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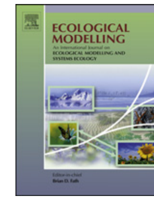

Disruption to benthic habitats by moorings of wave energy installations: A modelling case study and implications for overall ecosystem functioning

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ABSTRACT

This paper presents the research carried out in the marine renewables group of Heriot-Watt University, where the physical models of wave energy converters are first tested in the wave basin, and the results of their behaviour are then compared to the simulations performed using mathematical modelling. An OrcaFlex model is used to assess the scouring effect on bottom sediments and consequent disruption of benthic habitats, and open water tests are being conducted to compare the model performance with the actual observations. The output from OrcaFlex is then imported to Matlab, where the affected area is calculated using the time series of coordinates of touch down points of the mooring lines. The results show that the area of benthic habitats adversely affected by the leading mooring line on a typical wave energy converter (WEC) monotonically increases with the increase in wave height. In regular waves of 6 m height and 8 s period, the area of benthic habitats adversely affected by the mooring lines may exceed 60 m^2. In addition to the direct effect on benthic habitats, sediment erosion by mooring lines will effect a whole range of ecosystem processes, e.g. due to changes in biogeochemical cycling and light penetration. These issues should be given a due consideration in calculations of ecological risks and EIA of any moored objects.

1. Introduction

Historically, human society has developed with little consideration of environmental impacts. In particular, much of the recent (i.e. last few centuries) technological progress has been based on non-renewable energy sources (Odum and Odum, 1976). In the last century, however, rapid economic growth has increasingly begun to be restricted by the availability of energy supplies and abatements for pollution control (Meadows et al., 1972, 1992a,b). Consequently, growing environmental problems and associated public concern, together with the development of science (in particular natural and social sciences) and technology, have led to the emergence of a new branch of science called 'Industrial Ecology' (Korhonen, 2001; Korhonen and Snakin, 2005). According to the concept of Industrial Ecology, the sustainable development of Humankind and functioning of the global ecosystem, the Biosphere, should be reliant on the usage of renewable energy sources and efficient recycling of energy and matter (Krivtsov et al., 2004). Recently, therefore, the global usage of renewable energy has been developing with an accelerating pace (Jones and Rowley, 2002; Lund, 2007).

Renewable energy resources are abundant, inexhaustible and environmentally friendly (Muneer and Asif, 2007). Wave power, in particular, is deemed to be a very promising energy source, even in moderate wave climates and case studies in, e.g., Scandinavia have demonstrated its physical possibilities and environmental advantages (Henfridsson et al., 2007). It should be noted, however, that whilst planning and designing renewable wave energy installations, care should be taken as regards their environmental impact assessment (Langhamer et al., 2010). Such an EIA should, among other considerations, include an assessment of potential changes of their operational characteristics related to alterations in the wave regime and sea-level rise due to global climate change. One important aspect which is often overlooked relates to the interaction between moorings and the sea bed. Conventional moorings for floating wave and tidal energy converters sited in shallow water include heavy mooring lines which thrash violently against the sea bed during storms. This thrashing action disturbs the benthic community and can cause local sea bed erosion.

1.1. Modelling

OrcaFlex (Orcina Ltd.) is a marine dynamics modelling tool designed for static and dynamic analysis of a wide range of offshore installations, including, e.g., marine risers (rigid and flexible), moorings, and towed systems (see http://www.orcina.com/). It

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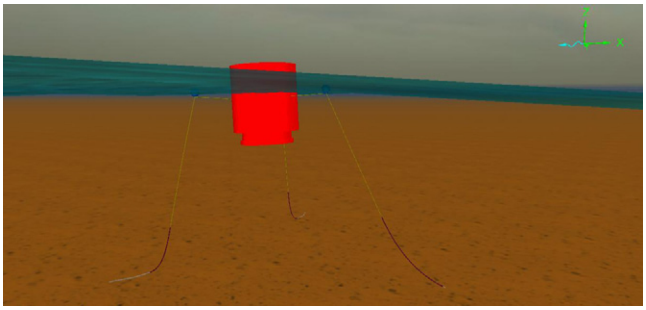

Fig. 1. Screenshot of the OrcaFlex model's window showing the relevant section of the water column and bottom sediments, and the simulated wave energy converter. Points were the mooring lines touch the bottom affecting the benthic habitats are shown in a light colour. The direction of wave propagation is indicated by a wavy arrow. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)

is a 3D non-linear time domain finite element program, widely used in the defence and oceanography sectors (Orcina, 2011), able to model complex interactions of vessels and industrial objects with water currents and a comprehensive choice of wave regimes. The equations used in OrcaFlex and the theory behind them are variously described elsewhere (Orcina, 2011). The model has a substantial validation track record (see http://www.orcina.com/SoftwareProducts/OrcaFlex/Validation/index.php); in particular, simulation of the touch down dynamics of mooring lines (the crucial variable for the research presented here) has previously been successfully validated (da Silveira and de Arruda Martins, 2005).

In ecological research, the OrcaFlex modelling software has previously been used to design a complex fish passage (Allyn et al., 2008). Applications of OrcaFlex in studies related to the renewable marine energy devices have also been reported (Cribbs and VanZwieten, 2010; Rhinefrank et al., 2010).

It should be noted here that OrcaFlex does not provide a calculation of the area of benthic habitats affected by mooring lines. However, after importing the OrcaFlex output into Matlab, the area of the affected sea bed can be estimated from the time series of touch down coordinates using a custom-made script. The latter program first determines maximum and minimum values of *X* coordinate, then splits the *X* interval into *N* subintervals. Then the maximum and minimum values of *Y* coordinate are determined for each interval. The area at each subinterval is subsequently calculated as (MaxYi-MinYi)*deltaX, and finally the total area is found by summation. Sea bed is assumed to be plane, and *Z* coordinate of the touch down point therefore equals the depth (i.e. is assumed to be at the sea bed).

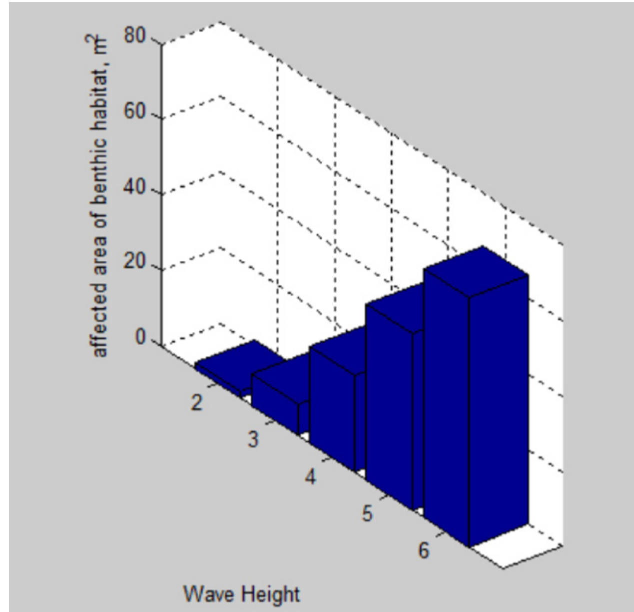

Fig. 3. Summary of the results showing the area of adversely affected benthic habitat in regular waves with period of 8 s and wave heights between 2 and 6 m. These values were calculated for the whole simulation period.

2. Results

Here we present the results of five modelling scenarios, carried out for a typical (height 19 m, diameter 16 m, mass 900 tonnes) wave energy converter (WEC) of an oscillating water column (OWC) type with a three point mooring installed in 40 m of water depth (Fig. 1), and wave regime conforming to regular waves between 2 and 6 m height with 8 s period. For simplicity, the wave climate was kept simple, and neither the wind effect nor tidal current was considered at this stage. An example of the OrcaFlex simulation time series is presented in Fig. 2. It is evident that after a transient interval at the beginning of the simulation, the model enters a steady cycle. The summary of the relevant results is presented in Fig. 3.

The results show that, in regular waves, the area of benthic habitats adversely affected by the mooring lines may exceed 60 m^2. If, however, only the duration of the steady cycle is considered, then

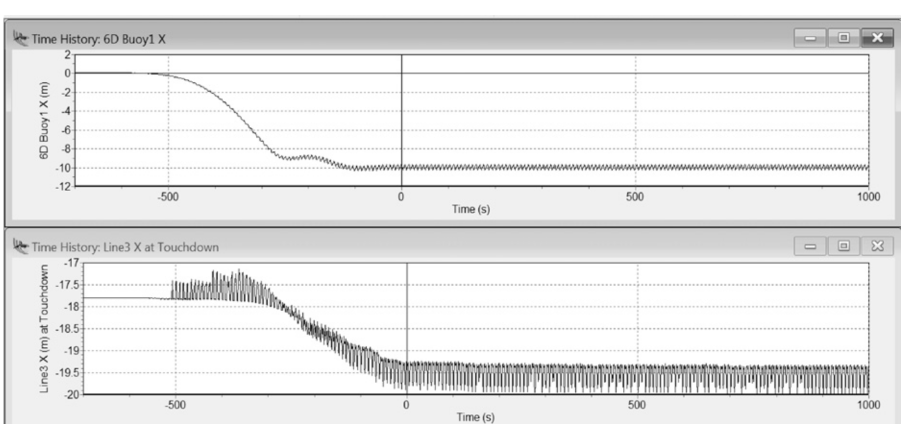

Fig. 2. A screenshot with an example of an OrcaFlex simulation time series showing changes in the position of the WEC along the *X* axis and the touchdown point of a mooring line along the *X* axis. This simulation was performed for regular waves (H = 4 m, T = 8 s). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)