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Snatch loading of a single taut moored floating wave energy converter due to focussed wave groups

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ABSTRACT

This paper concerns experimental measurements of the interaction of a taut moored floating body, representing a wave energy converter in survivability mode, with extreme waves. Focussed wave groups, based initially on NewWave theory, are used to generate the extreme waves, with crest amplitude exceeding the mooring's design capacity. Two data sets are presented and discussed. In the first the influence of wave steepness on model response and mooring load is investigated using non-breaking focussed wave groups. In the second the influence of wave breaking location is investigated using a plunging breaking wave. Both data sets exhibit snatch loading as the extension of the mooring is exceeded. The magnitude of this loading is not found to be strongly dependent on wave steepness, while the following motion response of the body is. Breaking location has a much greater effect than wave steepness on the magnitude of the mooring load, while significant influence of the body motion and displacement on the mooring load is demonstrated. Evidence is provided that the use of individual focussed wave groups is inadequate to assess fully the extreme loads experienced by a taut moored WEC due to the demonstrated dependence of mooring load on the body's motion and displacement.

1. Introduction

Regardless of their location in the ocean, wave energy converters (WECs) have two primary requirements: to provide efficient conversion in small to moderate seas and to survive storm conditions (Barstow et al., 2008, p. 52). An important factor to consider when assessing the ability of a device to survive storms is its response when hit by an extreme wave. The accurate prediction of extreme loading due to waves is therefore important in the design process of a WEC.

One approach that can be used to estimate the response is by conducting scaled experiments of the WEC in storm sea conditions. This requires long duration runs before a statistically reliable assessment of the extreme loading can be made. Such approaches are expensive, both in terms of time and facility use, and can be difficult to implement accurately due to the increasing influence of wave reflections.

An alternative approach for measuring extreme responses at scale is the use of focussed wave groups. These are generated by adjusting the phase relationship between wave components of different frequencies so that a concentration of energy is achieved at a specified time and location in the tank. Zhao and Hu (2012) use this technique to measure the interactions of an extreme wave with a floating body constrained to move in heave and pitch only.

A specific type of focussed wave group was introduced by Tromans et al. (1991) and is called NewWave. NewWave theory produces, for a given sea state, the average shape of the highest wave with a specified exceedance probability (Xu et al., 2008). This design wave has been used experimentally and numerically in various applications. Rozario et al. (1993) successfully compared the loads predicted by NewWave on a North Sea oil platform with simulations of random seas. Borthwick et al. (2006) measured wave kinematics of NewWaves impacting on a 1:20 beach plane, while Hunt-Raby et al. (2011) measured wave overtopping of embankments. The interaction of fixed cylinders with NewWaves has been studied to assess extreme wave impacts, relevant for a wide range of offshore structures (Walker and Eatock Taylor, 2005; Stallard et al. 2009a; Ransley et al., 2013; Zang et al., 2010).

NewWave groups have also been used previously to study extreme loading on floating devices. Stallard et al. (2009b) used this form of focussed wave to measure the response of a float suitable for a wave energy converter in extreme waves. In this study the float was not moored, but instead a fixed force was applied to the float, initially vertically, using a mass attached via a pulley above the float. Xu et al. (2008) studied extreme loading on

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the bow of an FPSO (Floating Production Storage and Offloading vessel) using NewWave theory, extending the theory to generate steep waves. Taylor et al. (1997) conducted simulations using a NewWave embedded into a random wave sequence to estimate the extreme response of a Jack-up. This simulated the effect of load history and structural dynamics which are not present when using an individual focussed wave group. Taylor et al. (1997) predict that for a dynamically-responding structure the extreme response does not necessarily correspond to the extreme surface elevation. This study has shown this to be the case.

In the experiments reported here focussed wave groups, based initially on NewWave theory, have been applied to measure the response of a generic wave energy converter to extreme waves. A single taut moored floating point absorber, representing devices such as the CETO, AWS (Stallard et al., 2009b), SeaBeav1 (Elwood et al., 2011) and the Uppsala University WEC (Waters et al., 2007), has been tested. The mooring was designed so that its extension was insufficient to fully accommodate the waves tested and extreme loads were hence generated in the mooring line and anchor. Full scale moorings are designed to try and avoid this form of loading due to the potential damage it can cause. These extreme loads reflect a worst-case scenario which these experiments aimed to investigate.

Two series of tests have been conducted. In the first a NewWave wave group was focussed at the front face of the device at its initial position. The steepness of this wave group was then increased, up to just before the wave breaks, while maintaining the physical location at which the group was focussed. This allowed the effect of wave steepness on the model's response to be assessed. The second series of tests investigated the response of the model to a plunging breaking wave. These were generated by increasing the steepness of the wave group further. A series of tests were conducted varying the theoretical focus location of the wave group so that the plunging breaker formed at different locations relative to the device. Repeat experiments were conducted to ascertain variability of the measurements.

In both test series the motion of the model and the mooring loads were recorded. By measuring the dependence of motion and loads on both wave steepness and breaking point an assessment could be made of the validity of using single focussed wave groups to measure extreme wave impacts on a single taut moored floating body. The data is also being used to validate a CFD numerical model of a floating WEC.

These measurements were conducted as part of the EPRSC X-MED project (Extreme loading of marine energy devices due to waves, current, flotsam and mammal impacts). They were also the first measurements to be conducted at Plymouth University's ocean basin (COAST Lab, 2013).

2. Experimental methodology

2.1. Model wave energy converter

There is a wide range of variability in the design of wave energy converters. Clément et al. (2002) stated that over 1000 wave energy conversion techniques were patented in Japan, North America and Europe by 2002, while over the last decade the development of device concepts has continued. These devices can be classified according to where they operate (Polinder and Scuotto, 2005; Barstow el al., 2008, p. 46). Shoreline devices include devices mounted on shore or on the seabed in shallow water and near-shore devices operate in 10–20 m water depths and up to a kilometre from the shore. This research is primarily concerned with the third category of devices, those in the offshore environment, which contains the most energetic wave climate. Offshore devices therefore have the potential to extract most energy, but are also exposed to the most extreme conditions during storms.

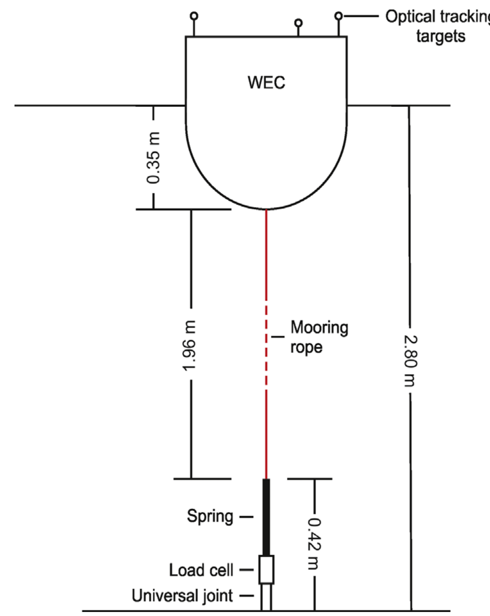

Fig. 1. Model set-up and instrumentation.

Devices can also be classified according to working principle. Falcão (2010) identifies 3 categories of devices: oscillating water columns, oscillating bodies and overtopping devices, each with a number of sub-categories. This study has been conducted on a floating body designed to represent a floating oscillating water column or floating oscillating body. Even within these subcategories there is a wide variability in both design and mooring arrangement, and in order to ensure that results are generally applicable, a simple buoy representing a generic WEC has been selected for investigation.

The design of the model is shown in Fig. 1. It is a 0.5 m diameter hemispherical floating body with a single taut mooring and a dry mass of 43.2 kg. The mooring consists of 1.96 m of Dyneema® rope (spring constant, $k \approx 35$ N/mm) in series with a linear spring ($k=0.064$ N/mm), which provides the mooring's extension. Four lengths of the same rope act as end-stops for the spring, preventing it from being overextended (Fig. 2). The initial and maximum lengths of the spring are 152 mm and 406 mm respectively. In still water the spring was extended to 257 mm, giving a further possible extension of 149 mm, 56% of the theoretical main wave crest of the initial NewWave (Fig. 3). This mooring arrangement is similar to that used by Eriksson et al. (2006) during full scale tests on a cylindrical buoy designed for use as a wave energy converter.

A model power take-off (PTO) has not been incorporated into the experimental set-up for a number of reasons. Firstly the wide range in design and properties of PTOs used by different devices would make modelling a meaningful 'generic' PTO difficult. Secondly some devices lock the PTO or disconnect from it during storms to avoid damage. Finally, this research is concerned with assessing the most extreme device reactions. Including a model PTO would extract energy and potentially damp the response of the device (Stallard et al., 2009b), which would therefore not represent the extreme.

A series of decay tests were conducted on the model and mooring system to measure its resonance frequencies. These were found to be 0.93 Hz for heave, 0.68 Hz for pitch and 0.04 Hz for surge.

2.2. Experimental layout and instrumentation

Measurements were conducted in a 35 m × 15.5 m ocean basin at Plymouth University's COAST laboratory. The variable floor depth