A Wave Energy Research Centre in Albany, Australia

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I. Keywords

Offshore renewable energy, wave energy, wave modelling, coastal engineering, hydrodynamics, geotechnical engineering, research, education, outreach.

II. Abstract

This paper presents some of the research currently undertaken by the newly established Wave Energy Research Centre at the University of Western Australia to support Carnegie Clean Energy in deploying a 1.5MW grid connected wave energy converter in Torbay, Albany, Western Australia. This includes the modelling of the wave resources in Torbay, wave tank testing and hydrodynamic modelling to characterise and predict the motion of the wave energy converter and some aspects of geotechnical engineering to optimise the foundations of the device.

III. Introduction

A Wave Energy Research Centre (WERC) was established early in 2018 in Albany, on the south coast of Western Australia. The centre is funded by the State Government Department of Primary Industries and Regional Development (DPIRD) and the University of Western Australia (UWA) to facilitate and support the development of offshore renewable energy through research, education and outreach.

A particular feature of the centre is the multidisciplinary approach across many aspects of ocean engineering, including wave modelling, coastal engineering, wave-structure interaction and geotechnical engineering. The centre is affiliated to the Oceans Graduate School at the University of Western Australia and is supported by a large group of over 40 ocean engineering researchers, including researchers from Curtin University in Western Australia.

The Research Centre's initial primary focus is to support the successful development of the Albany Wave Energy Project (AWEP) by Carnegie Clean Energy (CCE). As such, the scope of WERC's activities has initially a strong ocean engineering and oceanographic focus, in order to deliver research outcomes that will support the immediate needs of the wave energy developers in AWEP, including the deployment and monitoring of a large-scale prototype device commencing in 2019. These needs comprise (i) the modelling of the wave conditions and coastal processes in Torbay, a site characterised by consistent Southern Ocean swell that provides an average incident wave power of over 50kW/m, (ii) the definition of the site bathymetry, geophysical and geotechnical investigation for the design of the anchoring systems and power cable to the onshore grid, and (iii) preliminary hydrodynamics analyses undertaken to ensure optimum control and survivability of the proposed multi-moored CETO wave energy device.

In time, additional research issues will need to be addressed, particularly as a larger commercial project is developed. These would include research in areas of marine biology and ecology (impact of WECs on marine life, biofouling, etc.), material science, ocean governance, coastal management, grid integration and resource economics. These will be progressively included within the broader scope of WERC through additional collaborations within the UWA Oceans Institute and with other Australian universities, as well as through new funding initiatives that the Centre will pursue with various funding bodies, including the Australian Research Council.

IV. The Albany Wave Energy Project

The Albany Wave Energy Project is a Carnegie Clean Energy venture to install the latest generation CETO unit – CETO6M – off the coast of Albany (see Figs. 1, 2). Over a 12-month period commencing in the (Australian) summer of 2019/2020, the CETO6M unit will supply power to the local grid. The Project is supported by funding from DPIRD and the Australian Renewable Energy Agency.

CCE's CETO6M design features on-board power generation and multiple moorings (see Fig. 3). The CETO6M unit is 25 m in diameter, and is shallowly submerged below the free surface. Electrical power of up to 1.5MW is expected.

V. The Torbay test site

Southern WA is exposed to one of the most consistent and reliable sources of wave energy anywhere in the world. Long period (>12 s) swells arrive at the coast year round from the Southern Ocean with mean monthly offshore significant wave heights ranging from 2.9 to 4.5 m throughout the year. The Torbay site, ~ 10 km SW of Albany, faces directly toward the Southern Ocean and is fronted by high (>50 m) sea cliffs (Fig. 1, 2). Waves predominantly approach the coast from the SW and must traverse a number of shoals before reaching the proposed development site which, when coupled with the relatively wide continental shelf (~50 km), act to moderate the extreme conditions common offshore (frequently >5 m H_s). The tidal range in Torbay is small, being approximately 1 m.

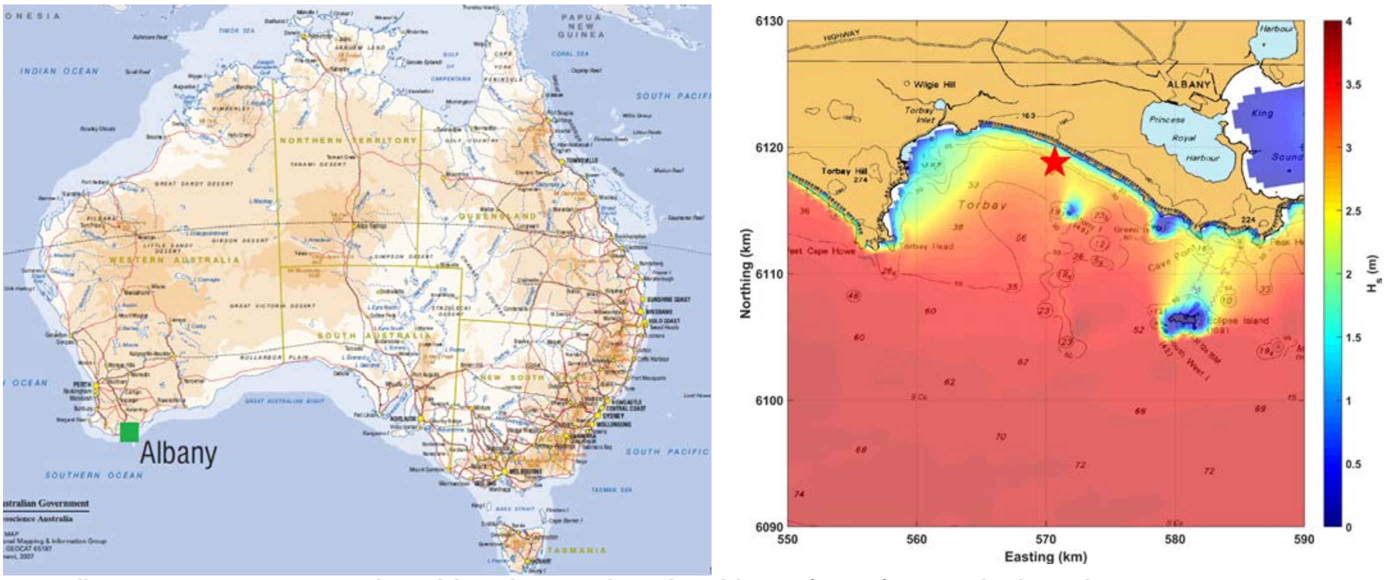

Fig. 1 *Albany (courtesy Geoscience Australia) and the Torbay site with sample model output for significant wave height, H_s, shown.*

The proposed development site is in 30 m depth which, given the relatively steep nearshore bathymetry, is just over 1 km from the shoreline. The funding provided to CCE by DPIRD was primarily for the installation of "common user infrastructure", which includes the required subsea and terrestrial infrastructure (e.g. subsea cabling and grid connection). After one year of exclusive access by CCE these assets will be available to other developers to trial their devices. Given the height of the sea cliffs and geologic conditions (limestone capped granite) all cabling will be installed using horizontal directional drilling from atop the cliff to just shoreward of the device. An existing 35 MW wind farm is installed atop the sea cliffs and will provide the grid connection point for AWEP.

The Torbay test site is about 50 km by sea from Albany Port, which is primarily a bulk products port dealing with grain and woodchip exports of around 3-4 million tonnes per year. Up to 20 cruise ships also visit Albany annually and use this port.


Fig. 2. *Torbay, looking South West.*

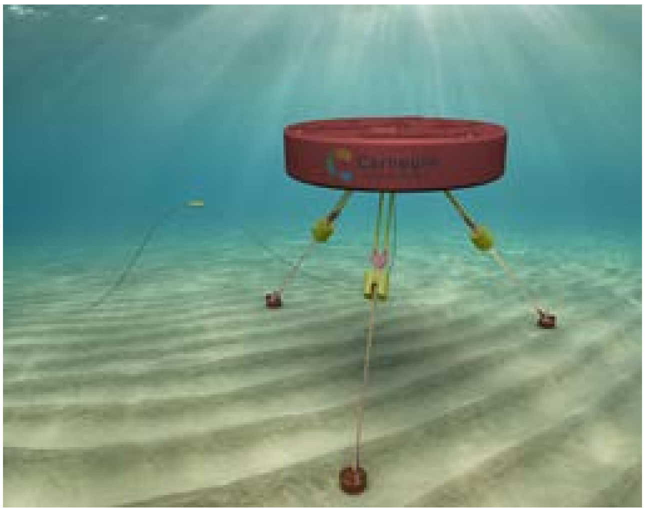
Fig. 3 *The multi-moored CETO6M wave energy converter.*

VI. Coastal processes (Programme 1)

The successful deployment and operation of operational WECs (including in the Torbay region near Albany) requires an accurate knowledge of, and ability to forecast, localised wave and current conditions to quantify the interaction and impact of the WECs with the coastal sediment dynamics and downstream/far-field effects of WECs on the wave field and coastal processes. The research activities within this Programme are designed to provide: (i) more accurate knowledge of wave resource availability at the development site; (ii) guide the design of the device(s), anchoring and cabling, (iii) determine safe working conditions, and (iv) develop understanding of the influence of WECs on the broader coastal environment (e.g. modification to incident wave energy to coastlines and potential influence on coastal erosion/accretion). The required knowledge will be developed through the four sub-programmes outlined below.

Programme 1.1: In situ observations: waves and currents

In order to understand the available wave resource and loads, optimise the design of the WEC device(s), and determine cut-offs for safe operation/maintenance, it is imperative to have an accurate knowledge of the wave and current conditions within the deployment region. In support of

AWEP, this is being achieved through the deployment of a dedicated directional wave buoy (Datawell Directional Waverider Mark 4) that also includes acoustic surface current measurements. This will provide long-term data on wave and current conditions at the development site, which will be critical in developing and validating the hydrodynamic models (see Programme 1.2 below). Once prototype device(s) are deployed, the data will also help optimise operation, determine when to cease operation and enter "survival mode" during extreme conditions, as well as determine when/if it is safe to conduct maintenance. An additional Waverider buoy will be deployed in deep water (>300 m depth) offshore. The offshore buoy, measuring waves in deep water un-impacted by the sea bottom, will quantify the offshore wave climatology and will be used to provide offshore boundary conditions for the numerical wave modelling (see Programme 1.2 below). All wave and current observations from the continuously operating buoys will eventually be available in real-time via a publicly-accessible website.

In addition to these sustained (long-term) wave and current observations at the development site and offshore, a number of more intensive process-focused field studies of the coastal hydrodynamics at Torbay will be conducted across a range of depths in and around the development site (<10 to ~30 m depth). A longer-term objective is also to include remote sensing observations from the adjacent cliffs inshore of the development site, including the installation of an X-Band radar for spatial measurements of directional wave properties up to ~3 km from the shoreline. Collectively, these additional observations will be used to support the development and validation of the numerical models that are being developed in Programme 1.2.

Programme 1.2: Coastal hydrodynamic modelling: waves and currents

Coastal numerical models are being used to expand the spatial coverage and resolution of the field observations, and most importantly predict the conditions that will likely occur in the future due to a range of scenarios based on the available climatology, including extreme events. The numerical modelling of the waves is based on using two classes of wave models: *wave-averaged (spectral) models*, in which the statistical properties of wave fields are predicted; as well as *wave-resolving (phase-resolving) models,* in which the individual waves are modelled. Wave-averaged models are best suited for larger areas whereas the wave-resolving models are only suited (given their high computational cost) for smaller (order several km) areas. A regional wave-averaged model extending from >300 m depth to the shoreline and extending for ~10 km on each side of the development site will be constructed with the numerical wave model SWAN [1]. The model, with ~10 m resolution in the development area, will be used to assess the wave conditions within the development site for a range of climatological and extreme conditions based on CSIRO's CAWCR 1979-2010 Wave Hindcast [2]. Once developed and validated with field observations, the SWAN model will be forced in real-time directly by directional wave measurements from the deep-water Waverider buoy (Programme 1.1) and local wind measurements, to produce continual real-time information on the wave field in the development area and broader Albany-Torbay coastal region.

Wave-resolving modelling will be carried out using the wave model SWASH [3] established for the Torbay area (nominally depths <50 m). This component will take advantage of new developments in SWASH to include WEC devices within the model, as detailed in Rijnsdorp et al. [4]. The SWASH wave model will be run using a subset of the conditions from the local wave climatology and forced with output from the wave-averaged (SWAN) model. The focus of the wave-resolving modelling will be to investigate nonlinear wave processes (including wave shape, wave-wave interactions, directional spreading, refraction and coastal reflections – sea-swell and long waves) and how they impact the performance of the WECs as well as the influence of diffraction in the presence of offshore bathymetry (headlands and islands in the region). This modelling will also be particularly important to understand wave shapes in extreme sea states, as an input to determining extreme device loads.

Finally, in parallel the wave-averaged SWAN model will be coupled to a regional circulation model using the Regional Ocean Modeling System (ROMS) [5], which will be calibrated and validated also using the field data set from Programme 1.1. The coupled wave-circulation model will be used to understand the magnitude and prevalence of currents within the development site driven by wind, tides, encroaching shelf currents, and wave-current interaction. A high-resolution model (<5 m) will also be nested within the larger model to specifically examine the waves, currents and sediment dynamics in the region in and around the devices and onshore to the shoreline. This will be done to both optimise WEC operation in the presence of coastal mean currents, as well as examine the effects that a WEC (and potentially future arrays of WECs and associated infrastructure) may have on the natural currents and sediment dynamics of the Albany-Torbay region.

Programme 1.3: Coastal sediment dynamics

The extraction of wave energy by WECs has the potential to significantly alter the spatial properties of the incident waves in the vicinity of devices, and at a sufficient scale, influence the broader coastal zone. The local morphology of seabeds and adjacent coastlines is, in general, largely dictated by the equilibrium response to the long term (100s of years) wave climate and sea level. Abruptly changing the characteristics of local wave fields thus has the potential to result in corresponding changes in the coastal processes and coastal morphology. The primary objective of Programme 1.3 will be to understand and predict how WEC arrays, as well as arrays of other marine renewable devices, alter natural wave, current, and sediment dynamics. While minimal coastal impacts are expected during CCE's initial deployment of a single CETO6M device, this Programme will also focus on the potential impacts of a large-scale wave farm (i.e. numerous WECs at the development site).

Programme 1.4: WEC-WEC interaction and influence on near-field hydrodynamics and sediment transport

In general, when arrays of WECs are deployed (either in the Torbay region in the future or other sites globally), individual WECs have the potential to strongly interact with each other. This is due to both the radiation of waves as a WEC moves with the waves, as well as through potential "wave shadows" in the lee of WECs, which may reduce performance in the centre or shoreward side of an array. As a result of these interactions, the layout and arrangement of WECs in an array is critical to optimise their performance. For example, if well designed, the radiation of waves from a WEC can be used to enhance the motions of adjacent WECs (i.e. introduce resonant motions) whereas if improperly spaced, these radiated waves can hinder the performance of adjacent WECs. Optimisation of the design and arrangement of WECs in an array for AWEP will be carried out using the wave-resolving SWASH model in Programme 1.2. This workstream will also have strong synergies with the improved knowledge of WEC-wave interactions through the activities of Programme 2.

VII. WAVE-WEC INTERACTION (PROGRAMME 2)

Understanding the hydrodynamics, or wave-structure interaction, of a WEC is a core requirement for predicting its performance, survivability, controllability and interaction with other WECs. Programme 2 aims to focus on these interactions, through a series of five sub-programmes described below.

Programme 2.1: Extreme response analysis

In determining the extreme response of a WEC the challenge is to determine not just the range of likely extreme sea states but also which waves within these sea states that will result in extreme WEC responses. A ‘design wave’ approach has been shown to work well for WECs which respond in a weakly nonlinear fashion [6] and there is some evidence that it works well for WECs where the response parameter of interest behaves in a more nonlinear manner [7]. Research at WERC will be directed towards investigating the viability of this concept using the example of the CETO6M device and the Albany site, which is challenging due to the long period waves in intermediate depth.

The extreme response of a WEC depends on the nature of the PTO behaviour in extremes - whether this be to decouple the PTO, revert to a passive survival mode or change the settings in some other way.

Programme 2.2: Development of hydrodynamic tools

Numerical models of different types are well-known tools for assessing wave-WEC interaction (e.g. [9], [10]). In such models, it is important to include the dominant physical effects, but is generally also important to minimise their computational cost. In this programme, customised models of a submerged CETO6M device will be developed, and validated with wave flume/basin tests (e.g. Fig. 4, 5).

Once again, the effect of the PTO/mooring system is crucial for accurate prediction of WEC motions. Thus the developed models must allow for changes in PTO operating strategy/control and be able to incorporate the specific PTO characteristics of the WEC deployed. The hydrodynamic model will form a key link in a full wave-to-wire model.

Programme 2.3: AWEP device monitoring

The opportunity to collect high quality full-scale data on device motions and performance simultaneously with measurements of the local wave field is the most exciting aspect of this Programme. It is clearly stated by Andrew Garrad [11], for example, that advanced measurement campaigns were of great importance in the development of the wind energy industry, and have been (lamentably) relatively uncommon in the wave energy sector. Full-scale data will provide the opportunity to test and validate models developed in Programme 2.2. This raises the possibility of addressing the fundamental issue of scaling, which is relevant for all numerical models of fluid behaviour validated using basin tests at reduced scale.

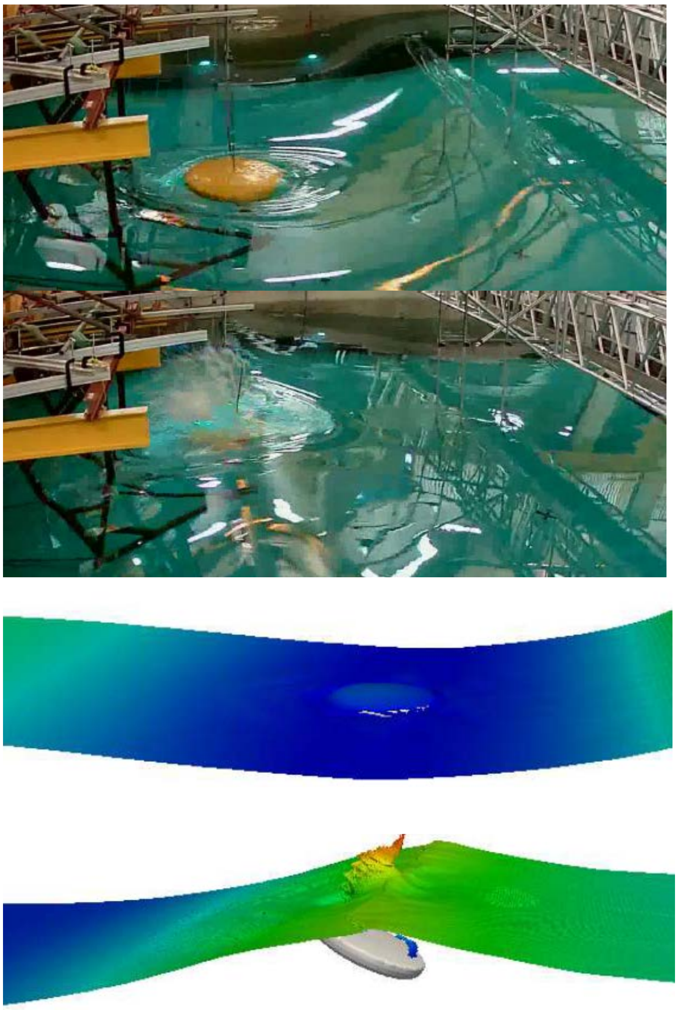

Fig. 4: Model scale testing of the CETO device. From [7].

Data collection considerations will be considered throughout the WEC design phase, so that sensors are considered part of the system. Sensors used will need to be extremely robust, to be able to withstand the hydrodynamic pressures they may experience.

Programme 2.4: Tools to assess extreme and operational performance of arrays

WECs spaced in close proximity (for example, when sharing anchors – Fig. 8) may interact strongly through the surrounding fluid. It is well known that these effects may be beneficial or detrimental in terms of power performance, though the specifics of the interaction will depend on the spacing and layout of the WECs, in addition to all of the other factors influencing individual WEC performance. In this programme hydrodynamic tools validated with full scale data will be extended to consider arrays. Working with Programme 1.4, these models will be compared with the performance of the coastal-scale models to evaluate the performance of each.

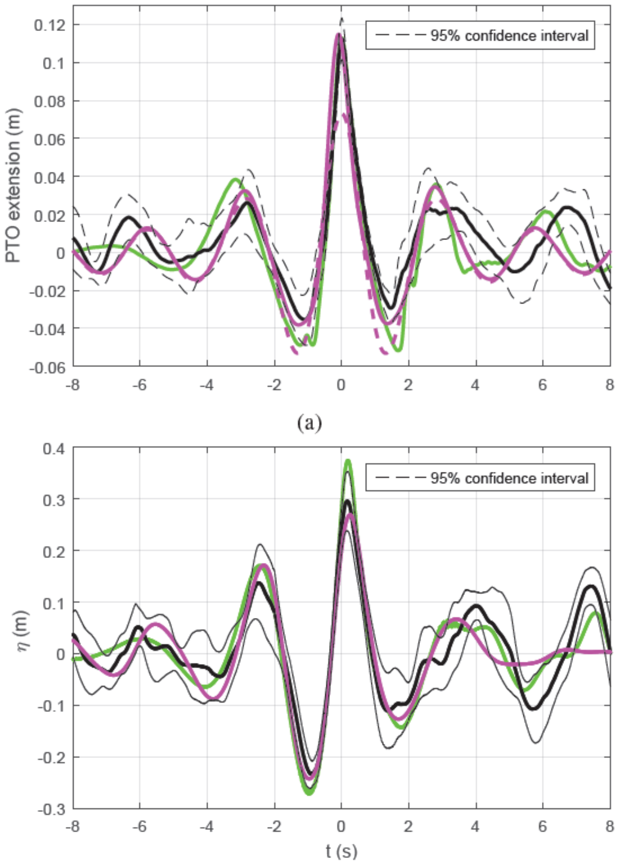

Fig. 5: (Top) extreme response of single-moored CETO device, lab scale, and (bottom) the associated design wave group. From [8] .

Most studies of arrays have focused on operational performance, though there is also the question of extremes. In extreme seastates the WECs are likely to be detuned, such that radiated waves will be of negligible importance. However, in a large array, potentially sharing anchors, it is important to consider whether WECs will experience the same extreme load – i.e. will all the WECs in an array experience the maximum load if a large wave passes through, and what will the phasing of the loads be?

Programme 2.5: Implementation of new design methods

Standards, guidelines and design methods for wave energy lag far behind the offshore oil and gas and even offshore wind industries. Through the course of the research outlined above general guidelines are expected to emerge on the best methodologies to use to estimate and confirm extreme responses of wave energy devices to enable efficient foundation design and general device survivability. The purpose of this workstream will be to package these findings together in a design guideline/method/recommended practice for the wave energy industry.

VIII. GEOTECHNICS (PROGRAMME 3)

Offshore floating renewables require reliable and economical anchoring systems that can perform in the type of seabed sediments encountered on the continental shelf, where marine renewables are expected to operate. Anchoring systems can contribute up to 22% of the total installed cost of an offshore wind turbine [12], and up to 30% of the total installed cost of a wave energy converter [13]. This is one order of magnitude higher than for oil and gas structures [14], and contributes significantly to the high levelised cost of offshore wind and wave energy. For marine renewable energy to be commercially affordable and competitive, a significant paradigm shift is required both in foundation technology and in foundation design.

WERC will be using AWEP as a living laboratory to better understand and characterise the performance of the foundation under the loads applied by the CETO6M and to subsequently undertake fundamental research in the field of geotechnical engineering to provide alternative and economical foundation solutions to the broader offshore renewable energy industry. The research activities initially undertaken by WERC are divided in four sub-programmes.

Programme 3.1 - Torbay seabed characterisation

Geophysical and geotechnical surveys are required to provide the seabed characterisation data necessary for the anchor (foundation) design for the CETO6M device. Standard practice would involve the following three stages. First, an initial desk study would be undertaken to assemble available information for the site, including approximate bathymetry, regional geology and identification of soil units at the seabed, potentially from previous works in the area. Second, a geophysical survey would be conducted to provide an indication of the local seabed and soil conditions. Third, a geotechnical survey would be carried out, involving penetrometer tests (e.g. cone penetrometer tests) at each foundation location, soil sampling to beyond the maximum depth of the foundation, and a comprehensive campaign of soil element testing to characterise the behaviour of the soil under the loading paths expected to be experienced by the foundations. The cost associated with such an approach is incompatible with the economics of marine renewable energy projects and research will be undertaken by WERC to help identify the minimal seabed characterisation requirement that would lead to the optimal (and most economical) foundation design. This includes notably the development of probabilistic methods that define the foundation design, not in terms of ultimate load, but in terms of probability of failure.

Fig. 6 *The 10 m diameter beam geotechnical centrifuge at UWA*

Programme 3.2 - AWEP foundation monitoring

The second phase of the research programme will consist of instrumenting the foundations and the mooring lines of the

CETO6M device to monitor the foundation performance during operating phases and extreme sea states. This will provide a unique opportunity for obtaining a better understanding of the foundation performance under the particular loading conditions applied by wave energy converters, and subsequently explore alternative foundation solutions and design approaches. Assuming the seabed in Torbay is constituted of weathered limestone overlaid by carbonate sand, the standard practice is the use of grouted piles. The mooring lines will be instrumented at the seabed to provide the time history of load magnitude and inclination at the pile head, as well as potential pile displacements.

Programme 3.3 - Performance of pile foundations under cyclic tensile inclined loading

The third phase of the research activity will consist of investigating the performance of pile foundations under the specific cyclic tensile inclined loading applied by CETO6M. The research will be supported by the field monitoring data collected in phase 2, and by modelling tests performed in the UWA geotechnical centrifuge (see Fig. 6).

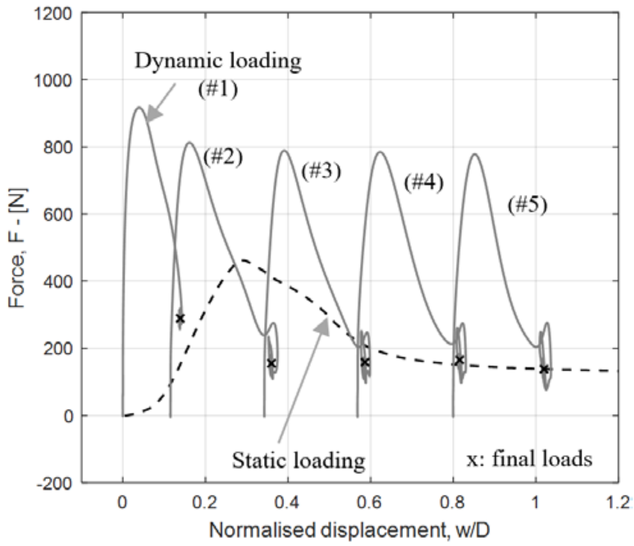

Fig. 7 Geotechnical centrifuge data showing that tensile capacity is much higher under dynamic than static loading

Preliminary investigations have demonstrated that under extreme sea states, the loading applied on the pile is dynamic in nature and that additional pile capacity can be mobilised from inertial, drainage and radiation damping effects, not generally considered for static loading (see Fig. 7). A better understanding of the pile performance under static and dynamic cyclic inclined tensile loading is expected to reduce the significant conservatism that is inherent in the current design practice that ignores dynamic resistance and does not specifically address tensile inclined loading.

Programme 3.4 - Influence of multidirectional loading on pile tensile inclined capacity

The transition from one single experimental wave energy converter to commercial developments of wave energy converters will require the assembly of multiple devices in an array, with each foundation anchoring a number of neighbouring devices (e.g. see Fig. 8). While this generates important economies of scale by reducing the number of foundations, it also introduces multi-directional loading conditions for which there is no design guidelines. Research will be undertaken to investigate the performance of foundations under multi-directional loading configurations that are relevant to AWEP, but also to other floating renewable devices (such as floating wind turbines). Experimental and analytical efforts have been initiated and show potential significant peak resistance reduction through multidirectional loading.

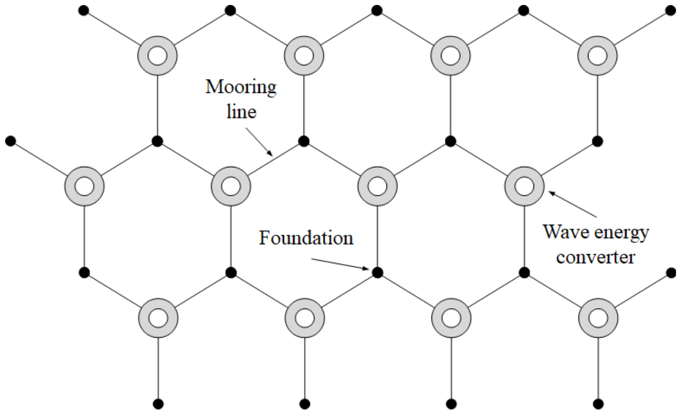

Fig. 8 An example array of wave energy converters with shared foundations

IX. Beyond AWEP

Common user infrastructure

Part of AWEP involves the development of common user infrastructure that will remain on site after the deployment and retrieval of the CETO6M device for any applicant to use. It will consist of a set of facilities that in effect transforms Torbay into a testing site available to the whole marine renewable energy industry. The facilities will include:

- an export cable enabling the connection of any wave energy device to the grid;
- a detailed wave resource assessment validated with measurements that can be used by any developer to help size/design their offshore renewable energy device;
- seabed investigation that will map and characterise the mechanical properties of the sediments enabling the design of any type of foundation; and,
- The foundations, which may be able to be re-used as anchoring points for other WECs.

In addition, AWEP will have developed local knowledge and capabilities, for example in the port infrastructure required to enable WEC deployment. WERC aims to continue to provide research relevant to the wave energy industry and the Albany site.

Developing an Australian test site was one of the key recommendations of the recent survey of the state of the Australian ocean renewable energy industry [15]. WERC will provide a base to allow this to become a reality.

Additional research pathways

Initially, the scope of WERC research as outlined above is limited to activities relevant to core engineering aspects of deploying a wave energy device, with some effort devoted to arrays. If a long-term array deployment is envisaged for Albany, significant additional research will be required, in areas including marine science – especially biological impacts, grid integration, legal and social issues including social licence to operate, and additional engineering including corrosion and maintenance.

A focus for Australian research and industry

WERC provides a potential focal point for Australian research and industry development in wave energy. To realise this potential, it is necessary to engage strongly with the other stakeholders in this field. To this end, the Australian Ocean Renewable Energy Symposium in November 2018 will bring academia and industry to Western Australia. WERC is also engaging with the national industry grouping, the Australian Marine Energy Taskforce (AMET). It is hoped that with interaction across the sector, WERC can catalyse emergence of a sustained and sustainable wave energy industry in Australia.

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