Optimizing WECs for Canadian Waters

Helen Bailey*, Bryson Robertson, Bradley Buckham

West Coast Wave Initiative, Institute for Integrated Energy Systems, University of Victoria.

*Corresponding author: hlbailey@uvic.ca

University of Victoria Institute for Integrated Energy Systems

ICOE 2014 INTERNATIONAL CONFERENCE ON OCEAN ENERGY

NOVEMBER 4-6, 2014
Halifax, Nova Scotia Canada

ICOE2014CANADA.ORG

The Simulation

The WEC - 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.

Numerical simulations

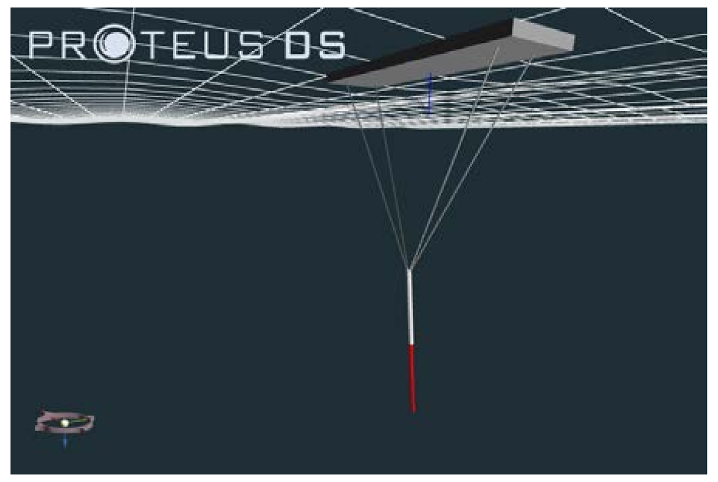
The simulation is modelled in the software package ProteusDS. This software package is a time domain, finite difference, numerical solver. The simulation summates the forces acting on the bodies and time progresses using a variable step-size Runge-Kutta algorithm and constraints the motion in the required 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.

The PTO is a hydraulic system, modeled as a columbic damper: it has a constant force opposing its velocity.

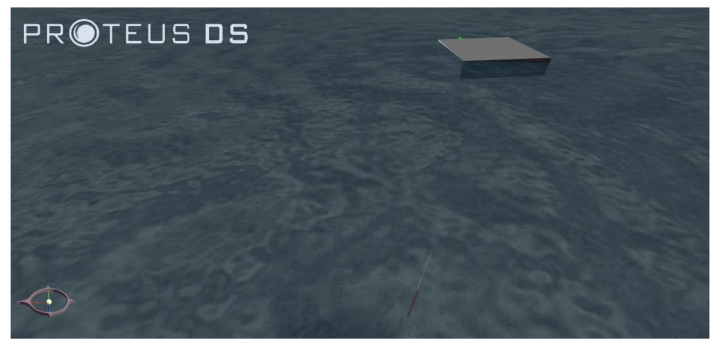
The bodies are panelized and for each panel with a wet centroid:

- The wave loading is calculated from the Froude-Krylov force based on the water pressure acting on the body.
- The hydrostatic force is based on the submerged volume of the submerged body calculated from the integral of the wetted panels.
- The viscous damping 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.

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



SurfPower shown within the ProteusDS environment.



SurfPower with different pontoon dimensions

Mooring constraints

The width of the SurfPower pontoon was chosen to allow a maximum 0.01% strain, in a large but not extreme storm event. The sea-state chosen was a 10 m amplitude (peak to trough) regular waves with a 15 s period. The SurfPower unit was held stationary during these tests to provide a smooth test profile. The width was then determined by finding the value that resulted in this maximum mooring force, allowing for a 0.0005 m tolerance on the width. This was ran for 30 s.

Young's Modulus	1.8 x10^{11} Pa
Strain chosen as maximum allowable	0.01%
Calculated allowable Stress	1.8x10^{7} Pa
Hydraulic cylinder thickness and diameter	0.01 m & 0.5 m
Area being stressed	1.57 x10^{-2} m^2
Maximum mooring force	2.83x10^{5} N

The parameters used for the maximum mooring force calculations

The simulation is modelled for 30 s in this sea-state and the highest mooring force experienced is compared to the maximum mooring force. A minimization function reduces the difference between the two, so that the tolerance on the width is 0.5mm.

Running the simulation for greater than 30 s was investigated, but this resulted in little difference to the mooring force.

Environment and Optimization

Optimization

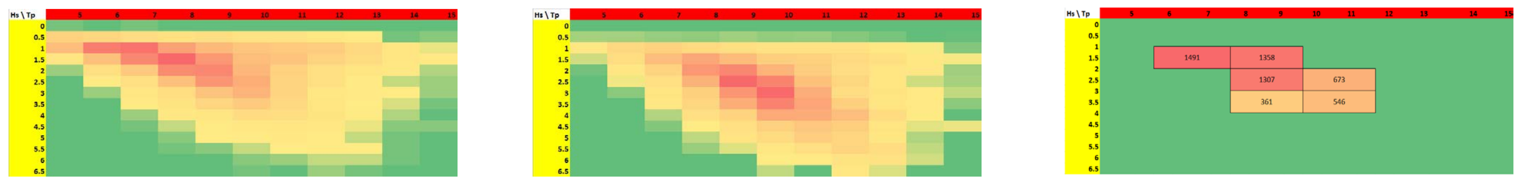
The objective function for the optimization is the summation of the product of the average power of the WEC and the number of hours of occurrence of each sea-state.

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.

Environment

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.



Wave Energy Resource – West Coast of Canada
Wave resource information. Left: Hours of occurrence of different sea-states. Middle: Total power in each sea-state. Right: The 6 chosen sea-states used for the optimization study.

Hs [m]	Tp [s]	Time [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%

Hs [m]	Tp [s]	Time [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%

Hs [m]	Tp [s]	Time [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		66%
Proportion of total time		64%

Representative Annual Wave Climate
Left: West Coast of Canada. Middle: East Coast of Canada. Right: Wave Hub, South East Coast of England.

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 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.

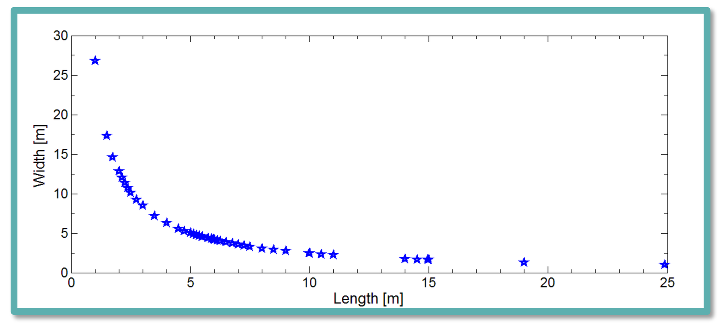
Results & Conclusions

Results

The optimal length of the device and hence the width, for the different locations and their associated energy captured are presented in the Table.

The relationship between the length and width is presented showing how by setting a maximum mooring influences this.

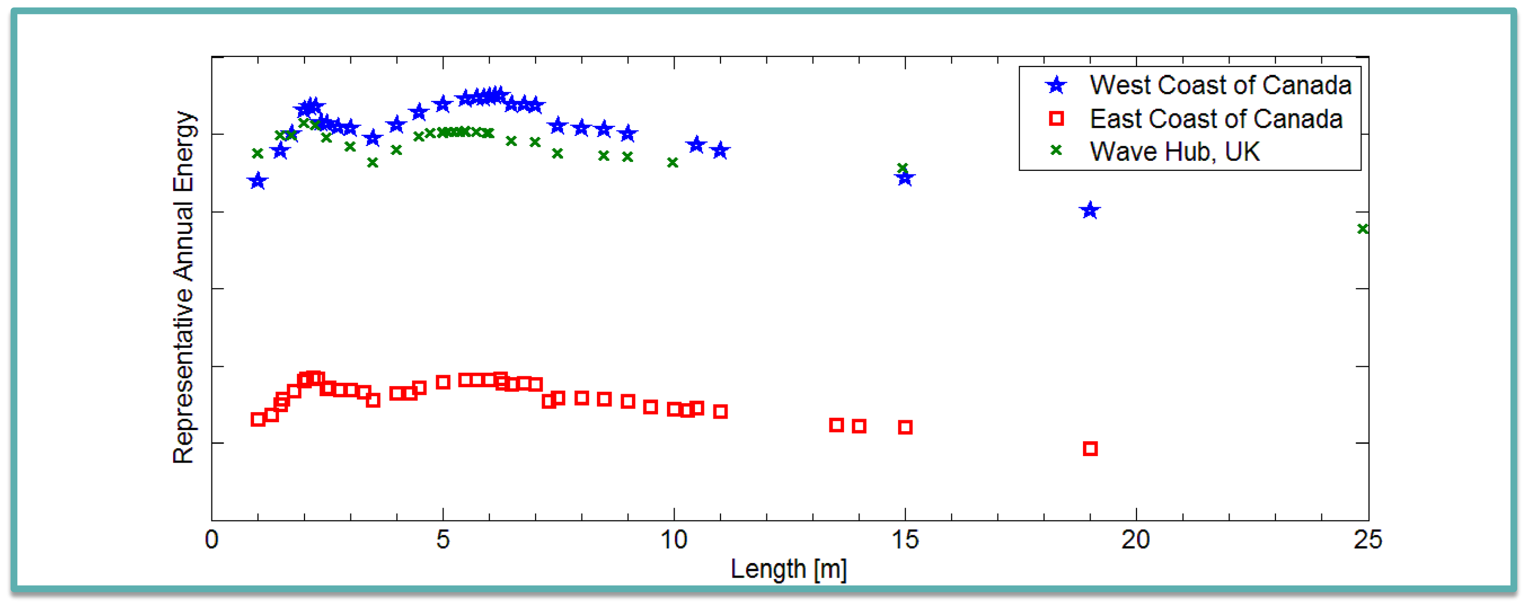
The optimizer typically found a maximum within 6 to 9 polls (13 – 19 different lengths tested). The results for dimensions of the pontoon that produce the highest representative annual energy are presented in the Figure below for all the different lengths tested. In this figure, similarities can be seen for all the different locations with two local maxima at approximately the same lengths present.



The relationship between the pontoon dimensions

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

The optimal dimensions for the different locations that have been tested



The Representative Annual Energy for the varying pontoon lengths and the different locations tested

Conclusions

These results show how different worldwide locations can affect the resulting optimized shape of a WEC. This demonstrates how a WEC shape that has been optimized for one location will not necessarily be optimum for a second, different location.

ACKNOWLEDGMENTS

NSERC CRSNG

Pacific Institute for Climate Solutions
Knowledge. Insight. Action.

Government of Canada Gouvernement du Canada

Canada

www.uvic.ca/wcwi