Attenuator Cost of Energy Reduction 2 (ACER2)

WES Novel Wave Energy Converter Stage 2 Project

Public Report

4c Engineering

This project has been supported by Wave Energy Scotland

1 Project Introduction

The Sea Power Platform is a two-body Wave Energy Converter (WEC) that has been under development since 2008. The WEC is classed as a floating attenuator device with energy extracted via the relative motion of two bodies connected by a hinged joint. A PTO system interfaces the two bodies at the hinge and extracts power by damping the motions of the device in wave climates.

The project team consisted of the following parties:

- **4c Engineering** – Project lead, project management, design & engineering activities, running of tank tests. Responsible for concept engineering and planning of Stage 3 test activities;
- **Sea Power Ltd** – Device developer and steering group member, input to project design, engineering and tank testing throughout. Drew on their experience of deploying an open water demonstrator device in Galway Bay to take responsibility for coordinating the marine operations planning, mooring design and FEED activities for a partial scale device;
- **OSCS Ltd –** Carried out marine operations planning
- **Rockall Research Ltd** – Advice on test model design & sensor selection followed by post-processing of load characterisation data.

The aim of the project was to advance our understanding of the Sea Power Platform: its response to extreme conditions and the effect of various types of control on both the loading (pressures, forces, moments, etc.) and expected power capture. The outputs of the project should identify a route to achieving the target LCOE cost of £150/MWh. Activities involved in delivering this included:

- Numerical modelling to optimise the device geometry for power capture
- Physical testing at two scales (1:25 & 1:50) & numerical modelling to produce a prediction of performance and loading at full scale;
- Estimation of annual power capture of a full-scale device at a range of deployment locations
- Development of the concept design of the full scale WEC;
- Front End Engineering Design of a partial scale open water demonstrator device;
- Operations planning for installation, maintenance & retrieval of a partial scale WEC;
- Planning of test activities for an open water partial scale WEC;
- Further development of a scalable, interactive cost model.

2 Description of Project Technology

The key features of the project technology, and its anticipated advantages are summarised as follows:

- Large stable platform floating on surface:
    - Straightforward access;
    - Minimal subsea work;
- Simple technology for converting wave motion to WEC motion – low risk, predictable;
- Novel modular tension bolted chassis
    - Allows long chassis structure to be broken down into smaller sections for transportation to final assembly area (reduced costs)
    - Improved fatigue life compared to welded joints
    - Allows option for chassis parts to be galvanised for corrosion protection
    - Avoids need for coded welders (reduced costs)

- Range of PTO options are applicable – rotary or linear. Primary rotary PTO option developed by Romax in earlier WES PTO project, this PTO option has two key advantages:
    - Reuse of existing (windpower) technology supply chain and know-how;
    - No endstop problems;

  Whilst the linear PTO option was not developed further during this project, the hinged WEC is suitable for a classic linear piston/ram type PTO which could be used in a number of ways: pressurising hydraulic fluid or pumping seawater for desalination or on-shore generation. Such rams are well suited to high force, low speed motion. The linear options allow the moment arm to be selected depending on the application.

- Range of control options – can enhance power extraction and/or limit loading

3 Scope of Work

The work carried out during the stage 2 project could be broadly split into 2 categories: "Scale model testing & Simulation" and "Engineering Development".

Scale model testing & Simulation
The primary objectives of the Scale Model Testing & Simulation workstream were to:

- Identify an optimised geometry for lowest cost of energy,
- Refine performance estimates,
- Characterise the structural loading experienced by the device,
- Validate numerical models through a suite of appropriately staged testing,
- Create a plan outlining the proposed Stage 3 testing programme, including objectives, activities, schedule and target outcomes.

To achieve these objectives, we carried out the following tasks:

- A package of numerical modelling work to identify an optimum geometry;
- Using the optimum geometry, a package of tank testing was carried out involving:
    - Model design & build,
    - Physical testing at two scales (1:25 & 1:50),
    - Post-processing of data & reporting
- Data from the tank testing was then used to calibrate a numerical model which could be interrogated for further performance & loading data;
- With a calibrated numerical model, an estimate of the mean annual energy production (MAEP) could be made;
- Performance & loading data was then used to inform plans for a partial scale open water demonstrator

Engineering Development
The primary objective of the engineering development workstream was to:

- Address and mitigate the main technology challenges associated with the full-scale concept design and small sea-going prototype

To achieve this objective, we carried out the following tasks:

- Updated a technology risk register and FMEA to highlight areas of the concept requiring particular attention
- Drawing in external support to complete packages of work on sub-systems identified from risk register/FMEA
    - Electrical systems
    - PTO integration

    - Hinge development
- Development of the optimum geometry identified in the scale model testing & simulation work to a concept engineering design level
- Worked with an experienced sub-contractor to produce a robust set of installation, removal, operation & maintenance plans for deploying an open water prototype at a suitable test site to demonstrate procedures required for full scale deployment
- Front-end engineering design (FEED) of a partial scale open water demonstrator (design based on a reduced scale version of the full-scale concept)
- Taking the MAEP from the scale model testing & simulation work and combining with costings derived from full scale concept work to develop the LCOE calculations.

4 *Project Achievements*

Key achievements of the project include the following:

- Improved tank testing campaign compared to ACER 1
    - Efficient use of test time (able to carry out more test runs than had been scheduled for);
    - Successful design, build & testing of two very different models within budget;
    - Excellent results from use of 3D printed sensor mounts and epoxy-coated CNC-cut foam to give accurate, customised geometry which met all functional requirements;
    - Improved signal quality - poor signal-noise ratio seen in ACER 1 was designed out through:
        - improved shielding of cables,
        - change of instrumentation from +/-10V to more noise tolerant 4-20mA sensors,
        - use of on-board signal amplification reducing susceptibility of signals to noise;
    - Data acquired both from
        - A set of standardised sea states as part of WES requirements
        - Additional sea states identified to allow full assessment of device response (both full characterisation of performance and survival sea states)
- Geometry optimisation resulted in a much more efficient use of material
    - Displacement of WEC was reduced by 61% with little change to the MAEP (effectively a much smaller WEC giving the same power output)
    - Considering capture width divided by displaced mass (metres/1,000 tonnes) gave an improvement of 40% from stage 1;
    - Considering MAEP/year/tonne of displacement, the improvement ranged from 222% to 240%
- Production of a very comprehensive package of marine operations plans which will allow accurate costings and confidence in plans for stage 3 test activities.
- The use of external experts has proven to be an efficient way to access very specific knowledge and experience without incurring large cost overheads. As the size of specific work packages grow in the future we may consider growing our in-house resource in certain areas (electrical engineering in particular) however in Stage 2, this approach to structuring resource has been successful.
- Third party review of physical testing & modelling – independent scrutiny of work carried out with feedback and recommendations for future work
- Engineering design reviews completed (Preliminary & Critical Design Reviews) – robust process and scrutiny of independent review with recommendations incorporated into plans for future work.

Lessons Learned

With hindsight, the project would have been even better if:

- To allow more repeats of seas of particular interest, a tighter definition of loading characterisation seas and design sea states had been achieved before tank testing;
- Mooring design was still in progress at time of tank testing and the project timeline did not allow for the tank testing to be pushed back further. As a result, testing was carried out with a mooring design which whilst a practical design for full scale, was unlikely to remain the preferred option. Use of a better developed mooring would have been preferable. As it stands, further testing will be required to inform the engineering design from a validated model testing with a representative mooring;
- The electrical side of the full-scale concept needs further development to match the progress on other sub-systems – from electrical layout through to PTO development & costing and further development of a proposal to address power quality and grid compliance.

5 Summary of Performance against Target Outcome Metrics

Affordability (CAPEX/OPEX)

- As the structural design was developed, certainty on costings has generally increased and existing gaps in knowledge have been filled. In particular, pontoon CAPEX significantly reduced from stage 1.
    - As a proportion of total CAPEX of WEC, pontoon CAPEX reduced from 48% to 23%,
    - Pontoon cost reduced to just 20% of the equivalent pontoon cost at stage 1.
- OPEX costs have built upon Sea Power's successful deployment of a partial scale device (although quite different geometry to the proposed stage 3 partial scale WEC) in Galway Bay. Reliability data produced as part of an updated FMECA was used along with O&M documentation to inform the estimated OPEX costs

Performance (Rated capacity/Power conversion efficiency)

- Effect of control type on power capture was investigated both through tank testing and numerical modelling. Scaled costings were used to calculate the LCOE for different scales (and power ratings).
- The target to "increase peak capture width by 10%" was effectively superseded by choices made during the geometry optimisation. As the scale of the WEC was effectively reduced, leading to a much lower displacement, peak capture width fell by 46% – however, normalising capture width by device displacement resulted in a 40% increase (in metres/1,000 tonne displacement).
- Peak capture width improvements of 10-21% were identified through the use of control strategy choices.

Availability (reliability/maintainability)

- FMEA reviewed and expanded to reflect development of the full-scale concept.
- Failure rates and MTBF values for all components were added to the FMEA. This was used to inform the maintenance strategy
- O&M plans were produced and WEC access limits identified, defining the conditions under which maintenance activities would be possible/allowable. This was used to inform the extent of offshore maintenance and the lost time and power associated with specific failures.

Survivability (survivability)

- Extreme conditions identified for target full scale sites
- Loading characterisation testing carried out at 1:50 scale along with further measuring of loads in 1:25 performance characterisation testing
- No slamming loads observed

- Overtopping of pontoons during extreme seas limited bending moments on chassis
- Device was observed to be stable in all axes during extreme seas, even in extreme focused waves equivalent to a 40m individual wave height.
- Results of testing used to inform structural design loads

Other (Manufacturability/installability/integratability/scalability/controllability)

- Storyboarding of manufacture, assembly & launch of full scale concept carried out to define infrastructure requirements
- Survey of existing port infrastructure carried out to identify suitable infrastructure
- Engagement with external experts on specific sub-systems requiring more detail for full scale concept. This built up knowledge on the electrical, hinge bearing & PTO integration sub-systems
- Installation requirements and durations for partial scale device identified as part of O&M planning
- A range of control strategies were employed to assess device response, loading & power capture. This allowed the preferred control system to be identified for optimum performance and the condition with lowest loads to be identified for survival mode.

6 Recommendations for Further Work

Full WEC system

- Design, build & deploy a partial scale WEC to increase the TRL of the current design, assess performance and gain experience in marine operations.

Modelling & Simulation

- Enhance load outputs from numerical model by adding additional load output nodes, allowing a more comprehensive understanding of the load distribution in the structure
- Improve PTO representation in numerical model
- Start modelling at array level to assess interaction of devices and extent of constructive/destructive interference in power trace

Electrical & Control

- Current WEC control strategy still fairly basic, future development could consider more advanced control. Studies should consider:
    - Four quadrant control to maximise conversion of energy from the waves
    - Adaptive wave by wave control (rather than setting control parameters according to average conditions)
- Review current WES control projects (or other literature from sector experts) and approach those deemed of interest
- Continue to develop a practical full-scale power smoothing and/or storage system

Moorings

- Continue looking at industry solutions to minimise mooring costs;
- Keep an eye on results of WES landscaping study on moorings
- Develop options for quick install & disconnect systems
- Develop options for full-scale, partial-scale & future commercial array

Pontoon design

- Investigate use of alternative materials for pontoons with the goal of reducing LCOE. Initial work has suggested that a polymer pontoon is feasible, partners for development of this option have been identified and an initial concept generated. This work should be continued, the design refined and progressed to large scale physical testing to validate the concept.

Onward development path

- Work with Sea Power to identify potential commercial partners – this builds on current partners identified and engaged with Sea Power.
- Build up the commercialisation plan

7 Communications and Publicity Activity

The following public promotion activities have been (or will be) carried out by 4c Engineering:

- Poster presentation displayed and project update at WES annual conference 2017.
- Video compilation of tank testing carried out during ACER 2 prepared for use at WES stand during All Energy.
- Images from project work incorporated into advertising materials.
- Images from project work used on flyer distributed at Scottish Development International (SDI) Scottish Pavilion at ICOE 2018 in Normandy.
- Updates to website blog.
- Various announcements using LinkedIn and twitter throughout the duration of the project. In particular, photos, GIFs and video clips taken during wave tank testing at FloWave.
- Website case study (coming soon).
- The selection of sensors for the performance tank test model was used as a case study for the Applied Measurements website.

Sea Power Ltd carry out their own additional activities relating both to WES projects and others such as their SEAI-funded large-scale demonstrator deployment at SmartBay

8 Useful References and Additional Data

Filename	Author	Status
WES-1088-000858 D12 Report - Device response to environment and control Rev C	4c Engineering	Confidential
WES-1088-000839 D34 Report - Loading Characterisation Rev C	4c Engineering	Confidential
WES-1088-000842 D33 Report - Performance Characterisation Rev F	4c Engineering	Confidential
WES-1088-000716 D04 Geometry Optimisation Report Rev A	4c Engineering	Confidential
WES-1088-000715 D24 LCOE Model for Sea Power Platform Rev K	4c Engineering	Confidential
WES-1088-000904 D38 D39 Estimation of Mean Annual Energy Production for Sea Power Platform	4c Engineering	Confidential
WP04g M14 D19 Seapower Platform FMECA & Availability RevA3	Sea Power	Confidential
Seapower Platform BoD RevG	Sea Power	Confidential
D15 WP04 Structural FEED Rev C	Sea Power	Confidential
WES-1088-000920 Operations Planning Deliverables WP05 D22 D23	OSCS Ltd	Confidential
WES-1088-000775 D35 Control Investigation Rev A	4c Engineering	Confidential
WES-1088-000876 D37 Report - Numerical Modelling Development & Validation	4c Engineering	Confidential
WES-1088-000722 D06 SPP Concept Layout Notes Rev A	4c Engineering	Confidential