case, addition of a horizontal plate at mid-depth results to increased extraction efficiency.

INTRODUCTION

Wave energy is known to provide a very dense energy resource. However, there are significant challenges with regards to the ocean deployment of Wave Energy Converters (WECs), making deployments costly and difficult as well as requiring periodic maintenance. The integration of wave energy devices with coastal structures provides a way of cutting these costs through shared purpose designs. Slotted breakwaters are a new design of breakwaters which make use of porous slots in order to dissipate wave energy, while using less material as compared to traditional breakwaters and allowing some level of exchange of seawater. This cuts the cost significantly, especially in deep water applications. Thus, a new design of a slotted breakwater with an Oscillating Water Column (OWC) is proposed.

An initial design is proposed for shallow water applications, which can be applied to projects, such as nearshore harbors. This design is further developed into a deep-water design, wherein a horizontal plate is attached at around mid-depth. This primarily serves to increase the power extraction from the OWC for a certain range of wave conditions (Deng et al. 2019), while keeping the breakwater easy to construct, using less material and maintaining a modular design.

METHODOLOGY

Experiments were performed in a small-scale wave flume (1:49 using Froude scaling). An orifice (opening ratio = 1%) was used to model a non-linear turbine, wherein the pressure drop through the orifice is

$$p_a(t) = \frac{1}{2}\rho_a C_f |u(t)| u(t), \qquad (1)$$

where u is the spatially-averaged velocity of air in the chamber, ρ_a is the density of air, and C_f is a loss coefficient. Using this relationship, we can derive an expression for the power extracted by the orifice using only the pressure difference,

$$P_{OWC} = A_{OWC}\sqrt{\frac{2}{\rho_a C_f}}\overline{|p_a(t)|^{3/2}}, \qquad (2)$$

where, A_{OWC} is the inside area of the OWC chamber. The air pressure inside the chamber was obtained using a differential pressure sensor. Finally, wave loading on the structure was obtained using a horizontal force balance. For deep-water application, the shallow water design was modified by adding a horizontal plate, around mid-depth.

MAIN RESULTS

Results show that there is a nearly linear increase of the energy efficiency with the wave amplitude, given that incident waves are weakly non-linear. A nearly constant transmission coefficient is observed under varying wave period (10% porosity case). This is due to the decreased wave reflection under shorter waves being balanced by the increased energy extraction of the OWC and dissipation by the slotted wall. The horizontal force on the structure is observed to increase under longer waves, while decreasing for a more porous wall.

By decreasing the porosity, we observe an increase in the reflection coefficient and viscous damping by the slotted barrier, with a decrease in the transmission coefficient. Under larger wave heights, a slight increase in extraction efficiency is observed for a less porous wall. Lastly, a smaller horizontal force on the structure under increasing porosity of the slotted wall is observed.

The addition of a horizontal plate around mid depth, below the chamber, results in increased extraction efficiency, while the effects on other parameters are less apparent. Further experiments are necessary for this case.

Non-dimensional parameters:

$$(\epsilon, C_R, C_T, C_V, C_D) = f\left(\frac{L}{B}, \frac{A_I}{B}, \frac{h}{B}, \varphi, \alpha, \frac{\rho_w}{\rho_a}\right) \qquad (3)$$

$$\epsilon = \frac{P_{OWC}}{P_I},\ C_R = \frac{A_R}{A_I},\ C_T = \frac{A_T}{A_I},\ C_V = 1 - C_T^2 - C_R^2,\ C_D = \frac{F_{x,max}}{Wh\rho_w g A_I} \qquad (4)$$

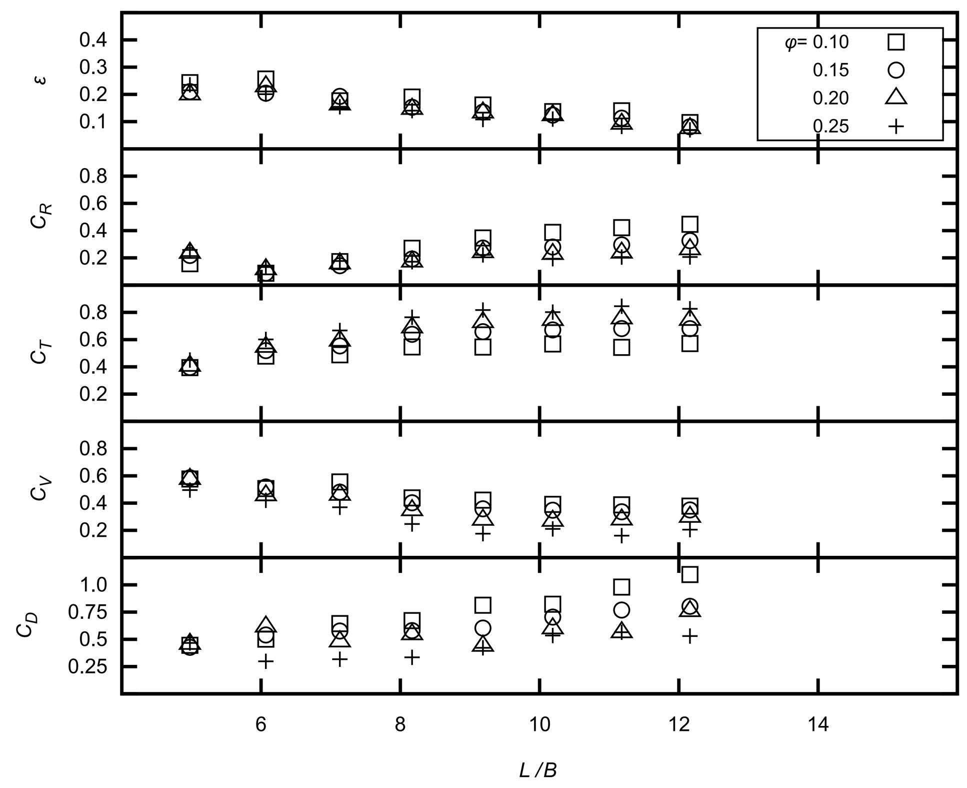

Figure 2. Parameters under varying wavelength and porosities at 17cm water depth (h/B = 1.21).

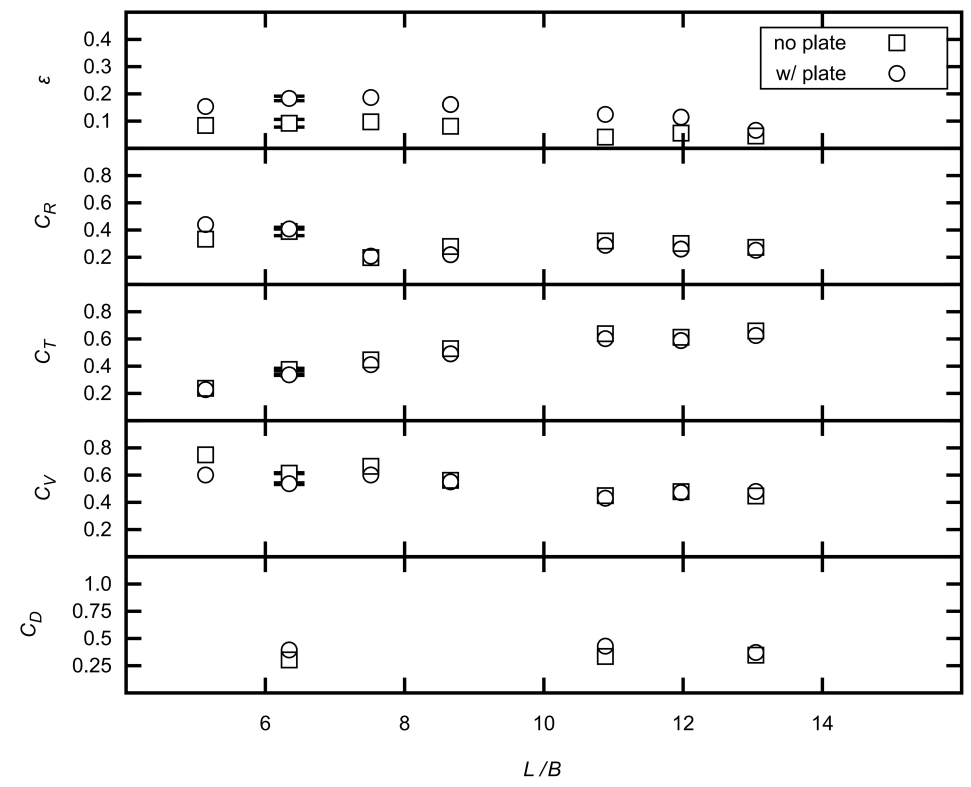

Figure 3. Parameters under varying wavelength for 15% porosity with and without horizontal plate (Water depth = 20cm, h/B = 1.43).

OBJECTIVES

- Propose a dual function design of an OWC-breakwater for shallow and deep-water applications.
- Quantify the performance with regards to energy extraction, wave transmission, viscous damping.
- Estimate the wave induced forces acting on the structure.

EXPERIMENTAL SET-UP

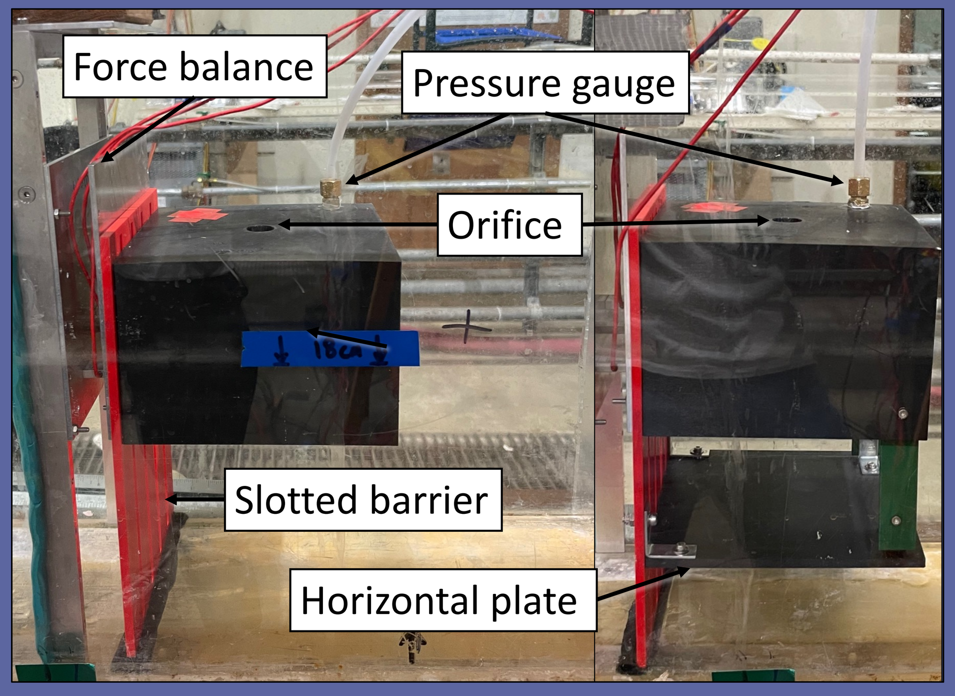

Figure 1. Model structure set-up without a horizontal plate (left) and with a horizontal plate (right).

CONCLUSIONS

- Increasing the wave height caused the transmission coefficient to decrease and the pneumatic efficiency to increase but did not have any noticeable influence on the reflection coefficient.
- Reducing the porosity of the slotted barrier from 25% to 10% increases the drag, viscous dissipation, and reflection coefficients, while decreasing the transmission coefficient, but has only a minor influence on the pneumatic efficiency.
- Addition of a horizontal plate at mid-depth results in an increased pneumatic efficiency.

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