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Beach response to wave energy converter farms acting as coastal defence

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ABSTRACT

One of the greatest challenges of coastal engineering today is the need for coastal protection in the changing climate scenario. Places which are nowadays protected will demand upgraded defences and more sites will require security; in all cases a large amount of resources will be needed to ensure beach maintenance and coastal safety. This may be an opportunity for the multi-purpose use of Wave Energy Converters (WECs) if the foreseen increase of energy demand in coastal areas is also considered. In this paper a group of WECs based on different operating concepts is numerically tested in front of two beaches, i.e. the Bay of Santander in Spain and Las Glorias beach in Mexico, representing two different case studies where the long-shore sediment transport is dominant. The hydrodynamics induced by these devices is represented by means of a 2D elliptic modified mild-slope model that is calibrated against new experimental results. The wave field is then used as input for the analytical calculation of the long-shore sediment transport and the coastline trend is estimated by applying the continuity of sediment equation. The characteristics of the selected numerical models give this work a first approach level. All the devices were found to produce a positive trend (accretion) at least in small areas. Recommendations are given to facilitate the selection of the device and the design of the farm layout for shore protection purpose.

1. Introduction

The expected increase in number and intensity of storms due to climate change, the present situation of coastal areas already severely exposed to erosion and flooding together with the need to preserve coastal ecosystems in a way acceptable to societies point the way for careful, long-term, innovative coastal defence strategies. Nourishment alone is one of the preferred protection techniques; however experience has already shown that its efficiency and lifetime is considerably increased when the shore is protected by hard defences. Also, local sand resources are limited, leading in many cases to the search for alternative sites for borrowed sand areas (off-shore deposits, dredging from river mouth and harbour entrance). As far as is possible, the hard defences should be climate proof (i.e. characterized by low sensitivity to sea level rise), environmentally friendly (i.e. constructed with eco-compatible materials) and eventually characterized by low visual impact on the horizon (i.e. submerged or low-crested).

Moreover, economic and social growth in coastal areas in the recent past, suggests that the local energy demand will continue to grow and lead to an increase of anthropogenic stressors on top of the climatic and environmental sources of threat. The sea space in particular may be subject to additional installations for aquaculture, exploitation of renewable energy, oil and gas, transportation, etc. Among these installations, Wave Energy Converters (WECs) are particularly interesting since they partially absorb waves in producing electricity and may thus reduce the wave energy incident on the littoral. It is, however, undeniable that implementation of many of the small scale WECs developed and scale tested worldwide is still far from being considered a reality as construction, operation and maintenance costs compared to the economic recovery times make them unaffordable.

The combination of these observations prompted the idea that the THESEUS project investigates a systematic way of using floating WECs for coastal protection. The concept of WECs as multipurpose structures may be a win–win alternative, making feasible the implementation of proven and newly developed devices and, at the same time, obtaining a certain degree of beach protection, although this will be limited by the specific features of the WEC (installation depth, layout of the array, etc).

So far the hydrodynamic performance of large parks of WECs and therefore their optimal mutual placement for energy absorption has been studied mainly through numerical models, Folley et al. (2012). This leads us to suppose a possible limitation; although a WEC farm can be used as coastal defence it has to be placed where it finds its optimal efficiency and this is not necessarily the best location for coastal protection, so a comparison between the performance of WECs as costal

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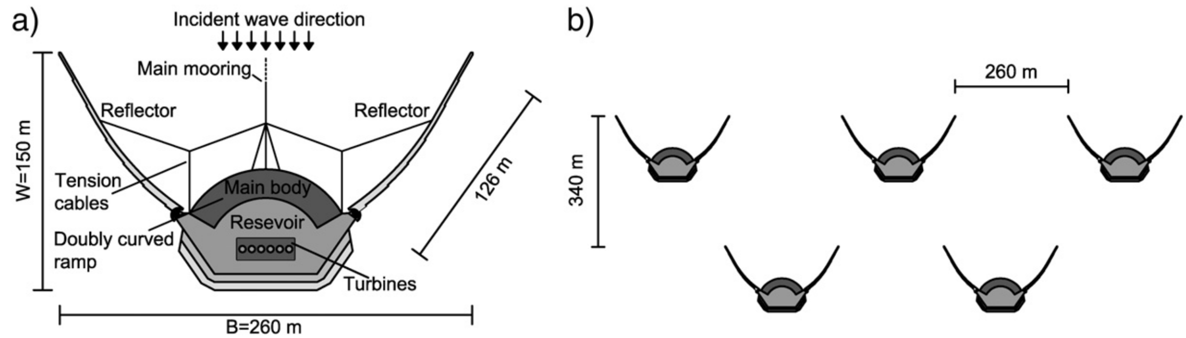

Fig. 1. a) Overall dimensions of the 24 kW/m WD-model. b) Distances between individual devices when positioned in a staggered grid.

defence and traditional alternatives would be unfair because of these spatial constraints.

The concept of the park effect dates back to 1980, when the pioneers Budal (1977), Evans (1979) and Falnes (1980) analytically studied the use of heaving axisymmetrical WECs under regular and unidirectional waves. Similar studies, i.e. following the linear potential flow theory, have been recently proposed by Child and Venugopal (2007) and by Garnaud and Mei (2009). However this approach is not applicable under irregular wave conditions or in the case of devices with Multiple Degrees of Freedom.

More realistic numerical codes are based on the boundary elements methods (BEM), such as WAMIT, ANSYS Aqwa, Aquaplus, etc. Examples of BEM calculation can be found for arrays of heaving point absorbers by Ricci et al. (2007) and floating Oscillating Surge Converters by Borgarino et al. (2011). However even the BEM codes have limitations, mainly related to the constraints of the uniform water depth, to the high CPU requirement and to their inability of modelling viscous effects directly, Li and Yu (2012).

Boussinesq and spectral wave models are designed for wave propagation over large domains accounting for sea bottom effects. The main limitation of these models is the impossibility to intrinsically simulate moving structures. WECs have been represented as porous layers with a given reflection/transmission coefficient by Millar et al. (2007), Venugopal and Smith (2007) and by Mendes et al. (2008). Beels et al. (2010) performed numerical modelling of WEC farms using mild-slope wave propagation models and sponge layer technique and Folley and Whittaker (2010), developed a spectral model to evaluate the performance of WECs.

The most significant conclusions from the numerical modelling of WECs were reviewed by Babarit (2013) in the form of guidelines for WEC farm layout. In particular, for small devices (whose typical long-shore dimension, B, is 10–20 m) deployed in small arrays (up to 20 devices), with a mutual distance around 10–20 B it is suggested that they be placed in limited number of wave farm lines. It is worth noting that the main target of most studies related to WECs is the generation of power by such installations. Therefore the wave farm design does not take into account secondary goals, for instance: the narrower the gap width the higher the wave absorption and therefore the lower the wave transmission; for information on the accessibility of the offshore wind farm in the lee of a WEC farm, the reader is referred to Beels et al. (2011).

Within the THESEUS project, four different WECs were studied as near-shore protection alternatives. These WECs included an overtopping device (Wave Dragon, www.wavedragon.net), multi-oscillating water-column device (Seabreath, www.seabreath.it), wave activated bodies (DEXA, www.dexawave.com), and a new concept (Blow-Jet). The wave transmission curve for a single device was experimentally derived (Nørgaard and Lykke Andersen, 2012; Ruol et al., 2011a; Zanuttigh et al., 2013) and the hydrodynamic interaction of multiple devices when placed in farms was numerically modelled (Angelelli and Zanuttigh, 2012; Nørgaard and Lykke Andersen, 2012).

Little attention has been paid so far to the response of the coastline in the presence of WECs. To the authors' knowledge, only Millar et al. (2007) studied the shoreline change due to a generic wave farm while Zanuttigh et al. (2010) and Ruol et al. (2011b) analysed the effects of a DEXA device on the long-shore sediment transport at a specific location.

The aim of this paper is to systematically analyse the performance of the same WECs examined in THESEUS in terms of coastal protection and to estimate the induced shoreline change. This analysis is performed numerically in a homogeneous way for all the devices, through the 2D porous mild-slope model from Silva et al. (2006).

More specific objectives of this paper are: to evaluate the coastline response to the modified wave field around the WEC farms and to provide the reader with design criteria for WEC installations for coastal protection.

In Section 2 a brief description of the devices is presented together with highlights of the transmission coefficient functions. Section 3 describes the study sites as well as the design of the WEC farm layout. It also shows the results of the 2D wave propagation model. The numerical model for the evaluation of the coastline response and its results are the object of Section 4 and the over-all conclusions are given in Section 5.

2. Description of the WEC devices

2.1. The Wave Dragon

In Nørgaard and Lykke Andersen (2012) the use of different concepts of Wave Energy Converters (WECs) for the combination of electricity production and coastal protection is discussed. One of the promising concepts is the Wave Dragon (WD) due to its size and large

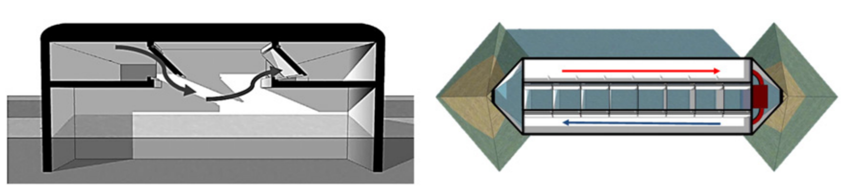

Fig. 2. Cross-section (left) and plan view (right) of Seabreath.