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Wave farm impact on the beach profile: A case study

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ABSTRACT

If wave energy is to become a fully-fledged renewable, its environmental impacts must be fully understood. The objective of the present work is to examine the impact of a wave farm on the beach profile through a case study. The methodology is based on two coupled numerical models: a nearshore wave propagation model and a morphodynamic model, which are run in two scenarios, both with and without the wave farm. Wave data from a nearby coastal buoy are used to prescribe the boundary conditions. A positive effect on the wave climate, the cross-shore sediment transport and, consequently, the evolution of the beach profile itself due to the presence of the wave farm was found. The wave farm leads to a reduction in the erosion of the beach face. This work constitutes the first stage of the investigation of the effectiveness of a wave farm as a coastal defence measure, and the accuracy of the quantification of the erosion reduction will be enhanced in future research. In any case, the overarching picture that emerges is that wave farms, in addition to providing carbon-free energy, can be used as elements of a coastal defence scheme.

1. Introduction

Marine renewable energy and, in particular, wave energy is called to play a major role in achieving the renewable energy targets of the European Union for 2020 — the so-called 20-20-20 targets (European Commission, 2007). Among other advantages, wave energy boasts one of the highest energy densities of the renewable energy sector (Clément et al., 2002). At present, the main research areas in wave energy are: (i) the characterisation of the resource (Cornett, 2008; Iglesias and Carballo, 2009, 2010, 2011; Pontes et al., 1996; Vicinanza et al., 2013); (ii) the development of the technology (Falcão, 2007; Falcão and Justino, 1999; Kofoed et al., 2006); and, finally (iii) the environmental impact of wave farms, including the impact on the physical environment with which this work is concerned.

Knowledge of the impacts, positive or negative, is important for the development of the different types of marine energy because an Environmental Impact Assessment (EIA) is required for any such project. In the case of wave energy, the studies so far have dealt with the impact of a wave farm on the wave conditions in its lee. As waves propagate through the wave farm, their height is reduced according to an energy transmission coefficient. This coefficient depends on the performance of the Wave Energy Converters (WECs) selected. Millar et al. (2007) used SWAN (Booij et al., 1999), a phase-averaged spectral model, to quantify the impact on the wave climate and the shoreline changes for the Wave Hub project (UK). Notional values of the transmission coefficient (0, 40, 70 and 90%) were used due to the lack of information about the performance of the WECs at the time. In the same vein, Palha et al. (2010) used the parabolic mid slope wave model REFDIF to perform a sensitivity analysis to study the impact on the shoreline using different layouts for the wave farm; and Vidal et al. (2007) studied the impact of a small wave farm on the wave climate and the nearshore sediment transport.

Another line of work used physical modelling to investigate the wave–WEC interaction. Carballo and Iglesias (2013) studied the modification of the nearshore wave climate using values of the energy transmission coefficient obtained from ad hoc physical model tests of a WaveCat WEC (Iglesias et al., 2008). Taking into account of these values, a sensitivity analysis was performed with different layouts of the wave farm to assess its impact on the nearshore wave conditions. Mendoza et al. (in press) compared the impact of two wave farms with different WECs on the coastline. The results showed that a wave farm nearshore could produce accretion to some extent in some sections of the beach. In this context, Ruol et al. (2011), Nørgaard et al. (2011) and Zanuttigh and Angelelli (2013) put forward the idea of using a wave farm for shore protection based on the reduction of the nearshore wave height caused by the wave farm.

If a wave farm is to be used for the purpose of coastal protection, it is essential to understand its impact on the beach profile — an aspect of great practical relevance that has not been investigated so far. This is the main objective of the present work, which is conducted through a case study: Perranporth Beach.

Perranporth Beach is a 3 km sandy beach located in Cornwall, SW England (Fig. 1). Composed of medium quartz sand (Austin et al., 2010), it has a semi-diurnal tidal regime and a tidal range of 6.3 m (macrotidal). The area has a great potential for wave energy (Thorpe, 2001); indeed, it was selected as the site for the Wave Hub Project, a grid-connected offshore facility for sea trials of WECs (Gonzalez et al.,

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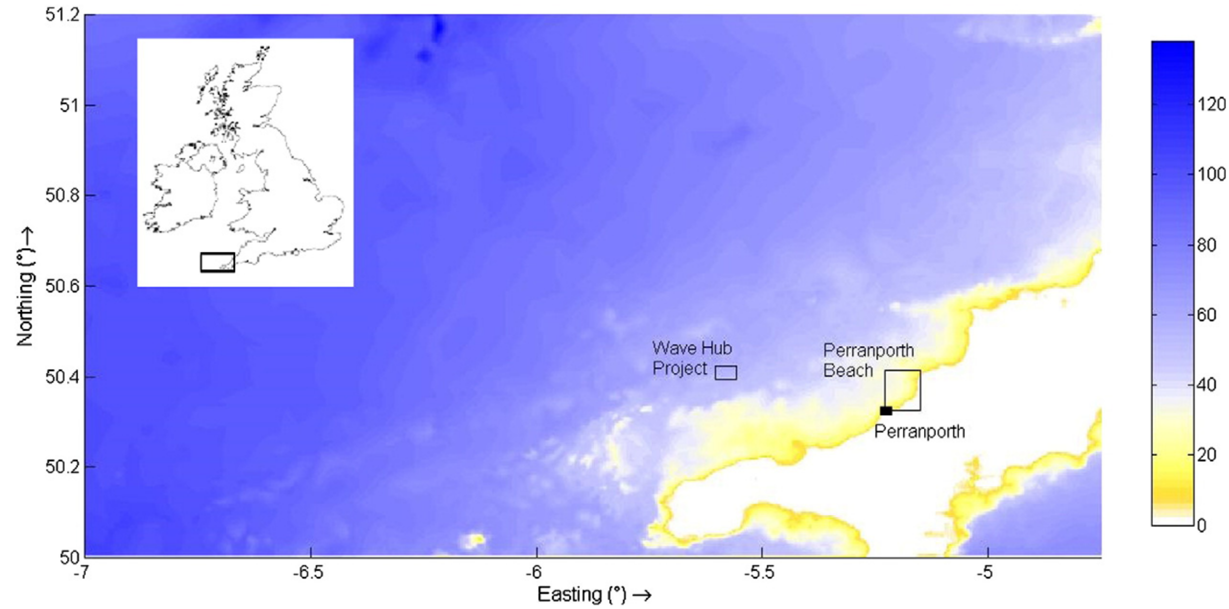

Fig. 1. Bathymetry of SW England including the location of Perranporth Beach and the WaveHub Project [water depths in m].

2012; Reeve et al., 2011). The study covered the period from November 2007 to May 2008, corresponding to the part of the annual cycle with the highest frequency of storms based on the onsite wave buoy data (Section 2.1). This time scale allows the assessment of the morphological changes in beaches, such as scarp formation, profile erosion and accretion, and bar evolution (Cowell and Thom, 1994).

Wave propagation was simulated using SWAN and the beach profile evolution with XBeach, a numerical model of nearshore processes (Roelvink et al., 2006). XBeach was successfully applied in a number of studies to describe the behaviour of beach profiles. Roelvink et al. (2009) assessed the beach erosion due to storms and McCall et al. (2010) focussed on the impact caused by hurricanes. Other authors, such as Jamal et al. (2011) and Williams et al. (2012), used XBeach to investigate gravel beaches. More recently, Pender and Karunarathna (2012, 2013) demonstrated that XBeach is capable of modelling the medium-term evolution of the beach profile of a sandy beach. Their results showed a good fit to the measured profiles after each storm period. On these grounds, XBeach is used in the present work to compare the evolution of the beach profile with and without the presence of a wave farm situated close to Perranporth Beach.

This article is structured as follows. In Section 2, the main characteristics of the data sets – which include wave, wind, tide and beach profile data – are presented, and the models are briefly described. This is followed by Section 3, in which the results describing the impact of the wave farm on the wave conditions and the evolution of the beach profiles are presented and discussed. Finally, in Section 4, conclusions are drawn concerning the effects of a wave farm on the beach profile and, on these grounds, its applicability for coastal protection purposes.

2. Materials and methods

2.1. Data

The wave data used for this study were hindcast and onsite wave buoy data. The directional wave buoy of the Coastal Channel Observatory located in front of Perranporth beach (Fig. 2), in approximately 10 m of water depth with reference to the local chart datum (LCD), provided half-hourly data. The wave buoy data were used in conjunction with hindcast data from WaveWatch III, a third-generation offshore wave model consisting of global and regional nested grids with a resolution

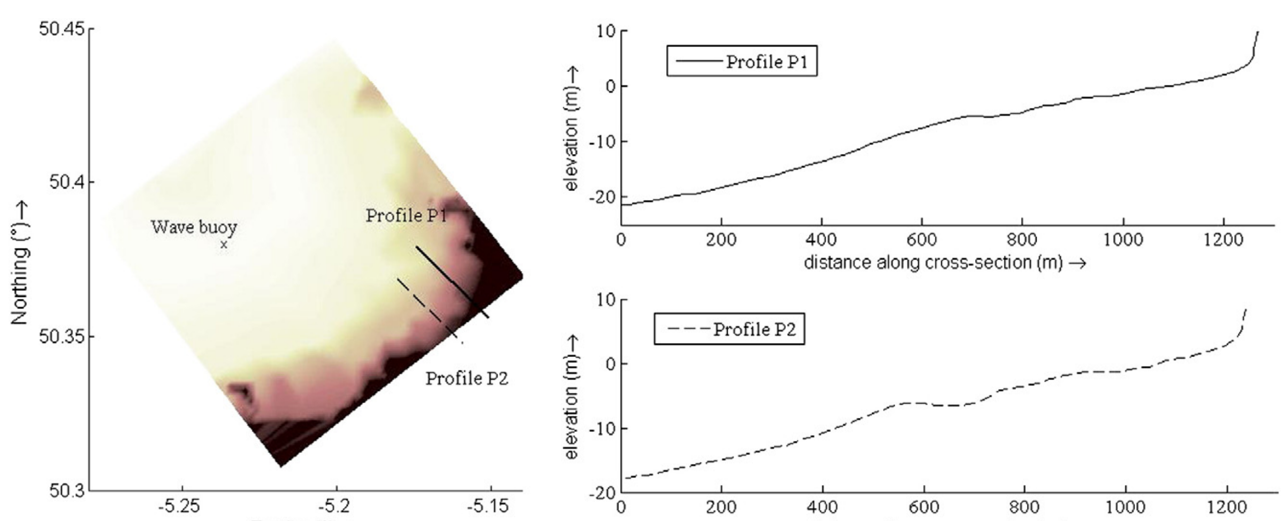

Fig. 2. Initial beach profiles (P1 and P2) including their location and the position of the wave buoy. Water depth in relation to local chart datum.