Supergen Offshore Renewable Energy

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Early Career Researcher Posters & Abstracts

UKRI Engineering and Physical Sciences Research Council

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Dynamic Subsea Power Cables in Offshore Renewable Energy – the Impact of Marine Growth

Dr Andrew Want[1] and Dr Rachel Nicholls-Lee[2]

[1]Heriot Watt University – Orkney; [2]University of Exeter

As the transition to decarbonising electricity generation accelerates, full scale prototype installations of offshore renewable energy (ORE) devices have been deployed; with larger commercial-scale farms planned in the next 10 years. Success in the sector is partly dependent on removing economic uncertainties associated with these new technologies. An important concern is the impact of marine growth (or biofouling) on the functionality and survivability of dynamic subsea power cables (dSPCs) used in floating wind and marine renewable energy technologies. Biofouling will increase loading on dSPCs and may affect the structural response. Coupled with exposure to extreme hydrodynamics forces in the resource-rich environments targeted for ORE deployments, dSPCs are highly vulnerable to fatigue failure. dSPCs are costly to repair and maintenance may result in a significant loss of revenue due to disruption in power supply.

Existing studies on marine growth on offshore infrastructure are mostly restricted to the Oil and Gas (O&G) sector and inferences to dSPCs are limited. The impacts of biofouling on dSPCs are likely to differ considerably from O&G applications in that: different component materials are used, with substrate being a major factor in the settlement and growth of marine organisms; installations are expected in 'data poor' regions without detailed knowledge of growth rates and species of biofouling organisms; and dSPC functioning is more complex than more well-studied mooring structures with the added roles of heat and electromagnetic fields generated during cable operation affecting marine growth. Furthermore, while existing standards and guidelines used in the ORE sector provide broad generalisations on marine growth, these are typically informed by surveys of large O&G structures with limitations on inferences of the impacts from biofouling on smaller diameter structures, such as cables.

This project is using a multi-disciplinary approach to gather and quantify information on the impacts to dSPCs from marine growth, and in the preparation of a larger scale research proposal to target knowledge gaps and test mitigations - the ultimate aim being to assist the ORE sector in lowering the levelized cost of energy. Specific objectives include: assessment of literature and investigation of current data on biofouling most pertinent to dSPCs and associated components; assessment of potential mitigations, including the latest antifouling strategies; characterisation of the impact of marine growth on hydrodynamic and structural response of dSPCs, with focus on fatigue life prediction; and appraisal of economic impacts and risks to assess installation, operation and maintenance costs of ORE farms.

These objectives are being achieved through a collaboration of marine ecologists, research engineers, and test centres and developers representing floating ORE technologies. Existing *in situ* survey data from ORE installations are being collated to identify key species, their seasonality, and knowledge gaps in the North Sea. Quantifiable biofouling data is being used to inform the expected loading consequences of marine growth on cable buoyancy and movement. OrcaFlex and ANSYS/UFLEX software are being used to model the impact of marine growth on cable structural response and predicted fatigue life. Discussions with the ORE sector are providing industry input into options to mitigate the impacts of marine growth and to better understand the cost implications to these deployments. The investigation initiated by this project will inform the direction and scope of the resulting large-scale funding proposal.

The Impacts of Marine Growth on Dynamic Subsea Cables

Andrew Want[1] and Rachel Nicholls-Lee[2]

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Dynamic subsea cables (dSPCs) are used in offshore wind and marine renewable energy technologies to transmit electricity from floating devices to the seabed. In comparison with subsea cables laying on or buried in the seabed, dSPCS are more vulnerable to fatigue and structural failure, owing to greater exposure to cyclic wave and tidal loads in the water column. Replacement of cables and components is costly in terms of materials, vessel use, and operational 'down-time', impacting the levelized cost of electricity generation. Lift and drag forces are exacerbated by **biofouling** - the settlement and growth of marine organisms on submerged structures – antifouling strategies are costly and only partially successful.

Biofouling: Existing studies on marine growth on offshore infrastructure are mostly restricted to the Oil and Gas (O&G) sector and inferences to dSPCs are limited. Biofouling on dSPCs differs from O&G applications in that: different component materials are used; installations are occurring in 'data poor' habitats; and more complex dSPC functioning includes generation of electromagnetic fields and heat during cable operation[1], affecting marine growth.

Figure 1: biofouling in the marine renewable energy sector (Images: A. Want)

In situ studies of biofouling indicate that hydrodynamic forces, i.e. wave exposure and tidal currents, play an important role in determining species composition[2]. Greater knowledge of fouling species at specific locations and applications, at different depths, and on various substrates may have implications on management strategies designed to minimise impacts on dSPC performance and, ultimately, may lower costs. For example: selectively scheduling of maintenance operations to periods when problematic growth is heaviest, or fouling is most easily removed may be a cost-effective strategy[3].

Dynamic subsea cables: Preliminary modelling of the impacts of marine growth on dSPC from wave and floating wind devices are being conducted based on drag-mediated responses in cable tension and curvature associated with biofouling[4] (Figure 2). Initial results indicate that heavy calcareous fouling may increase tension by >60%, while curvature may substantial increase or decrease depending upon the scale of the floating platform or device.

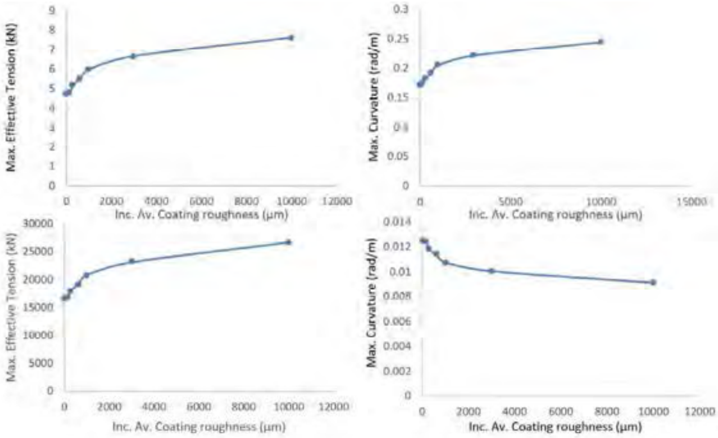

Figure 2: preliminary modelling of the impacts of heavy calcareous fouling on dSPC tension and curvature. Top: small-scale wave energy converter; bottom: 5 MW floating wind turbine.

These models are being refined with inclusion of mass of growth, as well as biofouling data specific to habitats targeted by the ORE sector, and will be modified to include a variety of floating devices. The inclusion of computational fluid dynamics to model the consequences of marine growth is being considered to further enhance these models. Findings may inform management decisions including antifouling actions as part of project cost analysis.

Key objectives:

- Literature review and data collation of existing biofouling studies pertinent to dSPC performance and survivability
- Assessment of potential mitigations including the latest antifouling strategies
- Characterising structural responses of dSPCs to marine growth, focussing on fatigue life prediction, and considering economic impacts
- Preparation of a large-scale proposal to target knowledge gaps and test mitigations
- Opportunities to engage with the offshore wind industry and the ORE sector are welcomed

References:

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2. Want *et al*. 2021. *Biofouling*.
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Measuring Wave Modulation by a Large Offshore Wind Farm

SUPERGEN ECR: David Christie, Bangor University

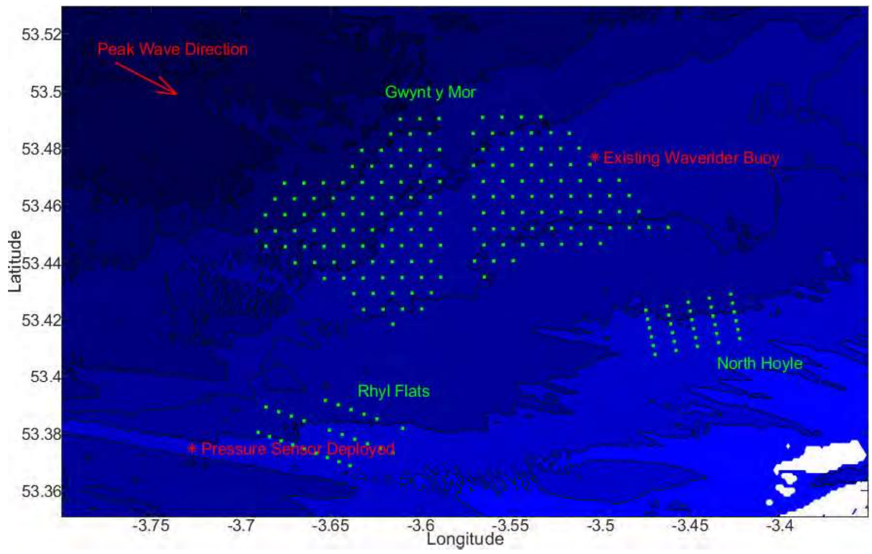
Offshore wind turbines scatter incoming waves, causing reflection and diffraction of waves in their immediate vicinity. This can affect sediment transport, coastal processes, structural loading, as well as the available wave resource for hybrid wind-wave developments.

Wave scattering from an individual turbine (a bottom-mounted vertical cylindrical monopile) may be calculated analytically. However, multiple turbines are significantly more difficult to calculate, since the incoming waves scattered by one turbine are affected by all its neighbours. Existing numerical treatments eg [Aguilera et al (2020)] can only consider selected monochromatic waves meeting a maximum of four turbines, and cannot cope with large arrays. By contrast, Gwynt y Môr has 160 turbines. The effect on the wave climate of this scale of development has not yet been modelled.

This research seeks to develop methodology to address the following questions: What effect do large, regular wind turbine arrays have on the wave climate? How significant is the effect and how far away do any effects persist? How do effects depend on wavelength, location, and turbine separation and configuration?

The project comprises a combination of data acquisition and modelling, using Gwynt y Môr and neighbouring developments as a case study. The funding has allowed the acquisition of a RBR Solo D|wave16 Logger (and sundries), a bottom-mounted pressure sensor for wave measurements. Initially, multiple short deployments were planned to test a highly simplified analytical modelling approach. Instead, a single, deployment (11th November 2021) will provide a full winter's worth of wave data for input to a more sophisticated numerical model.

Analytical treatments of waves around cylindrical structures use Hankel function decomposition to solve the Helmholtz equation, with Neumann boundary conditions on each scatterer, and a radiation condition. A numerical solver for precisely this system was recently developed by [Hawkins (2020)] for electromagnetic and acoustic calculations. This project is the first application to water wave scattering. Gwynt y Môr and Rhyl Flats wind farms may each be modelled using the nearby sensors for input wave data.



1 Locations of wind farms and sensor deployments

The numerical method was tested by calculating wave modulation around Gwynt y Môr, at peak frequency and direction (as measured by the nearby buoy). The wave field changes at wavelength scale, with spatially-averaged results showing a small increase upwave (due to reflection) and decrease downwave from the site. Extension beyond monochromatic waves to full directional spectra is currently ongoing.

Measuring Wave Modulation by a Large Offshore Wind Farm

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School of Ocean Sciences, Bangor University, Wales

Background

Offshore wind turbines scatter incoming waves, causing reflection and diffraction of waves in their immediate vicinity. This can affect sediment transport and coastal processes, structural loading, and the available wave resource for hybrid wind-wave developments.
What effect do large, regular wind turbine arrays have on the wave climate?

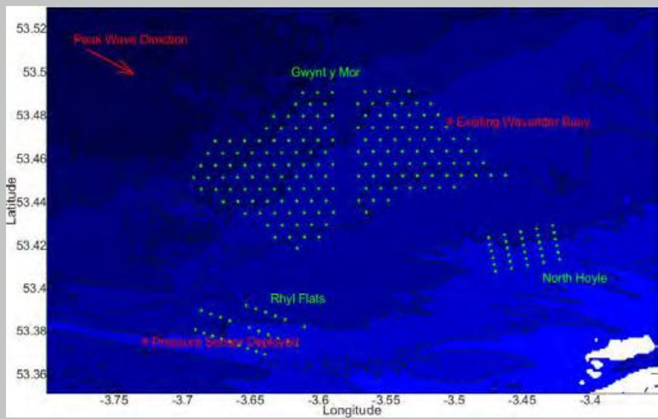
- Significance and spatial extent of wave modulation
- Dependence on wavelength, location, and turbine separation and configuration
- Trapping, resonance, selective absorption (Solid state physics, metamaterials)

How can we model the effects? Existing analytical treatments are restricted to ¡6 turbines and monochromatic waves - scattering from one cylinder is straightforward but array effects greatly increase complexity [1]. Can we neglect array effects for offshore wind structures? Or is there another way to calculate the fields? Use Gwynt y Môr and neighbouring developments as a case study

Gwynt y Mor wind farm (image: RWE)

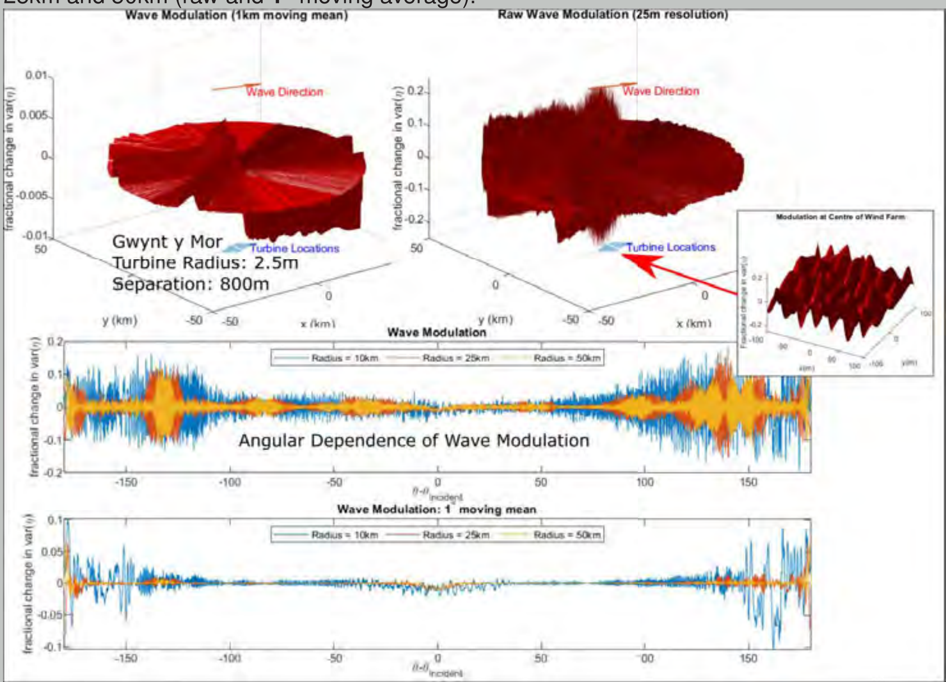
Methodology

The study combines modelling and data acquisition. We have acquired a RBR Solo D—wave16 Logger (and sundries) for wave measurement. Initially, multiple short deployments were planned to test a highly simplified analytical modelling approach. Instead, a single, deployment (11th November 2021) will provide a full winter's worth of wave data for input to a more sophisticated numerical model. Analytical treatments of waves around cylindrical structures use Hankel function decomposition to solve the Helmholtz equation, with Neumann boundary conditions on each scatterer, and a radiation condition. A numerical solver for precisely this system [2] has recently been developed (for electromagnetic and acoustic calculations) - this project is the first application to water wave scattering. Gwynt y Môr and Rhyl Flats wind farms may each be modelled using the nearby sensors for input wave data.



Example Results

The numerical method was tested on Gwynt y Môr, at peak frequency (corresponds to $\lambda = 60$m), and peak direction (based on measurements at co-located buoy). Upper plots show spatial dependence of wave modulation - both raw, where variations are of wavelength scale, and spatially averaged (2d moving average, 1km window). The lower plots show angular dependence (variation along circles centred on the Gwynt t Môr, with radii 10km, 25km and 50km (raw and 1° moving average).



Observations

- The numerical solver can readily be applied to large offshore wind array scattering calculations.
- By contrast, previous treatments were limited to < 6 turbines.
- Modulation varies on wavelength scale (and very sensitive to direction and wavelength)
- Averaged results show small systematic effects of turbines (order 1%): increase downwave, decrease upwave but persist over long distances.
- Analysis was for relatively small (5m diameter) monopiles.
- Trend is towards increasing turbine diameter, approaching 8m-10m - effect may become more significant (also for wider gravity-based structures).

Next steps

- The sample calculation was for monochromatic waves at peak period/direction.
- Full directional spectrum can be readily calculated by superposing solutions for each wavelength and direction.
- This is underway, and more results will be presented at OSM22.
- On recovery of sensor, can repeat analysis for Rhyl Flats.
- Effect of increasing radius can be investigated.

Acknowledgements

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References

1 https://doi.org/10.1590/2318-0331.252020190140
2 https://doi.org/10.1145/3381537

Hygro-thermal effects on the translaminar fracture toughness of composite laminates

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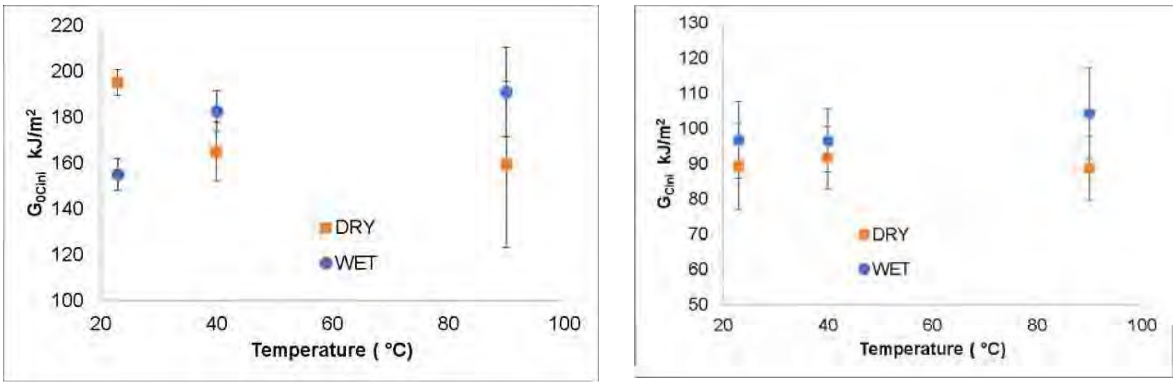
Abstract

The very high loads experienced by tidal and wind turbine blades push the material selection towards high-specific-strength materials, such as Glass- or Carbon-fibre reinforced thermoset polymers. The composite blades' load-carrying capacity primarily depends on the longitudinal strength and failure behaviour of the laminates. The longitudinal tensile failure is often controlled by the fracture toughness associated with tensile fibre (i.e., translaminar) failure. Compact tension tests on IM7/8552 (dry & wet) cross-ply ($[90/0]_{8S}$) and quasi-isotropic ($[90/45/0/-45]_{4S}$) laminates at three different temperature conditions (23 °C, 40 °C and 90 °C) revealed some intriguing insights. The fracture energy of dry cross-ply specimens decreases with the increase in test temperature as shown in Figure 1(a). Interestingly, the fracture energy of the fully saturated (wet) cross-ply specimens increases with the temperature. The fibre/matrix interface of the wet specimens alters and promotes the fibre pull-out failure of the laminates. The fibre pull-out length and the fracture process zone of the wet laminates increase with the temperature and result in higher energy dissipation. The fractographic analysis of the failure surfaces revealed that the wet specimens had more pulled out fibres/bundles than the dry specimens. The initiation facture energy of the dry quasi-isotropic laminates is not significantly affected by the increase in temperature as shown in figure 1(b). The initiation energy of the dry coupons slightly increases (~2%) as the temperature increase from 23 °C to 40 °C and decreases at 90 °C (~1%). However, the initiation fracture toughness of wet quasi-isotropic specimens tested at elevated temperature (90 °C) is ~17% higher than the room temperature (23 °C) dry specimens.



(a) (b)

Figure 1. Initiation fracture energy of the (a) 0° plies obtained from the translaminar failure of $[90/0]_{8S}$ cross-ply laminates and (b) $[90/45/0/-45]_{4S}$ Quasi-Isotropic laminates.

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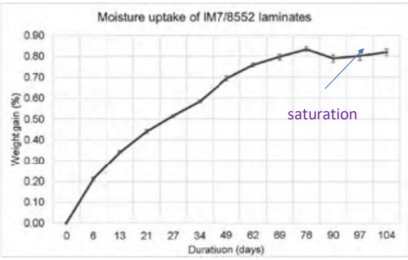
Hygrothermal effects on the translaminar fracture toughness of composite laminates

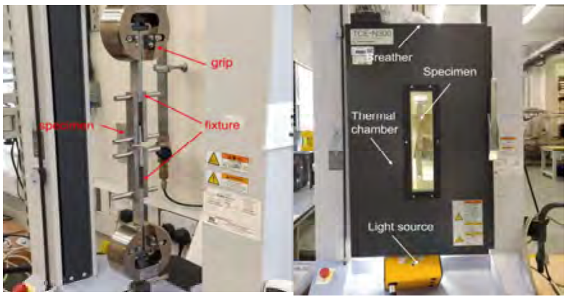
Ganapathi A Sengodan*, Shengkai Li, Giuliano Allegri and Stephen Hallett

The very high loads experienced by tidal and wind turbine blades push the material selection towards high-specific-strength materials, such as Glass- or Carbon-fibre reinforced thermoset polymers. The composite blades' load-carrying capacity primarily depends on the longitudinal strength and failure behaviour of the laminates. The longitudinal tensile failure is often controlled by the fracture toughness associated with tensile fibre (i.e., translaminar) failure. Compact tension tests on IM7/8552 (dry & wet) cross-ply ($[90/0]_{8S}$) and quasi-isotropic ($[90/45/0/-45]_{4S}$) laminates at three different temperature conditions (23 °C, 40 °C and 90 °C) revealed some intriguing insights. The fracture energy of dry specimens decreases with the increase in test temperature. Interestingly, the fracture energy of the fully saturated (wet) specimens increases with the temperature. The fibre/matrix interface of the wet specimens alters and promotes the fibre pull-out failure of the laminates. The fibre pull-out length and the fracture process zone of the wet laminates increase with the temperature and result in higher energy dissipation. The fractographic analysis of the failure surfaces revealed that the wet specimens had more pulled out fibres/bundles than the dry specimens.

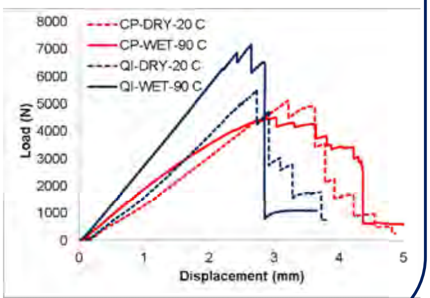
Wet specimens conditioned at 70 °C and 85% relative humidity



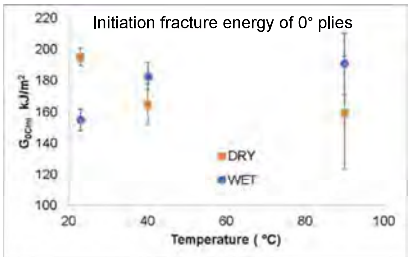
Compact tension test set-up with environmental chamber



Load-displacement curves of selected tests

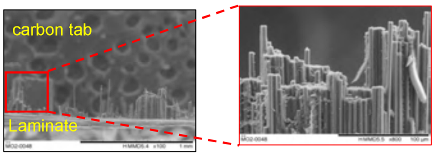


Cross-ply (CP) $[90/0]_{8S}$ laminates



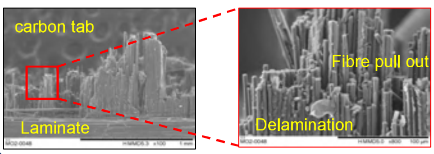
- Fracture energy of the dry specimens decreases with the temperature
- Fracture energy of the wet specimens increases with the temperature
- Temperature and moisture degrades the bulk matrix
- Moisture ingress promotes the fibre/matrix debonding

Fractography of Dry specimen tested at 20 °C



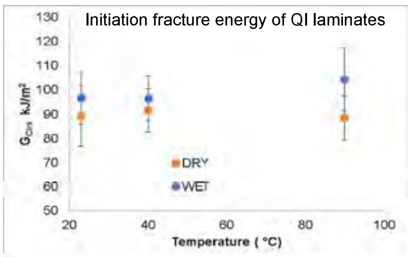
- Insignificant delamination between 0° and 90° plies
- Minimal debonding of fibre from matrix
- 0° fibre breakage normal to pre-crack direction

Fractography of Wet specimen tested at 20 °C



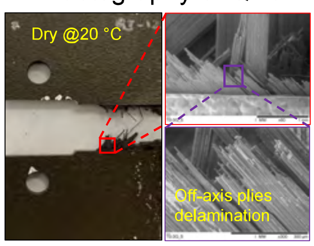
- Higher delamination than dry specimens
- Short fibre pull out noticed
- Weak fibre matrix interface promotes debonding
- Less energy dissipation than dry specimens

Quasi-isotropic (QI) ($[90/45/0/-45]_{4S}$) laminates

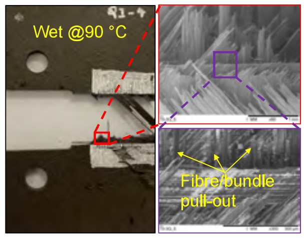


- Total fracture energy = delamination+ fibre-matrix debonding+ fibre pull-out + fibre breakage
- Temperature and moisture relaxes the inter-ply and intra-ply residual stresses and promotes the fibre pull-out
- Fibre/matrix debonding in wet specimens supressed at high temperatures

Fractography of QI laminates at crack initiation



- 0° fibre breakage normal to pre-crack direction
- Off-axis plies delamination after 0° fibre breakage



- 0° fibre pull-out creates broom like structures
- Less off-axis plies delamination than room temperature dry specimens

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Jamie Crispin – University of Oxford

Title: Analytical Solution for the Response of Pile Groups Under Dynamic Loads

Abstract: Installing piles in groups can allow the combined foundation to provide a larger stiffness than might be achieved with a single monopile. Large moments, such as those due to a wind turbine, are converted to axial loads, allowing smaller piles to be used. This advantage comes at the cost of efficiency; the piles in the group will interact with each other and, under static loading, the stiffness of the pile group will be lower than the sum of the stiffnesses of each pile. However, under dynamic loading (at a range of frequencies), the phase difference between the response of each pile can allow the combined group stiffness to be higher than the sum of its parts. Understanding this effect allows for more efficient design of pile group foundations. Current methods, even when using the simplified interaction factor approach, involve complex numerical continuum solutions and/or idealised homogeneous soil conditions. In this work, an approximate analytical solution has been developed, using a simplified energy approach to calculate dynamic interaction factors between each pair of piles. This approach can be applied to inhomogeneous soils by reducing the problem to a single integral that can be solved numerically or, for some specific cases, analytically. The resulting solution can be employed in simple hand calculations, useful for the early stages of design, including for determining the dynamic response of a pile group, or the natural frequency of a combined structure and foundation. The results compare well with those from numerical continuum solutions.

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Analytical Solution for the Response of Pile Groups Under Dynamic Loads

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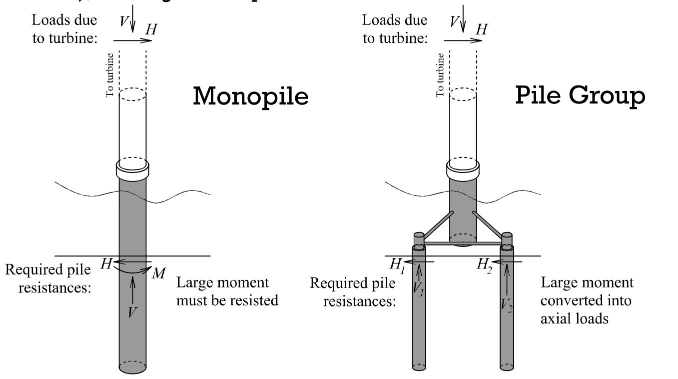
(1) Pile group foundations

Installing piles in groups can allow the combined foundation to provide a larger stiffness than might be achieved with a single monopile.

Large moments (e.g. due to a wind turbine) are converted to axial loads (as shown below), allowing smaller piles to be used.



However, piles in a group interact with each other, resulting in a pile group stiffness lower than the sum of the stiffnesses of each pile.

Under dynamic loading, the phase difference in pile response means piles can resonate, or destructively interfere with each other.

Predicting this effect is key to pile group design under dynamic loading.

(2) The Problem

Analysis of pile groups normally requires modelling the full problem in 3D. This is inconvenient, particularly at the early stages of design, where a simpler method would be useful to determine the optimal foundation dimensions.

In this work, a simplified energy method is applied to calculate interaction factors (3) under high frequency loading with the three step model (4).

The resulting solution (5) is easy to employ, can model any inhomogeneous soil, and compares well with numerical continuum results (6).

(3) Interaction factors

Introduced by Poulos (1968, 1971). Extended to dynamic loading, Kaynia (1982). Allow N pile groups to be analysed with superposition, so a 3D numerical model is not required.

$$\alpha_{21} = \frac{\Delta_{21}^*}{\Delta_{11}^*} = \frac{\textit{displacement of Pile 2 due to load on Pile 1}}{\textit{displacement of Pile 1}}$$

N simultaneous equations can then be obtained, one for each pile: $\Delta_i = \sum_{j=1}^{N} \frac{P_j^* \alpha_{ij}^*}{K_j^*}$

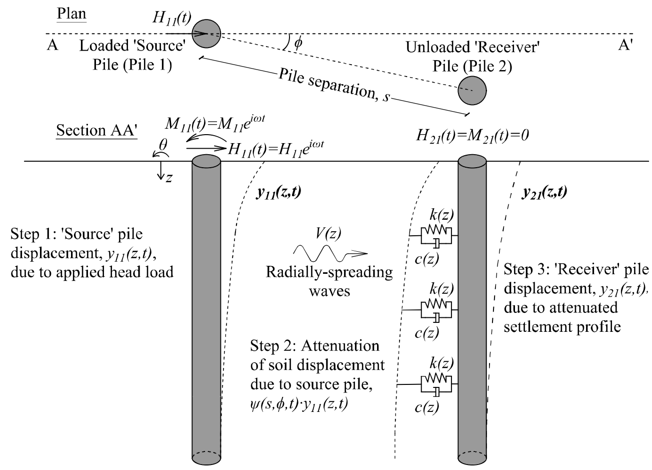
These are solved for the overall pile group response.

(4) Three step model

This model, by Mylonakis (1995), allows interaction factors to be calculated in closed form.

Based on the Winkler model, it requires free-field displacement attenuation function, ψ^* and dynamic Winkler impedance function $k^*(z) = k(z) + i\, c(z)$.

These can be related to soil properties, $(E_s, \nu_s, V_s, \beta_s)$, e.g. with the horizontal soil slice solution of Novak et al. (1978).



(5) Solution example (fixed head)

The resulting equation: $E_p I y_{21}^{*''''}(z) + \left[k^*(z) - \rho_p A_p \omega^2\right] y_{21}^*(z) = k^*(z)\psi(s,\phi) y_{11}^*(z)$

can be transformed to the weak form using Pile 2 boundary conditions:

$$\int_0^L E_p^* I y_{21}^{*''}(z) y_v''(z)\,dz + \int_0^L \left[k^*(z) - \rho_p A_p \omega^2\right] y_{21}^*(z) y_v(z)\,dz = \int_0^L k^*(z)\psi(s,\phi) y_{11}^*(z) y_v(z)\,dz$$

This can be rearranged for the interaction factor. By simplifying the result using the solution for pile fixed head stiffness, K_{11}^*, only one integral remains to be solved (fixed head case):

$$\alpha_{uF}^* = \frac{y_{21}^*(z)}{y_{11}^*(z)} = \frac{1}{K_{11}^*} \int_0^L k^*(z)\psi^*(s,\phi)\left[\chi_F^*(z)\right]^2 dz$$

where $\chi_F^*(z) = e^{-\mu z}\left[\cos(\mu z) + \sin(\mu z)\right]$, $\mu = \int_0^{L_a} \lambda^*(z)\,dz$, $\lambda^*(z) = \sqrt[4]{\frac{k^*(z) - \rho_p A_p \omega^2}{4 E_p^* I}}$

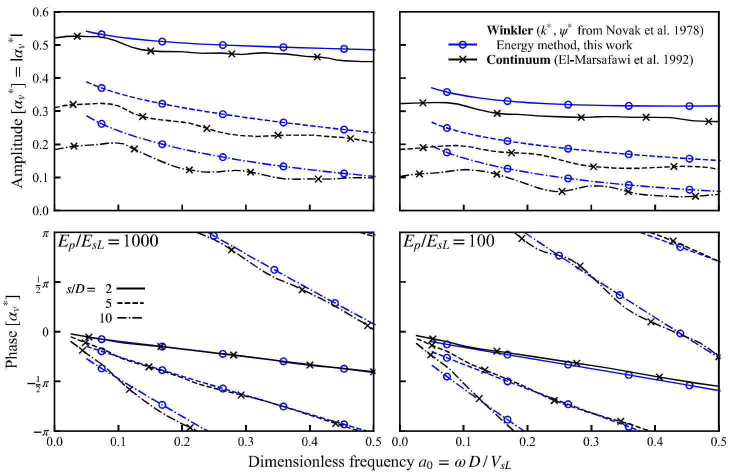
This integral is simple to solve numerically, and in some cases can even be solved analytically.

Equivalent solutions developed for axial loading and free head piles.

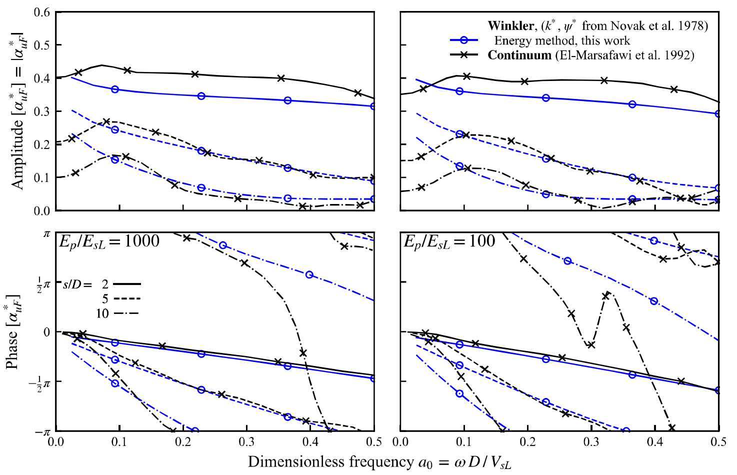
(6) Comparison to continuum solution:

Linear profile: $E_s(z) = E_{sL}\frac{z}{L}$ $\quad L/D = 20,\ \nu_s = 0.4,\ \beta_s = 0.05$ $\quad \rho_p/\rho_s = 1.25,\ \nu_p = 0.25,\ \beta_p = 0$

Axial Loading



Lateral Loading (Fixed head, $\phi = 0$)



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Acknowledgements: This work was carried out under the supervision of Prof. George Mylonakis, who provided valuable suggestions and guidance key to developing the solutions presented here. Thanks are also due to Prof. Byron Burne for his helpful comments and suggestions on the poster. This work was funded by EPSRC (grant number EP/N509619/1).

Multi-use platforms at sea (MUPS): an innovative way to manage offshore space and reduce coastal anthropic pressure

Abstract:

Offshore management is a future challenge for the development of sustainable growth for aquaculture and offshore renewable energy industries. The worldwide increase of demand for both industries requires developing efficient tools to optimize the use of the offshore space. The co-location of Offshore Renewable Energy (ORE) arrays with mariculture could aid UK government ambitions for 2030: 1) doubling aquaculture production (currently worth £800M per annum, mostly from salmon (£720M) and followed by mussels (£30M)); and 2) powering all homes with wind. The shared services of offshore mariculture and ocean energy could aid the development of exportable UK industries aligned with Blue Growth and UN sustainability goals. Multi-use platforms at sea (MUPS) has been hypothesized as a way to share services and reduce costs.

The Irish Sea is subjected to numerous industrial activities. ORE (offshore wind farms, tidal stream and tidal lagoon) will potentially occupy 6,564 km^2 in a near future, which corresponds to 14% of Irish Sea space. Furthermore, most ORE project are located in the eastern Irish Sea where blue mussels shellfisheries represent 40% to 50% of the UK production. In this area and in this context, it is important to study the feasibility of MUPS in order to minimize the impact of anthropic pressure on offshore and onshore habitats.

Supergen ORE hub ECR allowed us to acquire Lagrangian drifters in order to concurrently study larvae dispersal and oceanographic parameters. Indeed, the data collected will allow us: 1) to increase accuracy of hydrodynamic models by measuring the impact of wind on sea surface currents (1 m depth); and 2) to improve accuracy of Particle Tracking Model (PTM) by comparing trajectory of drifters with simulated particles. In the near future, a tool will be developed taking into account these results to define the best area for MUPS in the Irsih Sea, which could be applied : 1) waves, wind and tidal energy production potential; 2) biological and physical requirements needed for different species (seaweed, bivalves, fish and crustaceans); and 3) infrastructure requirements for aquaculture and energy devices.

Multi-use platforms at sea (MUPS): An innovative way to manage offshore space and reduce coastal anthropic pressure

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INTRODUCTION

Multi use platforms at sea (MUPS) way to: 1) share services; 2) reduce costs and 3) reduce anthropic pressure.

Offshore Renewable Energy (ORE): approximately 6,564 km^2 (14 % of space occupation).

Shellfisheries: *Mytilus edulis L.* aquaculture represents 40% to 50%.

OBJECTIVES

- **Define larvae pathways**
- **Using ORE structures to collect larvae**
- **Impact of ORE on larval recruitment**
- **Improve hydrodynamics and particle tracking models**

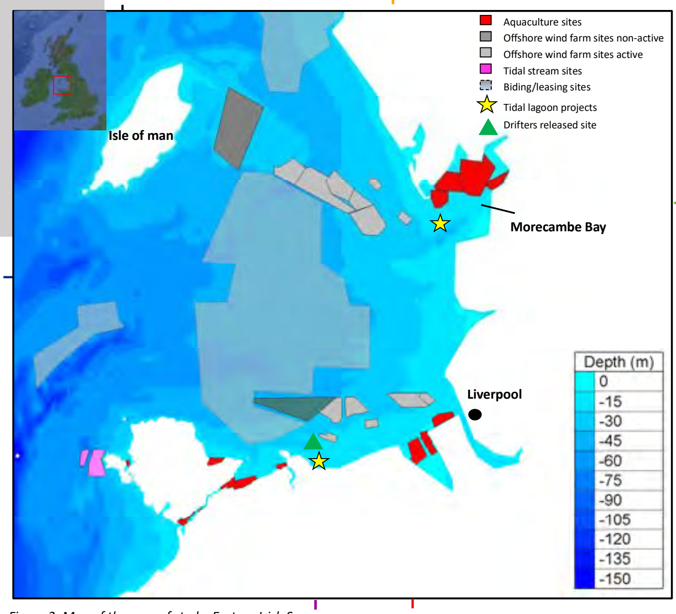


Figure 2: Map of the area of study: Eastern Irish Sea.

METHODS

Release drifters

- ✓ Different type of drifters (drogued/undrogued)
- ✓ From different sites (onshore/offshore)
- ✓ At different period (summer/winter)

Figure 1: Microstar drifter

Drifter ID	Type of drifters	Period of release	Start of release	End of transmission	Time step (min)
Micro 1	Drogued at 1 m	Summer	18/07/2021	12/08/2021	30
Micro 2	Drogued at 1 m	Summer	18/07/2021	12/08/2021	30
Micro 3	Drogued at 1 m	Summer	18/07/2021	12/08/2021	30

Output from drifters

- Position every 30 min
- Impact of wind on trajectory
- Impact of tide on trajectory
- Distance made by drifters
- Relative distance between drifters
- Sea surface temperature

Hydrodynamic Model | **Particle tracking model**

Improvement of models accuracy

RESULTS

Video of drifters dispersal

Legend

- Starting position
- Drifter position through time
- Drifter 1
- Drifter 2
- Drifter 3

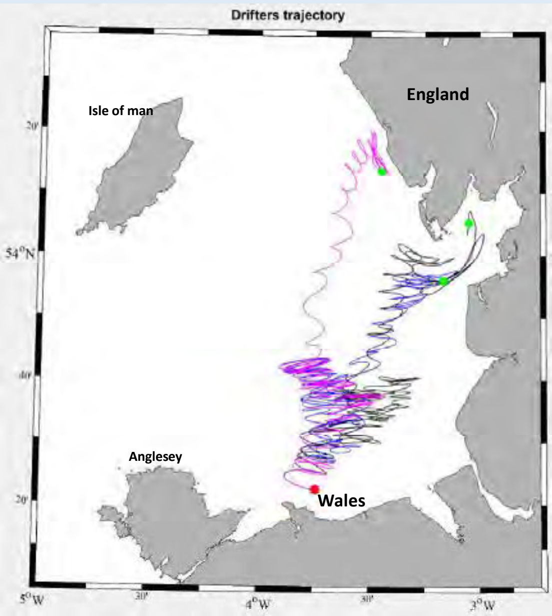


Figure 2: Drifters trajectory representing Micro 1 (blue line); Micro 2 (magenta line) and Micro 3 (black line)). The starting position (red dot) and final position (green dot) are also represented.

Table 1: Net distance (km) made by the drifters

Drifter ID	Micro 1	Micro 2	Micro3
Distance (km)	76.1	91.3	96.2

Applications

ORE applications:

- Improvement of accuracy of hydrodynamic models
- Impact of ORE on sea surface flows

MUPS applications:

- Define best ORE sites to develop offshore aquaculture
- Information on best ORE sites to catch larvae

Further applications:

- Ecology: Spread of invasive species, connectivity among populations
- Management: Define sites for Marine protected areas based on particles dispersal

Improvements

Data improvement

- Multiple drifters release during field campaign:
  - Release different types: deeper drogue (5m vs 1m), undrogued
  - Release during different season (winter vs summer)

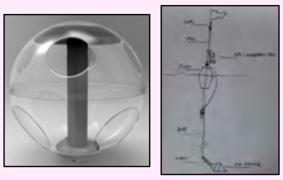


Figure 3: Undrogued drifter (left picture) and drifter with 5m depth drogue (right picture)

PRIFYSGOL BANGOR UNIVERSITY
SEEC Smart Efficient Energy Centre
Supergen Offshore Renewable Energy

Dual-Purpose Wave Energy Breakwater System

Dr.Krishnendu Puzhukkil[1] and Dr.Balaji Ramakrishnan[2]
[1]Research Fellow, University of Plymouth,
[2]Associate Professor, Indian Institute of Technology Bombay, India

Abstract

The hydrodynamic performance of dual-purpose wave energy breakwater system is investigated using experimental and numerical techniques. This system comprises of a chambered breakwater integrated with wave energy converters. Adopting a chamber width of the breakwater that matches the resonant period of the chamber and the incident wave period is found to improve the efficiency of the system to trap more wave energy inside the chamber. The trapped wave energy is effectively absorbed by dual sphere WEC installed inside the chamber near to the walls. The average power generation performance of the dual sphere wave energy converter is found to enhance by 63% after integration with the chambered breakwater. The reflection coefficient of the integrated system is found to be below 0.53. This integrated system can simultaneously protect the shoreline from erosion and extract energy from ocean waves.

Dual-Purpose Wave Energy Breakwater System

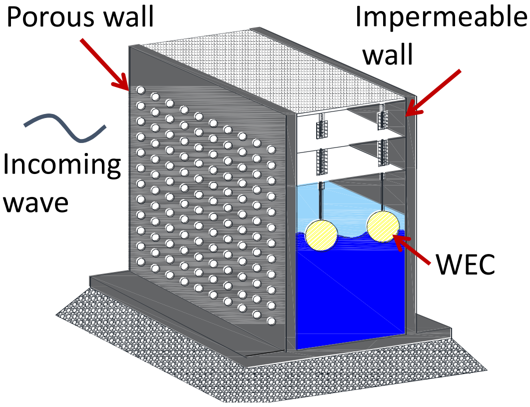
Dr. Krishnendu Puzhukkil[1] and Dr. Balaji Ramakrishnan[2]
[1]Research Fellow, University of Plymouth, [2]Associate Professor, Indian Institute of Technology Bombay, India

Introduction

- Rising demand for clean energy to reduce carbon emissions
- Meet long-term climate and sustainability goals

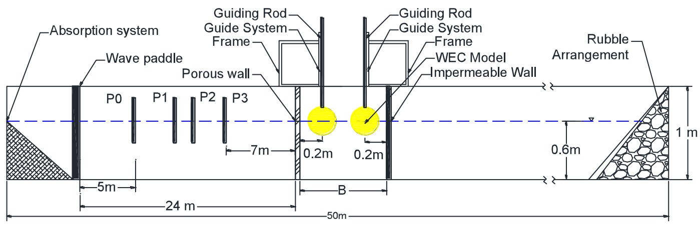
Motivation

To harness the wave power potential, simultaneously absorb the incident wave energy and protect the shoreline from erosion



Methodology

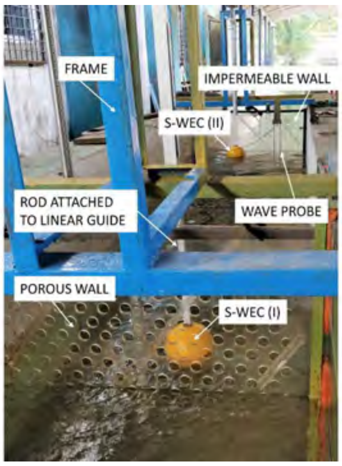
- **Experiment**: 50m x 1m x 1m wave flume facility
- Wave parameters: Wave height: 0.10m & 0.14m
- Wave period: 1.4s – 2.6s @interval of 0.3s
- Chamber width(B)/wavelength(L):0.53-0.63
- Porosity: 5%, 10%, 15% & 20%
- **Numerical**: Rhino3D-NEMOH-WEC-SIM

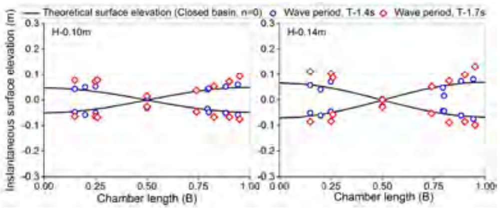


Model details

- **Chambered breakwater (CBW)** - comprises of a porous & an impermeable wall (acrylic sheet)
- Dimension - 0.98 m x 0.98 m x 0.01 m
- Porosity defined by circular holes (diameter 0.03m)
- Chamber width varied with respect to closed basin condition (incident wave period closely matches with the resonant period of chamber)
- **Sphere WEC (S-WEC)** -1:30 scale hollow model
- Outer & inner diameter of 0.15 m & 0.14 m
- Semi-submerged with freeboard of 0.075 m & draft of 0.075 m, Total weight of 0.80 kg

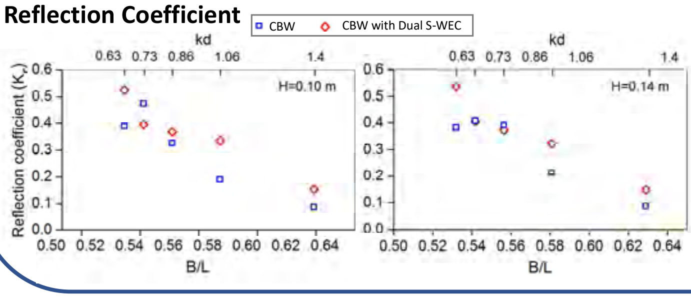
Results



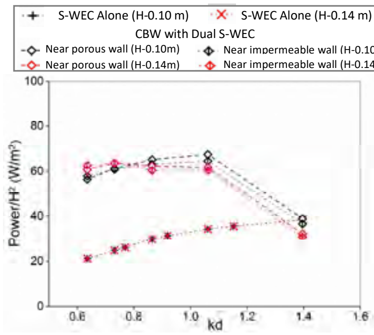


Wave Surface elevations at closer intervals inside the chamber

Reflection Coefficient



Average power generation performance



Conclusions

- 20% porosity of the seaside porous wall was found better among the tested range of porosities
- Reflection coefficient (ratio of reflected wave height to incident wave height) from the CBW with dual S-WEC is below 0.53
- Transmission of waves is nil due to the impermeable wall towards the lee-ward side of structure
- Introducing dual S-WEC models inside the CBW the power generation capability of the system was found to amplify by 63% when compared to the stand-alone S-WEC
- Performance of the S-WEC is maximum when the WEC is placed near (0.20 m) to the porous front wall or towards the impermeable wall

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Reducing mooring line loads from wave energy

[1]Yang, L., [1]Koutras A., [1]Topal F. and [2]Stagonas, D.

[1]Cranfield University, Bedford, UK
[2]University of Cyprus, Nicosia, Cyprus

This work explores the usage of hydrofoil in offshore floating platforms to reduce the wave induced loads on the mooring lines. Inspired by the nature, thrust can be generated in the wake of flapping foil by reversed von Karman streets, which is mostly used in ocean propulsion systems. It presents preliminary experiments with a hydrofoil retrofitted in a semi-sub model structure exposed to regular and irregular waves. Although still at a very early stage, the preliminary results presented here show that retrofitting a hydrofoil in a floating platform can lead in positive gains at, primarily, the surge forces acting (in these cases) at the model structure's centre of mass.

Reducing mooring line loads from wave energy

Yang L. Cranfield University

Koutras A. Cranfield University

Topal F. Cranfield University

Stagonas D. University of Cyprus

Introduction

- Excessive and violent platform motions in response to severe operational and survival storm conditions place considerable strain on the mooring system (lines and anchors) and, thus, on the platform's performance and survivability.

- Animals take advantage of their body shape and motion to produce an inverse vortex street, which in turn results in thrust production.

- A hydrofoil is used to reduce wave induced motions and therefore decrease the loads on the mooring system. The fundamental idea is that a suitably shaped and appropriately located hydrofoil will, for certain wave conditions, result in thrust generation and thus it will propel the floater against the waves. Such a (hydrofoil based) concept is of relatively low technology, low complexity and risk (e.g. minimum or even non-existing moving components for a rigidly fixed hydrofoil) but it provides, energy consumption free, thrust generation thereby reducing the strain to the anchors.

Experiment Settings

Figure 1: on the left, the model platform in the wave flume. At the top right, photograph of the model equipped with a hydrofoil. Below, on the tested hydrofoils and the, equivalent volume, sphere. At the bottom right, schematic of the mooring line arrangement used for all the tests.

Result

The initial analysis of our preliminary results shows that for certain (wave) attack conditions the use of a hydrofoil has the potential to decrease surge loads without increasing the heave loads. This, is best illustrated in Figure 2, where a section of the time history of the forces in surge and heave is presented.

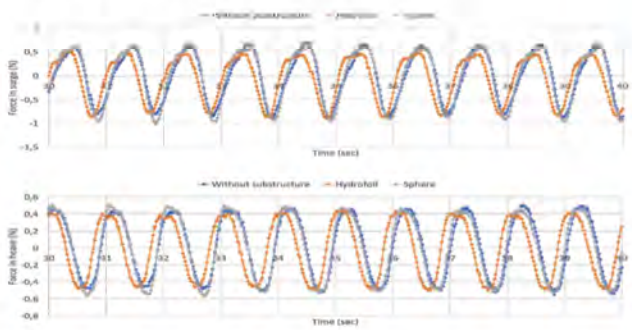

Figure 2: At the top and bottom, time histories of the surge and heave forces calculated from the acceleration measurements.

At the same time, visualising the flow behaviour in the experiments provided indications that reduction in surge accelerations and forces could be attributed to thrust being generated through the formation of an inverse vortex street, see Figure 3.

Figure 3: Flow visualisation indicating the formation of a Reversed von Karman streets.

Acknowledgements: L. Yang acknowledges the support from EPSRC Supergen ORE ECR Fund, Parametric study for flapping foil system for harnessing wave energy.

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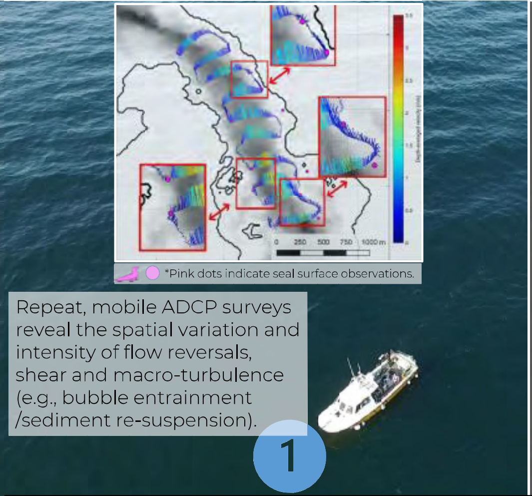
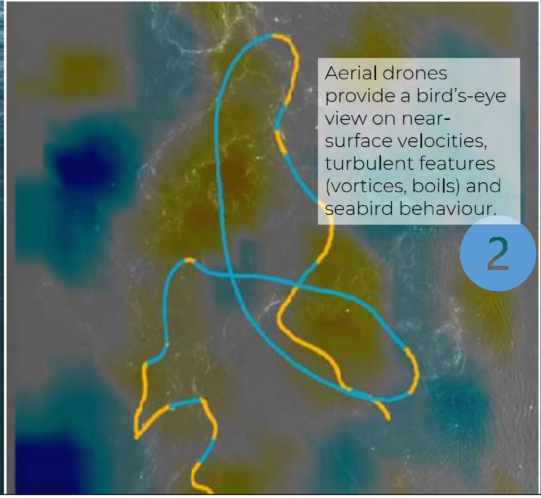
Abstract Supergen Assembly 2022

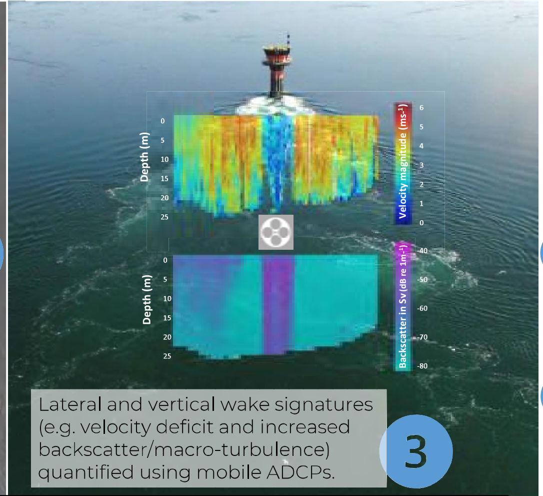
Dr Lilian Lieber, Research Fellow at the Bryden Centre, Queen's University Belfast

Drones for ocean energy research

Placing ocean energy converters in our most dynamic environments requires a better understanding of flow interactions, resulting environmental change and implications for marine life. For instance, direct measurements of flow velocities and fine-scale turbulence (~meters) are often limited by observational techniques, requiring innovation in the tools we have readily available. One such an innovation is the use of consumer-grade aerial drones in ocean energy research applications. In combination with other traditional sensors, such as acoustic Doppler current profilers (ADCPs), aerial drone imagery can provide quantitative measurements of flow velocities very close to the water surface, thereby complementing traditional sensors during both inflow and downstream assessments of floating tidal turbines. Flow patterns (e.g. velocities, shear) and turbulence structures (e.g. vorticity, upwelling boils) measured using drones and ADCPs in synchrony can provide direct engineering insight for the assessment of device performance and array spacing. Further, it can be used in environmental monitoring, providing a better understanding of the mechanisms underlying marine fauna habitat use. Here, we present some recent case studies demonstrating novel insight gained from using a combination of these approaches. We also introduce a two-stage feasibility study around the world's most powerful tidal turbine, the floating O2 structure (Orbital Marine Power) installed at EMEC (Fall of Warness, Orkney Islands), to inform on 1) industry-relevant flow measures and, 2) environmental interactions. Using a combination of ADCPs, aerial drones and broadband echosounders, the study will thus prove a low-cost, robust and reproducible monitoring approach to assess bio-physical interactions with floating tidal turbines. Given the steady increase of ocean energy converters in our coastal seas, this research is critical to understand the complex bio-physical interactions of devices with their local environment. Finally, the project's vision is to support the integration of various data streams, providing transferable knowledge and thus allowing for more transparency and flexible collaboration between industry and academia.







ECOLOGICAL INDICATORS — Lieber L, Nimmo-Smith WAM, Waggitt JJ & Kregting L (2018) Fine-scale hydrodynamic metrics underlying predator occupancy patterns in tidal stream environments. *Ecological Indicators* **94**: 397-408.

PROCEEDINGS OF THE ROYAL SOCIETY B — Lieber L, Langrock R, Nimmo-Smith WAM (2021) A bird's-eye view on turbulence: Seabird foraging associations with evolving surface flow features. *Proceedings of the Royal Society B* **288**: 20210592

COMMUNICATIONS BIOLOGY — Lieber L, Nimmo-Smith WAM, Waggitt JJ & Kregting L (2019) Localised anthropogenic wake generates a predictable foraging hotspot for top predators *Communications Biology* **2**:123

Aerial drones or Uncrewed Aerial Vehicles (UAVs)

- Cameras can be calibrated (1% error)
- Hovers (holding station) for flow and marine fauna tracking
- Transects to map flow features and animal distributions across a site

SUMMARY

Consumer-grade aerial drones are used to:

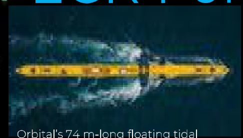
- **Track marine fauna movement and behaviour**
- **Map near-surface velocity fields** (mean velocities and turbulence) using Particle Image Velocimetry (PIV)

Such data can be used to investigate:

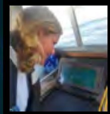
- associations between surfacing marine fauna and **dynamic surface flow features (vorticity, upwellings)**
- industry-relevant flow measures, e.g., surface turbulence affecting **device performance and array spacing**

Supergen ECR FUND

Offshore Renewable Energy



Orbital's 74 m-long floating tidal energy structure (2 MW capacity) installed at EMEC. **© Orbital Marine Power**



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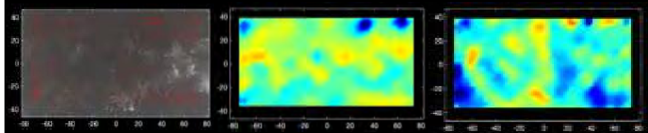

PIV techniques applied on drone imagery collected using hovers at a 100 m altitude.

This funded project addresses a key knowledge gap: traditionally, sensors mounted either on or near the structure measure current velocities; however, they cannot provide accurate measures of flow velocities and associated turbulence very close to the water surface. Such variables are of high relevance for floating tidal turbines during both inflow and downstream assessments and will be achieved by combining UAV surface flow mapping using PIV techniques with traditional in-water ADCP transects and seabed deployments.

The characterisation of the flows will therefore provide direct engineering insight for assessment of device performance and array spacing, to be further investigated by the industrial and academic partners. In addition, the data will be used to assess marine fauna (seabird and their prey) distribution around the device, thereby assessing environmental interactions.

The project's vision is to support the integration of various data streams, providing transferable knowledge and thus allowing for more transparency and flexible collaboration between industry and academia.

DRONES FOR OCEAN ENERGY RESEARCH

An Industry-Academia Collaboration

PLACING OCEAN ENERGY converters in our most dynamic environments requires a better understanding of resulting environmental changes and implications for marine life. Monitoring the fine scales is often limited by observational techniques and needs **innovation in our tools**:

CASE STUDIES

1. Mobile acoustic Doppler current profiler (ADCP) surveys provide detailed information on flow spatial variation. In combination with sighting data, such transect surveys inform on marine fauna distribution patterns on regional scales (~Kms).
2. Aerial drones are used to track seabirds using machine learning and to concurrently map surface velocity fields using Particle Image Velocimetry (PIV) techniques. We investigated links between foraging seabirds and dynamic surface flow features (vorticity, boils/upwellings). Vortices can trap material at their centers while conspicuous boils transport material to their peripheries, providing physical cues for possible prey items.
3. ADCPs reveal wake signatures underwater. The wake has the potential to up- and downwell material throughout the water column. Seabirds predictably forage over the wake of a tidal energy monopile structure during peak flood tides.

SUPERGEN ECR FUND

A two-stage feasibility study around Orbital's O2 floating tidal energy structure set in Orkney to inform on 1) industry-relevant flow measures and 2) environmental interactions. The study will prove a low-cost, robust and reproducible monitoring approach to assess bio-physical interactions with floating tidal turbines.

The approach uses drone surveys in combination with boat-based transects equipped with an ADCP and an EK80 echosounder.

The overall goal of the project is to generate industry-relevant data to be used in flow field characterisation, modelling of turbine array spacing, as well as for environmental impact assessments.

ACKNOWLEDGEMENTS

The Bryden Centre project is supported by the European Union's INTERREG VA Programme, managed by the Special EU Programmes Body (SEUPB). Drone application development in collaboration with Alex Nimmo-Smith (UoP). Statistical analysis in collaboration with James Waggitt (BU) and Roland Langrock (UoB). Shaun Fraser (NAFC), Daniel Coles (UoP) and Ana Couto (EMEC) are collaboraters in the Supergen ECR project.

Investigating the installation of innovative suction caisson anchors to support offshore renewable energy structures, a feasibility study

Moura Mehravar, Aston University, Birmingham, UK

Foundations and mooring systems can be accounted for >20% of total costs of offshore structures including costs of their installation; this cost is likely to increase nonlinearly the further we go offshore [1]. Therefore, innovative solutions that can reduce costs associated with offshore foundations including costs of materials, transportation of structures and equipment, and costs of machinery for installation are vital in sustainable developments of future offshore wind farms. Suction caisson anchors (SCAs) are considered as a highly attractive solution for deep waters and their advantages over other types of offshore foundations have been extensively documented [2-3]. They have simple installation and easy removal processes, and offer significant cost saving due to lower material requirements compared with other offshore foundations (e.g. piles).

Previous studies have demonstrated benefits of adding rectangular flanges/wings to caisson anchors (Figure 1a) to improve their pull-out [4-6] through numerical modelling. These studies have reported potential of additional capacity in orders of 30-40% compared with standard caisson anchors through generating additional pull-out capacity. However, so far, no studies have examined the mere feasibility and impacts of these additional structural elements on the installation process of the enhanced anchors. This has hindered their potential as an innovative solution to support offshore wind structures, thereby preventing their uptake by industry.

This study aims to examine and understand the installation process of a series of innovative SCAs relative to that of standard SCA in sand (Figure 1b). This will be carried out through finite element (FE) analysis using COMSOL-Multiphysics. Suction was prescribed at the mudline and soil resistance was estimated based on the soil properties and resulting seepage profile around the caisson wall and tip [7-8]. The model prediction of soil resistance to a caisson penetration (standard caisson with no flanges) was validated against field data (Tenby field trial, [9]. The validated numerical model was extended to investigate the installation performance of a series of innovative SCAs and to estimate the required suction for installation of the proposed SCAs at different depths. The results of suction predictions for the SCAs penetration were compared with a standard caisson in order to analyse the impact of the flanges on the installation resistance.

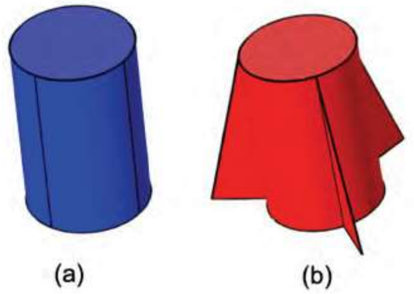

Figure 1: different arrangements of flanges attached to a standard caisson

References: [1] Bosma et al., Proc. of 11th EU Wave & Tidal Energy, France, 2015. [2] Houlsby GT, Ibsen LB, Byrne B., Australia. 2005, 75-93. [3] Byrne et al. Wind Engineering. 2002; 26(3):145-55. [4] Na et al., Proc. of the 7th international conference on Asian and Pacific coasts, 860-865 [5] Kwag et al. J. Offshore Mech. Arct. Eng 2010, 132(2) [6] Monajemi and Abdul Razek. 12th Int. Conf. of Association for Computer Methods and Advances in Geomechanics, 1-6 Oct, 2008.[7] Harireche O, Mehravar M, Alani AM. Ocean engineering. 2014, 88:164-73. [8] Mehravar M, Harireche O, Faramarzi A, Alani AM. Ships and Offshore Structures. 2017;12(7): 893-9. [9] Houlsby, G. T; Byrne, B. W. Proceedings of the Institution of Civil Engineers, Geotechnical Engineering. 2005, 158(3), 135-144.

Investigating the installation of innovative suction caisson anchors to support offshore renewable energy structures, a feasibility study

Dr Moura Mehravar, Assistant Professor in Civil Engineering at Aston University, Birmingham, UK (M.Mehravar@aston.ac.uk)

Introduction

Among various available foundations (see Figure 1), suction caisson anchors are one of the well-established and popular solutions to support offshore structures and in recent years they have been used in offshore wind turbine projects. Their ease of transportation, and installation are among many advantages they have over conventional foundations e.g. piles (Figure 2).

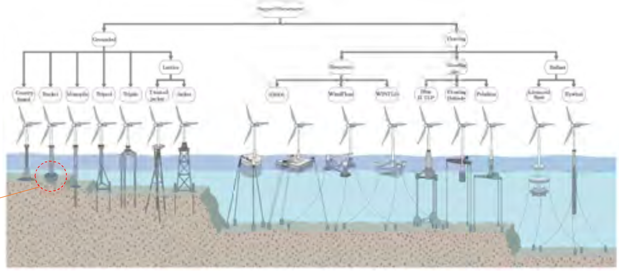

Figure 1: Example of most common grounded and floating turbine support structures [1]

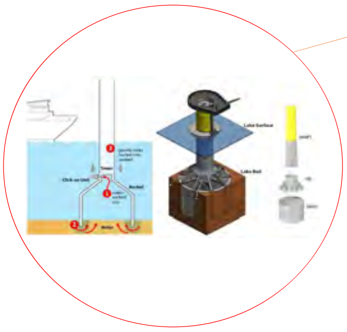

Figure 2: Example of most common grounded and floating turbine support structures [5]

Problem Statement

In recent years, to improve/enhance the static and dynamic behaviour of offshore wind turbine foundations, a series of novel hybrid systems of skirted/caisson foundations have been proposed based on a combination of two or more types of foundations or inclusion of additional structural elements [2-4]. Despite their promising results in improving the lateral and rotational stiffness, their potential applications in field are hampered by issues related to their construction and/or installation. Majority of the proposed hybrid foundations are complex, large and heavy structures. Construction, transportation, and installation of such foundations can be challenging and costly. A few examples of such hybrid foundations are shown in Figure 3.

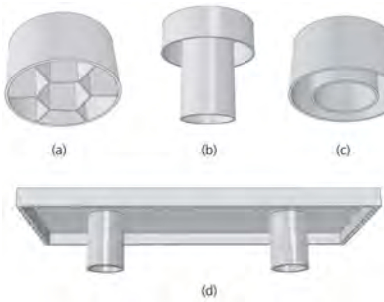

Figure 3: Examples of proposed hybrid foundations concepts in research studies: (a) CBF; (b) MSC; (c) double skirted caisson foundation; (d) skirted mat with caissons [6]

Project Aims

The main aim of this study is to examine and understand the installation process of a series of innovative suction caisson foundations relative to that of standard suction caisson using a series of finite element (FE) analysis and small scale experiments.

Proposed solutions and numerical simulations

Proposed solutions

Inspired by the shape of anchors that are used to secure vessels (Figure 4), a number of structurally enhanced anchor designs are proposed (Figure 5) with potentially enhanced pull-out and bearing capacity when compared against standard/conventional suction caisson anchors. Within this phase of the study, installation of the proposed foundations are studied.

Figure 4: Anchors are traditionally used to secure vessels

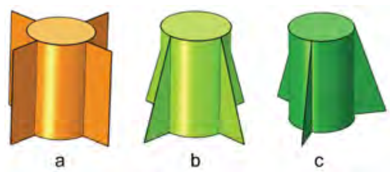

Figure 5: A few examples of flanged anchors

Finite Element Model (FEM)

- A 3D FE model of the problem was developed to predict the amount of suction required to install the flanged caissons at different penetration depth (Figure 6).
- The FEM was validated against published data (Tenby field trial), Figure 7.
- A region inside the caisson cavity subjected to piping was investigated at different stage of the installation.
- The validated FE model was extended to investigate the installation process of various flanged caisson with different flange size and explore the impact of the flanged base size on the installation resistances (Figure 8 shows the results of caissons with three flanges).

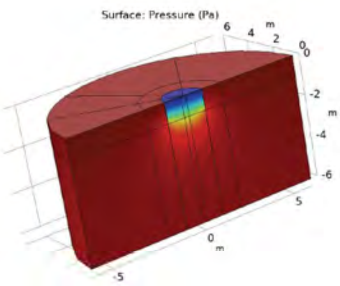

Figure 6: 3D FE model of the proposed foundations to simulate their installation

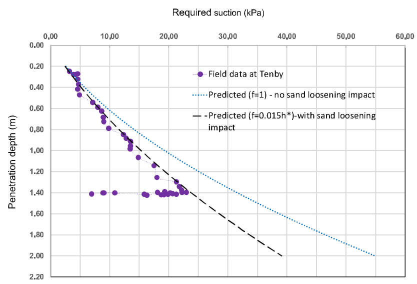

Figure 7: Typical results of the simulations validated against published data

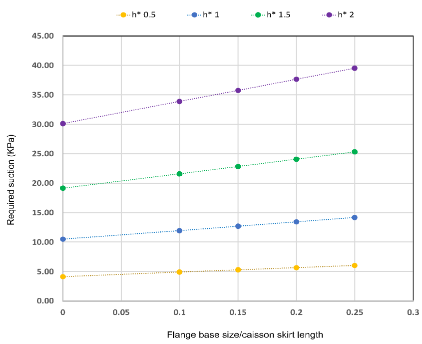

Figure 8: Impact of flange sizes on installation of caisson anchors

References:

[1] Rodrigues et al. (2016) energies, 9, 216.
[2] Fu et al. (2014), Canadian Geotechnical Journal, 51, 934-949.
[3] Kim et al (2016), Japanese Geotechnical Society Special Publication, 2, 1339-1342.
[4] Zhang et al. (2016), Journal of Offshore Mechanics and Arctic Engineering, 138, 061901.
[5] LEEDCo - Technical. (2022). Retrieved 11 January 2022, from http://www.leedco.org/index.php/70-resources/156-technical
[6] Faizi et al., (2020), Proceedings of the Institution of Civil Engineers – Geotechnical Engineering 173(5): 448–460.

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Supergen Offshore Renewable Energy

Upgrade of Power-Electronic Grid Emulator to Multi-Channel System & High Current Continuous Power Semiconductor Tester for Next Generation Offshore Wind, Tidal & Wave Converters

Paul Judge & Ross Mathieson

Project Summary

This project focused on upgrading and significantly expanding the capability of a custom-built Silicon Carbide MOSFET grid emulator which is primarily used for testing the performance of advanced wind-turbine converter topologies and control schemes. By increasing the number of converter channels from 1 to 2, the Grid Emulator will be capable of: bi-directional power-flow, increasing the type of converters that the grid emulator can be used with; emulating the DC side and AC side of a converter under test, allowing generator dynamics and DC-voltage disturbances to be included in tests; multi-port AC grid emulation for Microgrid tests. Through minor re-arrangements and the addition of high-current inductors the system is also capable of performing continuous operation testing of high-current power semiconductors, providing an experimental test bench for testing advanced active-gate driving and parallel operation of high-current Silicon Carbide MOSFETs.

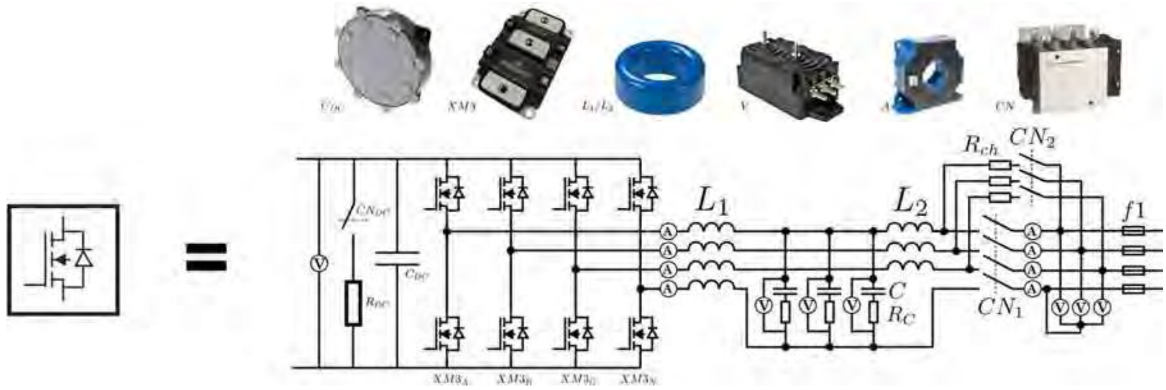


Figure 1 - Grid Emulator Four-Leg Power-Semiconductor Channel Showing Major Components

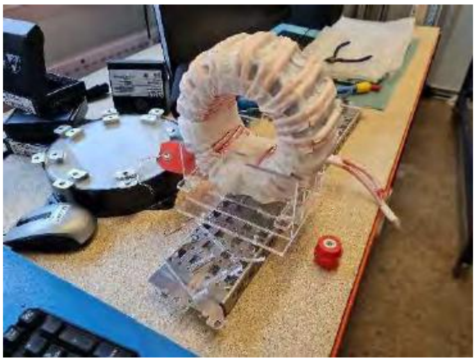
The power-electronic system is complemented by an Opal-RT Rapid Control Prototyping system, which is being used as the controller for both channels, in addition to allowing real-time power-system simulation or drive-train simulations which can be interfaced to hardware through the grid emulator system, allowing hardware-in-the-loop testing to be performed. The grid emulators controller will run on the Opal-RT systems FPGA at a control frequency of 200 kHz, resulting in an approximate 50 kHz Silicon Carbide MOSFET switching frequency, with an estimated resulting system large-signal bandwidth of 5 kHz. This high bandwidth will support the future expansion of research to aerospace and automotive applications.

During the duration of the project the majority of the main system components have been designed and constructed, with the team now in the position to start implementing the first channel within the overall systems cabinet. There has also been a significant transferal of design know-how from the research PIs to the 3 PhD students involved in the project, with each of them getting experience of PCB design, power converter busbar design, high-frequency inductor design and gate-drive design. The overall team will continue work on the grid emulator system, with the aim of commissioning both channels for summer 2022.

MOSFET Bridge Busbar & Heatsink

LCL Filter Capacitor & Sensors

LCL Filter Custom Wound Inductor

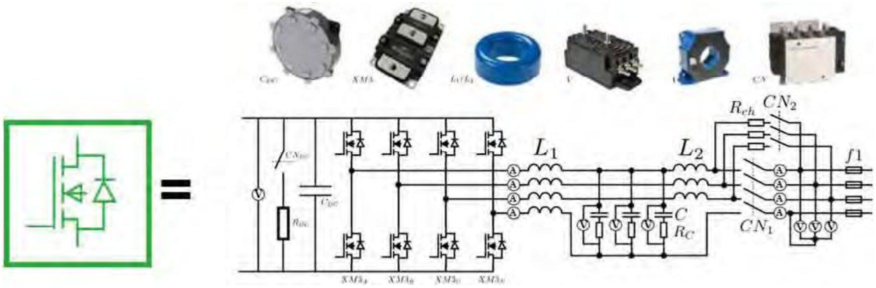


Upgrade of Power electronic Grid Emulator to Multi-Channel System and High Current Continuous Power Semiconductor Tests for Next Generation Offshore Wind, Tidal & Wave Converters

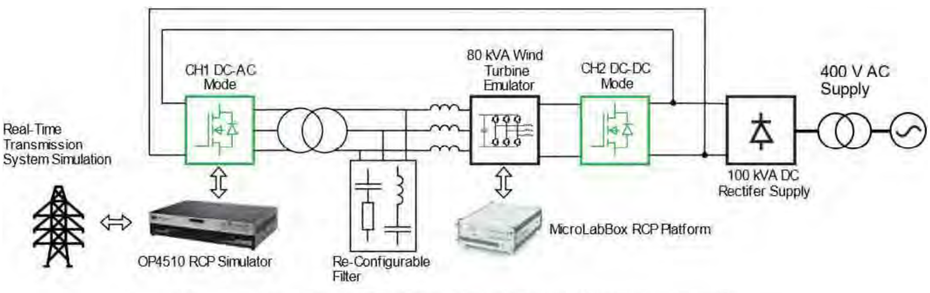
Dr Paul Judge & Dr Ross Mathieson

- The power-electronics group at Edinburgh have been building advanced hybrid converter topologies for renewables applications at ~80 kVA scale.
- Ambition is to be capable of performing advanced experimental testing of the performance of these converter topologies:
    - Grid Interaction studies.
    - Fault ride through testing.
    - Harmonic interaction studies.
- Commercial grid emulator units capable of doing the above with power ratings of ~100 kVA cost upwards of £200k.
- Aim of this project was to support the design and build of a custom grid emulator at a fraction of this cost – also has applications in semiconductor testing.
    - Pass on design and build experience to PhD students.
    - Support future grant applications and research.
- The grid emulator will use the latest generation Silicon Carbide MOSFETs to achieve high efficiency and control bandwidth.
- FPGA based control implemented on an Opal-RT Simulator
    - 200 kHz Control Frequency -> ~50 kHz Switching Frequency -> ~5 kHz Converter Bandwidth
    - Supports future expansion of research to aerospace and automotive.

Each channel of the grid emulator is a four leg two-level inverter with an LCL filter – The grid emulator system will have two of the channels



A dual channel grid emulator system allows numerous different experimental setups including emulation of DC system dynamics and AC system dynamics. Opal-RT system can be used to run real-time simulation of both, with interface to FPGA controller allowing power hardware in the loop experiments



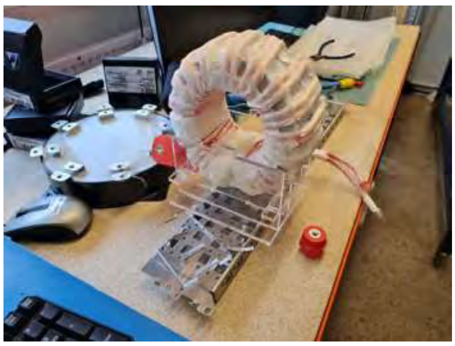
DC & AC Emulation for Converter Fault-Ride Through Testing

80 kVA Hybrid Converter Topology

MOSFET bridge busbar & heatsink

LCL Filter Capacitors and Voltage/Current Sensors

Custom designed and wound LCL filter inductor using ferromagnetic cores & Litz wire



Non-Destructive Testing of Dynamic Subsea Power Cables

R. Nicholls-Lee, P.R. Thies

Subsea power cables are a critical infrastructure sub-system in the generation and distribution of renewable energy globally. Subsea power cable failures are reported to account for 75-80% of the total cost of offshore wind insurance claims – in comparison, cabling makes up only around 9% of the overall cost of an offshore wind farm [1]. Such failures are costly to repair and may result in a significant loss of revenue due to disruption in power supply; for example, the cost for locating and replacing a section of damaged subsea cable can vary from £0.66 million to £1.71 million [2]. Most failures currently occur due to anchoring or fishing (trawling) damage; however, with the advent of the floating wind industry, and hence dynamic subsea power cables, a new loading regime in the form of cyclic wave and tidal loading is present. Methods of non-destructive testing (NDT) exist for a range of end uses in many aspects of industry and research. However, due to the complex layup of subsea power cables (with composite, plastic and metallic layers) no single technique is currently available that can accurately predict the occurrence, location and type of failure the cable experiences under dynamic loading. There is a need to develop a method for NDT of dynamic subsea cables to determine the lcoation, cause and type of fault to facilitate repairs and minimise both the associated insurance claims and operation and maintenance costs.

The aim of this work was to test and assess currently available NDT methods, used in other disciplines, for suitability in determining failure modes, mechanisms and locations on a dynamic subsea power cable under test at the DMaC facility in the University of Exeter. Conventional static subsea power cables perform poorly in dynamic locations, where cyclic wave and current loads are present, with structural failure mechanisms such as fatigue cracking and fretting occurring rapidly. A new generation of dynamic subsea power cables are being developed to exhibit superior structural performance when compared to static cables. Such cables can be tested in onshore experimental test rigs (e.g. DMaC), in order to characterise the overall properties of the cable (bend stiffness and tensile stiffness); however, even under controlled conditions it is not currently possible to determine exactly when and why failure starts to occur, in which layer of the cable it is occurring and what the exact failure mechanisms are.

During this work, three NDT methods were trialled, that had initially been identified as promising, on a cable under test at DMaC. The three techniques were: i) thermography [3], ii) eddy current testing [4], iii) spread spectrum time domain reflectometry [5]. The methods were assessed with regards to what information could be obtained from both a static and oscillating cable, how the results from one technique could potentially inform another technique, and ultimately if any of these techniques had the potential to be combined in the future to create a method of NDT for dynamic subsea power cables that can not only be used in controlled experimental facilities, but also on location at wind farms to determine the location and type of fault occurring in a cable thereby facilitating operation and maintenance activities. The results of the testing were very promising, with cable motions and interlayer movements being picked up on various levels by the three techniques.

[1] Strang-Moran, C. and O.E. Mountassir, Offshore wind subsea power cables: Installation, operation and market trends. 2018, ORE Catapult.
[2] Dinmohammadi, F., et al., Predicting damage and life expectancy of subsea power cables in offshore renewable energy applications. IEEE Access, 2019. 7: p. 54658-54669.
[3] Dulieu-Barton, J., Stanley, P., Development and applications of thermoelastic stress analysis, Journal of Strain Analysis for Engineering Design, Vol. 33, Iss. 2, p. 93-104, 1998
[4] Hughes, R., High-Sensitivity Eddy-Current Testing Technology for Defect Detection in Aerospace Superalloys, PhD Thesis, University of Warwick, 2015
[5] Furse, C., et al., Feasibility of spread spectrum sensors for location of arcs on live wires. IEEE Sensors Journal, 2005. 5(6): p. 1445-1450.

Acknowledgements: This work was supported by the EPSRC Supergen ORE Hub [EP/S000747/1] and a PRIMaRE Small Research Projects Fund. Thanks go to Prof. J. Barton, Dr R. Hughes, Dr G. Olafsson, A. Hernandez Arroyo (University of Bristol), and Dr G. Xu, N. Cartlidge (Viper Innovations) for their NDT expertise and participation.

UNIVERSITY OF EXETER

Supergen | Offshore Renewable Energy

NON-DESTRUCTIVE TESTING OF DYNAMIC SUBSEA POWER CABLES

Rachel Nicholls-Lee, Philipp R. Thies, *Renewable Energy Research Group, University of Exeter*

Introduction: Subsea power cable failures account for 75-80% of the total cost of offshore wind insurance claims – however, cabling makes up only around 9% of the overall cost of an offshore wind farm [1].

Such failures are costly to repair and may result in a significant loss of revenue due to disruption in power supply; for example, the cost for locating and replacing a section of damaged subsea cable can be up to £2 million [2].

Motivation: There is a need to develop a method for non-destructive testing (NDT) of dynamic subsea cables to determine the location, cause and type of fault to facilitate repairs and minimise both the associated insurance claims and operation and maintenance costs.

The aim of this work, was to test and assess currently available NDE methods, used in other disciplines, for suitability in determining failure modes, mechanisms and locations on a dynamic subsea power cable under test.

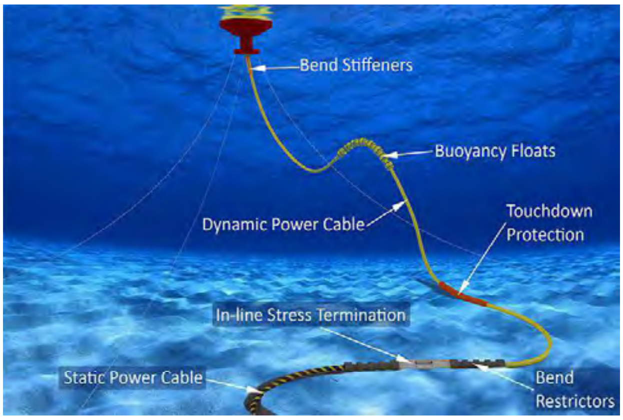


Figure 1: Components of a lazy wave dynamic subsea power cable assembly

Structural Cable Testing

Figure 2: Subsea power cable under test at DMaC

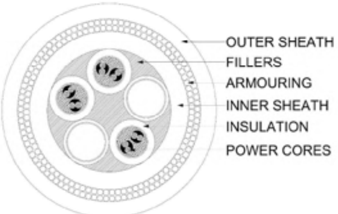
Physical testing is essential to understand the structural response of the cable. Key tests include; bend stiffness, axial stiffness, cycles to failure & verification of numerical modelling results.

There are several challenges associated with structural testing of subsea power cables:

- Cannot see internal damage – cable is tested to failure and dissected
- Repeatability – a cable sees >1.5M cycles in a lifetime = 2 months continuous testing
- Length restrictions – cables in operation often kms in length vs a few metres in a test rig
- No voltage during testing

A length of dynamic subsea power cable was tested in DMaC (Figures 2 & 3). Initially the cable bending and axial stiffness were determined. Subsequently, the three NDT methods were applied and the following testing undertaken:

- Sinusoidal bending – fixed & varying tension
- Manual bending
- Fault finding



Non-Destructive Testing Methods

Thermography [3] **-** relates thermal response from cyclic loading to the sum of the principal stresses. Can detect damage at various depths in structure. Pulse thermography and thermal data from cyclic loading were investigated. *(Figure 4)*

Eddy Current Testing [4] **-** Electromagnetic NDT technique used to detect damage/changes in material properties of electrically conducting components. Sensors applied externally to cable under test, to assess potential of technique to evaluate changes/damage. *(Figure 5)*

Spread Spectrum Time Domain Reflectometry (SSTDR) [5] **-** developed to locate hard faults along wire. Transmits small but recognisable signals in high noise environments, these reflect off changes of characteristic impedance, e.g. faults. *(Figure 6)*

Figure 6: SSTDR

Figure 5: Eddy Current Testing

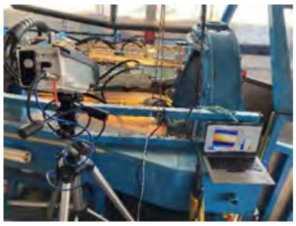


Figure 4: Thermography

Results

- **Thermograpy:** picked up helical winding of internal substructure of cable *(Figure 7)*
- **Eddy Current:** detected shifts in armouring (hysteresis apparent), and was also capable of monitoring dynamic changes due to movement with suitable sensitivity *(Figure 8)*
- **SSTDR:** All movements observed were found to be due to electro-mechanical changes in the cable, not external noise. SSTDR was accurate enough to detect the cable motions to the nearest degree. Specific events (frequencies) can be detected, for example VIV and freak waves. Can be installed on live cables. *(Figure 9)*

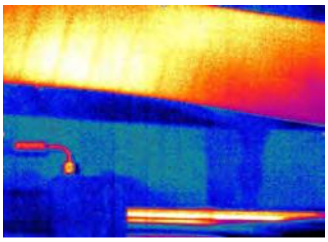


Figure 7: Thermography results

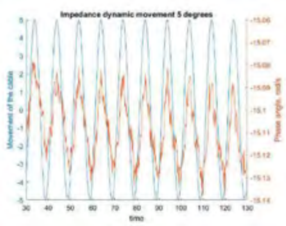


Figure 8: Eddy Current Testing Results

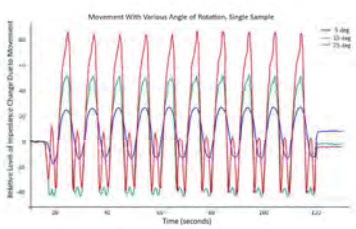


Figure 9: SSTDR results

Conclusions:

- There is a need for NDT methods for subsea power cables to understand structural failures and mitigate costly farm downtime and cable repairs.
- Three NDT methods have been assessed for use in monitoring subsea power cables; thermography, eddy current testing and Spread Spectrum Time Domain Reflectometry.
- Results were very promising, with all methods detecting various aspects of cable motion and structural response on cable under controlled, static and dynamic tests.
- There is significant potential for live monitoring of dynamic subsea power cable motions and faults using NDT.

Future Work:

- Further testing to calibrate methods for use in the real world
- Calibration of methods with each other to assess events
- Investigation of other NDT methods

References:

[1] Strang-Moran, C. and O.E. Mountassir, Offshore wind subsea power cables: Installation, operation and market trends. 2018, ORE Catapult.

[2] Dinmohammadi, F., et al., Predicting damage and life expectancy of subsea power cables in offshore renewable energy applications. IEEE Access, 2019. 7: p. 54658-54669.

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Physics-informed machine learning for rapid fatigue assessments in offshore wind farms

Robert C. Houseago [1], Agota Mockute [1], Elizabeth J. Cross [2], and Nina Dethlefs [3]

[1] Energy and Environment Institute, University of Hull (r.houseago@hull.ac.uk)
[2] Dynamics Research Group, Department of Mechanical Engineering, University of Sheffield
[3] Dependable Intelligent Systems Research Group, Department of Computer Science & Technology, University of Hull

Accurate and efficient assessment of offshore wind turbine monopile fatigue is required to inform maintenance and decommissioning decision making. Although, direct field-based measurements are limited and current industry standard modelling approaches are often devoid of fully non-linear waves, thus omitting critically important resonance effects. Here, numerical modelling is combined with machine learning to develop a meta-model capable of rapidly estimating monopile damage and fatigue. Fully non-linear wave kinematics were numerically modelled using higher-order boundary element methods to represent conditions recorded in the North Sea. These environmental simulations were implemented within numerical areo-hydro-servo-elastic engineering modelling of a reference turbine (NREL 5MW) with monopile foundations, for both operational and parked turbine configurations across a range of incoming wind conditions. The modelled fore-aft tower base bending moments are used to estimate of the corresponding structural damage using rainflow-counting methods, enabling identification of conditions associated with the largest damage loads. These data are applied within the development a meta-model based on convolutional neural networks to provide rapid assessment of monopile damage associated with any given environmental and operational condition.

Physics-informed machine learning for rapid fatigue assessments in offshore wind farms

Robert C. Houseago[1], Agota Mockute[1], Elizabeth J. Cross[2], and Nina Dethlefs[3]

[1] Energy and Environment Institute, University of Hull (r.houseago@hull.ac.uk)
[2] Dynamics Research Group, Department of Mechanical Engineering, University of Sheffield
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PROJECT AIM

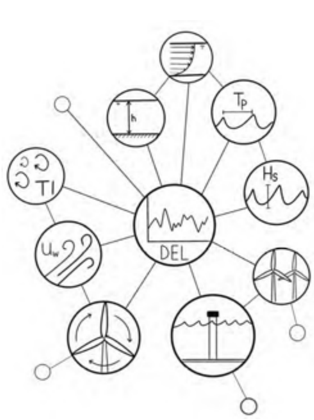
Quickly and accurately determine and forecast offshore wind turbine fatigue using physics informed machine learning, including nonlinear wave loading-induced resonance.

RATIONALE

There is a need for efficient and accurate damage / fatigue estimations of offshore monopiles throughout the structure lifespan, thus supporting maintenance and decommission decision making, yet this is currently computationally expensive.

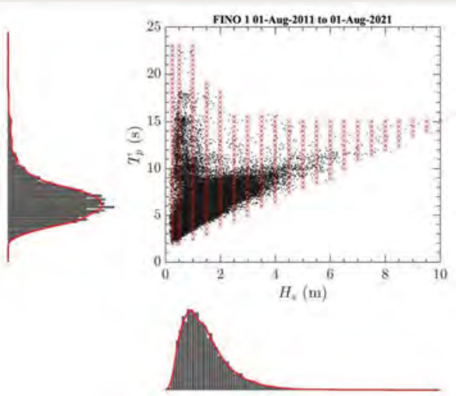
APPROACH

A meta-model is developed based on convolutional neural networks to determine the monopile damage that encompasses an extensive range of environmental conditions recorded in the North Sea, for both operational and parked turbines.

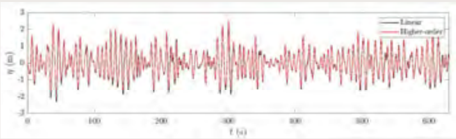


(1) ENVIRONMENTAL CONDITIONS

Produce an industry accessible environmental conditions library for customised non-linear wave kinematics.



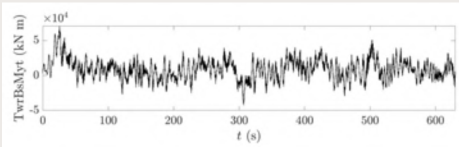
Peak wave period (T_p) and significant wave heights (H_s) measured (black dots) at the North Sea research platform FINO1. Red crosses indicate conditions numerically simulated for the library.



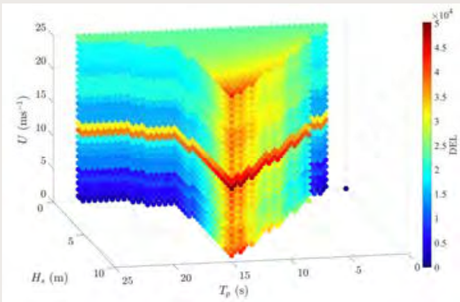
Example time series of water surface elevations from numerical produced using linear and higher-order boundary element methods.

(2) MONOPILE FATIGUE SENSITIVITY

Estimate monopile fatigue for various environmental (ECs) and operational conditions (OCs), and identify critical damage cases.



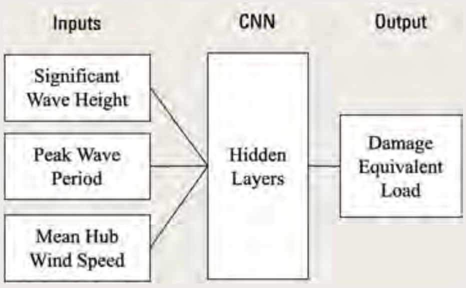
Example tower fore-aft mudline bending moment output from areo-hydro-elastic-servo simulator (FASTv7). Damage is subsequently estimated using rainflow-counting methods.



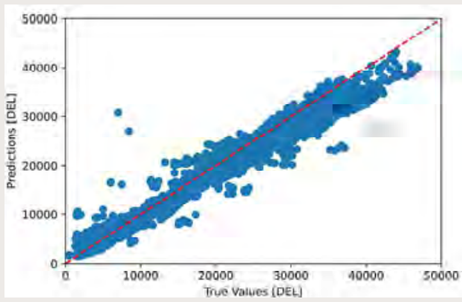
Monopile Damage Equivalent Load (DEL) for simulations based on the NREL-5MW monopile wind turbine during operational conditions.

(3) RISK FORECAST MODEL

Develop a predictive physics-informed machine learner for lifetime fatigue damage of offshore wind turbine monopiles.



Convolutional Neural Network (CNN) model architecture for monopile Damage Equivlant Load (DEL) prediction for various ECs and OCs.



Test data results for the machine learning model.

ONGOING RESEARCH

- Acquisition of experimental and field data to validate model results.
- Further model development to calculate accumulated fatigue and implement into lifetime assessments.
- Upscale research outputs to a wind-farm scale for turbine specific evaluation.

UNIVERSITY OF HULL

The University Of Sheffield.

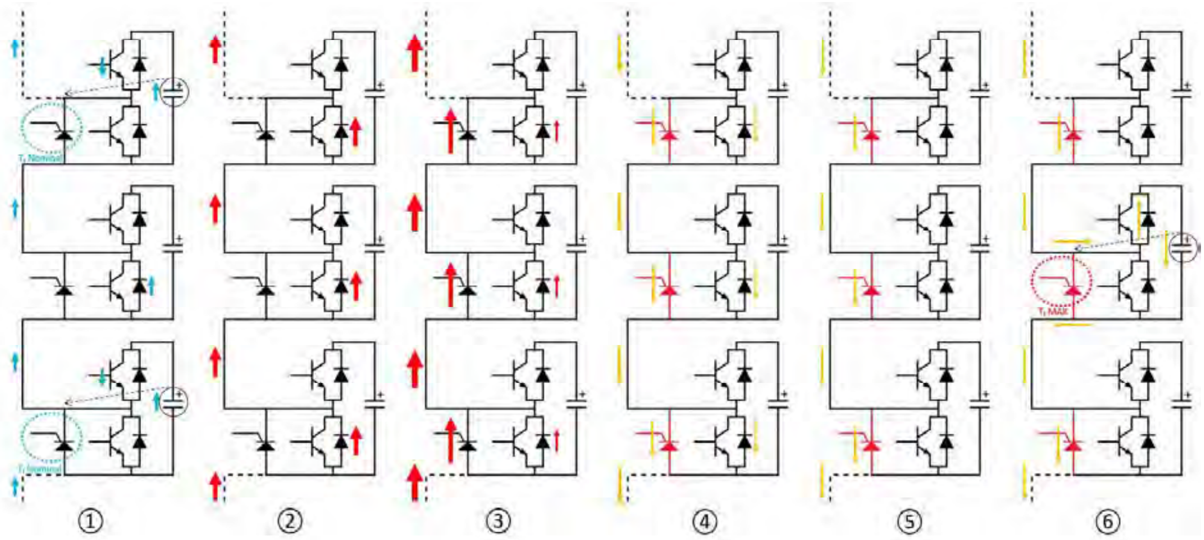
Supergen Offshore Renewable Energy

SuperGen ORE Hub ECR Fund Report

Optimisation of Compact Wide-Bandgap-Enabled Power Electronics Converters for Offshore Wind Farms

Dr Ian Laird & Dr Saeed Jahdi - University of Bristol

Initial VSC-HVDC converters had 2-level and 3-level structures. These were simpler to control. Many challenges as hundreds of series-connected devices had to be switched simultaneously. MMC converters remove this issue. Pole-to-pole DC fault imposes a significant risk. DC cable fault is rare, however more likely when overhead lines are used. The bottom anti-parallel diode provides a low resistance path for the DC fault current to circulate across all bottom IGBT/diode modules. The bypass thyristor will not mitigate the fault current but will provide a safe bypass path. As soon as the current in each arm reaches a pre-defined value, the thyristors will be fired, and the current is diverted.



The steps to mitigate the current can be listed as:

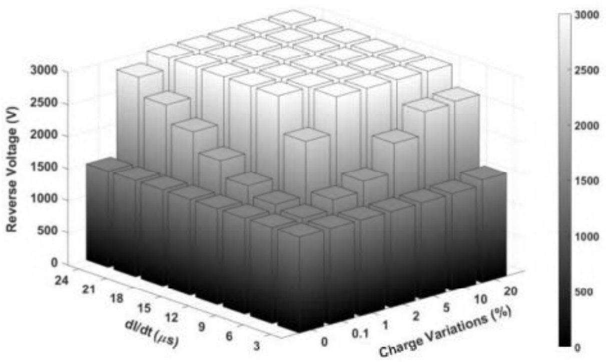
1. DC fault occurs and current starts to rise. 2. Current reaches pre-defined value and thyristors fire. 3. Fault increases while bypassed in thyristors. 4. AC breakers disconnect and converter turns-off.

Failure in devices can be either in open-circuit mode or short-circuit mode. The latter is more risky. The sequence of events in protection against a DC fault is as follows:

1. Normal operation
2. Instigation of Fault
3. Thyristors Fired
4. Fault removed, and devices recover
5. All diodes recovered
6. Some thyristors recover & others still recovering.

On top it can be seen that:

1. Synthesized fault current
2. Reverse recovery current in silicon and SiC thyristor at +20% and -20% charge profiles.



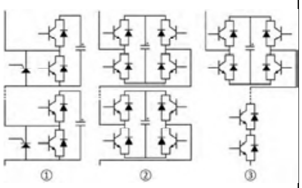
3D plot of the worst-case reverse voltage depending on recovery charge variations and fault dIF/dt of silicon device. N.B., the SiC thyristor reverse voltage is constant at 1.5 kV. The increase of dIF/dt or charge difference rapidly results in additional reverse blocking requirement on the fast-recovered silicon thyristors, while the reverse voltage for SiC device consistently remains at its share of DC line-to-line voltage, irrespective of capacitor voltage, charge variation or dIF/dt.

Optimisation of Compact Wide-Bandgap-Enabled Power Electronics Converters for Offshore Wind Farms

Dr Ian Laird, Dr Saeed Jahdi
University of Bristol

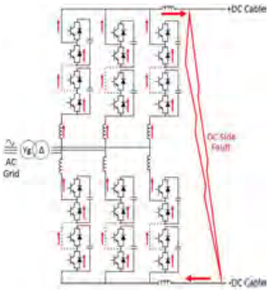
Introduction:

- Initial VSC-HVDC converters had 2-level and 3-level structures.
- These were simpler to control.
- Many challenges as hundreds of series-connected devices had to be switched simultaneously.
- MMC converters remove this issue.

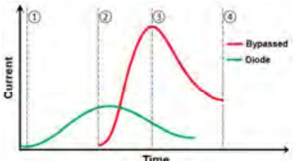


MMC-VSC-HVDC CONVERTERS AT DC FAULTS:

- Pole-to-pole DC fault imposes a significant risk.
- DC cable fault is rare, however more likely when overhead lines are used.
- The bottom anti-parallel diode provides a low resistance path for the DC fault current to circulate across all bottom IGBT/diode modules.



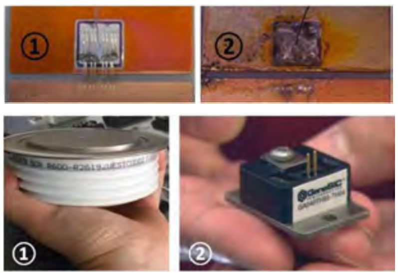
- The bypass thyristor will not mitigate the fault current but will provide a safe bypass path.
- As soon as the current in each arm reaches a pre-defined value, the thyristors will be fired, and the current is diverted.



- The steps to mitigate the current can be listed as:
  1. DC fault occurs and current starts to rise in the diode.
  2. Current reaches pre-defined value and thyristors fire.
  3. Fault increases while mostly bypassed in thyristors.
  4. AC breakers disconnect and converter turns-off.

STATE OF THE ART OF SIC THYRISTORS:

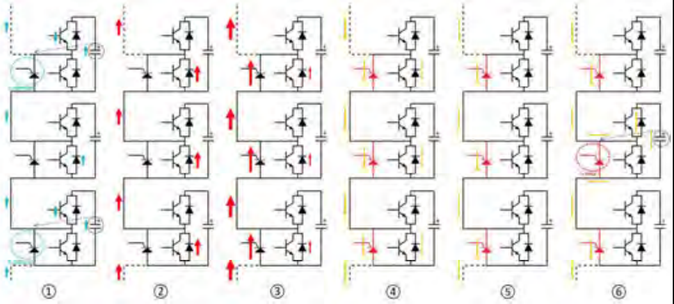
- Failure in devices can be either in open-circuit mode or short-circuit mode. The latter is more risky.
- In below, the typical 4-inch 6.5 kV Silicon thyristor disk and 6.5 kV Silicon Carbide thyristor in SOT-227 package with 8.2*8.2 mm die area cut from a 3 inch 4H-SiC wafer can be seen.



SIC THYRISTORS AS HB-MMC PROTECTION:

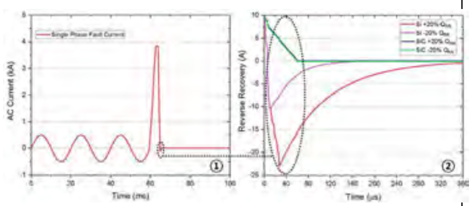
The sequence of events in protection against a DC fault is as follows:

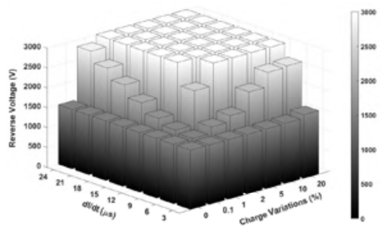
1. Normal operation
2. Instigation of Fault
3. Thyristors Fired
4. Fault removed, and devices recover (yellow arrows)
5. All diodes recovered, and Thyristors continue to recover
6. 6. Some thyristors recovered while others are still recovering.



MODELING THYRISTORS AT DC FAULTS:

- On top it can be seen that:
  1. Synthesized fault current
  2. Reverse recovery current in silicon and SiC thyristor at +20% and -20% charge profiles.
- 3D plot of the worst-case reverse voltage depending on recovery charge variations and fault dIF/dt of silicon device. N.B., the SiC thyristor reverse voltage is constant at 1.5 kV.
- The increase of dIF/dt or charge difference rapidly results in additional reverse blocking requirement on the fast-recovered silicon thyristors, while the reverse voltage for SiC device consistently remains at its share of DC line-to-line voltage, irrespective of capacitor voltage, charge variation or dIF/dt.





Conclusion

- SiC thyristors can relax the electro-thermal stress on the silicon thyristors following bypassing of a DC fault current.
- The key feature in SiC thyristors enabling them to tackle this stress is the very low stored recovery charge in the drift region of device.
- Majority of today's SiC thyristors are designed with asymmetrical blocking capability.
- Symmetrical or asymmetrical structures which are designed in favour of reverse blocking capability are sought. The surge current of the devices also need to increase, which depend on production of defect-free substrates. These are expected to be available in foreseeable future.
- Therefore, it can be argued that production of high current SiC thyristors with considerable reverse blocking capability will eliminate the main failure risk of silicon thyristors and will displace the silicon thyristors and other complex fault management techniques in protection of HB-MMC-VSC-HVDC converters at DC faults.

References:

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[2] B. Li and et al., "A dc fault handling method of the mmc-based dc system," Int. Jour. Electrical Power Systems, vol. 93, pp. 39 – 50, 2017.
[3] M. Barnes et al., "Voltage source converter hvdc links: State of art and issues going forward," Energy Procedia, vol. 24, p. 122, Dec 12.
[4] G. Tang et al., "A lcc and mmc hybrid hvdc topology with dc line fault clearance capability," Jour. Elect. Pow. Syst., vol. 62, p. 419, 2014.
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Innovative and cross-disciplinary wave energy research, aiming to develop a revolutionary Smart Control Algorithm (SCA)

Liang Li, Saishuai Dai
University of Strathclyde, Department of Naval Architecture, Ocean and Marine Engineering

Despite decades of research and development, large-scale wave energy deployment is hardly seen due to many remaining challenges. From the economic point of view, the Levelized Cost of Electricity (LCoE) of wave energy is still higher than other sustainable energy recourses, e.g. offshore wind. Technically, reliability and survivability of wave energy converters (WECs) in extreme waves conditions are not yet fully resolved. This project conducts innovative and cross-disciplinary research about wave energy, aiming to develop a revolutionary Smart Control Algorithm (SCA) to tackle the two challenges mentioned: increase power capture and reduce potential damage to the device.

Based on Artificial Intelligence (AI) techniques, the SCA forecasts future wave loads and implements tailored control actions to the WEC. Control of the WEC is realized by the well-known declutching control, where the PTO system is loaded and off-loaded alternately according to the forecasted future wave loads. During operational conditions, the PTO system is controlled in such a way so that the device will resonant with the incoming wave and thus maximizing the power output. When the SCA predicts an extreme event, the WEC is locked in position to prevent potential structural damage.

Tank test of a truncated cylinder has been carried out to measure the wave force acting in the heave direction. The measured force was used to validate the force prediction capability of the SCA algorithm. The SCA algorithm will later be implemented on a controller board, together with a mechanical control system, the SCA will be accessed in terms of power output and device response under extreme conditions.

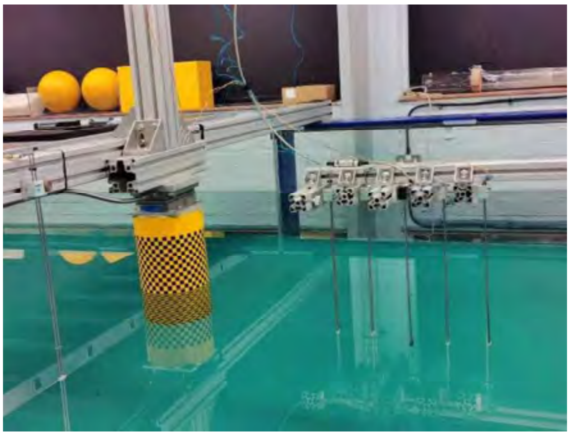


Figure 1 Measurement of the wave force acting on a fixed truncated cylinder representing a floating point absorber.

Smarter, Greener, and Safer: utilization of artificial intelligence to increase efficiency and survivability of a buoy wave energy converter

Liang Li, Saishuai Dai

University of Strathclyde, Department of Naval Architecture, Ocean and Marine Engineering

BACKGROUND & MOTIVATION

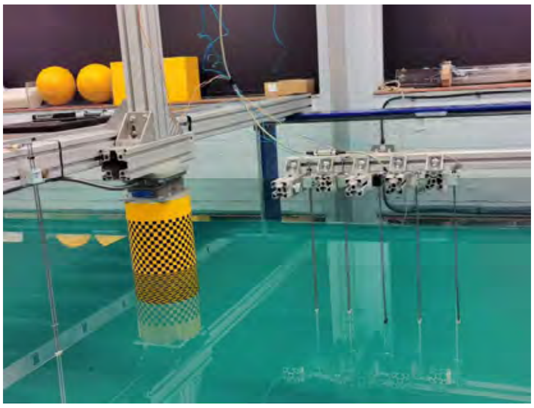
- Despite decades of research and development, large-scale wave energy deployment is hardly seen due to many remaining challenges. From the economic point of view, the Levelised Cost of Electricity (LCoE) of wave energy is still higher than other sustainable energy recourses, e.g. offshore wind. Technically, reliability and survivability of wave energy converters (WECs) in extreme waves conditions are not yet fully resolved.

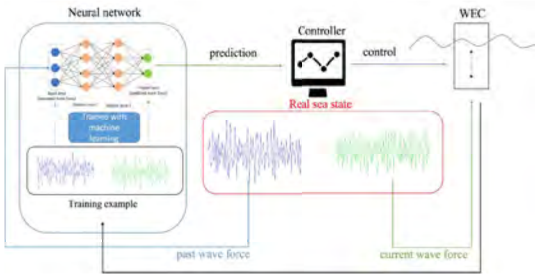
BJECTIVE

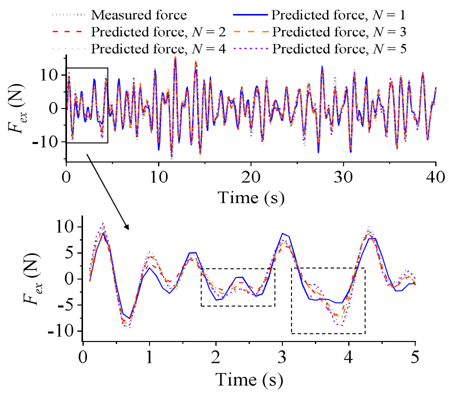
- This project conducts innovative and cross-disciplinary research about wave energy, aiming to develop a revolutionary Smart Control Algorithm (SCA) to tackle the two challenges mentioned: increase power capture and reduce

Methodology

- Based on Artificial Intelligence (AI), the SCA forecasts future wave loads and implements tailored control actions to the WEC. Control of the WEC is realized by the well-known declutching control, where the PTO system is loaded and off-loaded alternately according to the forecasted future wave loads. During operational conditions, the PTO system is controlled in such a way so that the device will resonant with the incoming wave and thus maximizing the power output. When the SCA predicts an extreme event, the WEC is locked in position to prevent potential structural damage.







Result & Future work

Tank test of a truncated fixed cylinder was carried out to provide validation data sets in both regular and irregular waves, where the wave force in the heave direction was measurement. The predicted force matched with the measurement force well as indicated by the figure shown on left. Mechanical control system with the above control algorithm will be implemented to investigate the power output and survivability under extreme wave loadings.

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Unsteady Loading Tidal Benchmarking Project: Poster Abstract

Sam Tucker Harvey

January 12, 2022

Uncertainty in tidal turbine loading is a major contributor to conservatism in rotor design and hence elevates the levelised cost of energy. This uncertainty originates not only from a lack of knowledge of the flow field at a particular site, but also from lack of understanding of the fundamental physics which govern the loading and performance of tidal turbines in unsteady and turbulent flow regimes. In order to reduce this conservatism and the costs associated, the mathematical and engineering models utilised in turbine design must be improved. To facilitate the development of these models requires scale experimental data for validation. However, few well-documented experimental data sets are available for tidal turbines, especially at scales large enough to achieve Reynolds number independence and comparability to full scale devices.

The tidal turbine benchmarking project will conduct a large laboratory scale experiment on a highly instrumented 1.6 m diameter tidal rotor. The turbine will be instrumented for the measurement of spanwise distributions of flapwise and edgwise bending moments and will be tested in well-defined flow conditions, including wave generated unsteadiness and freestream turbulence. The turbine will be pulled through a long towing tank to achieve the required incident current and wave conditions. The experimental testing will be followed by two rounds of blind benchmarking in which engineers from academia and industry will be invited to predict the loading experienced by the turbine under prescribed turbulence and wave conditions. The benchmarking rounds and staged release of experimental data will enable engineers to understand the limitations of their models and provide data to enable modelling improvements.

As towing tank facilities by their nature have very low levels of freestream turbulence, a carriage-mounted turbulence grid has been developed to allow the level of turbulence to be elevated in the benchmarking experiments. The turbulence grid, which is constructed of aluminium extrusions mounted to a rectangular outer frame as shown in Figure 3, is designed to allow for varying levels of turbulence to be produced by altering the number of bars. Before experiments can be performed with the benchmarking turbine behind the turbulence grid, the flow behind the turbulence grid must be characterised. This characterisation was performed with the use of an Acoustic Doppler Velocimeters (ADVs), in particular the Nortek Vectrino. Velocity measurements were made at a series of cross-stream locations within the intended turbine plane, while seeded water was introduced into the towing tank prior to each set of experimental runs. The variation of the streamwise velocity across the region that will be occupied by the turbine was found to be small, varying within 0.5% of the mean value over this region. The velocity deficit was also found to be small, with a mean value of $0.917U_\infty$ across the same region, with a corresponding mean streamwise turbulence intensity of 3.5%.

Unsteady Loading Tidal Turbine Benchmarking Study: Turbulence Grid Flow Characterisation

Sam Tucker Harvey[1] and Richard Willden
Department of Engineering Science, University of Oxford
[1] email: sam.harvey@eng.ox.ac.uk

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1. Introduction

Tidal turbines operate in a hostile hydrodynamic environment dominated by unsteadiness created by

- **Waves**
- **Turbulence**
- **Platform motion**

The unsteady loading due to these effects is not well predicted using current modelling techniques, often resulting in over-conservatism in designs.

To aid in the improvement of the mathematical and engineering models used in the design of tidal devices, the benchmarking study will provide a well-documented dataset from a highly instrumented 1.6m tidal rotor. Two rounds of blind benchmarking will be performed in which engineers from academia and industry will be invited to predict the loading under prescribed turbulence and wave conditions.

2. Turbine Design and Instrumentation

Figure 1 below illustrates the benchmarking turbine design and instrumentation. The turbine will measure the rotor torque and thrust with a torque/thrust sensor, while individual blade root bending moments will be obtained from strain gauges within the hub. Further to this, two of the blades of the benchmarking turbine are instrumented for the spanwise distributions of bending moments with strain gauges, while the final blade is instrumented with Fibre Bragg Sensors (FBG). To allow the blades to be instrumented internally, they are constructed with two parts (A and B) that are adhered together allowing the formation of an internal cavity, as illustrated in Figure 2.

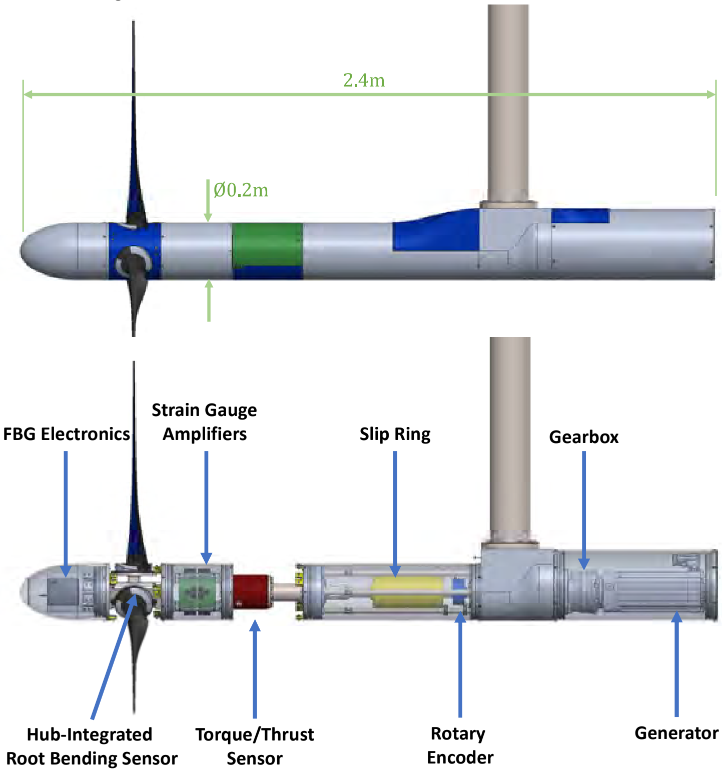


Figure 1: benchmarking turbine design

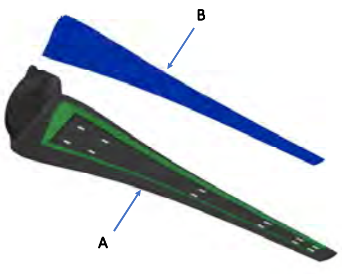


Figure 2: blade construction

3. Turbulence Generation

The turbine will be tested in a towing tank facility with a low level of freestream turbulence. To elevate the turbulence level, a carriage mounted turbulence grid has been implemented, as illustrated in Figure 3. The grid is 2.4×2.4m in size and mounted 5m in front of the intended turbine plane. The grid can be constructed in three different configurations to provide varying levels of freestream turbulence.

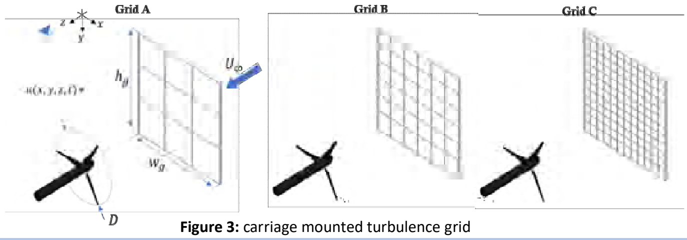


Figure 3: carriage mounted turbulence grid

4. Turbulence Grid Flow Characterisation

To characterise the flow field behind the turbulence grid prior to performing experiments with the benchmarking turbine, Acoustic Doppler Velocimeters (ADVs) were utilised to measure the flow velocity in the intended turbine plane without the benchmarking turbine. A Nortek Vectrino was used to obtain measurements, while seeding was introduced into the towing tank prior to each set of experimental runs.

Figure 4 illustrates the measured profile of mean streamwise velocity behind the turbulence grid. U_∞ denotes the freestream flow velocity, while z^* is the vertical coordinate normalised with the turbulence grid width with respect to its centre. Across the region that will be occupied by the turbine, which is shaded in yellow and green for the nacelle and blade respectively in figure 2, the mean streamwise flow velocity was $0.917U_\infty$ with a variation of just $\pm 0.5\%$. Over the same region the streamwise turbulence intensity was found to have a mean value of 3.5%. Figure 5 shows the velocity spectra measured in the intended turbine plane at the grid centre. The results can be seen to conform to the theoretical power law decay, especially for the vertical velocity component.

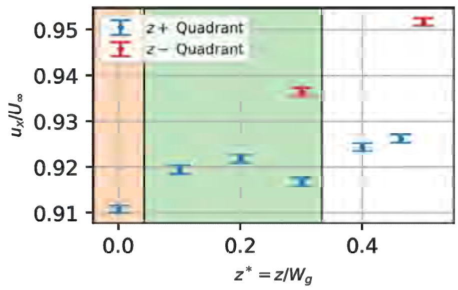


Figure 4: mean streamwise velocity profile

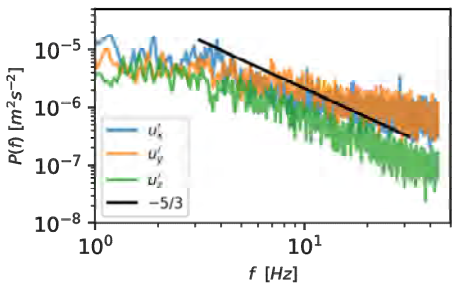


Figure 5: velocity spectra at grid centre

5. Conclusions

- The unsteady loading tidal benchmarking project aims to provide a well documented dataset that will aid in the improvement of mathematical and engineering models utilised in tidal turbine design
- The benchmarking turbine has been designed to incorporate in blade measurements of the edgewise and flapwise bending moments using both Fibre Bragg sensors and strain gauges
- The flow behind the turbulence grid developed for the project has been characterised and is close to uniform with a mean streamwise turbulence intensity of 3.5%

Using Digitalisation for Decarbonisation

Shen Li

Department of Naval Architecture, Ocean and Marine Engineering

University of Strathclyde, Glasgow

Abstract

The climate crisis has driven the rapid development of the renewable energy sector in the past decades, as it is probably the greenest and the most sustainable solution to accomplish the ambitious decarbonisation and net-zero target, and yet ensuring a sufficient provision of energy to power the modern society. Many renewable energy devices, such as offshore wind turbines, are deployed to operate in a remote and harsh ocean environment. For a safe operation and reliable power production, the structural integrity of these infrastructures is of paramount importance. Traditionally, the integrity of renewable energy infrastructure is maintained via regular site inspections, which is scheduled based on experience in terms of the critical areas to be inspected and the inspection time. Nevertheless, this fails to advise the optimal maintenance plan and is limited by the accessibility of certain critical structural components. Moreover, the poor environmental condition is a hazard for our fellow surveyors. To resolve this issue, the emerging digitalisation synergising Structural Health Monitoring (SHM) and Digital Twin (DT) technology is a smart solution. In this approach, the virtual representation (i.e., digital twin) of the physical system is updated through the real-time measurements collected by a dedicated sensing package. Advanced structural integrity assessment is performed on the updated digital model, which offers diagnostics and prognostics for the physical system. This provides the asset manager with quantitative basis for decision-making. University of Strathclyde is now working toward the development of this revolutionary approach. One of the challenges is to verify the state-of-the-art sensing devices for monitoring the responses of structures working in a marine environment. In the light of this, a novel test rig is developed to in the hydrodynamic lab, by which the verification of prevailing sensors such as fibre optical strain gauges can be performed and moreover the measurement uncertainty can be assessed.

Using **Digitalisation** for **Decarbonisation**

- Recent research in the River Clyde for offshore renewable sector

Dr. Shen Li
Department of Naval Architecture, Ocean and Marine Engineering
University of Strathclyde, Glasgow

Background

Digitalisation refers to a process of converting information into a computer-readable format, by which a system, or asset etc. is adapted to be operated with the use of computers and the internet.

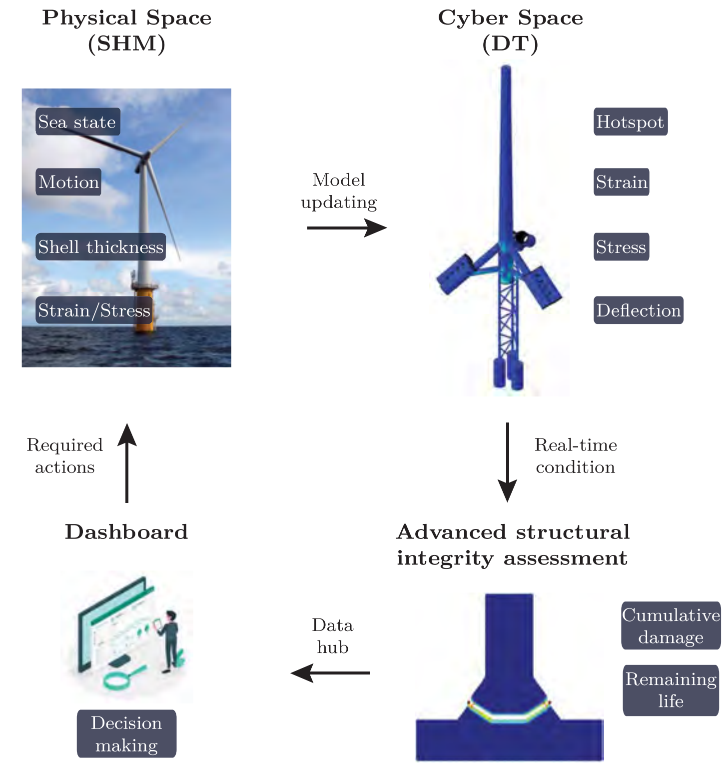
Decarbonisation refers to the reduction of carbon dioxide (CO2) emission into the atmosphere. The usage of renewable energy sources is the ultimate solution.

Motivation

Condition monitoring of offshore renewable assets is highly important for the safe operation of the entire industry. Traditionally, this is carried out by surveryor inspection based on an experience-based schedule and inspection location. However, regular inspection fails to advise the optimal maintenance plan, limited by the accessiblity, and unables to provide rapid response following an emergent event. Moreover, the harsh working environment is a hazard for our fellow surveyors.

Solutions

Digitalisation synergizing the **S**tructural **H**ealth **M**onitoring (SHM) and **D**igital **T**win (DT) technology is a smart solution.

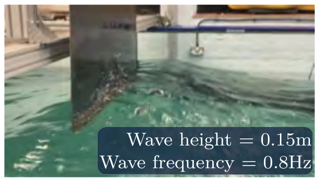


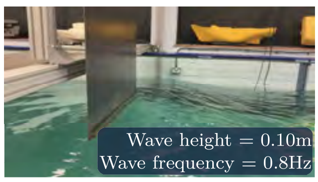
Developments

A novel test rig is developed in the hydro lab at University of Strathclyde to verify the capability of state-of-the-art sensing devices for monitoring motion and structural responses in a marine environment. This also allows us to gain an enhanced understanding on the uncertainty of the measurement.

Inertia Measurement Unit

Fibre Bragg Grating strain gauge





Wave energy extraction from a floating flexible circular plate

by S. Michele and S. Zheng

We present a theoretical model to investigate the hydrodynamics of a floating flexible circular wave energy converter (WEC). Decomposition in rigid and bending elastic modes of the plate allows us to investigate power extraction efficiency in monochromatic incident waves. We show that plate elasticity increases the number of eigenfrequencies, which has a positive beneficial effect on power output. We also show how plate radius and power take-off (PTO) distribution affect the response of the system and the consequent absorbed energy. This work highlights the need to extend theoretical studies and experimental investigations on flexible devices, currently seen as the future of WEC technology.

Wave energy extraction from a floating flexible circular plate

Simone Michele (simone.michele@plymouth.ac.uk)
Siming Zheng (siming.zheng@plymouth.ac.uk)
University of Plymouth, Plymouth, United Kingdom

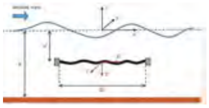
Abstract:

We present a theoretical model to investigate the hydrodynamics of a floating flexible circular wave energy converter (WEC). Decomposition in rigid and bending elastic modes of the plate allows us to investigate power extraction efficiency in monochromatic incident waves. We show that plate elasticity increases the number of eigenfrequencies, which has a positive beneficial effect on power output. We also show how plate radius and power takeoff (PTO) distribution affect the response of the system and the consequent absorbed energy. This work highlights the need to extend theoretical studies and experimental investigations on flexible devices, currently seen as the future of WEC technology.

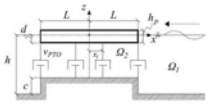
Motivations of the study

- Compared with the conventional rigid-body-based WECs, the WECs made from flexible materials are not only advantageous for the larger potential of wave power absorption but also believed to offer improved performance/survivability and reduced cost in respect to steel/concrete alternatives;
- In the last decade, there has been a growing trend towards flexible body WECs, e.g., flexible plate WECs, bulge wave devices, and SQ devices;
- One way to attract funds and confidence in industry is to consider light and flexible materials instead of bulky metallic components;
- Further analytical/experimental work is needed to understand the global hydrodynamic behaviour of flexible WECs.

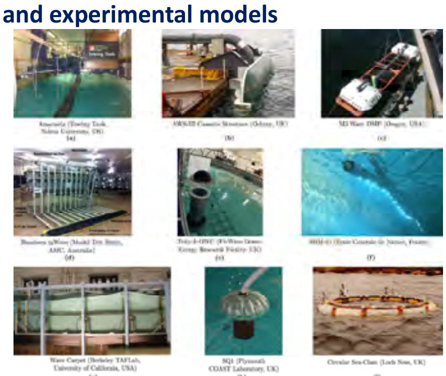
Examples – Theoretical and experimental models



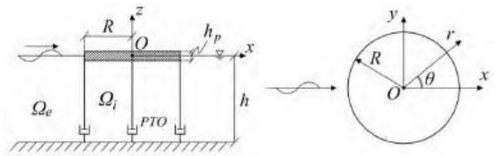
E. Renzi. Hydroelectromechanical modelling of a piezoelectric wave energy converter (2016)



S. Michele, F. Buriani, E. Renzi, M. van Rooij, B. Jayawardhana and A.I. Vakis. Wave Energy Extraction by Flexible Floaters (2020)



Mathematical model



View from above and horizontal cross-section of the flexible circular WEC

Governing equations and boundary conditions

Dynamic equation

$$D\nabla^4 W = q - \rho_p h_p W_{tt}, \quad r \in [0, R]$$

Laplace's equation

$$\nabla^2 \Phi = 0$$

W represents the plate displacement, t denotes time, q is the transverse distributed load positive in the z direction, D represents the flexural rigidity, ∇^4 denotes the biharmonic operator in cylindrical-polar coordinates, ρ_p is the plate density

No-flux at the seabed

$$\Phi_z = 0, \quad z = -h,$$

Linearised kinematic and mixed boundary conditions on the free surface

$$\zeta_t = \Phi_z, \quad \Phi_{tt} + g\Phi_z = 0, \quad z = 0, \ r > R$$

Kinematic condition

$$\Phi_z = W_t, \quad z = 0, \ r \in [0, R]$$

Harmonic expansion

$$\{\Phi, \zeta, W\} = \mathrm{Re}\left\{(\phi, \eta, w)e^{-i\omega t}\right\}$$

$$\begin{cases} \nabla^2\phi = 0, & \text{in } \Omega, \\ \phi_z = -i\omega\eta, & z = 0, \ r > R, \\ \phi_z = \dfrac{\omega^2}{g}\phi, & z = 0, \ r > R, \\ \phi_z = -i\omega w, & z = 0, \ r \in [0, R], \\ \phi_z = 0, & z = -h, \end{cases}$$

Mode expansion

$$w = \zeta_h w_h + \zeta_p w_p + \sum_{m=0}^{\infty}\sum_{n=0}^{\infty} \zeta_{mn} w_{mn}$$

where ζ represents the complex amplitude of each modal shape w, h denotes heave, p pitch, whereas mn denotes the bending modes

Diffraction velocity potential

For $r>R$

$$\phi_D^{(e)} = -\frac{iAg}{\omega}\sum_{n=0}^{\infty}\cos n\theta \left\{\frac{\cosh k_0(h+z)}{\cosh k_0 h}\left[\epsilon_n i^n J_n(k_0 r) + A_{0n}^D \frac{H_n^{(1)}(k_0 r)}{H_n^{(1)\prime}(k_0 r)\big|_{r=R}}\right] + \sum_{l=1}^{\infty} A_{ln}^D \frac{K_n(\overline{k_l} r)\cos \overline{k_l}(h+z)}{K_n'(\overline{k_l} r)\big|_{r=R}\cos \overline{k_l} h}\right\}$$

For $r<R$

$$\phi_D^{(i)} = -\frac{iAg}{\omega}\sum_{n=0}^{\infty}\cos n\theta \left\{B_{0n}^D\left(\frac{r}{R}\right)^n + \sum_{l=1}^{\infty} B_{ln}^D \frac{I_n(\mu_l r)\cos \mu_l(h+z)}{I_n'(\mu_l r)\big|_{r=R}\cos \mu_l h}\right\}, \quad \mu_l = \frac{l\pi}{h},$$

k_0 represents the propagating wave, $\overline{k_l}$ represents the evanescent wave, $H_n^{(1)}$ is the Hankel function of first kind and order n, I_n K_n are the modified Bessel functions of order n, whereas A_{ln} and B_{ln} are unknown complex constants. Substituting in the matching conditions $\phi^{(i)} = \phi^{(e)}$; $\phi_r^{(i)} = \phi_r^{(e)}$ and integrating over $z \in [-h, 0]$, yields an inhomogeneous linear system in the complex constants A_{ln} , B_{ln} which can be solved numerically.

Radiation velocity potential

General solution for pitch, heave or bending mode α for $r>R$

$$\phi_\alpha^{(e)} = \sum_{n=0}^{\infty}\cos n\theta \left\{A_{0n}^\alpha \frac{H_n^{(1)}(k_0 r)\cosh k_0(h+z)}{H_n^{(1)\prime}(k_0 r)\big|_{r=R}\cosh k_0 h} + \sum_{l=1}^{\infty} A_{ln}^\alpha \frac{K_n(\overline{k_l} r)\cos \overline{k_l}(h+z)}{K_n'(\overline{k_l} r)\big|_{r=R}\cos \overline{k_l} h}\right\}$$

The radiation potential solution in $r<R$ is given by the homogeneous part $\phi_{\alpha h}^{(i)}$ and a particular solution that accounts for the plate vibration in $z = 0$. The homogeneous component reads

$$\phi_{\alpha h}^{(i)} = \sum_{n=0}^{\infty}\cos n\theta \left\{B_{0n}^\alpha\left(\frac{r}{R}\right)^n + \sum_{l=1}^{\infty} B_{ln}^\alpha \frac{I_n(\mu_l r)\cos \mu_l(h+z)}{I_n'(\mu_l r)\big|_{r=R}\cos \mu_l h}\right\}, \quad \mu_l = \frac{l\pi}{h},$$

whereas the structure of each particular solution differs from one another.

The particular solutions for the rigid heave and pitch mode are given by

$$\tilde{\phi}_h = -\frac{i\omega}{2h}\left[z^2 + 2hz - \frac{r^2}{2}\right] \qquad \tilde{\phi}_p = -\frac{i\omega r\cos\theta}{8h}\left[4z^2 + 8hz - r^2\right]$$

whereas the particular solution for each bending elastic mode is given by

$$\tilde{\phi}_{mn} = -i\omega R\frac{\cos n\theta}{\lambda_{mn}}\left\{\frac{\cosh\frac{\lambda_{mn}(h+z)}{R} J_n\left(\frac{\lambda_{mn} r}{R}\right)}{\sinh\frac{\lambda_{mn} h}{R}} + \frac{\cos\frac{\lambda_{mn}(h+z)}{R} I_n\left(\frac{\lambda_{mn} r}{R}\right)}{\sin\frac{\lambda_{mn} h}{R}}T_{mn}\right\}, \quad n = 0, 1, \ldots$$

As before, by matching the velocity potentials in $r=R$ yields a sequence of linear systems in the unknowns $A_{ln}^\alpha = B_{ln}^\alpha$ forced by the particular solutions $\widetilde{\phi_\alpha}$

Plate response and generated power

Given the effect of all the external forces, the dynamic equation can be expanded as

$$D\nabla^4 W + \rho_p h_p W_{tt} + \rho g W + \left[\sum_{i=1}^{I}\frac{1}{r}\delta(r - r_i)\,\delta(\theta - \theta_i) + \frac{1}{2\pi r}\delta(r)\right] v_{PTO} W_t + \rho\Phi_t = 0$$

where ρ is the fluid density. The third term represents the hydrostatic pressure, the fourth term denotes the effects of localised forces due to the PTO systems, δ is the Dirac delta function and the last term represents the dynamic pressure exerted by the wave field. Note that the second term in the brackets take into account a localised force given by a PTO device located in $r = 0$, therefore the Dirac delta function is defined differently. By using both harmonic expansion and dry mode decomposition we get

$$\begin{aligned}
&\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}\zeta_{mn}\left\{w_{mn}\left\{\frac{D\lambda_{mn}^4}{R^4} - \rho_p h_p\omega^2 + \rho g - i\omega v_{PTO}\left[\sum_{i=1}^{I}\frac{1}{r}\delta(r - r_i)\,\delta(\theta - \theta_i) + \frac{1}{2\pi r}\delta(r)\right]\right\}\right. \\
&\left.-i\omega\rho\sum_{n=0}^{\infty}\cos n\theta\sum_{m=0}^{\infty}\left\{B_{0n}^{mn}\left(\frac{r}{R}\right)^n + \sum_{l=1}^{\infty}B_{ln}^{mn}\frac{I_n(\mu_l r)}{I_n'(\mu_l r)\big|_{r=R}} - \frac{i\omega R}{\lambda_{mn}}\left[\frac{J_n\left(\frac{\lambda_{mn} r}{R}\right)}{\tanh\frac{\lambda_{mn} h}{R}} + \frac{I_n\left(\frac{\lambda_{mn} r}{R}\right)}{\tan\frac{\lambda_{mn} h}{R}}T_{mn}\right]\right\}\right\} \\
&+(\zeta_h w_h + \zeta_p w_p)\left\{-\rho_p h_p\omega^2 + \rho g - i\omega v_{PTO}\left[\sum_{i=1}^{I}\frac{1}{r}\delta(r - r_i)\,\delta(\theta - \theta_i) + \frac{1}{2\pi r}\delta(r)\right]\right\} \\
&-i\omega\rho\left\{\zeta_h\left[B_{00}^h + \sum_{l=1}^{\infty}B_{l0}^h\frac{I_0^{(1)}(\mu_l r)}{I_0^{(1)\prime}(\mu_l r)\big|_{r=R}} + \frac{i\omega r^2}{4h}\right] + \zeta_p\cos\theta\left[B_{01}^p\frac{r}{R} + \sum_{l=1}^{\infty}B_{l1}^p\frac{I_1^{(1)}(\mu_l r)}{I_1^{(1)\prime}(\mu_l r)\big|_{r=R}} + \frac{i\omega r^3}{8h}\right]\right\} \\
&= Ag\rho\sum_{n=0}^{\infty}\cos n\theta\left\{B_{0n}^D\left(\frac{r}{R}\right)^n + \sum_{l=1}^{\infty}B_{ln}^D\frac{I_n(\mu_l r)}{I_n'(\mu_l r)\big|_{r=R}}\right\},
\end{aligned}$$

The complex modal amplitudes can be found by multiplying both sides of by each of the modal shape functions w and then integrating with respect the plate wetted surface.

The resulting system can be written in the following matrix form

$$\mathbf{M}\{\zeta\} = \{F\}$$

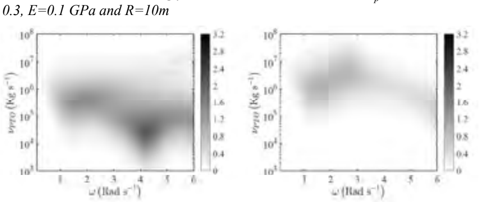
where $\mathbf{M}$ is the coefficient matrix, $\{F\}$ is the exciting force vector, whereas $\{\zeta\}$ is the vector containing the modal amplitudes. Expression above suggests that the continuous floating plate is equivalent to a system of linear coupled forced harmonic oscillators. Once the response of the system is found, the average generated power by the plate and the system efficiency is simply

$$P = \frac{1}{2}v_{PTO}\,\omega^2\sum_{i=1}^{I}\left|w(r_i, \theta_i)\right|^2 \quad \Longrightarrow \quad C_W = \frac{k_0 P}{E C_g}, \quad E = \frac{1}{2}\rho g A^2,$$

where w represents the amplitude of plate oscillations corresponding to the PTO location (r_i, θ_i) and E is the total energy

Effects of the PTO distribution

Let us consider the following parameters: $A = 1$ m, $h = 10$ m, $h_p = 1$ m and $\upsilon = 0.3$, $E = 0.1$ GPa and $R = 10$m

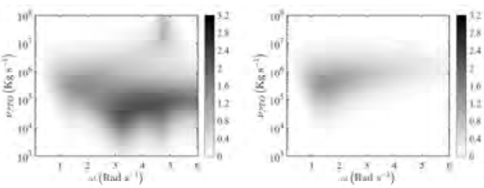


Behaviour of C_W versus frequency of the incident waves ω and PTO-Coefficient. (a) 5 PTO devices located in $r = 0$ and $r_i = R$, $\theta_i = [0, \frac{\pi}{2}, \pi, 3\pi/2]$ (b) Single PTO device located at the center of the plate.

When the number of the PTOs increases, the bandwidth of C_W increases too and the system also becomes more efficient. From a theoretical point of view, this distribution maximises the radiated waves in the direction opposite the incident waves

Effects of plate flexural rigidity

A parametric analysis is performed for a softened plate characterized by a smaller value of the Young's modulus $E = 0.05$ GPa and an idealized rigid plate. The 5 PTO devices are located in $r = 0$ and $r_i = R$, $\theta_i = [0, \frac{\pi}{2}, \pi, 3\pi/2]$ whereas the plate radius is $R = 10$ m.

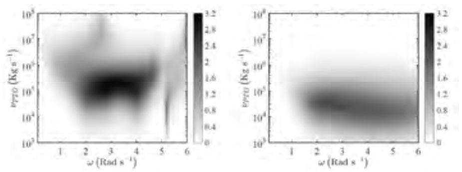


Behaviour of C_W versus frequency of the incident waves ω and PTO-Coefficient. (a) Flexible softened plate (b) Rigid plate

When the flexural rigidity of the plate decreases, the efficiency of the system increases significantly. When the plate is rigid there are no contributions from the bending modes and the dynamics is governed by pitching and heaving motion only The overall efficiency is clearly smaller with respect to the cases shown so far because we reduced the number of eigenfrequencies and the resonances of the natural bending modes.

Effects of plate dimensions

Here we investigate the effects given by two different values of plate radius $R = [15; 5]$ m, fixed Young's modulus $E = 0.1$ GPa and fixed PTO distribution. The 5 PTO devices are located in $r = 0$ and $r_i = R$, $\theta_i = [0, \frac{\pi}{2}, \pi, 3\pi/2]$ whereas the plate radius is $R = 10$ m.



Behaviour of C_W versus frequency of the incident waves ω and PTO-Coefficient. (a) R=15m (b) R=5 m

For $R = 15$ m the efficiency bandwidth and C_W increase because of increased number of eigenfrequencies in the range of interest. On the contrary, the case of smaller radius $R = 5$ m, shows smaller overall efficiency with a single visible peak. These results suggest that the plate radius R plays an important role on power extraction efficiency, however one should take care of its effects on plate structural resistance that could penalize the receiver behavior and durability in real seas. In fact, larger dimensions mean also larger loads.

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Damage tolerant hybrid composites for safer and higher performance composite offshore wind turbine blades

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Offshore wind turbines are becoming larger in capacity and size with wind turbines in the region of 10-15 MW being now commercialised [1]. As offshore wind turbine geometries become larger, damages in the rotor blades are more likely to occur given the variability of the wind patterns over a larger rotor area. Studies have shown that damage increases equivalent load for the flapwise blade root moment is 45% compared to the upstream turbine [2]. To mitigate damages in offshore wind turbine blades, hybrid reinforcement on the blade spar or at the root can be used as a damage deterrent failure mechanism within the blade structure. New mechanisms combining rotation and fragmentation of fibres achieving high strains and gradual failure in multi-directional carbon fibre laminates have already been devised [3]. These hybrid composites will thus be investigated in this project when used in an offshore wind turbine blade subjected to real-site wind loading.

(a) (b)

Figure 1. (a) Blade turbine assessed in this project [4] and (b) test rig used to undertake loading tests as it was used in [6].

The wind turbine blade assessed in this project is the 15 MW turbine designed by NREL and DTU [4]. The blade is 117 m in length and is composed of a number of different aerofoils along the blade length, see Fig 1a. Thrust and bending moment will be evaluated at peak power conditions using the open-access FAST code [5]. Stress and strain characteristics will then be evaluated in ANSYS to feed into the experimental set-up.

The experimental set up will demonstrate gradual failure of hybrid composite blade under flexural loading, producing highly-nonlinear load–displacement curves and progressive brush-like failure with large deformations [6]. Results will show implementation of damage mode maps to achieve a laminate architecture that is more damage tolerant and thus enhances blade performance.

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Damage tolerant hybrid composites for safer and higher performance composite offshore wind turbine blades

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Supergen Offshore Renewable Energy

UNIVERSITY OF Southampton

University of Strathclyde Glasgow

Why?

Offshore wind turbines are becoming larger in capacity and size. As these **turbines become larger, damages in the rotor blades are more likely to occur given the variability of the wind patterns** over a larger rotor area. In this project, we proposed to produce high performance hybrid composites that retain their integrity even after substantial damages.

What?

To achieve optimal failure scenarios in wind turbine blades, new hybrid composite architectures will be explored. The hypothesis is that these will **increase the safety and performance of the blades when they are exposed to a variety of extreme loading patterns.** To achieve damage tolerance, the failure process will be altered to absorb energy and reduce laminate stiffness without immediately resulting in full through thickness cracks.

How?

Step 1. Get blade geometry and modelling parameters; wind speeds, operational point of the turbine

Step 2. Generate modelling scenarios to capture the blade structural characteristics, e.g. thrust loading, bending moments, shear loads, etc

Step 3. Generate composite coupons using glass fibre and thin-ply carbon fibre hybrid composites

Step 4. The competition between damage modes will be exploited to avoid damage localisation and achieve well-spread damage to produce multi-directional laminates that can maintain integrity whilst absorbing the applied energy.

Step 1 (ongoing)

Tidal turbine blade

Based on existing literature

- Small scale device
- Experimental and numerical approaches
- Full access to blade parameters and estimations

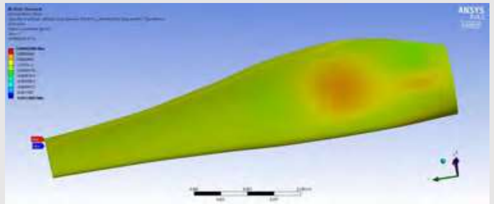
Wind turbine blade

Based on existing literature

Pros:

- Full scale turbine
- Vast information from developed models such as FAST

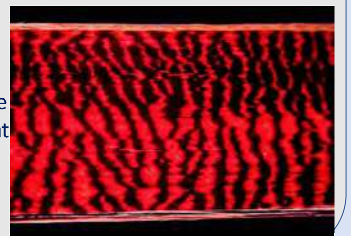
Step 2 – modelling (ongoing)



NREL's open access FAST code using blade element momentum theory will be used to assess loading and bending moments associated with the blade sections. This can be complemented with Ansys models.

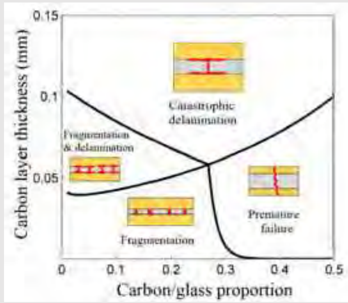
Step 3 – Damage tolerant composites

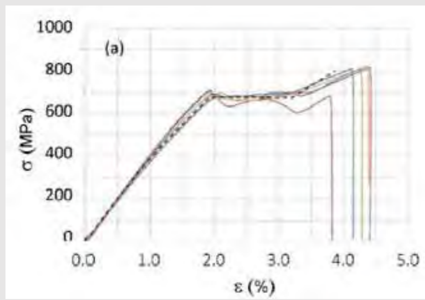
Materials used is a combination of glass fibre and carbon fibre hybrid composite that promotes damage tolerance.



Step 4 – Expected results

Preliminary tensile testing have shown the propensity of the hybrid composite to withstand sudden failure by having the low strain carbon fibre fragmentation dispersed as shown in the image above.





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Avoiding unforeseen consequences in tidal turbine blade design

Dr. Stuart Walker, University of Exeter

Electricity generated from tidal streams via underwater turbines has significantly lower greenhouse gas emissions than fossil-fuel derived electricity. However, the materials, manufacture, operation and end-of-life treatment of a tidal stream turbine incurs greenhouse gas emissions and other environmental impacts, such as water consumption, land use, and human toxicity. Whilst many parts of a tidal stream turbine can be recycled, turbine blades cannot, and in common with the wind energy industry, may present a future environmental problem for the sector.

Tidal stream capacity is forecast to be over 1GW by 2030, which using current methods will ultimately produce around 6000 tonnes of non-recyclable blade waste. This waste is currently disposed of in landfill or incinerated, both of which have greenhouse gas and human health impacts. To address a growing waste management problem, this poster presents initial results from a larger study which aims to understand the environmental impact of tidal stream turbine blades manufactured from a range of materials and using a range of methods.

Tidal stream turbine blades are conventionally manufactured from non-recyclable reinforced polymer composite materials, namely glass fibre and carbon fibre composites. This study also considers flax fibre composites made using conventional epoxy resins and recyclable resins, which at the end-of-life can be separated from the fibre and recycled as a polymer. A finite element model is used to develop material cases and Life Cycle Assessment is used to study the impacts of each combination of materials and treatment methods.

Compared to a glass fibre composite turbine blade, steel blades are around 2.5 times heavier, and have significant manufacturing emissions. Carbon fibre composite blades weigh less than glass fibre, but cause greenhouse 80% greater gas emissions, and human and ecosystem health risks, so are also not recommended. The best environmental performance of the cases considered was a flax fibre composite. This material offers greenhouse gas emissions around 50% lower than glass fibre materials when manufactured using conventional epoxy resin, and around 40% lower when manufactured using recyclable epoxy resin, which also enables the reuse of the fibre and may further reduce environmental impact. Initial results suggest that the cost of these materials are similar to or lower than conventional composite materials.

Avoiding unforeseen consequences in tidal turbine blade design

Dr. Stuart Walker
University of Exeter (s.walker7@exeter.ac.uk)

MOTIVATION

A major driver for the development of renewable energy is the need to reduce the greenhouse gas emissions of electricity generation.

Tidal stream turbines allow low-emission electricity to be generated, but themselves cause emissions due to materials, manufacturing, operation and end-of-life treatment.

Blades are a key area of concern since the materials used are often non-recyclable, and the manufacturing processes used can be energy intensive.

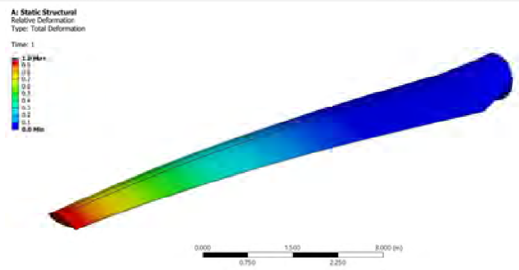
CASES

This study compared blade materials, manufacturing methods and end-of-life treatments.

Glass fibre, Carbon fibre, Flax fibre → {Conventional resin, Recyclable resin} → Resin transfer moulding, Monocoque moulding, Powder heated mould → {Landfill, Incineration}, Composting

Steel → Folding → Recycling

PERFORMANCE

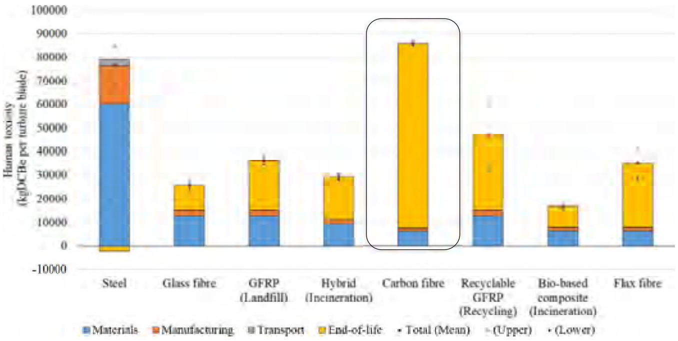


To ensure comparable hydrodynamic performance, we calculated the mass of each material required to match the deflection of a standard glass fibre blade.
Materials with lower Young's Modulus compensated by increasing second moment of area, and thus thickness and mass.

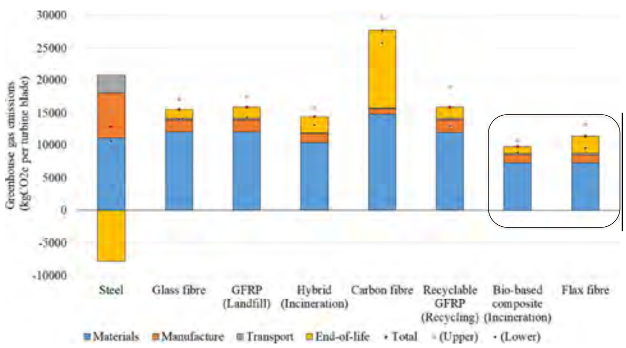
	Glass fibre	Carbon fibre	Flax composite	Steel
Density (kg/m³)	1900	1200	1200	7850
Young's Modulus (Pa)	3.5×10^{10}	1.68×10^{11}	4.8×10^{10}	2×10^{11}
Blade Mass	2530	1024	1489	5551

RESULTS & CONCLUSIONS

We calculated embodied greenhouse gas emissions, water consumption, land use and human toxicity results for 28 combinations of blade material, manufacturing method and end of life treatment.



- End-of-life treatment is significant, particularly to greenhouse gas emissions and human toxicity. The incineration or landfill of carbon fibre composites has large negative impacts.
- Powder resin, as used in the heated mould method, also has potential for significant human health impacts.
- Steel has by far the most energy intensive manufacturing process.



- Bio-based fibres can be composted to avoid landfill, but first require recyclable resin to allow separation. The combination of these products yields greenhouse gas emissions 50% lower than conventional glass fibre turbine blades.
- Costs appear in line with glass fibre composites, but this material is at an early developmental stage.

MORE

This poster presents only a few results. Full details of this work can be found in:
A life cycle assessment comparison of materials for a tidal stream turbine blade, Walker, S. & Thies, P., Applied Energy, Vol 309, March 2022

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Investigation into the Coupling of a Wave Energy Converter with a Reverse Osmosis Desalination Plant

Tapas K. Das, Matt Folley, Carwyn Frost
Queen's University Belfast, Northern Ireland

Abstract:
The present research focuses on the direct coupling of wave energy converters to reverse osmosis desalination plant powered by pressurised water from the primary power take off system. Although reverse-osmosis desalination plant driven by renewable energy currently exists, they have mostly used an electric pump to provide a relatively stable saline water flow. Direct coupling to the hydraulic output of a WEC poses several challenges the most significant being that reverse-osmosis (RO) plant does not normally operate in variable inflow conditions and consequently there is very little published research in this area. As not all WEC concepts are suitable for direct hydraulic coupling to RO plant, it is essential to develop a target specification and apply it to current and proposed technology. The poster will present the development strategies of an experimental setup of a wave powered desalination plant.

Investigation into the Coupling of a Wave Energy Converter with a Reverse Osmosis Desalination Plant

Tapas K. Das, Matt Folley, Carwyn Frost
Queen's University Belfast

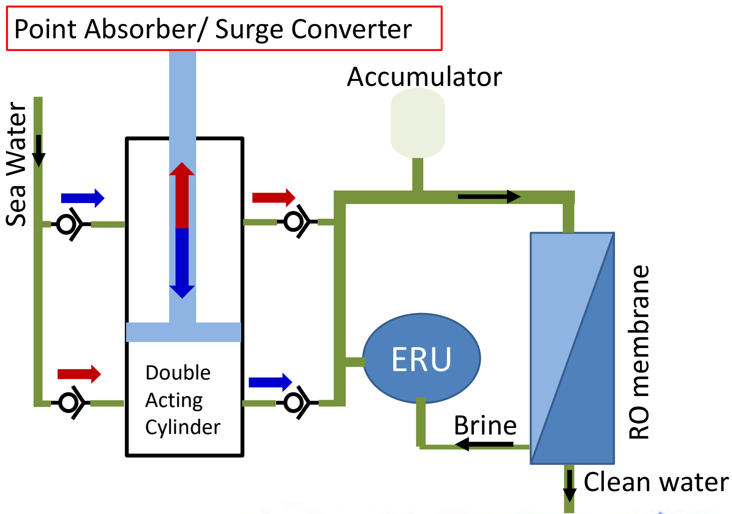
Introduction

Direct coupling to the hydraulic output of a wave energy converter (WEC) to a desalination plant poses several challenges the most significant being that reverse-osmosis (RO) plant does not normally operate in variable inflow conditions. This research investigates the direct coupling of wave energy converters to reverse osmosis desalination plant powered by pressurized water from the primary power take off system.

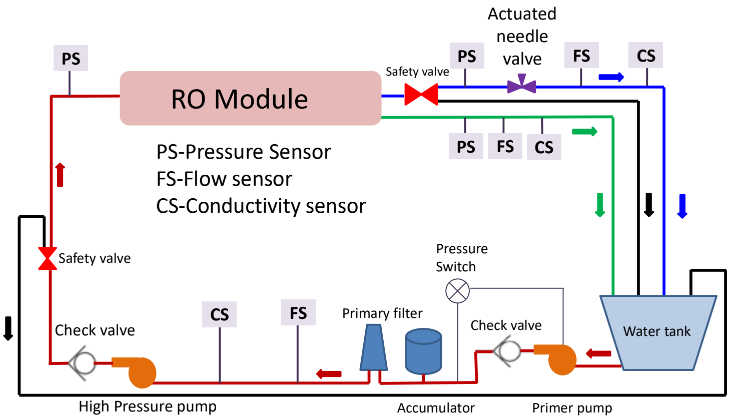
Project Activities & Objectives

- Physical modelling
  - ➢Understand how variable pressure/flow impacts RO plant water quality and specific energy consumption
  - ➢Understand how RO plant water quality and specific energy consumption may vary with membrane life due to variable pressure/flow.
- Numerical modelling
  - ➢Understand how the design of the wave energy technology influences the expected flow into the RO desalination plant.
  - ➢Two wave energy converters investigated
    - Heaving point absorber
    - Oscillating wave surge converter
- Guidelines
  - ➢Develop guidelines for wave-powered desalination plant design to minimize cost of water.

A Wave Powered Desalination Plant



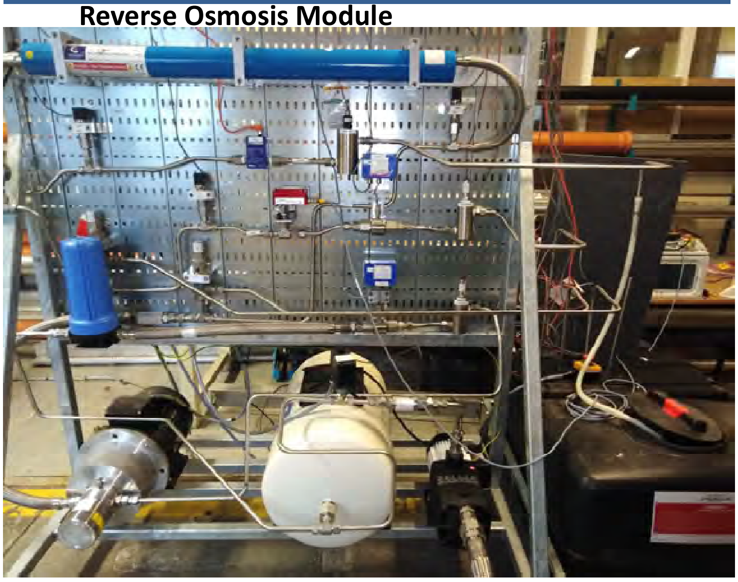
Schematic of Experimental Setup



Feed water   Retentate/Brine   Permeate/Clean water

Desalination Experiment Rig

Reverse Osmosis Module



High Pressure Pump   Accumulator   Water Tank

Project Outcome

- ➢Develop understanding
  - ❑ Understanding physical processes taking place in reverse osmosis plant
  - ❑ Correlation between the numerical and physical predictions
  - ❑ Investigate the design of wave powered desalination with or without flow conditioners such as accumulator
- ➢Stimulate interest in deploying WEC technology for desalination
- ➢Create road map wave-powered desalination

Work carried out under the DesWEC Project,
funded as a Supergen Flexible Funding

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An LES-AL Study of the DTU 10MW Reference Wind Turbine

Abstract

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Department of Engineering Science, University of Oxford

The objective of the present research is to develop computationally efficient but high fidelity CFD techniques for wind and tidal turbine simulation. To do this we combine the high fidelity Large-Eddy Simulation (LES) approach with the actuator line (AL) turbine representation, immerse boundary body representation and efficient meshing strategies. The project also involves detailed evaluation of the influence of those techniques on wake physics, both steady and unsteady.

The selected test case is a single-rotor DTU 10MW reference wind turbine, at an operation point of $U_\infty = 10\ m/s$, slightly below rated power. Two grid generation techniques are investigated: the OpenFOAM Octree and the ICEM CFD O-grid. The total cell counts of the 2 grids are kept roughly the same around 50M, with similar resolution of the refined wake regions. However, the grid quality of the 2 meshing techniques exhibits some differences (e.g. the Octree always has an aspect ratio of 1.0, while the O-grid has a much larger aspect ratio of 10~100 in core regions).

The current research suggests that the Octree based grids are able to provide similar turbine performance, as well as mean wake flow field, when compared to O-grid techniques. And it is observed that the Octree grid preserves turbulent structures and statistics better than the O-grid. Another advantage of the Octree grid is that the computational speed are found to be approximately 10 times faster compare to the O-grid mesh due to higher computational efficiency. Such advantage in efficiency leads to the potential to improve the resolution quality of the unsteady wake structures for high fidelity CFD simulation method such as LES. Our future work will be aiming at improving the performance of the AL method, as well as the near- and far-wake flow field analysis using the Octree meshing strategy.

An LES-AL Study of the DTU 10MW Reference Wind Turbine

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DTU 10MW RWT

Objectives:

- ➢ Development of computationally efficient simulation techniques for high fidelity CFD simulations; Actuator Line (AL) turbine representation, Immersed boundary body representation, Efficient meshing strategies.
- ➢ Including detailed evaluation of influence of techniques on wake physics.

Configuration & simulation set-up:

- ➢ Single-rotor, operated at slightly below rated power, $U_\infty = 10\ \mathrm{m/s}$.
- ➢ Nacelle and tower represented by the immersed boundary method for computational efficiency
- ➢ 2 grid generation methods compared: OpenFOAM Octree and ICEM CFD O-grid; total cell count ~50M, with similar refinement in wake regions.
- ➢ Simulation speed (at 3600 timesteps per rotation)
  - Octree: 1.9×10^3 core-hours / rotation
  - O-grid: 14.7×10^3 core-hours / rotation

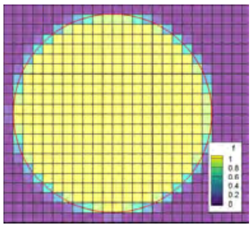
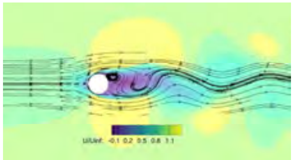


Fig. 1 Example of the immersed boundary method (top) and applied to a cylinder test case (bottom).



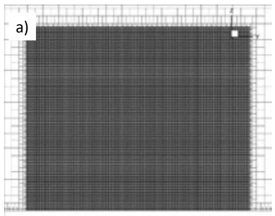
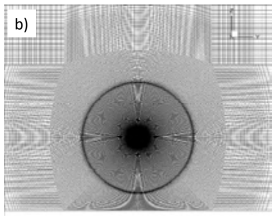


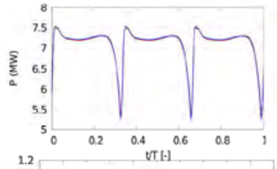
Fig. 2 a) Octree & b) O-grid meshes.

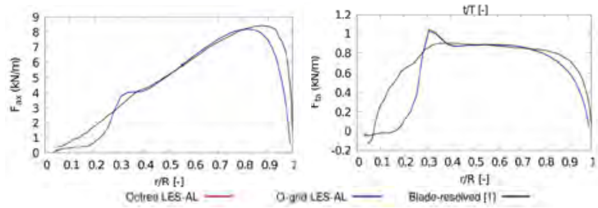


Turbine performance and wake profiles

Turbine performance

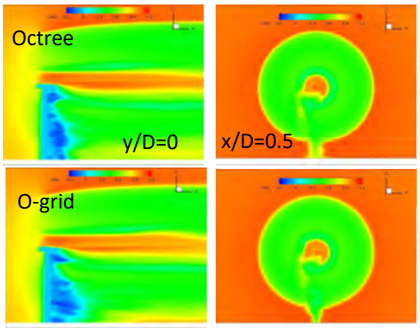
	Blade-resolved [1]	Octree LES-AL	O-grid LES-AL
C_P	0.494	0.463	0.463
C_T	0.838	0.781	0.781

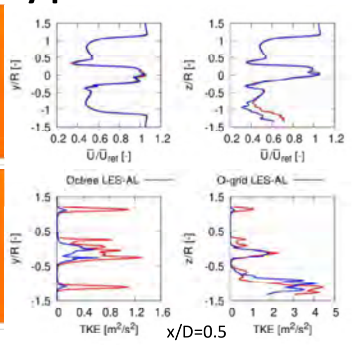




- Overall performance of LES-AL turbine compares well to blade resolved for both meshing strategies.
- Spanwise force distributions compare well except tip regions.
- Differences between LES-AL cases and blade-resolved [1] are due to lift-drag polars, tower wake effects and tip-loss correction.

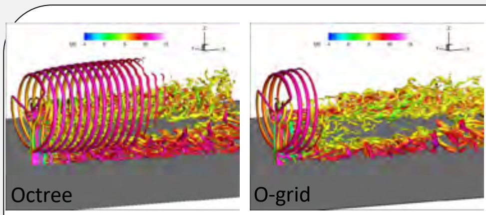
Wake velocity profiles



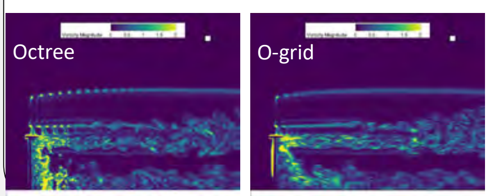


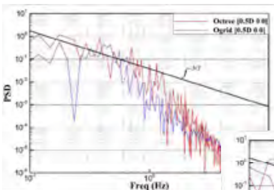
- Mean velocity and TKE field are similar between the 2 meshing strategies.
- The accelerated region towards the blade root is consistent with reduced root loads, which are due to the choice of lift-drag modelling coefficients in the AL representation of the root aerofoil sections.
- Octree case shows a reduced TKE decay rate compared to O-grid case.

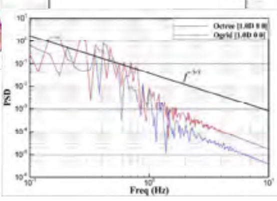
Unsteady flow analysis



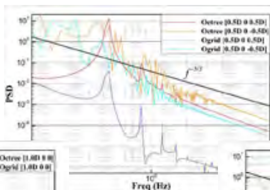
Iso-surfaces of λ_2 coloured by velocity (top)
Vorticity magnitude (bottom)

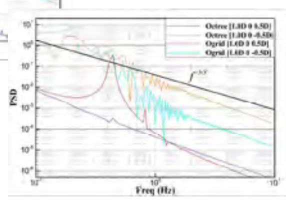






Streamwise velocity spectra in the nacelle wake region at x/D=0.5 and x/D=1.0.





Streamwise velocity spectra in the tip shear region at x/D=0.5 and x/D=1.0, z/D=±0.5

- Visualisation of the turbulent structures (left) suggests a higher dissipation rate for larger turbulent structures, e.g. tip vortices, in the O-grid case compared to the Octree case.
- Both meshing strategies show a similar dissipation rate in the nacelle wake.
- Tip shear region spectra demonstrate that the Octree meshing approach preserves higher turbulence levels which is consistent with flow structure visualizations.

References

[1] DTU Wind Energy Report-I-0092, C. Bak, F. Zahle, R. Bitsche, T. Kim, A. Yde, L.C. Henriksen, A. Natarajan and M.H. Hansen, July 2013, available from: https://rwt.windenergy.dtu.dk/dtu10mw/dtu-10mw-rwt

Acknowledgement

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Progress on the assessment of materials manufacture and performance in flexible WECs

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Wave energy converters (WECs) based on flexible materials could provide a better solution than traditional WECs with rigid materials regarding cost, survivability, overall performance, etc. The flexible component of WECs requires outstanding fatigue performance under numerous deforming cycles in the marine environment. Therefore, the assessment of the material selection, mechanical and fatigue performance is vital for designing flexible WECs. In this work, natural rubber with nylon fabric reinforcement has been selected and examined. A biaxial fatigue setup has been established for flexible membrane materials, and the sample design was modified with the help of finite element analysis (FEA). The scanning electron microscope (SEM) was adopted in investigating the rubber-nylon interface and crack propagation under fatigue loading. The results show that the resorcinol formaldehyde latex (RFL) sizing was applied to the nylon fibre bundle (cord) rather than a single fibre. Thus, the rubber latex cannot penetrate “into” the nylon cord, and defects can be observed at the interface. Therefore, the filler design and manufacturing process need to be improved to increase the interfacial bonding between filler and matrix. Apart from the rubber materials, thermoplastic elastomers (e.g., ethylene-propylene copolymer) will also be investigated for comparison in future work.

Progress on the assessment of materials manufacture and performance in flexible WECs

Supergen Offshore Renewable Energy

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Motivations:

- Wave Energy Converters (WECs) based on flexible materials can provide a better solution than traditional WECs with rigid materials regarding cost, survivability, overall performance, etc.

Fig.1 Prototype of a flexible WEC in Plymouth COAST Laboratory [1]

- The flexible component of WECs requires outstanding fatigue performance under numerous deforming cycles in the marine environment.
- Assessment of the material selection, mechanical and fatigue performance is vital for designing flexible WECs.

FlexWave project: "FlexWave seeks to improve the design, manufacture and survivability of flexible WECs.", for more information, please visit the project home page: https://www.plymouth.ac.uk/research/offshore-renewable-energy/flexwave

Methods:

- Natural rubber with nylon fabric reinforcement has been selected and examined (at the first stage).

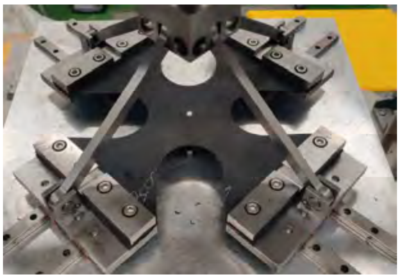

Fig.2 Biaxial fatigue test setup

- A biaxial fatigue setup has been established for flexible membrane materials, and the sample design was modified with the help of Finite Element Analysis (FEA).
- The Scanning Electron Microscope (SEM) was adopted in investigating the rubber-nylon interface and crack propagation under fatigue loading.

Sample design for biaxial fatigue test:

- Different sample designs for the biaxial fatigue test were studied by FEA.
- Load is more centralised at the cross-section area of two axes in design with reinforcement on the arm, improving the efficiency of the fatigue test.

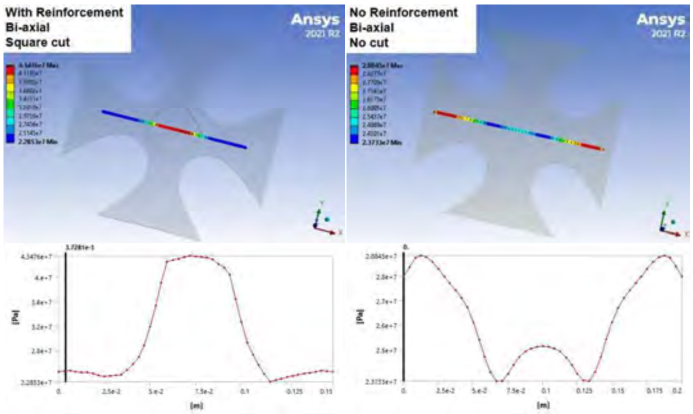

Fig.3 FEA results of the stress distribution of biaxial test with different sample design

Rubber-nylon interface investigation:

- Resorcinol Formaldehyde Latex (RFL) sizing was applied to the nylon fibre bundle (cord) rather than a single fibre.
- Rubber cannot penetrate "into" the nylon cord, and defects can be observed at the interface.

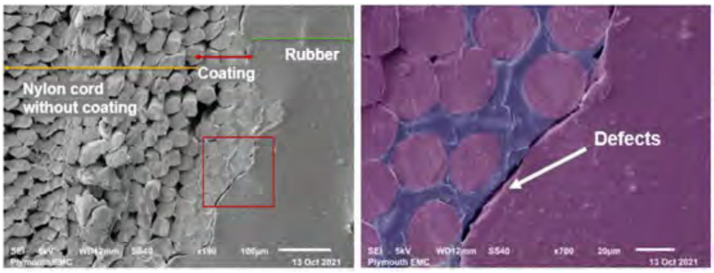

Fig.4 SEM images of the cut surface of the natural rubber/nylon fabric composite

Conclusions and future work

- The sample design for the biaxial fatigue test is important for evaluating the fatigue performance of flexible materials.
- The filler design and manufacturing process need to be improved to increase the interfacial bonding between filler & matrix.
- Apart from the rubber materials, thermoplastic elastomers (e.g., EPC) will be investigated.

Reference: [1] https://www.supergen-marine.org.uk/supergen-grand-challenges/deformable-flexible-fabric-WEC

Acknowledgement: This project (FlexWave) is funded by Engineering and Physical Sciences Research Council (EPSRC).

University of Southampton | University of Oxford | University of Plymouth | UKRI Engineering and Physical Sciences Research Council