Effects of the shape and size of a mooring line surface buoy on the mooring load of wave energy converters

KRIVTSOV Vladimir†, LINFOOT Brian, HARRIS Robert E.

School of Built Environment, Heriot-Watt University, Edinburgh EH14 4AS, United Kingdom

Received 31 October 2011; received in revised 15 November form 2011

Abstract: This paper describes the physical model testing of a wave energy device undertaken in the Heriot-Watt wave basin during October 2010 as part of the SUPERGEN2 project funded by the UK EPSRC (Engineering and Physical Sciences Research Council), and provides an analysis of extreme mooring loads. Tests were completed at 1/20 scale on a single oscillating water column device deployed with a 3-line taut mooring configuration. The model was fully instrumented with mooring line load cells and an optical motion tracker. The tests were preceded by calibration of instrumentation and the wave test environment, and carried out in long crested waves regimes with 12 combinations of peak period $T_p$ and significant wave height $H_s$. The main objective for these experiments was to examine the effect of shape and size of the tethered buoy on the leading mooring line on the maximum mooring loads and the excursion of the device. Comparison of the loads at different configurations of the tethered buoy suggests that the results are consistent with the hypothesis that the mooring forces should depend on the change in stiffness of the mooring system. In particular, the results indicate that with the spectral peak period close to the natural period of the moored device of 8 s, peak loads in a configuration with a smaller buoy may be considerably higher than those with a larger buoy. However, when $T_p$ was dissimilar, a harder mooring with a smaller spherical buoy appears to result in lower peak loads. The exact configuration should, therefore, be chosen according to the prevalent conditions of any particular location, and will also depend on the design and expected maintenance schedule, as well as matters related to the risk to navigation, environmental effects and the conservation status of the area.

Keywords: mooring load; wave energy converter; spherical buoy

1 Introduction

This paper describes the physical model testing of a wave energy device undertaken in the Heriot-Watt wave basin (10 m×12 m, operational depth 2.85 m) during October 2010 as part of the SUPERGEN2 project funded by the UK EPSRC (Engineering and Physical Sciences Research Council), and provides an analysis of extreme mooring loads. Tests were completed at 1/20 scale on a single oscillating water column device deployed with a 3-line taut mooring configuration (Fig. 1) adopted from our previous studies. The wave energy converter (WEC) was fully instrumented with mooring line load cells and an optical motion tracker. The tests were preceded by calibration of instrumentation and the wave test environment, and carried out in long crested waves regimes with 12 combinations of peak period $T_p$ and significant wave height $H_s$. The main objective for these experiments was to examine the effects of shape and size of the surface buoy on the leading mooring line on the maximum loads and the excursion of the device. In total, four series of tests were performed for four different buoys. Buoys 1, 2 and 3 can be seen in Fig. 2. Buoy 4 was of elongated shape; it is not shown...
in Fig. 2. Due to logistical and technical problems, not all the tests on this buoy were completed, and the results related to this particular buoy should be treated as preliminary.

2 Results and discussion

The results show that the wave motion induces a complex motion dynamics of the device, consisting of both wave frequency and low frequency components approximating to the natural frequency of mooring system. This interplay is particularly apparent in the surge motion, and in the loads in the leading mooring line. Comparison of the loads at different configurations of the tethered buoy suggests that the results are consistent with the hypothesis that the mooring loads should differ (Fig. 3). In particular, the results give an indication that when the spectral peak $T_p$ is close to the natural period of the moored device (i.e. peak period of 8 s or 10 s), peak loads in a configuration with a smaller buoy (i.e. buoy 1) may be considerably higher than those in a larger buoy configuration (e.g. buoys 3 and 2).

Fig. 4 shows that the right tails of the data from larger buoy configurations have the steepest slope (and consequently lower values for extreme loads), whilst the configurations with buoys 1 and 4 are characterized by smaller slopes of the right tail, and consequently higher values for extreme loads. Fig. 5 demonstrates the same pattern from a different aspect using a quantile - quantile plot. On this plot, the data from the same distribution are expected to cluster along the $y=x$ line (i.e. the line with 45 degrees slope). It is evident, however, that this is not the case and, for the same probability values, the mooring loads for a smaller buoy configuration are much higher than for a larger buoy configuration.

It is known that the natural period of the moored device is close to 8 s\cite{2}. The magnitude of the extreme loads in this work was remarkably higher when the peak period was close to 8 s (Fig. 3). For $T_p=10$ s and 8 s, out of four configurations tested, those with the buoys 2 and 3 were clearly better (i.e. in terms of alleviation of extreme mooring loads) than those with buoys 1 and 4. Hence if the prevalent peak periods during the real deployments are expected to be similar to the natural periods of the moored devices, then larger buoys of cylindrical shape are likely to be desirable in order to alleviate the extreme loadings and the consequent damage.
Fig. 3 Summary of the full scale results for maximum values of surge (i.e. motions along horizontal coordinate), and mooring loadings on the lower LC1 and upper LC4 leading mooring lines of different configurations with buoys 1 to 4, where $H_s$ is the nominal significant wave height, and $H'_s$ is the measured value of $H_s$.

Fig. 4 Gumbel plot for extreme mooring loads of different configurations with buoys 1 to 4 at the peak period of 10 s and surge magnitude of 4 m, where LCT is the peak mooring tensions on the lower leading mooring line, with the probability of loading peaks exceeding 500 kN shown on the vertical axis.
Fig. 5 Quantile - quantile plot for extreme loads (kN) of configurations with Buoys 1 and 2 in long crested sea conditions at the peak period of 10 s and significant wave height of 4 m, where + represents the load points at the specified probability levels and – the theoretical line $y=x$.

It should be noted, however, that at $T_p=12$ s the best performer was buoy 1. In particular, the maximum loads for the lower mooring line did not differ significantly in relation to $H_s$ at this configuration. It was shown in SuperGen Marine 1 that soft moorings can be subject to line-stretching and top-end dynamics that can lead to significant dynamic loadings, increasing the probability of direct or longer term fatigue failure of mooring components. Additionally, the negative effect of dynamic loads on the conversion efficiency of a floating device was described. Hence if the prevalent peak periods during the real deployments are expected to be dissimilar to the natural periods of the moored devices, then somewhat harder moorings (e.g. with smaller buoys) may be desirable to alleviate wear and tear.

3 Conclusion

The experiments reported here have clearly shown that the characteristics of the tethered buoy on the leading mooring line are important for the magnitude of surge and extreme loadings. Softer moorings with larger buoys appear to be better in alleviating extreme loads in those sea states where $T_p$ is approaching to the natural period of the moored device. However, when $T_p$ is dissimilar, a harder mooring with a smaller spherical buoy appears to be better in this respect. The exact configuration should, therefore, be chosen according to the prevalent conditions of any particular location, and will also depend on the design and expected maintenance schedule, as well as matters related to the risk to navigation, environmental effects and the conservation status of the area.

4 Acknowledgements

This study was conducted as part of the SuperGen project. The SuperGen Marine II consortium is supported by the UK Engineering and Physical Sciences Research Council under grant EP/E040136/1.

References


