

Impact of wave energy converter (WEC) array operation on nearshore processes

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Abstract

Before wave energy converter (WEC) arrays can be used to generate electricity at large scale, their environmental impacts need to be understood. Here, we examine the impact of large-scale WEC array operation on sand bars. Sand bars have an important role in natural coastal processes, since they protect our coastlines from the impact of storm waves. Since the wave climate between a WEC array and the coast will likely be modified by large-scale energy extraction, this could disrupt the natural process which maintains sand bars, affecting the location of wave breaking. We examine this hypothesised impact through application of a 1D cross-shore wave and sediment transport model. The model is applied initially to simulate natural sand bar formation. Wave energy is subsequently extracted at the model boundary, representing WEC array operation, and the morphodynamic impact assessed. Our results demonstrate that, under certain conditions, WEC array operation can lead to enhanced sand bar formation. Since reduced water depth over the bar enhances depth-induced wave breaking, WEC array operation could provide enhanced coastal protection from storm waves.

Keywords: Sand bars, Sediment dynamics, Wave energy converter (WEC) array, Wave model

1. Introduction

To reduce greenhouse gas emissions and aid sustainable development, there is an urgent need to support our electricity generating capacity through the development of low carbon technologies, particularly

those generated from renewable sources [1]. The ocean is a vast and largely untapped energy resource, which could be exploited by a range of technologies, including tidal and wave energy converters. The practically extractable worldwide wave energy resource has been estimated in the range 2000-4000 TWh/year, and so wave energy has been highlighted as a key contributor to the future global energy mix.

Any large-scale offshore wave energy converter (WEC) array has the potential to alter the wave climate between the array and the coast [2]. Within this region, sand bars remove energy from storm waves, and so have an important role in natural coastal protection due to depth-induced wave breaking [3]. Sand bars typically move shoreward when wave energy is low, and move offshore when waves are more energetic [4]. Since WEC array operation could modify the nearshore wave climate, and hence disrupt the natural process which maintains sand bars, WEC operation could have a role in coastal protection due to changes in the location of depth-induced wave breaking.

2. Case Study

To test this hypothesised impact of WEC array operation on nearshore morphodynamics, a case study was examined in southwest Wales, UK, a location suitable for exploiting the wave energy resource, with an annual mean wave power of around 20 kW m⁻¹ [5]. The cross-shore bathymetry profile includes a sand bar in water depth of around 8 m relative to mean sea level (Fig. 1). Bathymetry data was obtained from combining Admiralty chart data with a local bathymetric survey.

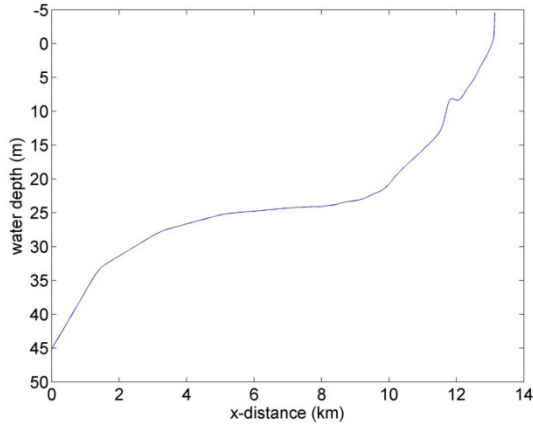


Figure 1: Cross-shore bathymetry profile. The sand bar is located at approximately $x = 12$ km, where water depth is around 8 m relative to mean sea level.

3. Cross-shore profile model

The cross-shore profile model, UNIBEST-TC, contains a wave propagation model (Fig. 2) which calculates wave energy decay along a profile, including the effects of shoaling, refraction and energy dissipation

$$\frac{\partial}{\partial x}(EC_g \cos \theta) = -D_w - D_f$$

where E is wave energy, Cg is group velocity, θ is the angle of incidence of the wave field, D_w is the dissipation of wave energy due to breaking, and D_f the dissipation due to bottom friction. After calculating the orbital velocity and mean current profile, bed load and suspended load are calculated, allowing the change in bed level z to be calculated using the depth-integrated mass balance equation

$$\frac{\partial z}{\partial t} + \frac{\partial q_{bed+sus}}{\partial x} = 0$$

The model includes feedback between the evolving bathymetry and the hydrodynamics.

Energy was extracted from the boundary of the model by considering the percentage joint distribution of T_p and H_s for one year of wave buoy data collected near the offshore model boundary (Fig. 3). The curve in Fig. 3 shows the theoretical relationship for a deep-water wave steepness of $1/20$. Energy was extracted from the model boundary by using this curve to reduce T_p and H_s in relative proportions to account for 10% reduction in wave energy due to WEC array operation. Although this is a relatively simple approach to account for WEC array operation at the model boundary, it is sufficient to enable a first order examination of the environmental impact on nearshore processes.

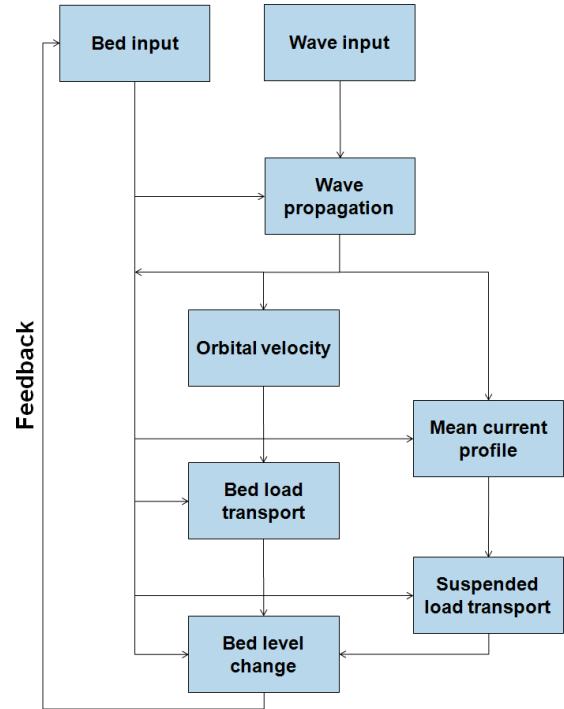


Figure 2: Overview of the cross-shore wave and sediment transport model, UNIBEST-TC.

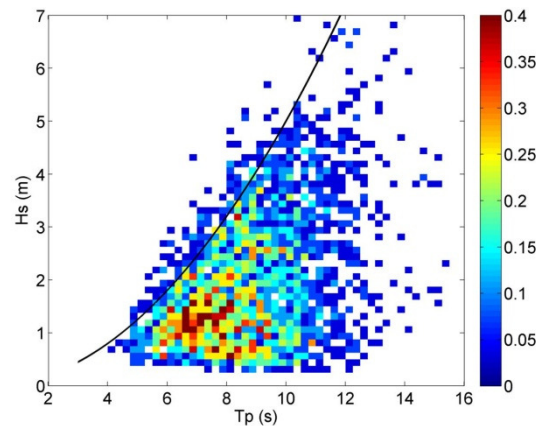


Figure 3: Percentage joint distribution of T_p and H_s for one year of wave buoy data collected near the offshore model boundary.

4. Results

The cross-shore profile model was applied to a range of model simulations, each of duration 6 months. Wave forcing at the boundary was held constant for each of these 6 month simulations, with wave periods in the range 3-10 s. For the 'natural' simulations, generally the sand bar migrated offshore when $T_p \geq 7$ s (Fig. 4). Subsequently, the simulations were repeated with 10% wave energy extracted at the model boundary using the methodology outlined in Section 3. Typical outputs are shown in Fig. 5 for a range of wave conditions. Generally, WEC array operation led to enhanced deposition at the bar and erosion of the bed seaward of

the bar, when $T_p \geq 7$ s. More details for $T_p = 7$ s are shown in Fig. 6.

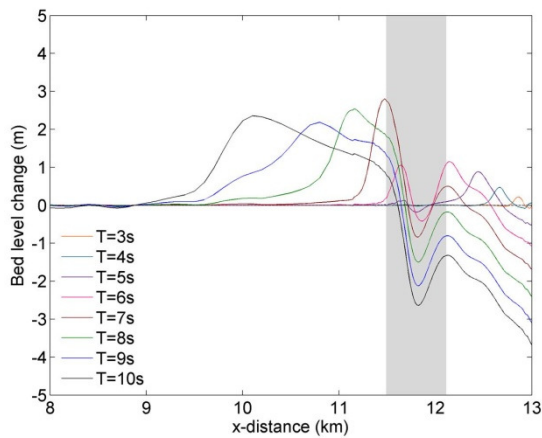


Figure 4: Natural change in bed level after 6 months of simulation. Grey shading indicates position of sand bar at the beginning of each simulation.

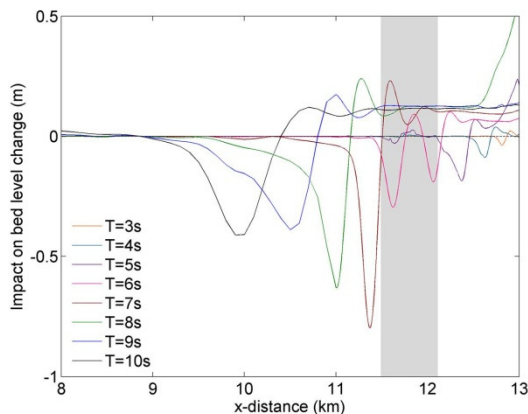


Figure 5: Impact of 10% energy extraction on bed level change after 6 months of simulation. Grey shading indicates position of sand bar at the beginning of each simulation.

5. Conclusions

Under certain conditions, WEC array operation can lead to enhanced sand bar formation. Since reduced water depth over the bar enhances depth-induced wave breaking, WEC array operation could provide enhanced coastal protection from storm waves. However, this hypothesis remains to be tested for variable wave

forcing over seasonal timescales, and for more realistic WEC array energy extraction scenarios.

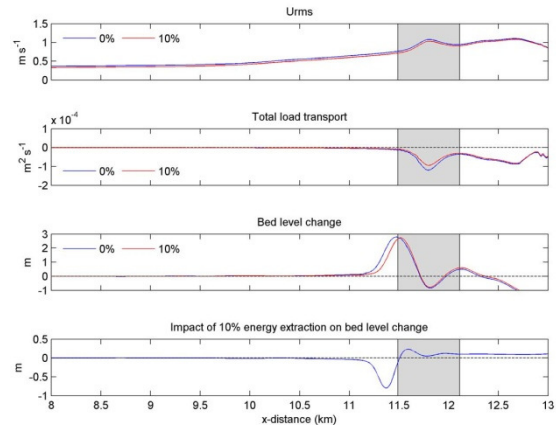


Figure 6: Impact of 10% energy extraction after 6 months of simulation for $T_p = 7$ s. U_{rms} is the root-mean-square wave orbital velocity at the bed. Grey shading indicates position of sand bar at the beginning of each simulation.

Acknowledgements

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References

- [1] A.S. Bahaj (2011) Generating electricity from the oceans. *Renewable & Sustainable Energy Reviews* 15, 3399-3416.
- [2] M.A. Shields, D.K. Woolf, E.P.M. Grist, S.A. Kerr, A.C. Jackson, R.E. Harris, M.C. Bell, R. Beharie, A. Want, E. Osalusi, S.W. Gibb & J. Side (2009) Marine renewable energy: The ecological implications of altering the hydrodynamics of the marine environment. *Ocean & Coastal Management* 54, 2-9.
- [3] K.M. Wijnberg & A. Kroon (2002) Barred beaches. *Geomorphology* 48, 103-120.
- [4] E.L. Gallagher, S. Elgar & R.T. Guza (1998) Observations of sand bar evolution on a natural beach. *Journal of Geophysical Research* 103, 3203-3215.
- [5] ABPmer, The Met Office & Proudman Oceanographic Laboratory (2008) Atlas of UK Marine Renewable Energy Resources. Tech. Rep., Department for Business Enterprise & Regulatory Reform.