

WAVE BASIN MODELLING OF WAVE ENERGY CONVERTER ARRAYS TO EXPLORE IMPACTS ON NEARSHORE PROCESSES AND SHORELINE REALIGNMENT

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INTRODUCTION

The growing demand for decarbonised energy supplies and the protection of coastal environments in a changing climate provide a promising opportunity for the co-location of wave energy generation and coastal protection solutions. Evidence suggests that arrays of wave energy converters (WECs) may function in combination to provide coastal protection by absorbing and deflecting the incoming wave energy and converting it into power output (Abanades et al. 2014). The nature of WECs extracting energy from incident waves and modifying the surrounding wave field (i.e., from combined reflection and radiation) has the potential for changes to the local wave climate and coastal environment. The wave energy industry is currently still in its early development stages, with limited available information on the real-world performance and effects of WEC arrays deployed in the nearshore. In the absence of full-scale WEC array deployments, large-scale physical laboratory testing provides a valuable tool to deepen our understanding and obtain new insights, facilitating the development of control strategies and supporting the validation of numerical models.

This paper presents the approach used in the physical modelling of an array of generic oscillating water columns (OWC). A combination of wave flume and wave basin experiments were conducted to characterise a single OWC, wave shadowing by arrays of multiple OWCs, and the resulting effects on the planform coastline morphology by using a lightweight sediment model.

The results of these experiments are currently being used to develop and validate numerical methods that can capture the complex WEC array interactions and integrate them into widely used coastal numerical models (Cui et al. in review). The methodologies in this study can provide insights to future WEC developers to experimentally explore site specific effects of proposed WEC arrays on local nearshore wave and current conditions and their influence on beach morphology.

METHODS

The experiments were conducted in three stages in the facilities of the Water Research Laboratory, UNSW Sydney, Australia.

Stage 1: These tests were conducted in a 3 m wide by 32.5 m long wave flume with a constant water depth of 1 m. The focus of the flume testing campaign was to establish a detailed characterisation of the OWC parameters (draft, orifice damping, air volume) on power absorption and wave heights in the lee of a single device (Cohen et al. 2023). A total of 135 runs were conducted, encompassing 44 parameter combinations, including monochromatic and irregular wave conditions.

Stage 2: Arrays of OWCs (from stage 1) consisting of 8 or 16 devices were tested to explore the influence of different array configurations on wave heights and wave direction in the lee of the array. These tests were conducted in a 16 m wide, 28 m long wave basin equipped with a segmented multi-element wave maker capable of generating multi-directional wave conditions. The array configurations were divided into two categories: (1) five 'generic' setups involving regularly spaced identical OWCs, and (2) five tailored configurations with targeted optimisation goals. The generic configurations consisted of two 8-device spacings in a single line with adjustments made to OWC parameters, and three 16-device spacings arranged in 1, 2 or 3 rows with OWC parameters kept constant (e.g., Figure 1). The tailored configurations aimed to enhance salient formation, broaden wave energy absorption bandwidth, influence wave refraction, and simulate a worst-case erosion scenario. Comparative assessments were conducted against both an empty basin (i.e., no OWC devices) and configurations with inactive OWCs (i.e., blocked device entrances), allowing a comparison with conventional offshore-detached breakwaters. A total of 224 test runs were conducted encompassing 28 unique array-parameter configurations.



Figure 1: Array of 16 Oscillating Water Columns in the Wave Basin, arranged in two rows and equally spaced.

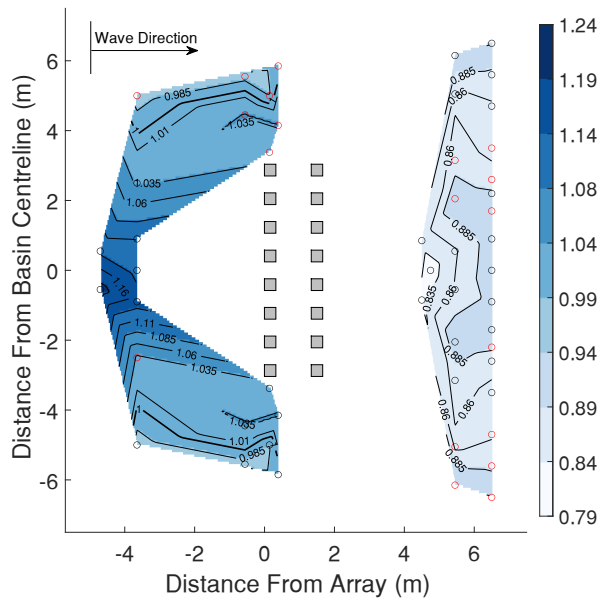


Figure 2: Reflection and Transmission Coefficient resulting from Array of 16 Oscillating Water Columns (grey squares) in the Wave Basin. Black circles indicate wave probe locations, red circles indicate the mirrored wave probe locations along the centreline, used in the in the colourmap interpolation.

Stage 3: In this final phase of testing, the 3D model was used to undertake a mobile shoreline sediment tracer study (e.g. Nielsen et al. 2000) to assess the influence of different WEC array configurations on shoreline alignment. A planar 1:15 constant slope bathymetry was installed across the full width of the wave basin in the lee of the WEC array. Lightweight sediment (granulated PVC with a $D_{50} = 0.4$ mm and density of 1.34 t/m^3) was used to construct a shoreline section of the profile extending from $2 H_s$ (significant wave height) below still water level (SWL) up to above the maximum run up level (R_{max}). Initial testing was conducted without any WEC in place to verify equilibrium shape of the beach and obtain a baseline dataset for comparison. Four different WEC array configurations from Stage 2 were then tested and the resulting beach width and shape were subsequently measured (through 3D LIDAR shoreline mapping) and compared to the baseline shoreline data.

RESULTS AND DISCUSSION

The extensive experimental program yielded diverse data encompassing various parameters, ranging from the detailed performance characteristics of individual WEC devices to the complex interactions within an array of devices and their resulting wavefield (e.g., Figure 2), and the wavefield impacts on the beach. This comprehensive dataset is now being used to validate numerical models, as it captures effects from a wide spectrum of scales and operational conditions, bridging gaps between array performance and sediment transport. This can be especially valuable to numerical modelers, as it allows them to verify and refine complex models that integrate these diverse scales. Furthermore, the methodologies employed contribute to the toolkit of WEC researchers and physical modellers, providing valuable insights into the understanding, design, and optimization of WEC arrays for coastal protection and energy generation applications.

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