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Characteristics of orifices for modeling nonlinear power take-off in wave-flume tests of oscillating water column devices

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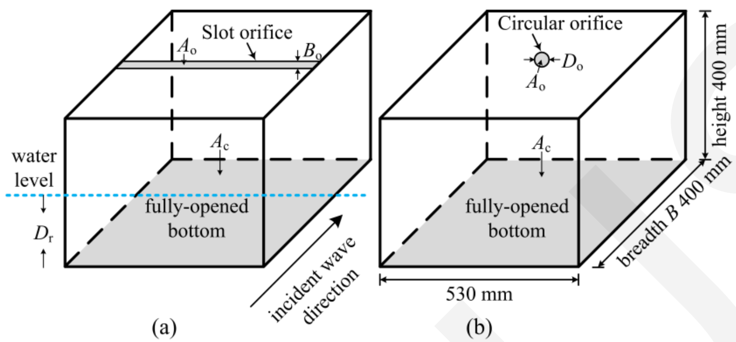
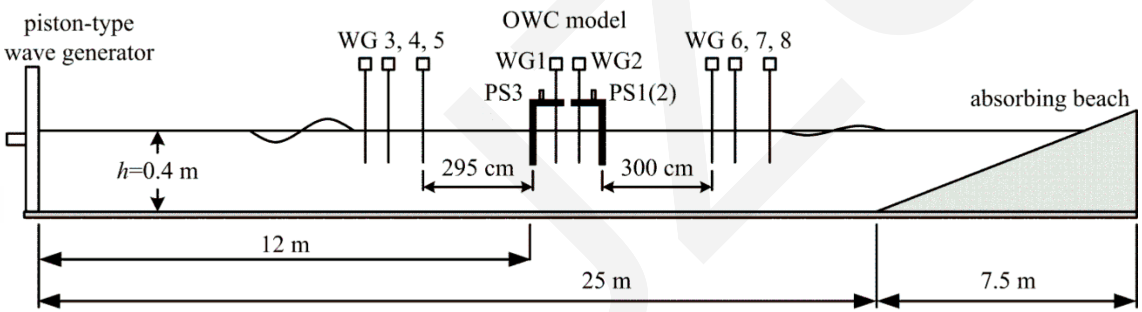
Highlight

- Nonlinear power take-off is modeled using either slot or circular orifices.
- A two-point method is employed to reconstruct the water surface inside an OWC chamber.
- Effects of the orifice shape and opening ratio on the power take-off characteristics are examined.
- Empirical formulas for the quadratic loss coefficient of two types of orifices are proposed.
- A method for calculating power extraction using pressure measurement is recommended.
- Power extraction calculation can be done for arbitrary chamber shapes and incident angles.

Experiments



OWC models: (a) using a slot orifice to model the PTO, and (b) using a circular orifice to model the PTO



WG: wave gauge; PS: pressure sensor

A sketch of the experimental set-up

The geometric parameters of the OWC model and the test conditions

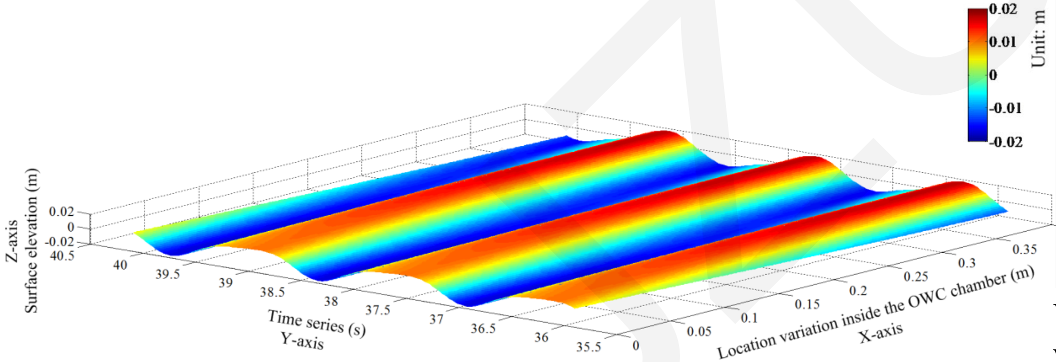
Parameters	Ranges
OWC model breadth B	0.4 m
OWC model height	0.4 m
OWC model draft D_r	0.10, 0.15, 0.20 m
Slot orifice	Breadth B_o =2.5 mm (α =0.625%), 5.0 mm (α =1.25%) and 7.5 mm (α =1.875%)
Circular orifice	Diameter D_o =41.0 mm (α =0.625%), 58.0 mm (α =1.25%) and 71.0 mm (α =1.875%)
Water depth h	0.4 m
Wave period T	0.9-1.6 s at 0.1s interval
Incident wave height H_i	0.035 m
Wave length L	1.22-2.84 m
Relative breadth B / L	0.141-0.327
Relative draft D_r / h	0.25, 0.375, 0.50

The instantaneous spatial profile of the water surface inside the OWC chamber can be reconstructed by a superposition of the waves propagating in opposite directions.

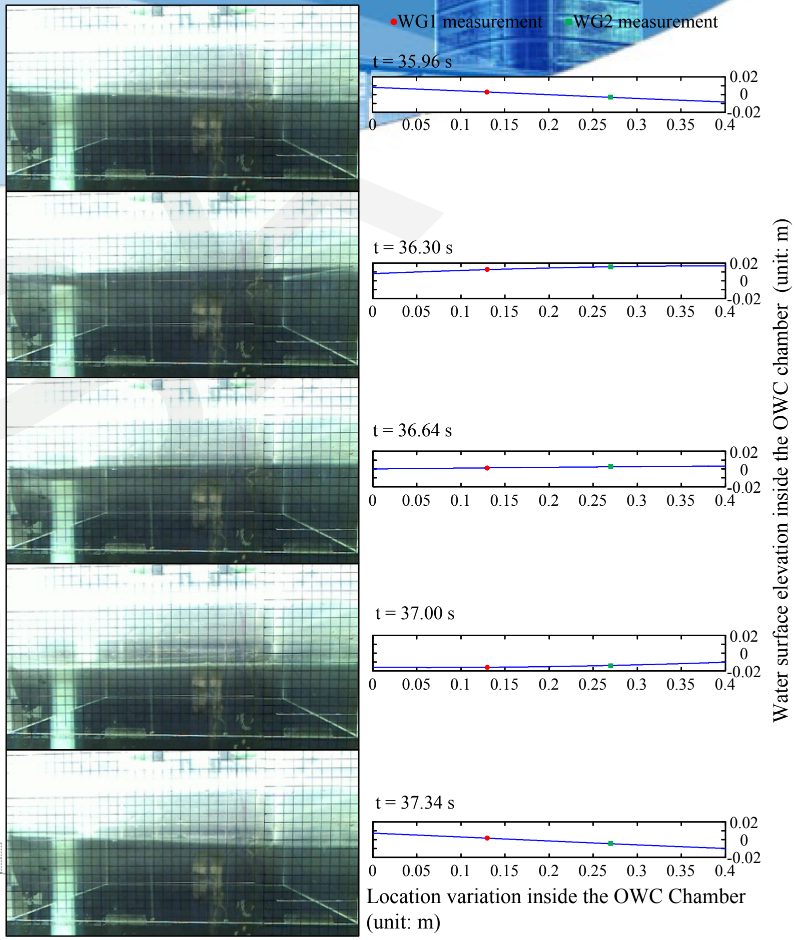
Reconstructed water surface inside OWC chamber

Test conditions:

Slot orifice of 1.25 % opening ratio
10 cm OWC model draft
1.4 s wave period



Variation of the water surface elevation inside the OWC chamber with space and time



Water surface elevation inside the OWC chamber during one wave period.

Left: snapshots of the video recordings.

Right: the surface elevations measured by WG1 and WG2, and the reconstructed water surface elevation inside the OWC chamber.

The time instants are the same for the left and right panels.

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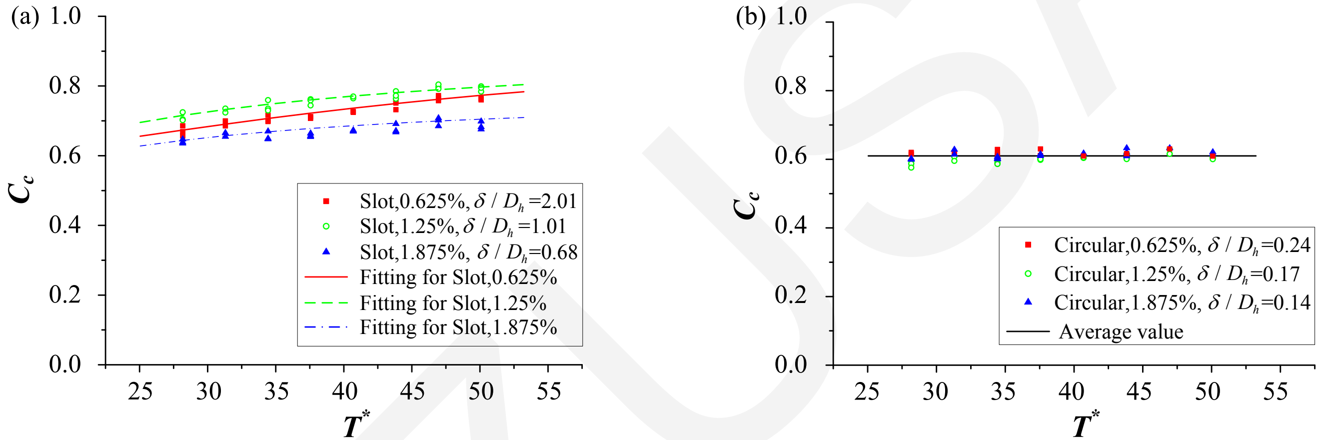
Orifice characteristics for modeling nonlinear PTO



Variations of contraction coefficient with dimensionless wave period for (a) slot orifices and (b) circular orifices

Empirical formula for contraction coefficient:

$$C_c = 0.61 \quad \text{for} \quad \delta / D_h < 0.5 \quad \text{(circular orifices)}$$

$$C_c = \tanh(\frac{\pi}{2}\frac{\delta}{D_h}) - 0.4\tanh(\frac{5\pi}{T^*}\frac{\delta}{D_h}) \quad \text{for} \quad 0.5 < \delta / D_h \le 2.01 \quad \text{(slot orifices)}$$

Quadratic loss coefficient: $C_f = \left(\frac{1}{\alpha C_c} - 1\right)^2$

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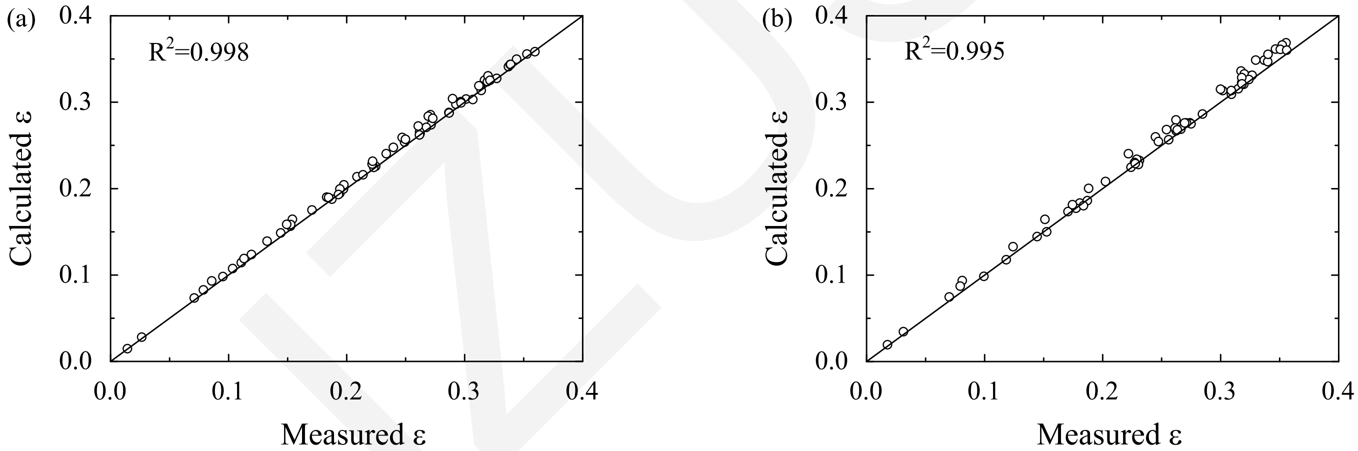
Calculating power extraction using pressure measurement

Period-averaged power extraction rate by the OWC device per unit length:

$$\overline{P}_o = \frac{B}{T}\int_{t_0}^{t_0+T}\sqrt{\frac{2|p(t)|^3}{\rho_a C_f}}dt$$



A comparison of the measured and calculated power extraction efficiency for (a) slot orifices and (b) circular orifices

It can be seen that the correlations between the measured and calculated values of power extraction efficiency were very good for both the slot and circular orifices.

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Conclusions

- It has been demonstrated that the spatial non-uniformity inside the OWC chamber can be well captured by the proposed two-point measurement method.
- Six orifices, including two shapes and three opening ratios, were used to model the nonlinear PTO characteristics, our results showed that the effects of both the relative thickness and oscillatory airflow were negligible for circular orifices which can be considered as thin-walled, but noticeable for slot orifices which can no longer be considered as thin-walled.
- Empirical formulas for the quadratic loss coefficient were proposed, which allows us to (i) design orifices characteristics for laboratory tests of OWC devices, and (ii) accurately measured the power extraction of various OWC devices by only measuring air pressure in the OWC chamber.
- It was also shown that the pressure coefficient was more reliable than the amplification coefficient as an indicator of the power extraction performance of an OWC device.

Previous publications related to this work

- **Fang He**, Zhenhua Huang, Adrian Wing-Keung Law, 2012. Hydrodynamic performance of a rectangular floating breakwater with and without pneumatic chambers: An experimental study. ***Ocean Engineering***, 51, 16-27.
- **Fang He**, Zhenhua Huang, Adrian Wing-Keung Law, 2013. An experimental study of a floating breakwater with asymmetric pneumatic chambers for wave energy extraction. ***Applied Energy***, 106, 222-231.
- **Fang He**, Zhenhua Huang, 2014. Hydrodynamic performance of pile-supported OWC-type structures as breakwaters: An experimental study. ***Ocean Engineering***, 88, 618-626.
- **Fang He**, Zhenhua Huang, 2016. Using an oscillating-water-column structure to reduce wave reflection from a vertical wall. ***Journal of Waterway, Port, Coastal and Ocean Engineering-ASCE***, 04015021.
- **Fang He**, Mingjia Li, Zhenhua Huang, 2016. An experimental study of pile-supported OWC-type breakwaters: energy extraction and vortex-induced energy loss. ***Energies***, 9(7), 540.