WaveNet Series 12

WES Novel Wave Energy Converter
Stage 1 Project
Public Report

Albatern Ltd.

This project has been supported by Wave Energy Scotland

1 Project Report

1.1 Project Introduction

Albatern are the developers of the WaveNET: a modular wave energy harvesting system that captures energy from the relative motion between an array of mechanically interconnected floats. The WaveNET exploits interacting array dynamics to improve yield while reducing cost through shared infrastructure and integrated on board balance of plant: larger arrays produce power at a lower per unit cost. The WaveNET is currently being developed at two different scales; the 6S (currently in testing at Mingary Bay), has a rated capacity of 7.5kW and is being developed for off-grid sites, and the 12S (the focus of this NWEC project) which aims to incorporate novel and innovative features in order to scale up for grid connected applications.

The project was managed and reviewed by David Findlay, Chief Technical Officer of Albatern. The hydrodynamic modelling, tank testing activities, analysis and reporting were led by Vivien Mavel assisted by Anthony MacDonald (IDCORE PhD student). The underlying concept development and concept structural engineering was led by Leah Barker Ewart (IDCORE PhD student) while the hydraulic concept engineering was led by Kenneth Reid assisted by Sarah Acheson (IDCORE PhD student). The control and instrumentation system design and implementation was led by Bin Li assisted by Calum Kenny (IDCORE PhD student). The mechanical design of the scaled model was led by Graham Terry assisted by Alex MacMillan and Richard Sue (Edinburgh University students). The manufacture and assembly of the scaled model was led by Neil Taylor assisted by Hector Fleck, Udhayan Gunawardena and Richard Gregson. The levelized cost of energy (LCOE) analysis was performed by Ciaran Frost (IDCORE PhD student).

Several challenges had to be overcome to make the NWEC project a success:

- A concept design achieving the design targets in terms of power output had to be developed
- A scaled model with sufficient degrees of freedom and control to model an interconnected array had to be designed and build as well as a scaled power take off mechanism (PTO) with sufficient torque had to be developed
- Sufficient power output had to be measured in the tank to back up the concept development
- Performances in the tank had to match the numerical model estimates
- Concept engineering calculations had to be performed to insure the feasibility of the full scale device
- A LCOE of £150/MWh had to be achieved

The present report addresses how these different challenges have been overcome.

1.2 Description of Project Technology

Similar to the 6S, the Series 12 (12s) version of the WaveNet is s an interconnected array of buoys. The main difference with the 6s is that all the buoys are identical (Nodes) and connected together by horizontal link arms. Another innovation introduced in the 12S is the use of concrete. Concrete is a material that is suitable for an offshore environment, it is cheap, long standing and strong. The use of concrete drove the initial dimensions of the node.

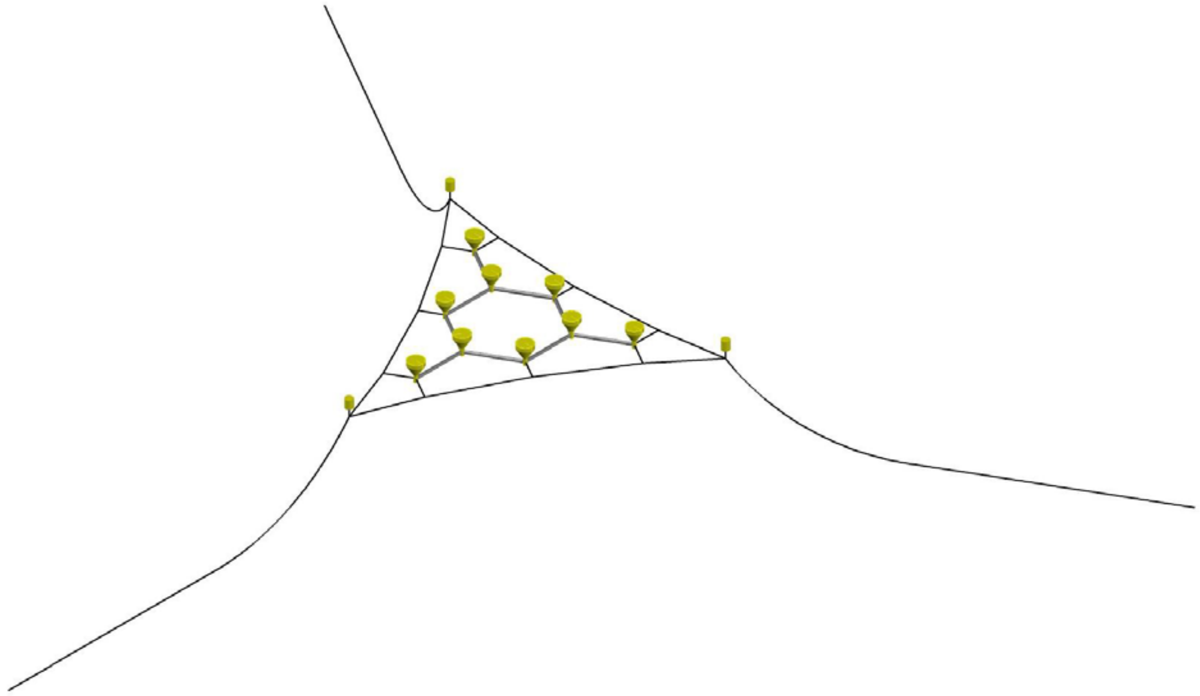

Figure 1: Overview of a 12S WaveNet 1Hex array with mooring system

Each individual Node can move relative to the link arm it is attached to around three axis of rotation. The relative motion between the Nodes and the link arm is captured by hydraulic rams mounted between the two bodies.

1.3 Scope of Work

The first piece of work undertaken during the NWEC project was to get from an initial design scope to an outline design. To do so several iterations of design assessment were performed. At each iteration the new design was assessed based on performance established through numerical modelling with Ansys Aqwa. The main variables being changed during this process were the Node shape and sizes as well as the link arm length and angle.

An 18^{th} scale model of the outline design was developed to be tested at the Flowave TT wave tank in Edinburgh. The model consisted of nine nodes and nine link arms and incorporated 45 brushless DC motors allowing the control of 45 degrees of freedom, (five per link). The Nodes and link are connected together through a ball joint, allowing motion around two axes at each end of the link arm Additionally each link arm is constructed in two halves, each of which could rotate around their own axis. The rotation at each articulation drives a DC motor allowing the control of the stiffness and damping of that joint. A torsion load cell mounted on the shaft of the motor measured the torsion load in each link arm

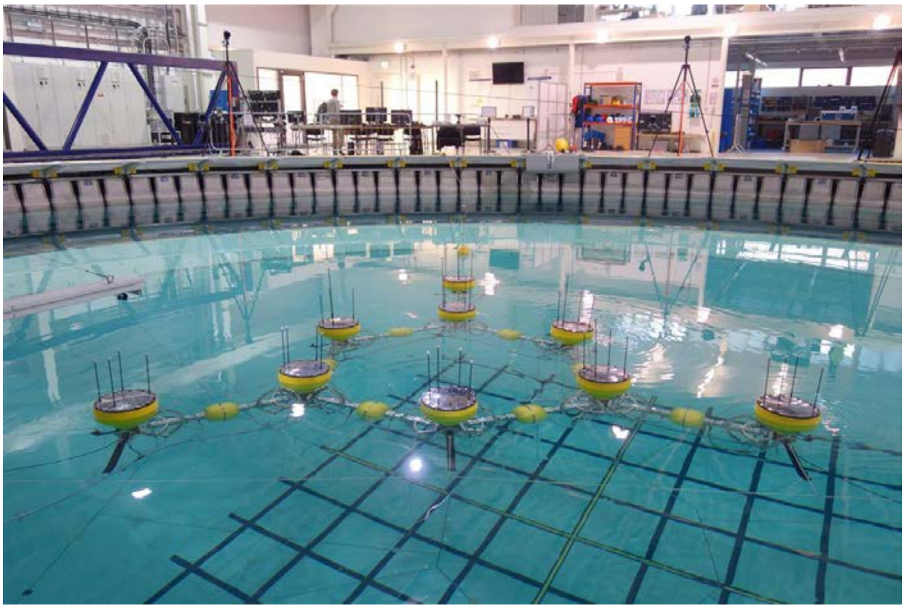

Figure 2: View of the 12s 1Hex array 18th scale model

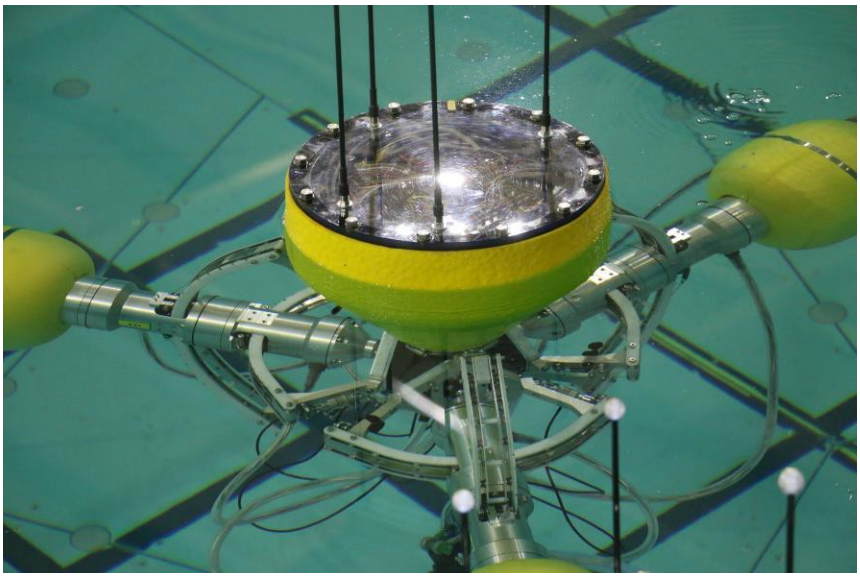

Figure 3: Zoom on a node connected to three link arms

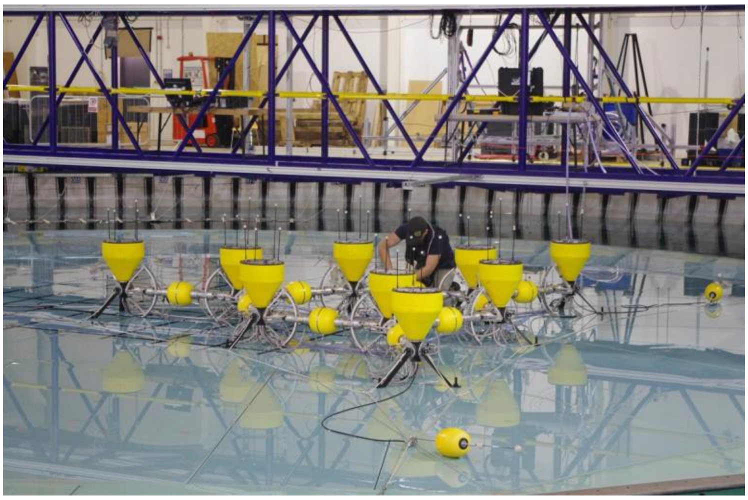

Figure 4: 1Hex model on Flowave's raisable floor

The tank testing activities were divided into two sessions. A Squid array made of four Nodes and three link arms was tested in a first session running from the 14th of September 2016 to the 27th. This initial testing allowed the collection of baseline data to assess the change in behaviour when increasing the size of the array, and allowed for any model troubleshooting to be carried out on a smaller model, before testing a larger array. The second session focused on a 1Hex array as seen in Figure 2. The six degrees of freedom of each Node were monitored using Qualisys cameras. The instantaneous position, velocity and torque of each of the 45 motors were monitored providing information about the power captured in each joint. Inline load cells were mounted on the wire drive gearing mechanism to quantify the mechanical power in the joint as opposed to the power transferred to the motors. Mooring load cells measured the mooring loads in the three catenary legs holding the mooring grid in place.

The tank testing focused on:

- Undamped frequency response of the array
- Identification of the optimum damping for a set of 11 regular sea states and 12 irregular sea states defined by WES
- Power output, motion and loads at optimum damping for 11 regular sea states an 21 irregular sea states to build up a power matrix
- Exploratory runs investigating directional sea states, currents and damping strategies

The purpose of all these tests was first of all to quantify the power that can be captured by the newly developed concept through tangible measurement and secondly to validate the numerical model used to develop the concept. The existing numerical model of the 1Hex was compared to the tank test results in terms of frequency response amplitude in motion, velocity and power; overall captured mechanical power and mooring loads.

Beyond the concept development and tank testing activities, initial concept engineering has been carried out as well an LCOE analysis. Structural calculations were performed for the link arms and the nodes based on the operating torques established during the tank tests. A full scale mooring solution has also been designed for a 1Hex array and finally an LCOE analysis was performed.

1.4 Project Achievements

The design and completion of the scaled model was the first major achievement of the NWEC project. Albatern have put together one of the most complex wave energy models ever made with 45 controllable degrees of freedom in the process overcoming many of the challenges related to scaled power take-off such as achieving sufficient torque and controlling the damping of the device.

A second achievement is that all the data collected, methodologies, uncertainty calculations, instrumentation calibration and strategy have been validated by the European Marine Energy Centre (EMEC) contracted as an independent third party. This gives confidence in the design team and the experimental set up, and provides independent validation of the data used to analyse the behaviour and performance of the device.

Another achievement is that the measured performances of the device was satisfying and lined up with the performances aimed for during the concept development in terms of capacity factor at a benchmark site on the West Coast of Harris.

A significant achievement was the verification of the numerical model. On average across 21 sea states the tank testing results in terms of total mechanical power are within 12% of the numerical model prediction with a maximum discrepancy of 32%. In terms of mooring loads the estimation from the numerical model are within 8% of the load measured in the wave tank on average across the 21 sea states testes, the maximum discrepancy being of 23%.

Some aspects of the testing could have been improved: the wire drive mechanism providing the gearing of the electrical motors was vulnerable and broke several times in steeper sea states. This fault is specific to the scaled down model and not inherent to the device itself but it caused down time during the testing.

The instrumentation could have been improved by incorporating more inline load cells measuring the mechanical power on every joint. The number of load cells being limited to the six joints most excited by the waves. This allowed quantification of the electro-mechanical efficiency of those joints and allowed the quantification of the overall mechanical power by applying that efficiency to all the other joints, however, monitoring the mechanical power on every joint would have been more satisfying.

1.5 Summary of Performance against Target Outcome Metrics

Table 1: Summary of performance against target outcome metrics

Outcome metric	Summary performance
Affordability	LCOE analysis showed an initial cost of £315/MWh and for a 1Hex array and £150/MWh after 55MW of installed capacity
Performances	Performances measured in the tank matched numerical model very well and corresponded to the design targets
Availability	Modular architecture of the array and multiple level of redundancy provide good availability. Tank testing showed that loss of functionality of one node did not impede the entire system
Survivability	The mooring system tested in the tank show good compliance and low peak to mean load ratios

1.6 Communications and Publicity Activity

At the time of publication no official communication or publicity activity has been made.

Several papers are due to be published using the results from the tank testing and are summarized in

Title	Authors	Journal/Conference	Status
Experimental Investigation of Array Effects for a Mechanically Coupled WEC Array	A. McDonald, Q. Xiao, D. Forehand, D. Findlay	EWTEC 2017	Abstract submitted
Control and Instrumentation Topologies for an Integrated Wave Energy Array	Kenny, C. J., Findlay, D., Lazakis, I., Shek, J., Thies, P.R.	Proceedings of the 2nd International Conference on Renewable Energies Offshore 2016	
Optimising structural loading and power production for floating wave energy converters	L. Barker Ewart, D. Findlay, N. Barltrop, P.R. Thies, T. Stratford	EWTEC 2017	Abstract submitted

1.7 Recommendations for Further Work

The next steps to take from here are:

- The detailed engineering design of the device
- Dry testing of the power take of solution
- The testing of a part scale device that can be deployed at sea and integrate a hydraulic power take off system