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Sea Trials of a Wave Energy Converter in Strangford Lough, Northern Ireland

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Abstract: This paper describes a campaign of WEC (wave energy converter) testing and presents a selection of the results related to the measured motions and mooring tensions. A 1:20 physical model has been successfully deployed using a three point mooring installed at sea (Strangford Lough, NI) in 10 m depth. In calm weather the overall dynamics of mooring tensions is dominated by the tidal cycle due to the progressive lifting of the heavy chain with the increase in water depth on the flood and gradual lowering on the ebb. In fresh winds the dynamics is very complex, but can be studied with the aid of mathematical modelling. A simulation model was used to assess the dynamics of the mooring lines, and the results of open water tests have been compared with the model's performance. The results indicate that, in general, the model shows a reasonable agreement with the observations. The WEC's motions and the measured loads on the leading mooring line appear to relate to the concurrent environmental conditions. The data obtained can therefore be used for the model's calibration and further improvements, which is valuable for improving the WEC's design and operational characteristics. This may be important not only in relation to the issues of reliability and power take off, but also in terms of minimising the adverse effects of mooring lines on bottom sediments, as well as indirect effects of the eroded particles on a wide range of aquatic processes.

Key words: Bottom sediments, mooring loads, meteorological data, model simulations, optimisation, Orcaflex, CRESS, wind waves.

1. Introduction

Robust moorings are indispensable for harvesting the energy of waves. Tests in wave basins and at sea help to further our understanding of the dynamics of mooring loads in relation to the sea state. Here we present a selection of the results obtained in a campaign of sea trials of a WEC (wave energy converter) in Strangford Lough, Northern Ireland. These tests followed the previous lab research, where physical models of wave energy converters were first tested in a wave basin and the results of their behaviour were then compared to the simulations performed using mathematical modelling [1, 2].

2. Materials and Methods

A 1:20 model has been successfully deployed using a three point mooring installed at sea in 10 m depth and tested in the open water conditions. A picture of the WEC and a schematic diagram of the mooing used are presented in Fig. 1 and Fig. 2 respectively.

Measurements of 6Df (degrees of freedom) motions were obtained using a MICRO-ISU BP3010 IMU (inertial motion unit) manufactured by "BEC Navigation Ltd", which was installed close to the COG (centre of gravity). The digital signal was logged to the GigalogF dasta logger via RS232 port, and after downloading processed using a suite of custom made Matlab scripts to calculate estimates of heave, pitch, roll, sway, surge and yaw. It should be noted that due to the restrictions on data storage, only 10 minutes worth of data were recorded every hour during the normal operation of the equipment.

Unfortunately, no reliable wind data were available for Strangford Lough locality per se. However, the

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Fig. 1 WEC in strong winds at Strangford Lough.

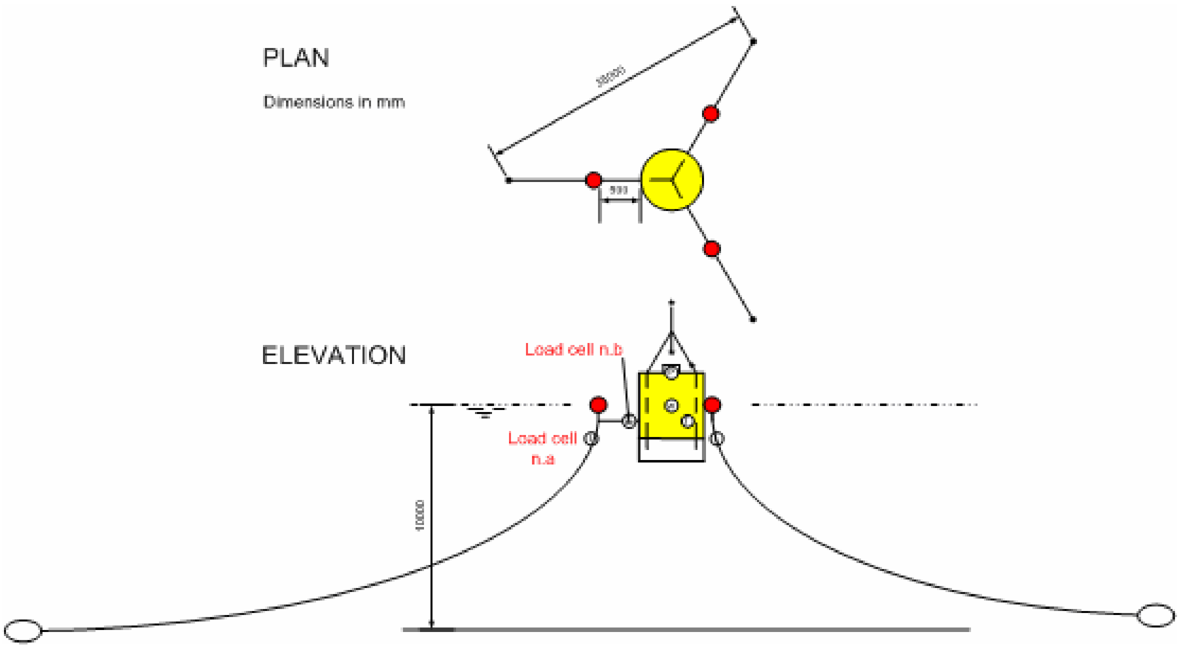

Fig. 2 Schematic diagram of the mooring, note that only one load cell was installed at this stage of the research.

winds measured at the Orlock Head weather station are of a good quality, and deemed to be broadly representative for the region. These data were downloaded (with permission) from the website of the BADC (British Atmospheric Data Centre).

An OrcaFlex modelling scenario was designed to simulate the WEC and the environmental conditions concurrent with the second set of results presented here. Estimates of the Hs (significant wave height) and Ts (average period for waves with H ≧ Hs) were obtained using CRESS (Coastal and River Engineering Support System) using a variable depth fetch of 4.76 km. The typical measured value of wind strength for this period was 17 m/s. However, given that the wind measurements from Orlock are at 10 m height, that was converted using a conversion factor of 0.78 to wind at 2 m height (as used by Shaw [3], p. 251), making u = 13.265. This is still likely to be an overestimate, hence 13 m/s was used in the CRESS calculations, giving Hs = 0.6 m and Ts = 2.86, the latter value was converted to Tp using a conversion factor of 0.95 [4], giving Tp = 3.01 s. These values of Tp and Hs were used within Orcaflex to generate an ISSC (International Ship and Offshore Structure Congress) type wave spectrum.

3. Results

The first deployment of the WEC was carried out in August 2011 using RV "Cuan Cat". The operations were carefully planned, and subsequently carried out during a suitable weather window. The weather was freshening during the deployment, and the wind was quite fresh towards the end. However, any considerable increase in wave height was apparent only after the deployment operations had finished.

The wind subsequently subsided and mainly remained light (2-8 m/s) till 11 am on Aug. 23, when it showed a considerable increase peaking at 11 m/s by midday (Fig. 3). The sea trials subsequently continued until late autumn, but were hampered many times buy harsh weather, logistics and issues of equipment failure. In particular, both the mooring and the measuring equipment were severely damaged during hurricane Katya in September. Nevertheless, the experiment yielded some interesting results, selections of which are presented below.

3.1 August Results

Mooring loads for most of this period are presented in Fig. 4, whilst a short fraction of the mooring loads dynamics is illustrated in Fig. 5. It is evident that the signal is fairly clean, and that it represents a complex interplay between motions of different frequencies. The overall dynamics of mooring tensions is dominated by the tidal cycle due to the progressive lifting of the (relatively) heavy chain with the increase in water depth on the flood and gradual lowering on the ebb. There is also an interesting pattern of sudden jerks (up to 300 kN full scale) during the flood's midtide. The peak mooring loads on the ebb are, generally, less prominent.

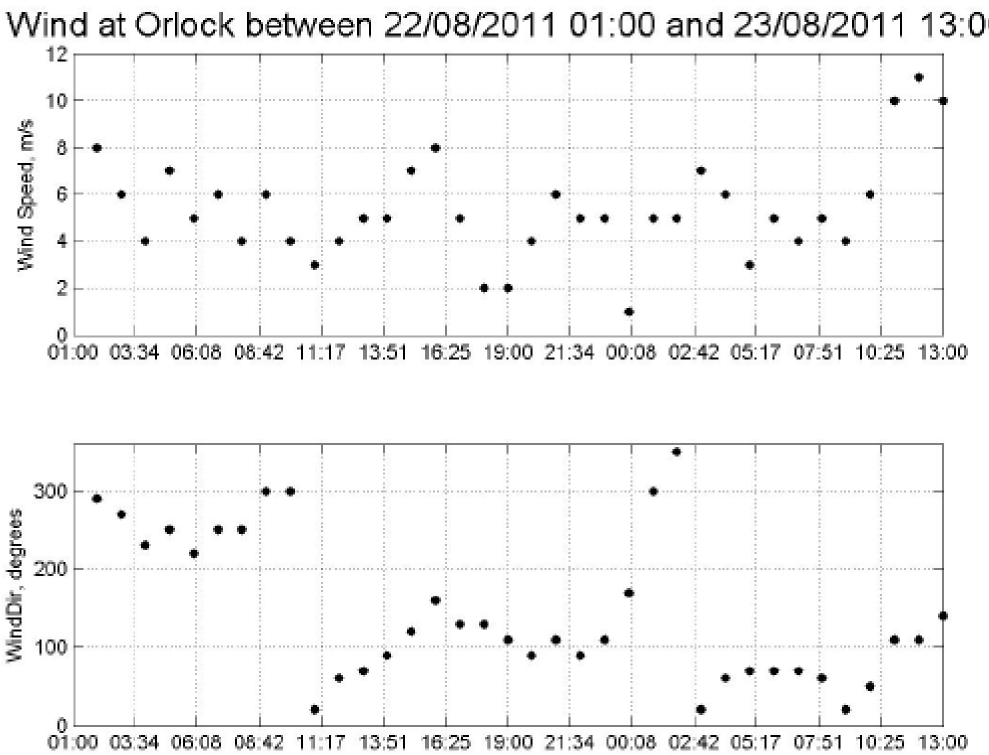

Fig. 3 Wind measurments at the Orlock Head weather station for August results.

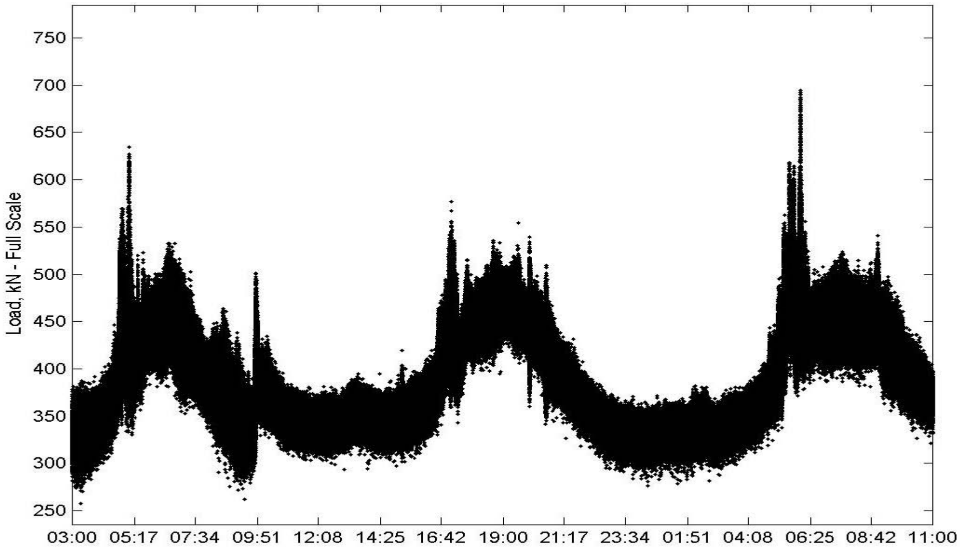

Fig. 4 Mooring loads for August results.

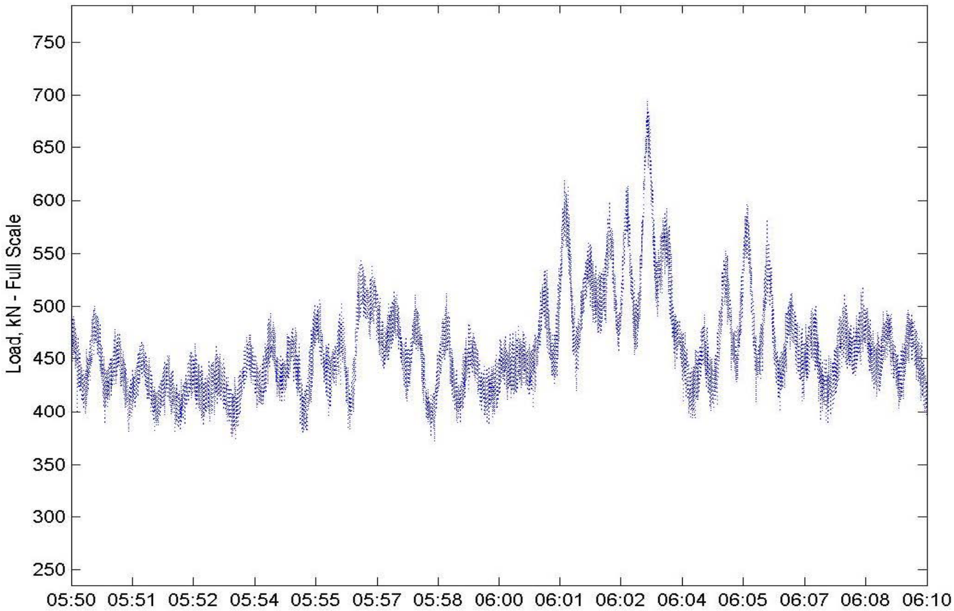

Fig. 5 An example short-term dynamics of mooring loads.

An example of the 6Df motions obtained using an IMU is shown in Fig. 6. It is obvious that in these light winds most of the observed motions of the WEC are rather limited. An exception to the above, however, is yaw, which is characterised by a low frequency wave of > 200 s period and the range of approximately -30 to 30 degrees. This motion is likely to be chiefly attributed to the interplay between the mooring's natural frequency characteristics and the resulting combination of wind and stidal forces, and should be investigated by further research.

Fig. 7 presents a relationship between mooring loads and heave, whilst Fig. 8 gives a joint density distribution for minima and maxima of the heave's rainflow cycles, all values there are recalculated for full scale.

3.2 October Deployment

After the damage caused by hurricane Katya, the equipment had to be repaired, and the mooring was subsequently redeployed in mid October. The dataset collected in October contains a period of very valuable

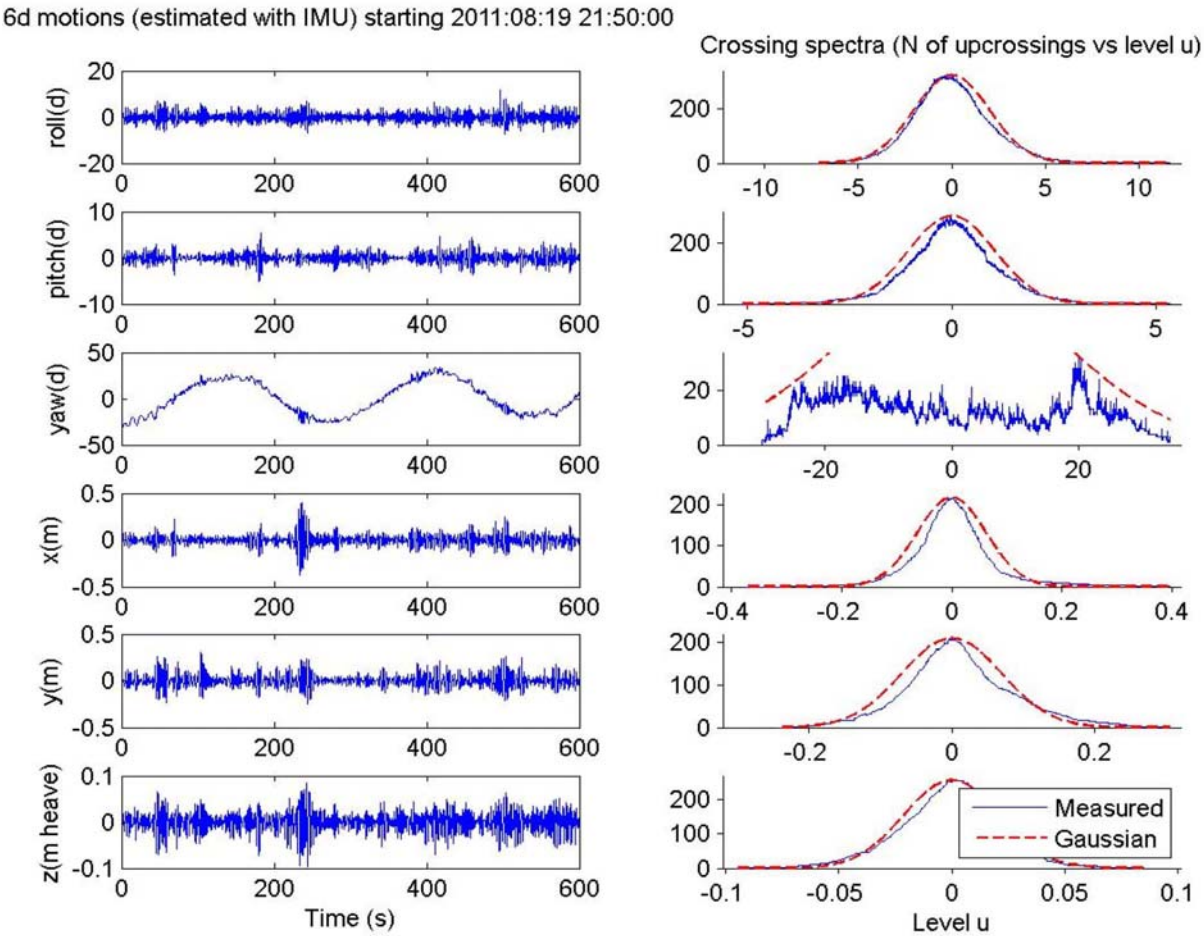

Fig. 6 An example of 6DF motions obtained using an IMU.

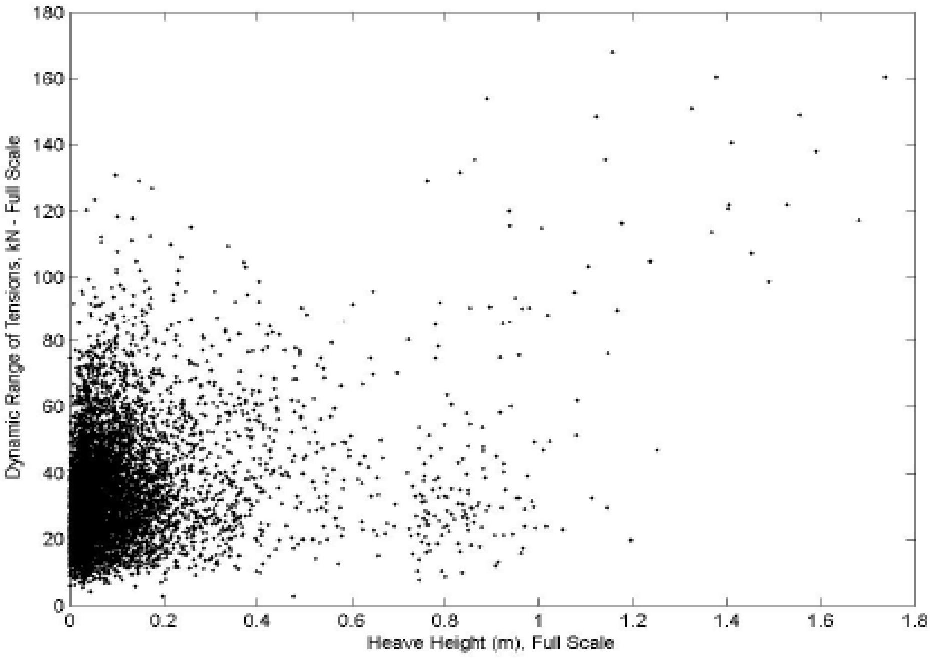

Fig. 7 Relationship between mooring loads and heave for the first set of results.

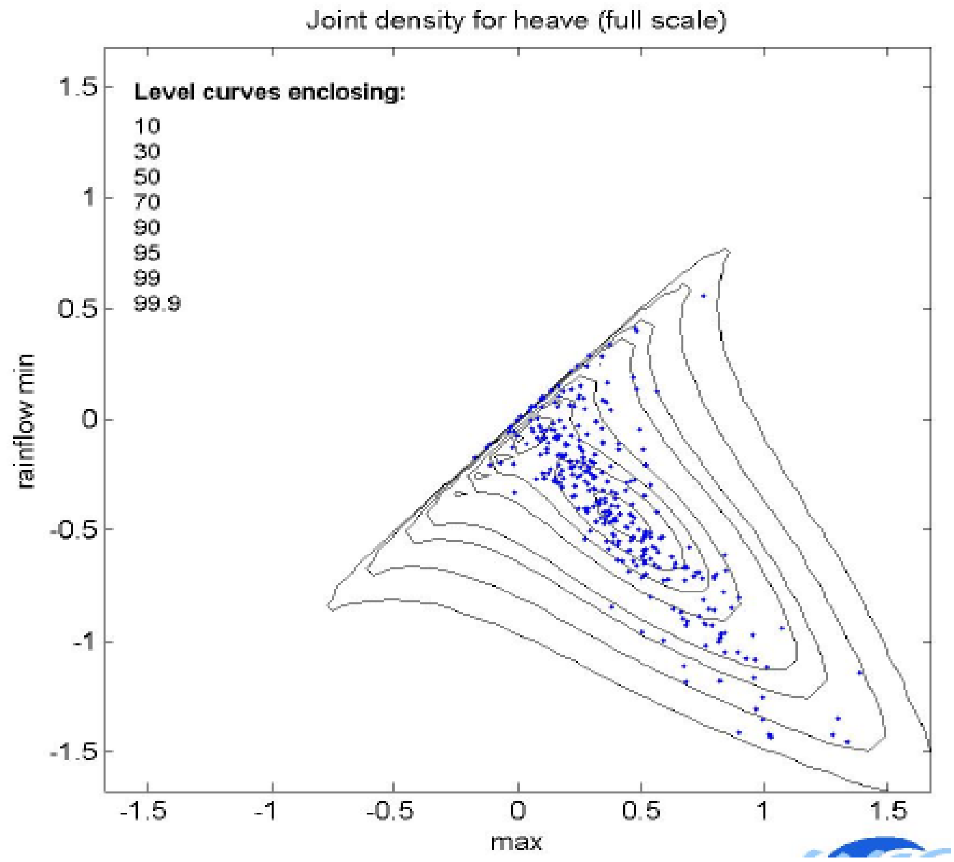

Fig. 8 Joint density distribution for minima and maxima.

data collected in fresh winds of a steady SW direction (Fig. 9). It can be seen that on Oct. 20 the wind started to increase in the late afternoon from 13 to 17 m/s, and then remained fairly steady for 6 hours (with a peak of 18 m/s at 22:00), eventually decreasing after midnight.

Summary of the mooring tensions on the leading mooring line collected during this period of fresh winds is shown in Fig. 10. During this time the mean value of the dynamic range of mooring tensions ranged between 42 and 107 N, whilst the maximum values between 112 and 292 N. A histogram for the peak mooring loads is given in Fig. 11. It is evident that only a few cases exceed 240 N.

4. Discussion

It has previously been shown that the bulk of mooring tensions may be described by either normal or logistic distribution, whilst extreme value distribution shows a reasonable fit to the tail [1]. From a preliminary inspection of our histograms it appears to be the case for the results presented here as well.

4.1 Modelling

Histogram of modelled mooring tensions for the August scenario is presented in Fig. 12 whilst a selection of modelled motions is given in Figure 13. It is evident that these figures are all of the credible order of magnitude, which gives some confidence in the model. The discrepancies between the simulated and observed ranges may be attributable to the model's simplifications, the lack of current and wind influences in the model, the limitations imposed by the sampling rate, and the differences between the observed and the simulated wave regimes.

It should be noted, however, that whilst in relatively smaller and moderate waves investigated for the purpose of this paper (e.g., Hs up to 0.6 m, which is 12 m full scale) the model's behaviour seems reasonable, in high waves (data not shown) it is currently rather erratic (data not shown). The WEC jerks violently in high seas and the mooring tensions appear too large. Further experimental and modelling work is therefore needed to investigate these effects

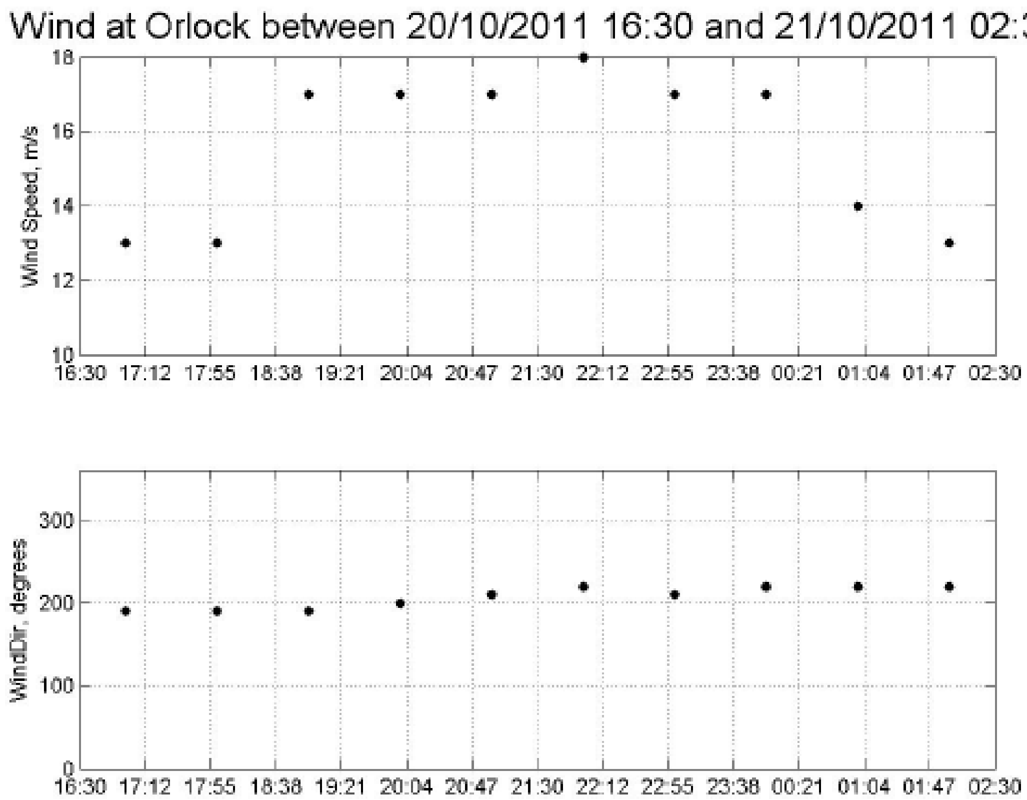

Fig. 9 Wind measurements at the Orlock Head weather station for October results.

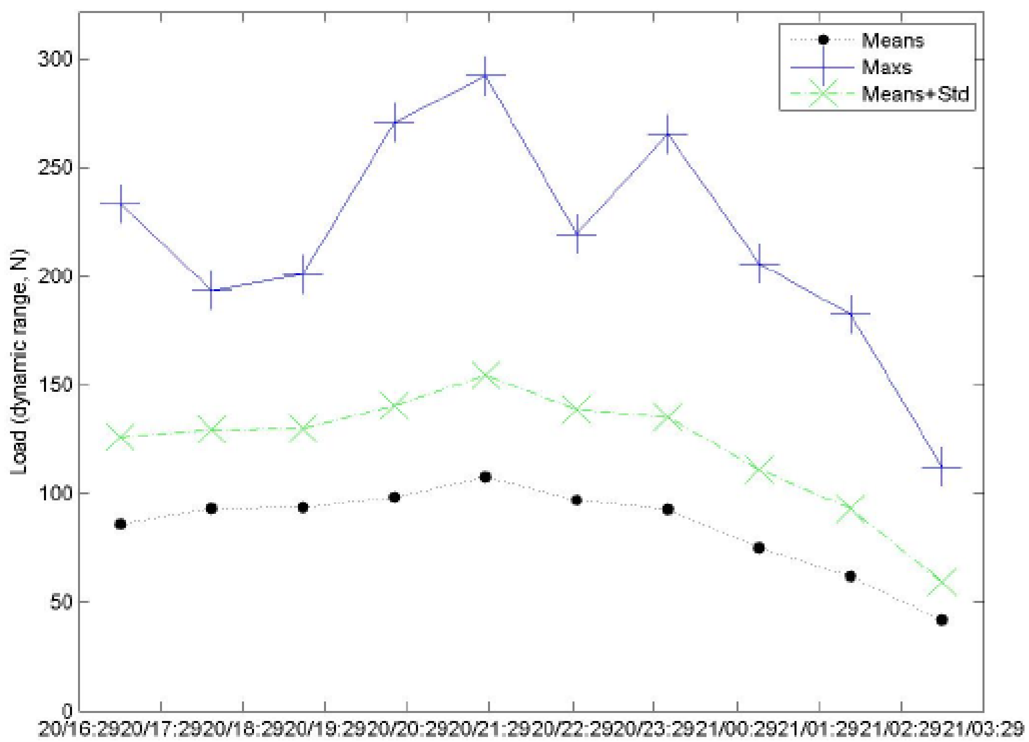

Fig. 10 Summary of mooring tensions results during the fresh winds in October.

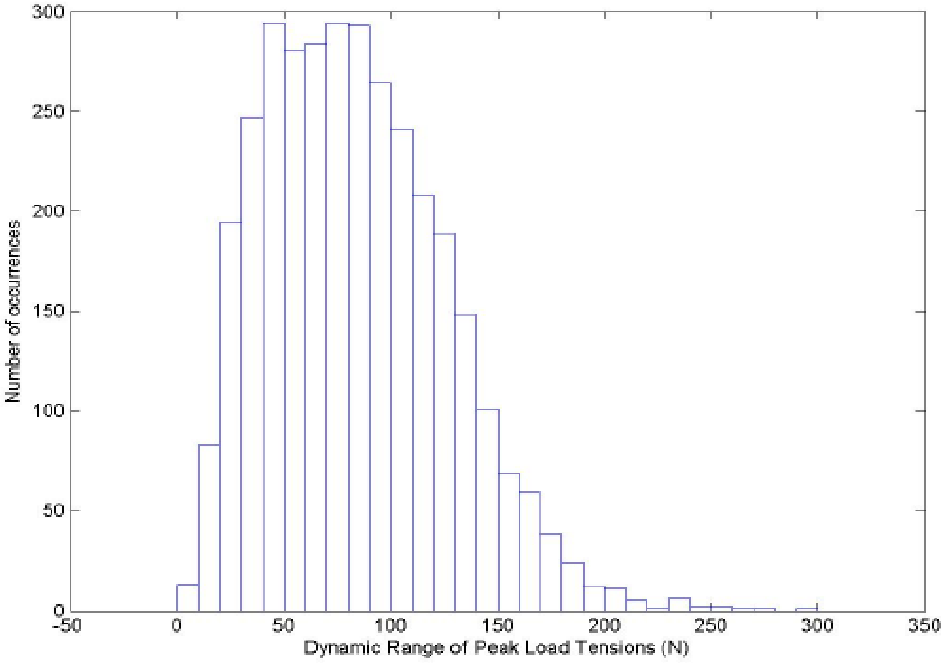

Fig. 11 Histogram of peak loads for October results.

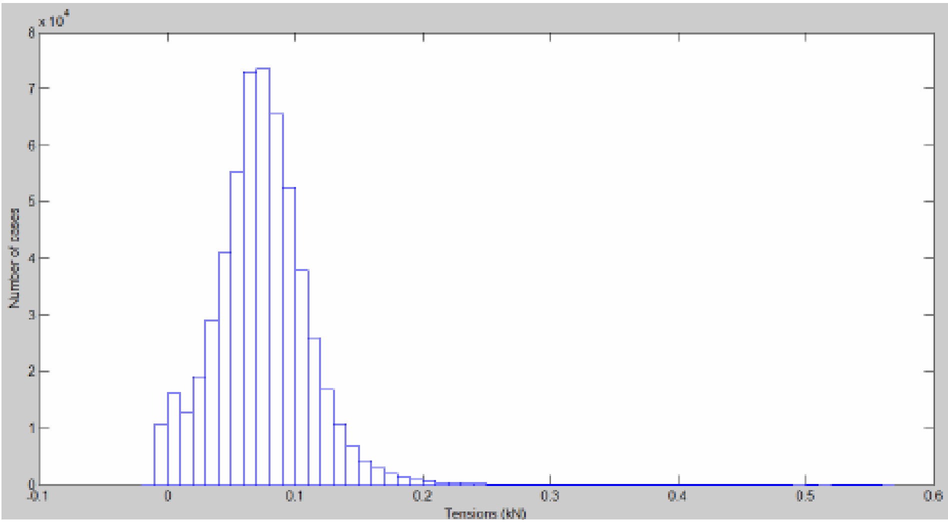

Fig. 12 Histogram of modelled peak loads in conditions simulating October results.

and improve the model, as well as to optimise the design of the mooring.

4.2 Limitations of the Study and Further work

The results of this study have been restricted by its scope, time and financial constraints, weather conditions, reliability of the equipment used, and a whole range of logistical issues. Nevertheless, the research presented here provides some important information on the behaviour of the experimental system tested. The data collected are useful for modelling, and, together with the model's results should be helpful for planning the further research and practical applications.

Considering the issues of reliability of the equipment and logistical constraints encountered during the research presented here, we suggest that the "wave tank" stage should follow by a "fresh water" stage, preferably carried out in a local sheltered reservoir located close to the laboratory to minimise logistical efforts.

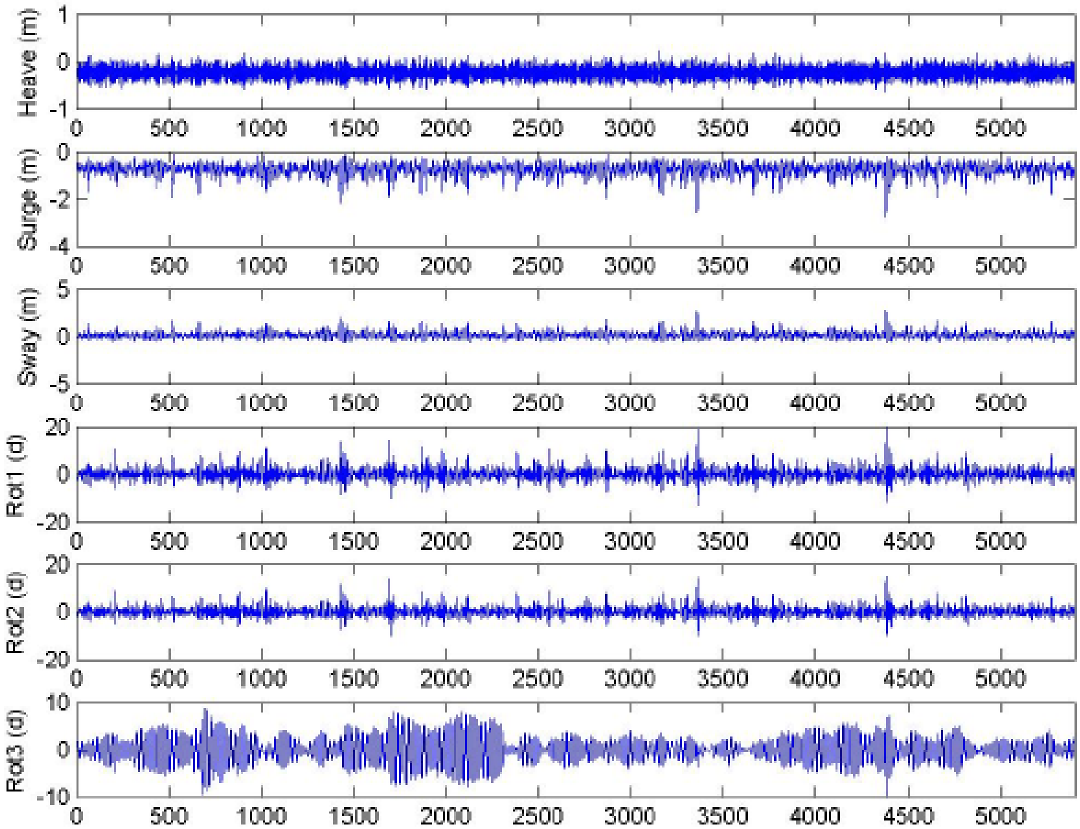

Fig. 13 Time series (0 to 5400 s) for the modelled WEC's motions in conditions simulating October results, the beginning of simulation followed a 200 s period of pre-simulation.

The extreme mooring loads in arrays of WECs may show a considerable increase compared to a single WEC installation [1]. Further research should therefore aim at measuring mooring forces in a farm of devises. It should be noted, however, that such a study will be very costly and would have to overcome some considerable increase in logistical constraints.

5. Conclusions

The WEC's motions and the measured loads on the leading mooring line appear to relate to the concurrent environmental conditions. In calm weather the overall dynamics of mooring tensions is dominated by the tidal cycle due to the progressive lifting of the (relatively) heavy chain with the increase in water depth on the flood and gradual lowering on the ebb. In fresh winds the dynamics is very complex, but can be studied with the aid of mathematical modelling. The results show that, in general, the model captures the most important aspects of the WEC's dynamics.

The data obtained can therefore be used for the model's calibration and further improvements, which is valuable for improving the WEC's design and operational characteristics. This may be important not only in relation to the issues of reliability and power take off, but also in terms of minimising the adverse effects of mooring lines on bottom sediments, as well as indirect effects of the eroded particles on a wide range of aquatic processes [5-7].

Acknowledgments

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