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OPTIMIZING WECS FOR CANADIAN WATERS

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ABSTRACT

The global distribution of wave energy is not homogenous, nor are the wave characteristics that combined, represent the annual wave climate. This paper looks at the effect of these global variations on the resulting optimized shape of a Wave Energy Converter.

The example Wave Energy Converter used in this study is SeaWood Designs' SurfPower. SurfPower is a buoyant pontoon that moves freely and reacts against a sea-bed mounted hydraulic cylinder. This optimization uses the length of the main pontoon of the WEC, which is perpendicular to the incoming wave direction, as the variable to be changed. The maximum permissible mooring force is used to determine the width for each tested length of the pontoon.

The locations considered in this paper are the West and East Coasts of Canada, and Wave Hub, in the South West of England. The results show that although the trend in the overall representative energy recovered for the varying lengths is similar, with two local maxima, for the different locations. The resulting global maximum lengths can be significantly different.

Keywords: Wave Energy Converters (WECs), SurfPower, Shape optimization,

1. INTRODUCTION

The global distribution of wave energy is not homogeneous; wave climates vary considerably for different locations around the world. The annual wave climate characteristics at different geographic locations will feature different annual significant wave heights, periods, spectral distributions, energy transport and seasonal variations. Therefore, the wave climate characteristics at a proposed deployment site are primary design constraints. A WEC designed for one location may require basic shape, mass properties and/or PTO system modifications to extract the most energy per year at a second location.

An example Wave Energy Converter (WEC) is being used for this work to demonstrate the differences in its shape optimization based on different worldwide locations. The main power capture body dimension of the WEC has its dimensions optimized, with a second dimension determined by limiting the maximum mooring force experienced in large waves.

In this paper we consider the effects of the wave climate at three different locations, on the East and West Coast of Canada, and in the South West of England.

2. MODELLING

2.1. SurfPower

The Wave Energy Converter (WEC) used as an example in this paper is Seawood Designs' SurfPower device. This WEC concept consists of a buoyant pontoon that floats on the surface of the ocean. The pontoon can move freely except it cannot rotate, in yaw, due to a propriety yaw control system. The pontoon is connected, via a hydro-dynamically invisible rigid bridle, to a hydraulic cylinder. The hydraulic cylinder only provides a resistive force during the up-stroke, it offers no resistance for its down-stroke. It is fixed to the seabed and is free to rotate, in pitch and roll around this attachment point. The system is based in 40 m of water depth [1].

The depth of the pontoon is 1 m and the mass is chosen so that when combined with the cylinder mass, it has a draft of 0.25 m. The PTO resistive force is 150 KN. These and all other model parameters are kept constant for this study. An image of the SurfPower unit, within the ProteusDS environment, is presented in Figure 1.

2.2. Numerical simulations

The simulation is modelled in the software package ProteusDS. This software package is a time domain, finite difference, numerical solver. The simulation summates the forces acting on the bodies and time progresses using a variable step-size Runge-Kutta algorithm and constraints the motion in the required orientations or relative orientations. The forces included are the wave loading, the hydrostatic buoyancy force, the PTO force, and the viscous drag; these forces operate on both the bodies mass and their, frequency independent, added mass.

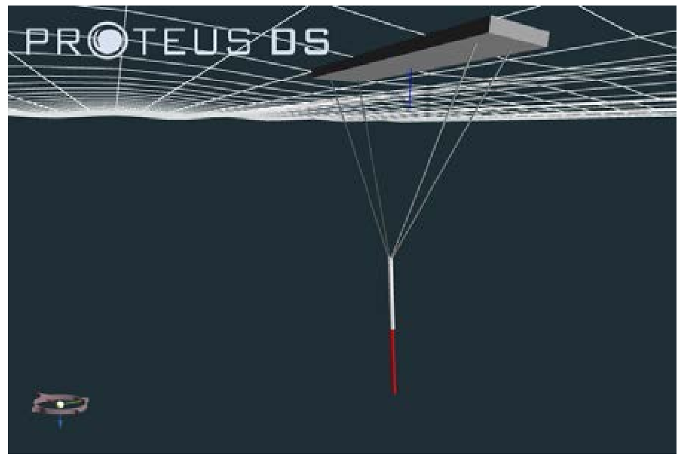

Figure 1: SurfPower device modelled in the ProteusDS environment

The wave loading is calculated from the Froude-Krylov force based on the water pressure acting on the body. The body is panalized and for each panel, the pressure at its centroid (if wet) is taken and multiplied by its area [2].

The viscous damping is also calculated on each wet panel centroid. This is calculated, for each orthogonal direction, based on the area of the panel, a damping coefficient and the square of the relative velocities in the predefined orthogonal directions. For this model the damping coefficient was obtained from scaled experimental data. Further details of the method and the experimental testing is presented by Nicoll et al [3].

Hs	Tp	Time
[m]	[s]	[hr]
1.5	7	1491
1.5	9	1358
2.5	9	1307
2.5	11	673
3.5	9	361
3.5	11	546
Proportion of total power		75%
Proportion of total time		65%

Table 1: Representative wave resource for the West Coast of Canada.

Since the PTO is a hydraulic system, it is modeled as a columbic damper: it has a constant force that opposes its velocity.

The hydrostatic force is based on the submerged volume of the submerged body calculated from the integral of the wetted panels.

Limitations

The wave excitation force has been calculated from the Froude-Kroylov force only and ignores the effects of wave scattering. Wave radiation forces are not calculated however a frequency independent added mass term, derived from scaled experimental results, is used.

2.3. Wave resource

West Coast of Canada

The known wave climate is typically split into 1 s, 0.5 m bins based on the upcoming TC-114 Technical Standard. To reduce the number of computational runs need to represent a typical year of data, the hours of occurrence of the sea states accumulated into 2 s, and 1 m bins. The top 6 bins are chosen based on the hours of occurrence and the annual amount of power that contain. These are shown in the Table 1, with their hours of occurrence. Combined, these represent 65% of the total hours of waves and 75% of the total power.

The data is from an Axys wave measurement buoy at Estevan point, off the West Coast of Vancouver Island; latitude 49.37 N, longitude 233.46 E [4].

East Coast of Canada, Halifax

Data was obtained for Halifax harbour, at latitude of 44.5 N and longitude of 63.41 W, over a year from May 2011 [5]. This was at a water depth of 53 m. The 8 sea-states chosen represented 63% of the time and 65% of the annual power, see Table 2.

Hs	Tp	Time
[m]	[s]	[hr]
0.5	9	1035
1.5	7	951
1.5	8	1494
1.5	11	596
2.5	9	358
2.5	11	259
3.5	9	106.5
3.5	11	117
Proportion of total power		65%
Proportion of total time		63%

Table 2: Representative wave resource of Halifax, the East Coast of Canada.

Wave Hub, UK

This data is from Wave Hub, which is a wave testing site, located in the South West of England, at latitude 50.36 N, longitude 5.67 W. The data was transformed to peak period from the zero crossing period using a factor of 1.4, as presented within the same report were the data was provided [6].

The resulting peak period bins are therefore of a different size to the example above. Due to the smaller peak period bins the most prominent 8 sea-states have been chosen and these represent 63% of the time and 65% of the total power, see Table 3.

Hs	Tp	Time
[m]	[s]	[hr]
1.5	7.7	1638
1.5	9.1	1305
1.5	10.5	639
2.5	9.1	771
2.5	10.5	482
2.5	11.9	228
3.5	10.5	254
3.5	11.9	219
Proportion of total power		65%
Proportion of total time		63%

Table 3: The representative power for Wave Hub, South East of England.

Simulated Wave Climate

The wave spectrum used in this work is the JONSWAP spectrum. The number of waves used depends upon the peak frequency and is set so that the repeat period of the sea-state is approximately equal to the simulation length. The waves have a cosine exponential spreading function [2] and the primary direction is perpendicular to the length of the pontoon. The phases of the waves were randomly assigned for each sea-state, and kept the same for each time that sea-state was tested.

2.4. Optimization

Width calculation

The mooring force that the WEC experiences, in this work, is deemed to be an important constraint. Increasing the capability of the system to cope with larger mooring forces would involve higher costs to ensure survivability and reliable operation.

For a set length, the width is calculated that results in the mooring force reaching a predetermined limit. The maximum mooring force allowed is based on having a maximum strain on the hydraulic cylinder of 0.01%. This is based upon certain assumptions about the cylinder, presented in Table 4. This sea-state would be considered to occur fairly regularly, in typical storm conditions, as opposed to a 10 year or 100 year storm. A wave has been chosen to represent this is a 10 m peak to trough, 15 s period, regular wave. In order for a smooth mooring force with changing pontoon dimensions, the WEC was held stationary during this test. Tests have been conducted with the WEC having end-stops and free to move as for the other simulations; however, for small variations in the pontoon dimensions, the resulting maximum mooring force was not a smooth function.

Young's Modulus	1.8×10^{11} Pa
Strain chosen as maximum allowable	0.01%
Calculated allowable Stress	1.8×10^{7} Pa
Hydraulic cylinder thickness and diameter	0.01 m & 0.5 m
Area being stressed	1.57×10^{-2} m^2
Maximum mooring force	**2.83×10^{5} N**

Table 4: The parameters used for the maximum mooring force calculations.

The width was calculated from finding the mooring force that was close to the maximum mooring force. The mooring force was run for two wave cycles and the maximum mooring force obtained. Longer mooring force tests were conducted but the maximum mooring force stayed consistent for these tests.

Length Calculation

The objective function for the optimization is the summation of the product of the average power of the WEC and the number of hours of occurrence of each sea-state.

Due to the complexity of the simulations behind the objective function, with having data from 6 or 8 different sea-states, the WEC having 6 degrees of freedom (5 for the pontoon and the relative motion of the hydraulic cylinder) and the sea-states containing between 57 and 96 superimposed waves, the resulting objective function is not smooth. Therefore an optimization technique that did not rely on the gradient was required, a direct search optimization technique, called *patternsearch* within the *Matlab* environment was used.

The 6 or 8 sea states to be tested were run for 180 s each. These ran in parallel and when they were all complete, they were multiplied by the number of hours of occurrence of that sea state and the representative annual power was obtained. This representative annual power was the value used in the objective function. Different starting lengths were run to ensure that the maximum was indeed a global maximum. This was confirmed by visual inspection.

3. RESULTS AND DISCUSSION

The optimizations were run for the different sea-states for the different locations; using different starting points as appropriate. The tolerance of the optimization was set at 0.05 m. The optimizer typically found a maximum within 6 to 9 polls (13 – 19 different lengths tested). The optimal length of the device and hence the width, for the different locations and their associated energy captured are presented in Table 5.

The results for dimensions of the pontoon that produce the highest representative annual energy are presented in Figure 2 for all the different lengths tested. In this figure, similarities can be seen for all the different locations with two local maxima at approximately the same lengths present.

Location	Optimal length [m]	Width [m]
West Coast of Canada	6.125	4.09
East Coast of Canada	2.2	11.64
Wave Hub, UK	2.0	12.83

Table 5: The optimal dimensions of the pontoon for the different locations and the resulting representative annual energy recovered.

These results show how different worldwide locations can affect the resulting optimized shape of a WEC.

The relationship between the length and width is presented in figure 3. This shows how by setting a maximum mooring force and finding the largest width that results in equalling the maximum mooring force you can have a relationship between the two dimensions of the pontoon.

4. CONCLUSIONS

This work has demonstrated that a WEC shape that has been optimized for one location will not necessarily be optimum for a second, different location.

Acknowledgements

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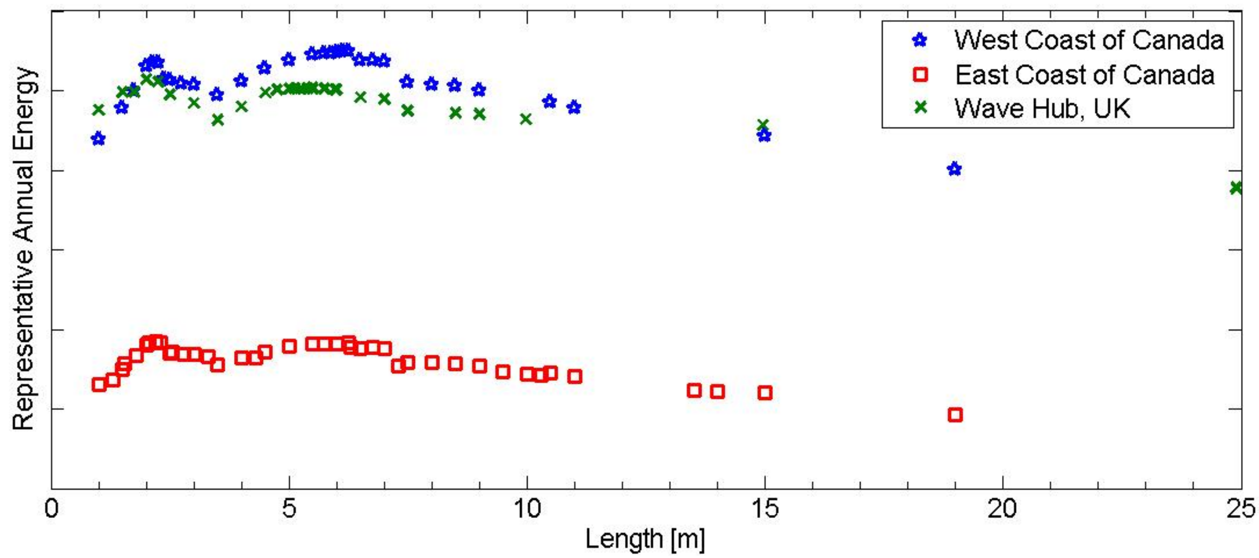

Figure 2: The representative annual energy recovered for the different sea-states tested.

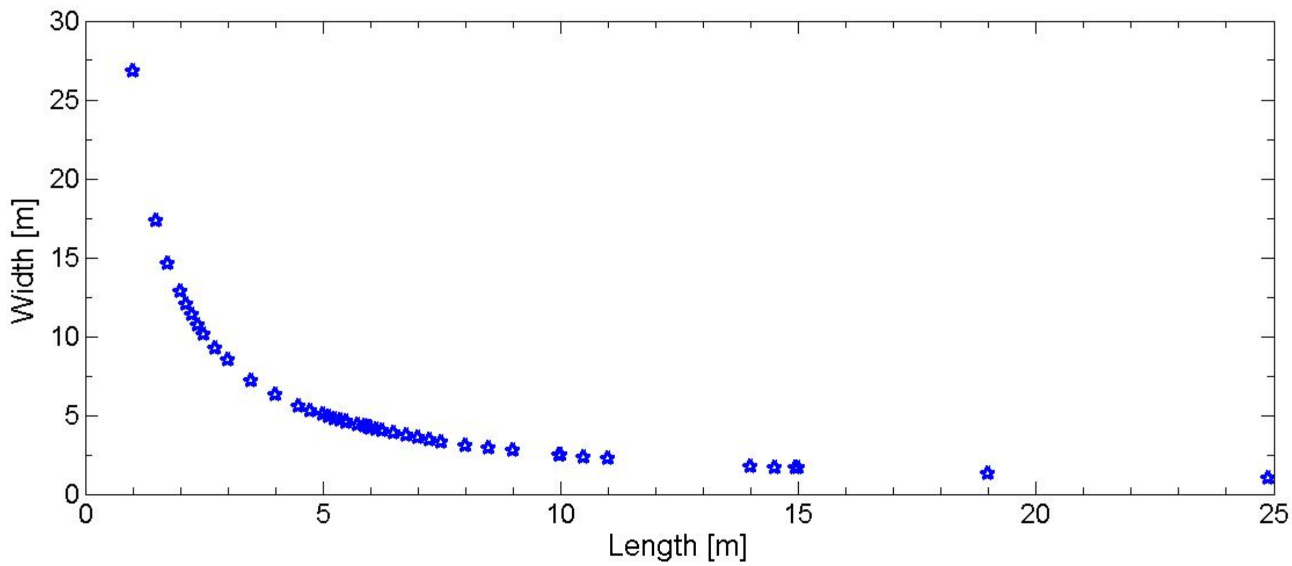

Figure 3: The relationship between the length and width of the pontoon

REFERENCES

[1] H. Bailey, J. Ortiz, B. Robertson, B. Buckham, and R. Nicoll, “A Methodology for Wave-To-Wire WEC simulations,” in *Marine Renewable Energy Technology Symposium (METS2014)*, 2014.

[2] DNV, *Recommended practice DNV-RP-C205 environmental conditions and environmental loads*. 2010, p. Table 3–1.

[3] R. S. Nicoll, C. F. Wood, and A. R. Roy, “Comparison of Physical Model Tests With a Time Domain Simulation Model of a Wave Energy Converter,” in *ASME 2012 31st International Conference on Ocean, Offshore and Arctic Engineering. American Society of Mechanical Engineers*, 2012.

[4] B. R. D. Robertson, C. E. Hiles, and B. J. Buckham, “Characterizing the near shore wave energy resource on the west coast of Vancouver Island, Canada,” *Renew. Energy*, vol. 71, pp. 665–678, Nov. 2014.

[5] Fisheries and Oceans Canada, “Observed Wave Data Results,” Accessed Sept, 2014, 2014.

[6] K. Nielsen and T. Pontes, “Generic and Site-related Wave Energy Data,” 2010.