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Optimising layout of wave energy converter arrays with respect to wave amplitude gradients associated with beach erosion

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1 Introduction

Dual-purpose wave energy converters (WECs) are proposed to not only capture renewable energy from waves, but also to provide coastal protection. The design of the "protection" aspect involves both reducing wave height and controlling longshore currents downwave of arrays (or 'farms') of the WECs. These longshore currents are responsible for sediment transport and are driven by the *gradient* of wave-radiation stress, as explained in *e.g.* Nam and Larson (2010). The gradient of radiation stress is further related to the gradient of wave amplitude. As such, the initial design considerations of dual-purpose WECs involve describing both the wave amplitude and the gradient of the wave amplitude around the array.

If there were only one possible array layout, the above tasks can be accomplished by BEM (boundary element method) software or formal analytical approaches such as multiple scattering; however, when the array layout is to be *optimised*, the aforementioned approaches can be prohibitively time-consuming, especially for medium- and large-sized arrays. To enable array optimisation, a fast semi-analytical method was developed in Cui *et al.* (2024). The method can find an array layout best for wave reduction in several minutes on a laptop computer for an array involving 8 devices. However, Cui *et al.* (2024) did not discuss the gradient of the wave amplitude. This gap is dealt with in this paper using an array of 16 OWCs (Oscillating Water Column) as an example. Wave energy extraction for electricity generation will not be discussed in this paper but we note in passing that it can be quantified by an increased damping of the system.

2 Material and methodology

The schema of an individual OWC used in the array is given in figure 1(a), adapted from Cohen *et al.* (2023). With a rectangular cross-section measured 0.2×0.3 m, its immersion depth is 0.565 m into a constant water depth of 1 m. From tests in a wave flume by Cohen *et al.* (2023) in regular waves of 0.02 m amplitude, figure 1(b) shows its amplification factor (the amplitude of internal motion divided by the amplitude of incident waves). Figure 1(c) shows the normalised wave amplitude map computed by the method in Cui *et al.* (2024). Taking a cross-section of the map at $x = 9.2$ m (an imaginary "beach" location), figure 1(d) shows the wave amplitude along the section.

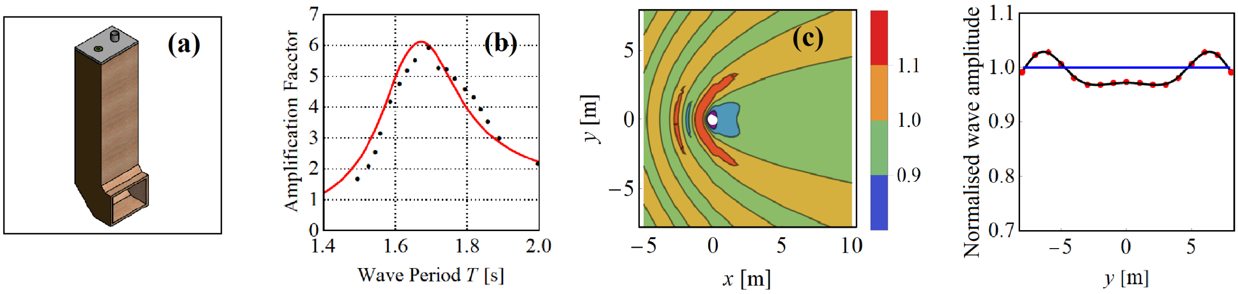

Figure 1. (a): an OWC device; (b): theoretical amplification factor curve (red) plotted against experimental data (black dots); (c): theoretical normalised wave amplitude map for $T = 1.5$ s. An OWC is placed at (0,0), represented by a white dot; (d): black curve is the theoretical normalised wave amplitude curve for $T = 1.5$ s at $x = 9.20$ m; red dots are BEM results.

Array calculations are performed by the method in Cui *et al.* (2024). The array involves 16 OWC devices arranged arbitrarily but confined to three rows to an area measuring 6×3 m; the array is then placed in a wave basin where a 15.5 m wide artificial beach with mobile model sand is constructed 9.2 m downwave of the array.

To enable comparison, the array is firstly optimised to maximise wave amplitude reduction at $x = 9.2$ m, similar to the case in Cui *et al.* (2024). Here "wave reduction" is measured by integrating the wave amplitude over the beach length. After this, the array is optimised with a different objective, *viz.* to reduce both wave amplitude and total gradient of wave amplitude at $x = 9.2$ m. The "total gradient" here is quantified by integrating the absolute value of gradient over the beach length. The results are shown in the next section.

3 Results

Figure 2(a) and (b) show the array best for amplitude reduction: the wave amplitude is reduced by 13.91% at $x = 9.2$ m, but the wave amplitude curve has a somewhat irregular large-gradient form. Figure 2(c) and (d) show an array optimised for both a decent wave reduction (reduced by 9.04%) and a smaller gradient, resulting in a "smoother" amplitude curve. The time to perform each optimisation on a laptop PC is about 20 minutes.

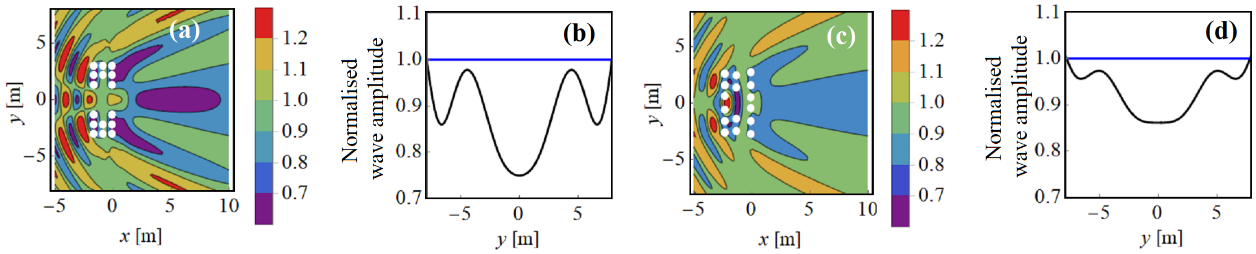

Figure 2. (a): normalised wave amplitude map around an array of 16 OWCs (white dots). The array is optimised to minimise wave transmission at $x = 9.20$ m, for $T = 1.5$ s; (b): theoretical normalised wave amplitude curve at $x = 9.20$ m; (c): normalised wave amplitude map for an array optimised against both wave transmission and wave amplitude gradient at $x = 9.20$ m for $T = 1.5$ s; (d): normalised wave amplitude at $x = 9.20$ m.

4 Discussions and Conclusions

The shape of the "wave shadow" (wave amplitude reduction) in figure 2(b) is somewhat irregular. This may lead to a confused longshore current pattern which, from a beach protection point of view, may be inferior. On the other hand, the wave shadow in figure 2(d) is similar to that of a traditional "wall-like" breakwater (Nam and Larson , 2010)), thus it is envisaged that the array in figure 2(c) can generate a longshore current similar to that of a traditional breakwater and nourish the downwave beach. Detailed calculations of longshore currents are left for future studies.

Acknowledgements

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References

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