Performance Assessment of a Novel Active Mooring System for Load Reduction in Marine Energy Converters

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Project team

- Innovate UK (TSB) co-funded project to develop an Intelligent Active Mooring load-control System (IAMS)

A

UNIVERSITY OF EXETER

Expertise in the development of marine mooring systems. Performance, reliability and durability testing and analysis.

B

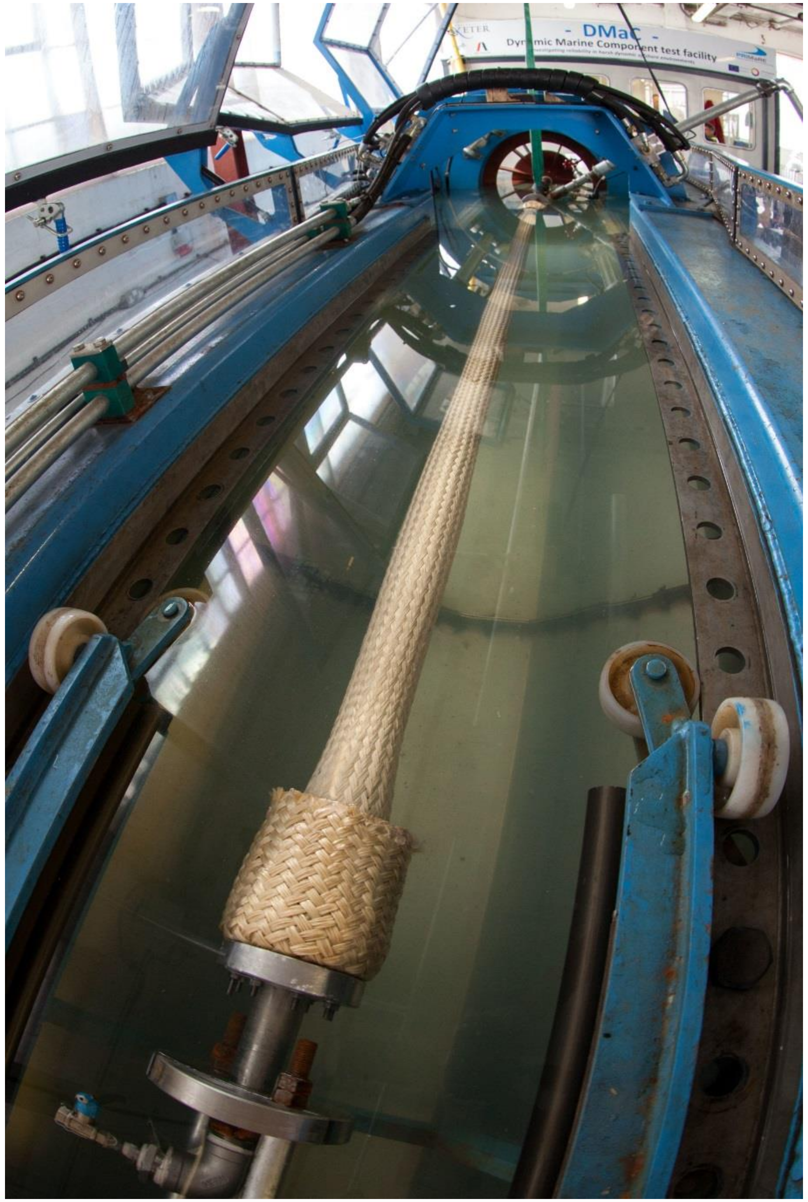
AWS

Experienced wave energy technology developer and project lead partner. Leading on control system design and system modelling.

C

TEQNIQA SYSTEMS

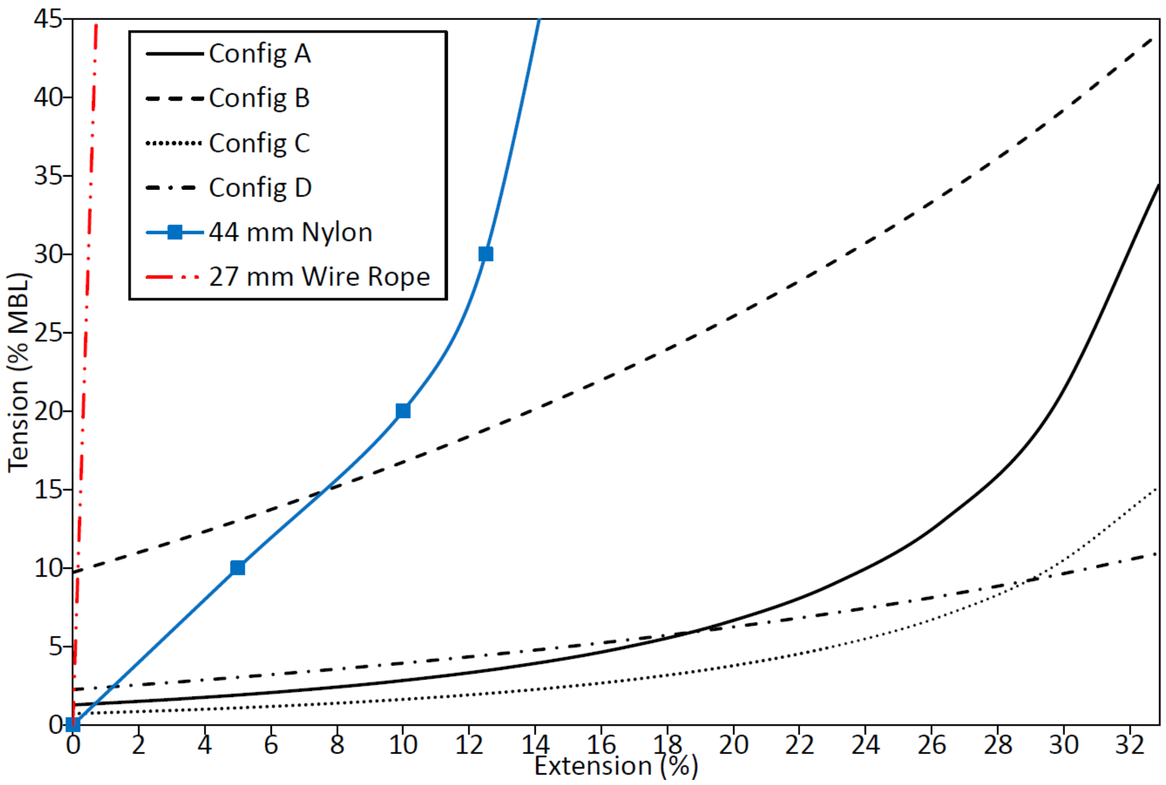
Expertise in materials development. Leading on scale demonstrator design, manufacture and initial testing and optimisation



Project background

- Reliability and storm survival of Marine Energy Converters are critical to commercial development and deployment[1]
- The system will reduce mooring loads by de-coupling the line stiffness from the Minimum Breaking Load (MBL) allowing significant reductions in structure and anchoring requirements
- Active control of the stiffness characteristics allows enhanced energy extraction in Wave Energy Converters (WECs)
- Controllable pre-tension will aid maintenance and installation and provide tidal range compensation.

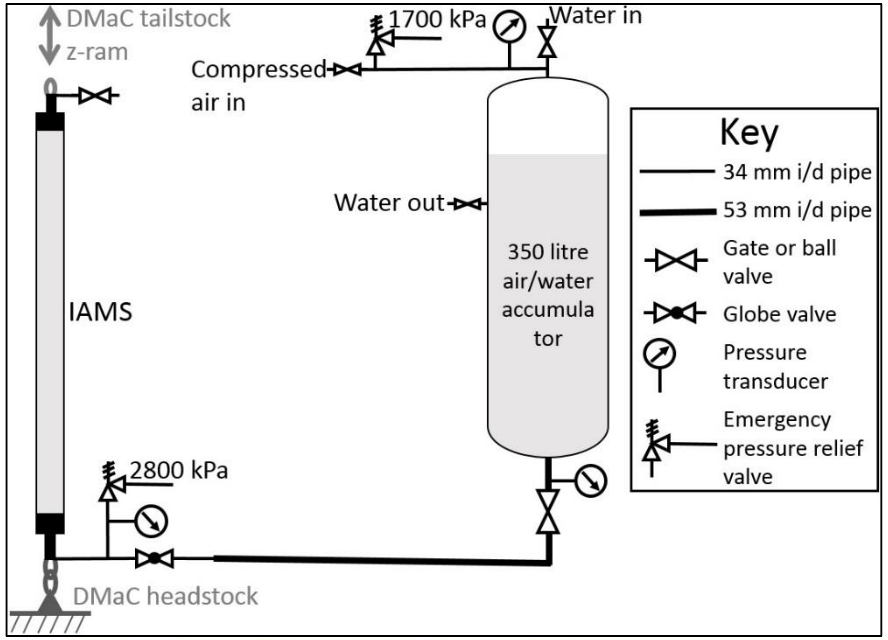
Intelligent Active Mooring System (IAMS)



- Axial loads are supported by a hollow braided Vectran rope.
- Extension is resisted by a water-filled bladder inside the hollow braid connected to a hydraulic accumulator
- Stiffness is controlled by adjusting the volume and pressure of air in the accumulator.

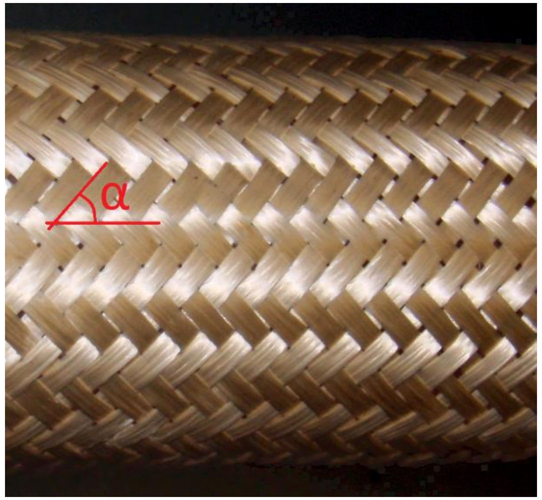
Physical model tests

- Scale model prototypes were built by Teqniqa Systems
- Tests were carried out at the Dynamic Marine Component (DMaC) test facility in Falmouth
- Pressure supply system is not representative of the planned system



Static model

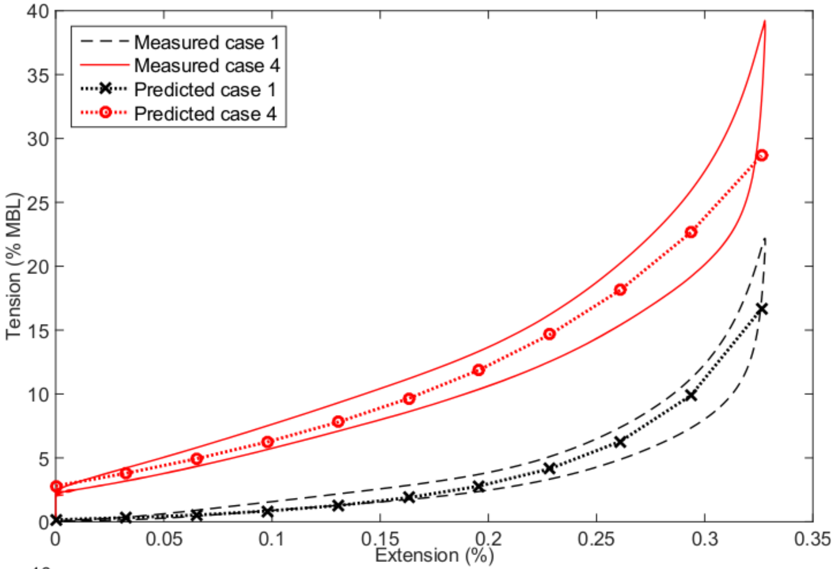
The tension is calculated as $T = PA\left(\frac{2}{\tan^2 \alpha} - 1\right)$

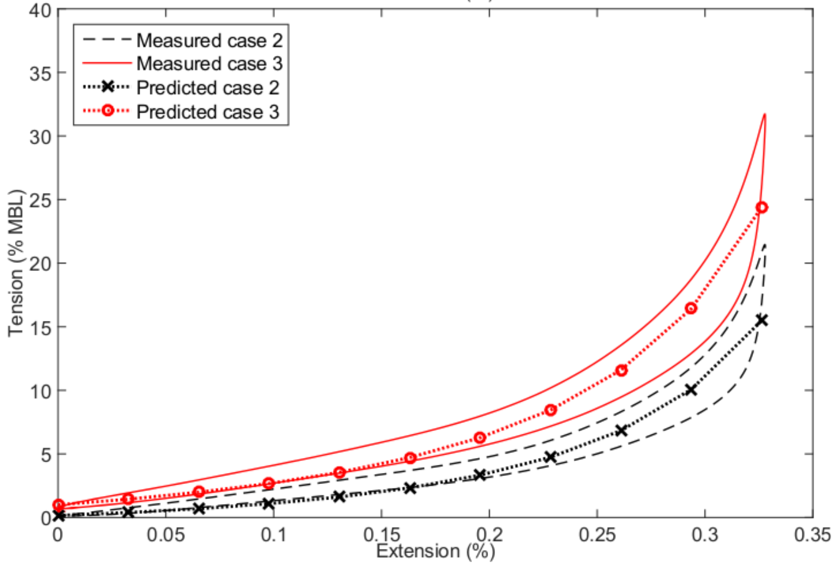


Where A is the cross-sectional area, α is the braid angle and P is the pressure. At time t_1 the pressure P_1 is:

$$P_1 = P_0(V_0/V_1)^\gamma$$

Where γ is 1.4 for air

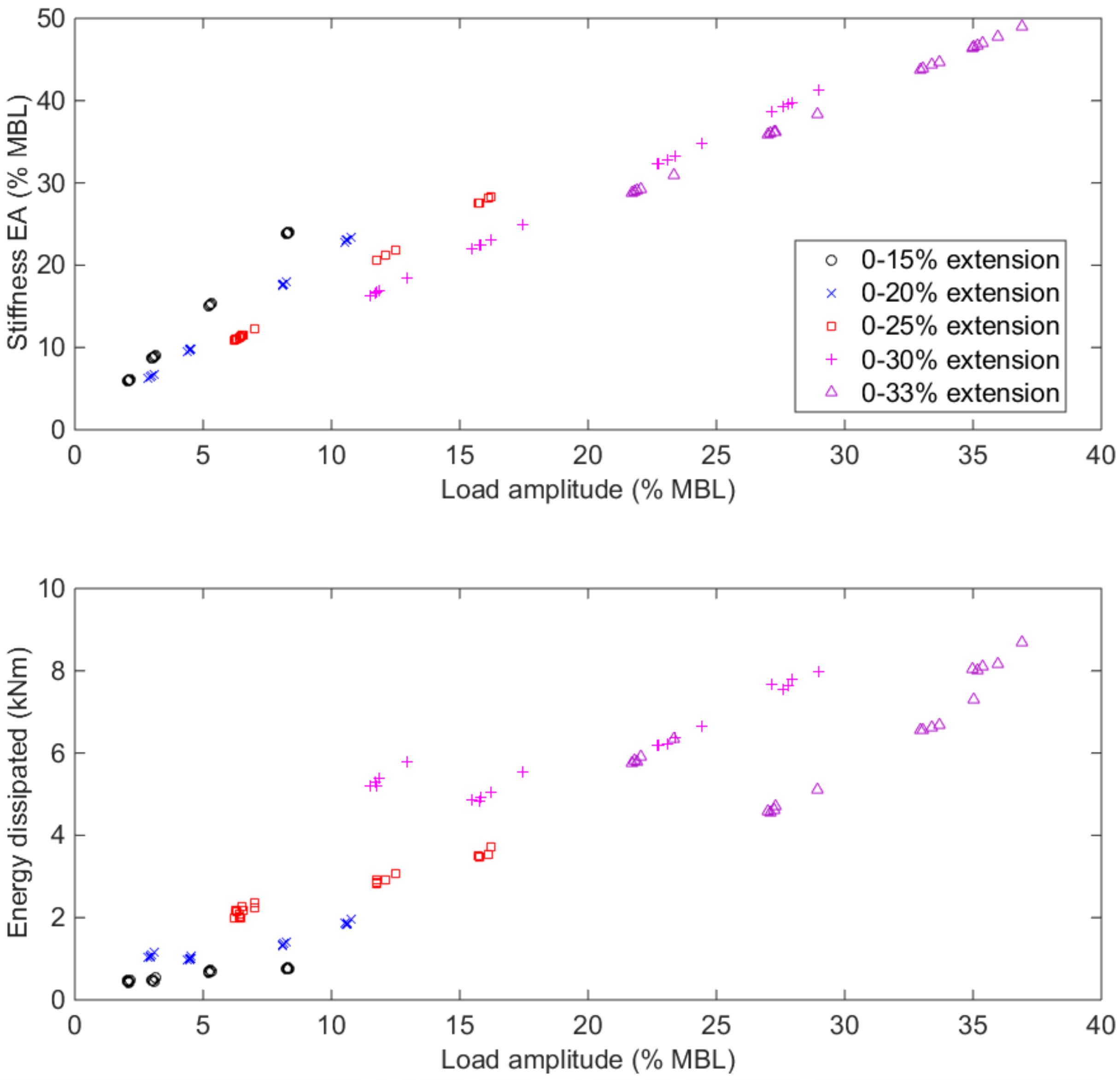




- Static predictions of load extension curves validated against DMaC test results.
- Static model does not include braid-on-braid friction.

Dynamic test results – regular waves

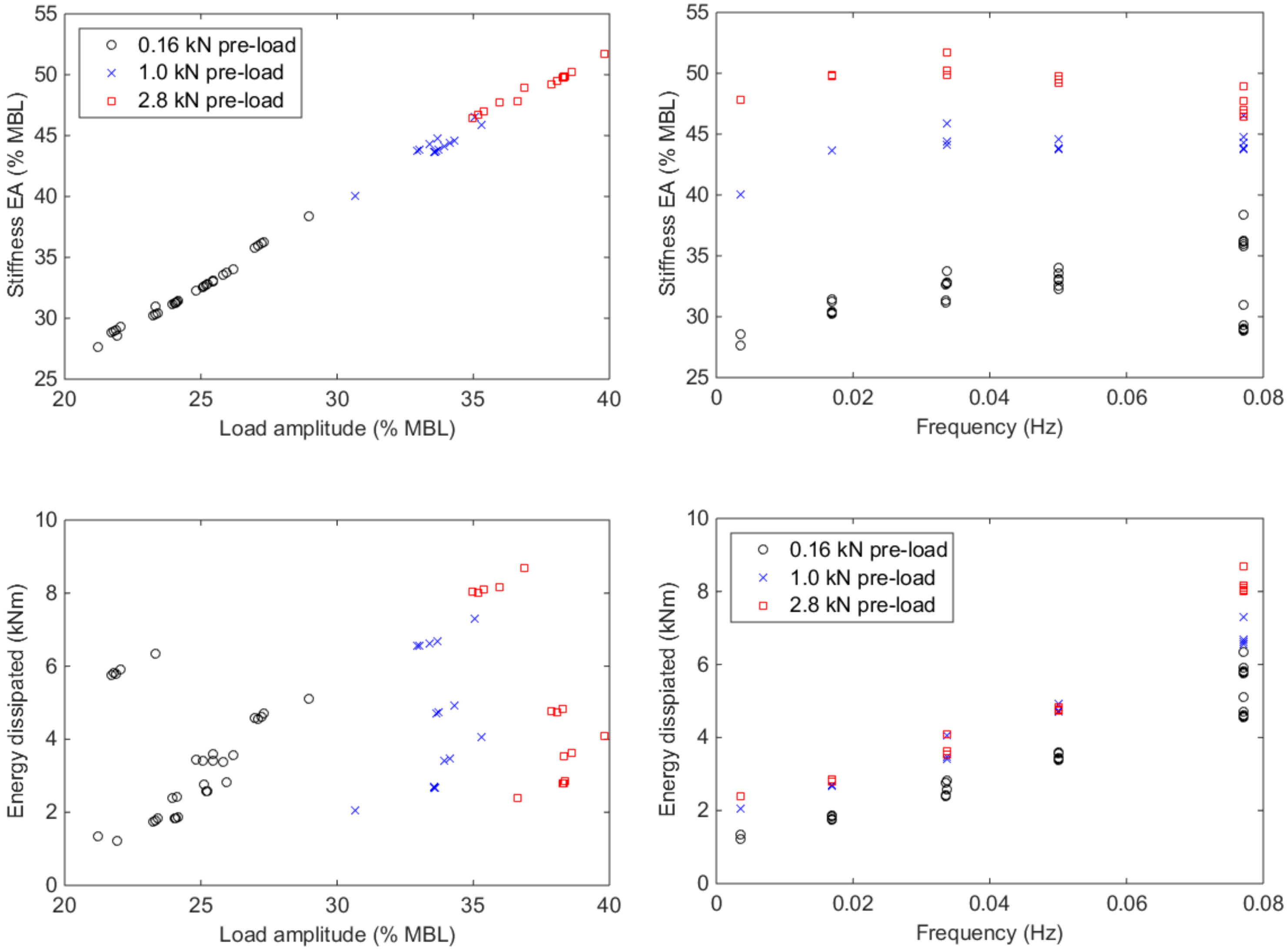
- Stiffness increases with increasing load amplitude. Rate of increase is related to the strain and the pre-load.
- Energy dissipation increases with increasing strain. Pre-load has a small effect on the energy dissipation compared to strain.
- Results have been corrected to remove the effect of the pressure supply system



Dynamic test results – regular waves

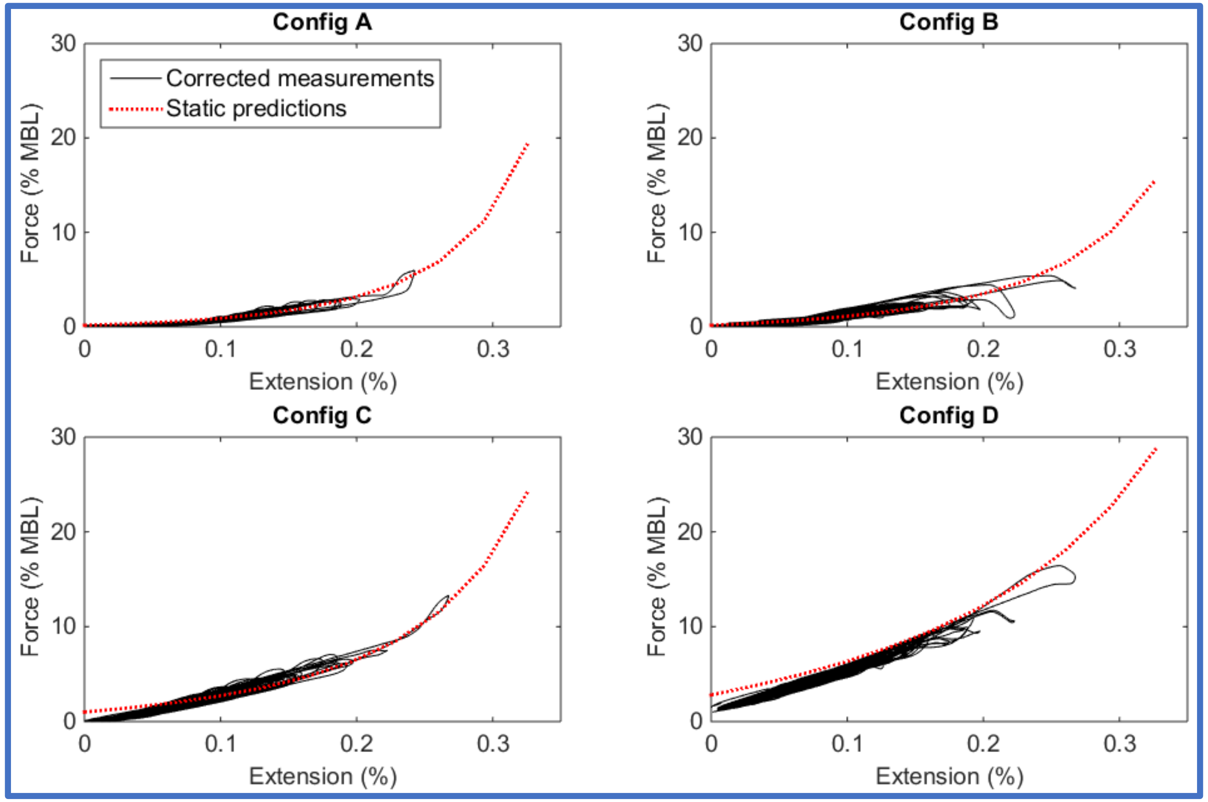
Results shown are for the full range of extension (0-33% extension)

- Stiffness is primarily related to load amplitude
- Energy dissipated increases with increasing frequency

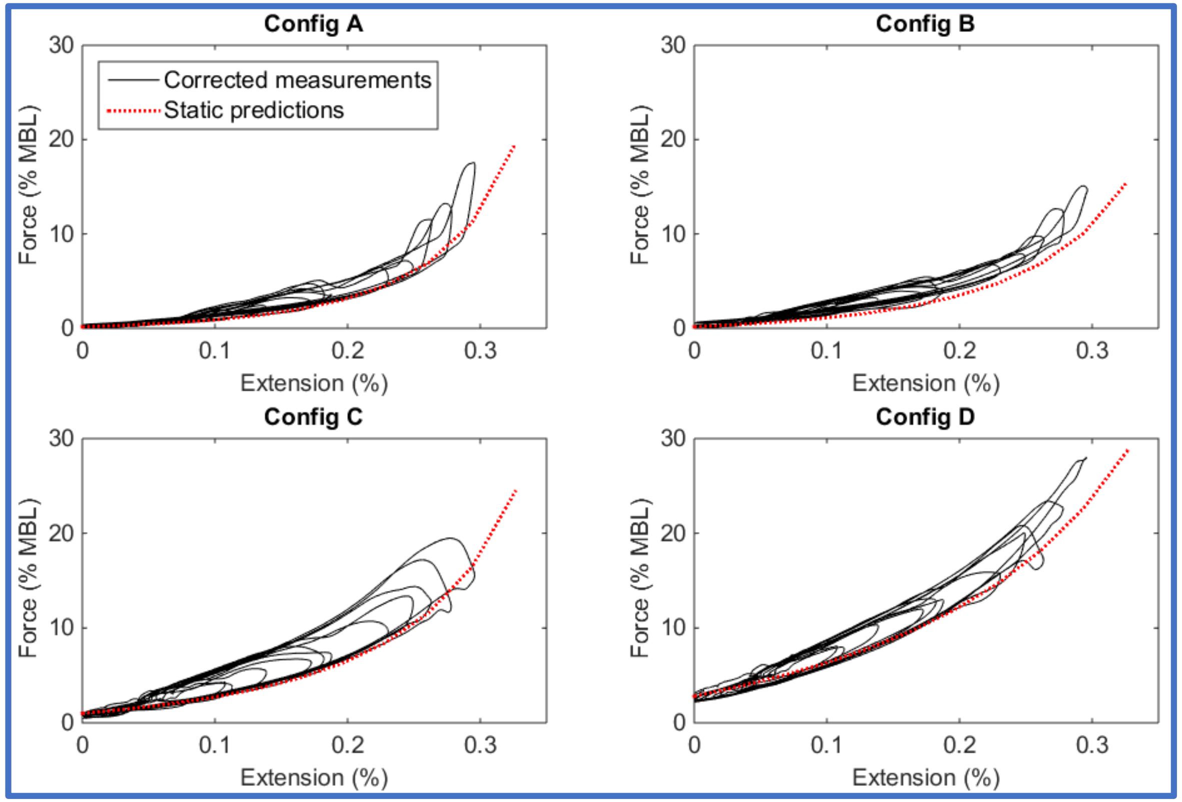


Dynamic test results – irregular waves

Load-extension curve follows predicted curve well for both typical sea states and extreme conditions



Typical sea state – H_s = 2.4 m



Extreme sea state – H_s = 6.5 m

Dynamic numerical model

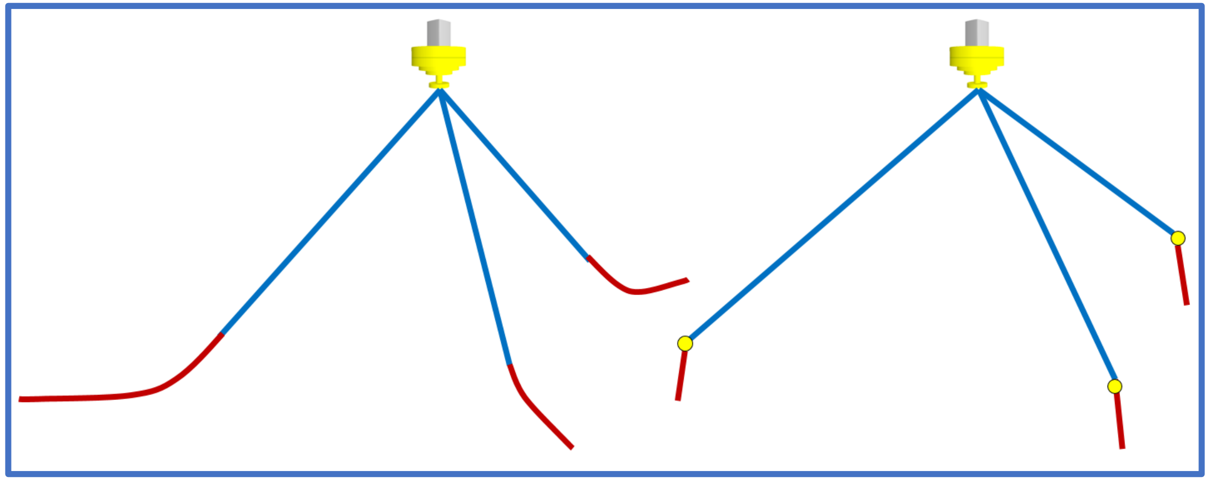
A dynamic mooring system model was developed as part of the programme using Orcaflex[2].
The model was based on the South West Mooring Test Facility (SWMTF)[3] buoy in Falmouth Bay.

Two layouts were used each with three lines:

- Catenary system – 41 m of chain and 20 m of braided nylon rope

- Taut moored system - 5 m of chain and 46 m of braided nylon rope

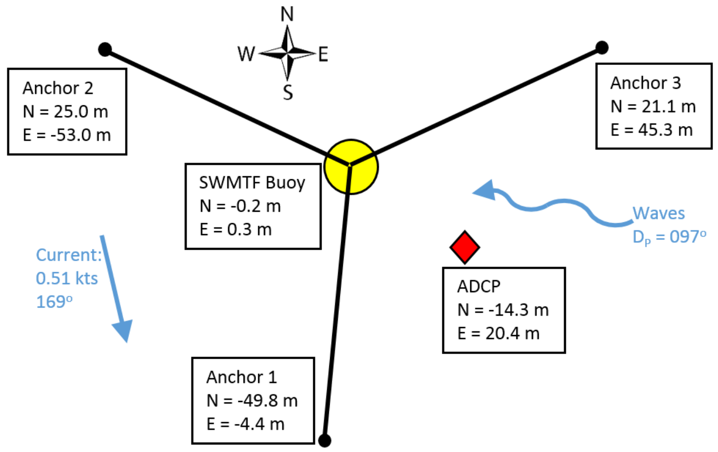
IAMS was substituted in to replace the top 10 m of the braided nylon ropes

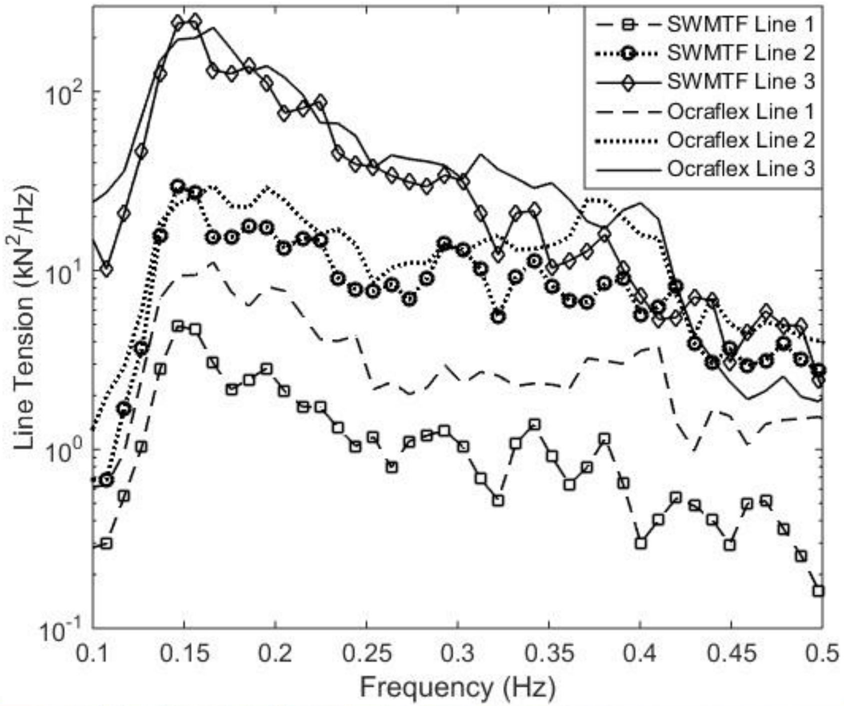


Dynamic numerical model

- Validation data was from the SWMTF buoy following on from previous work in the Exeter group[4,5]
- A typical sea state (Hs = 2.44m) was chosen for validation with most of the loading on line 3
- Overall the Orcaflex model was able to reproduce the SWMTF line tensions and positions well

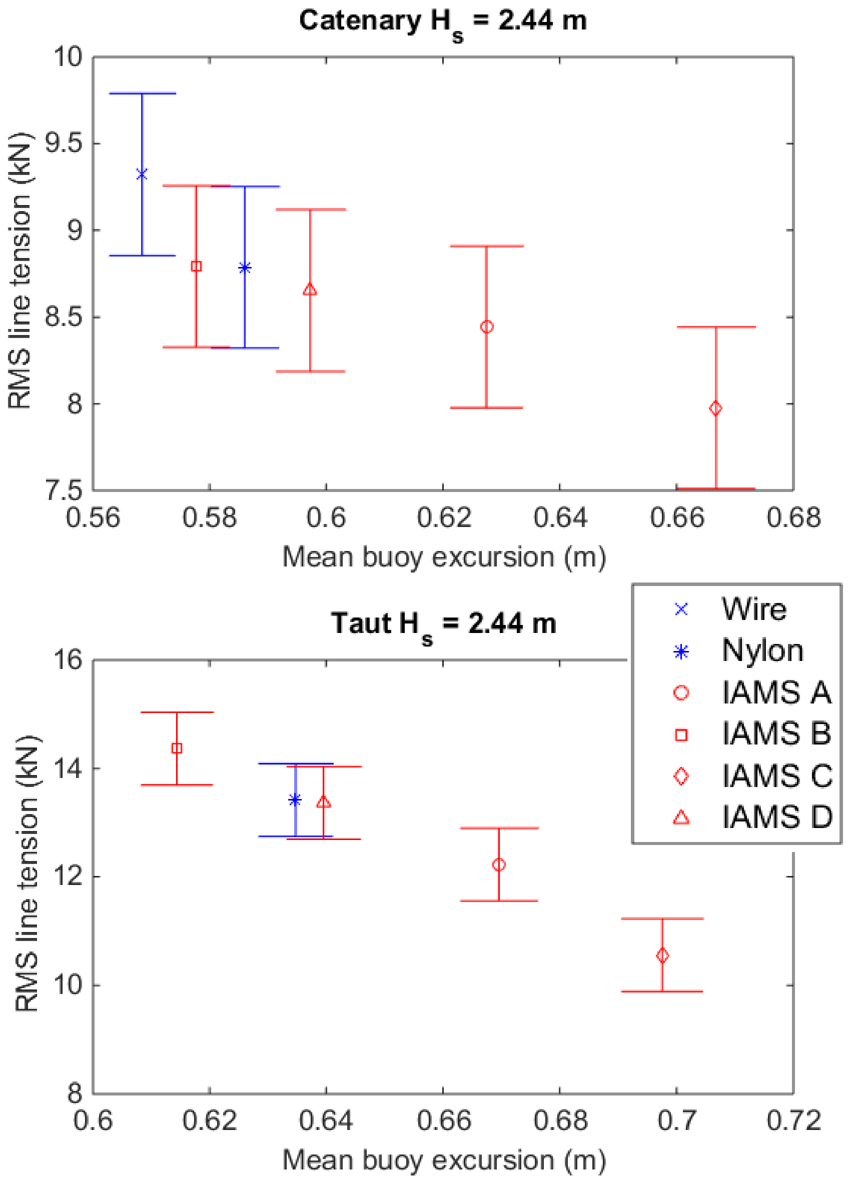
	Standard deviations				Root mean squares		
	Surge m	Sway m	Heave m	Angular vel. rad/s	Line 1 kN	Line 2 kN	Line 3 kN
SWMTF	0.47	0.40	0.55	0.31	2.37	4.86	8.82
Orcaflex	0.77	0.41	0.59	0.23	4.06	6.25	8.78
Difference	63%	0%	7%	-26%	71%	29%	-1%





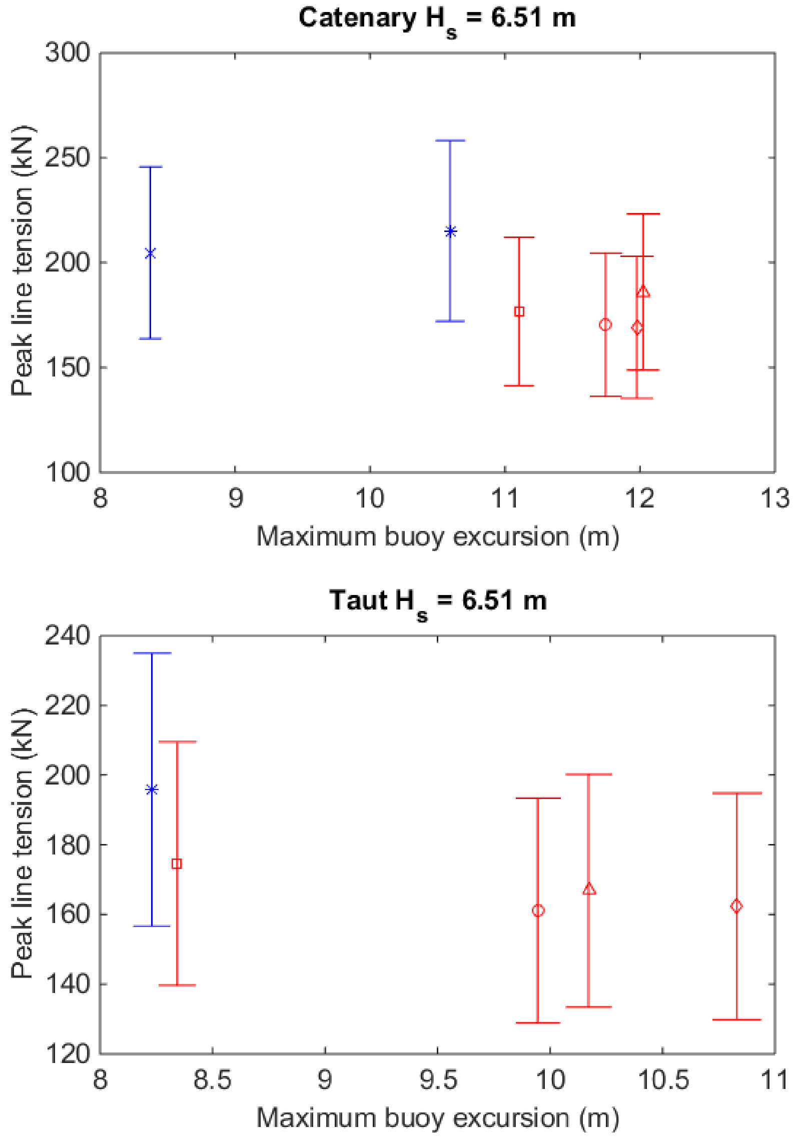
Dynamic numerical model – normal operating conditions

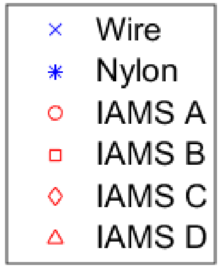
- IAMS gives significantly reduced rms line tensions in some configurations compared to the braided nylon only (9% for the catenary system, 21% for the taut moored system)
- The mean buoy excursion increases as the rms line tension decreases, however mean excursion is less than 1 m in all cases
- Results for wire ropes in place of the braided nylon lines are shown for catenary system only



Dynamic numerical model – extreme storm conditions

- IAMS gives significantly reduced peak line tensions compared to the braided nylon lines (14% to 21% for the catenary system, 11% to 18% for the taut moored system)
- The mean buoy excursion increases up to around 12 m as the rms line tension decreases (note the footprint is roughly 50 m diameter)





Single system failure mode testing

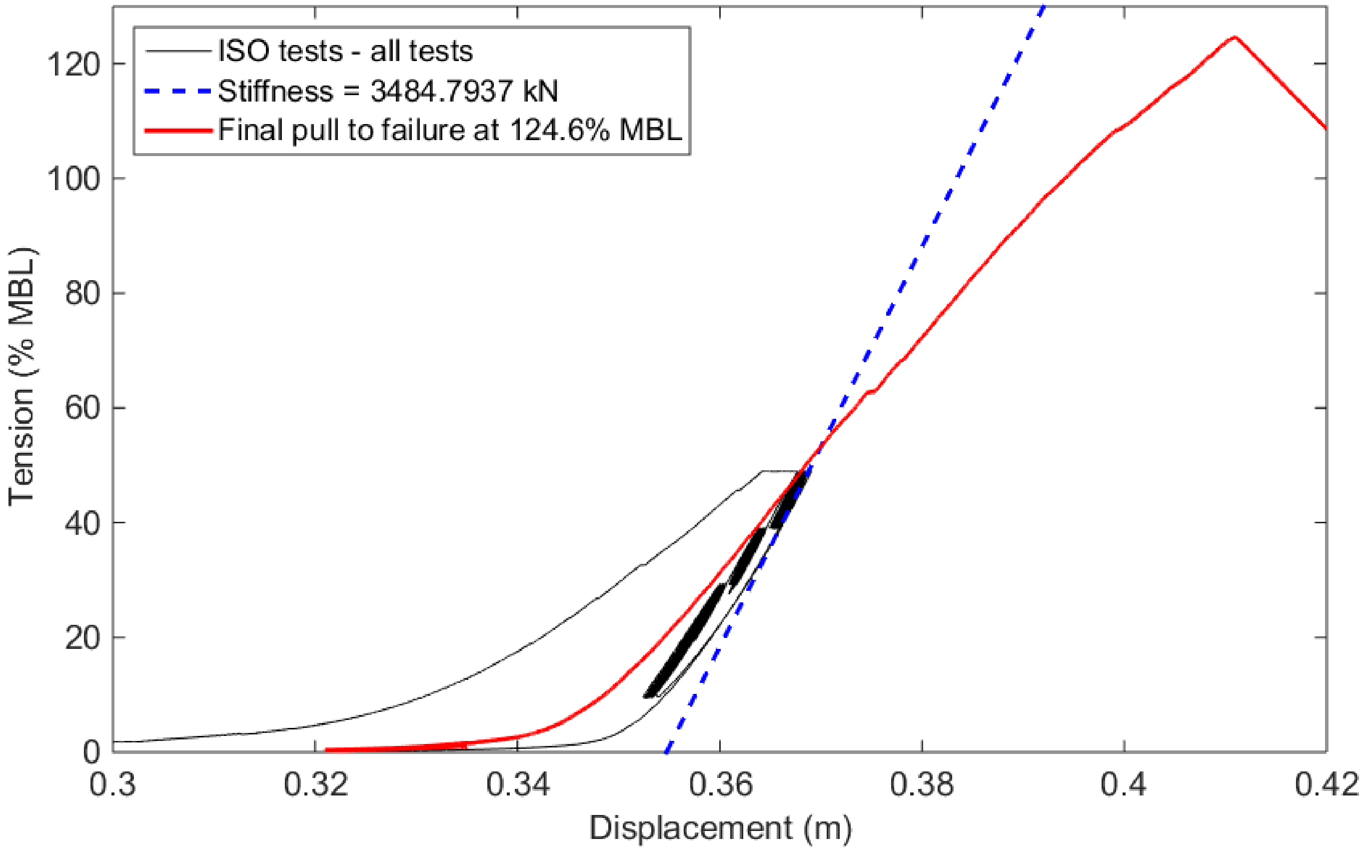
ISO 18692 Test Schedule

1. 50% MBL for 30 mins
2. 100 cycles at 10-30% MBL at 30s period
3. 100 cycles at 20-30% MBL at 10s period
4. 100 cycles at 30-40% MBL at 10s period
5. 100 cycles at 40-50% MBL at 10s period
6. Pull to failure

- Bladder failure mode testing was carried out at DMaC following ISO 18692[6], but with only two samples. This is testing the properties of the Vectran (a liquid crystal spun aromatic polyester) braid and the end plates

- Creep was very low and stiffness was high as expected for Vectran

- Final failure occurred by end plate pull out at around 1.2 times MBL both times



Summary

Performance Assessment of a Novel Active Mooring System for Load Reduction in Marine Energy Converters

1. The load-extension curve of the novel mooring system can be altered in response to the prevailing metocean conditions

2. Altering the load extension curve allows a wide range of performance characteristics including:
   - Significantly reduced peak line tensions compared to braided nylon lines in storm conditions (up to 21% for the systems modelled)
   - Significant reductions in normal operating line tensions can also be achieved (again up to 21% for the systems modelled)

3. Failure mode testing demonstrates reliable and predictable component integrity behaviour

4. The novel mooring system has multiple potential benefits: improving long term reliability and survivability while reducing peak loads and minimising the mooring footprint thus providing overall system cost reduction

5. Possible additional functionality could include energy recovery or use as a position actuator for certain types of device

Thank you. Any questions?

Acknowledgements

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References

1. Thies PR, Johanning L and McEvoy P (2014) A novel mooring tether for peak load mitigation: Initial performance and service simulation testing. International Journal of Marine Energy 7: 43–56. DOI:10.1016/j.ijome.2014.06.001.
2. Orcina Ltd (2015) Oracflex Version 9.8a Help Documentation. URL http://www.orcina.com/SoftwareProducts/OrcaFlex/Documentation/Help/.
3. Johanning L, Spargo A and Parish D (2008) Large scale mooring test facility - A technical note. In: Proc. of 2nd Int. conference on Ocean Energy.
4. Herduin M (2015) MRCF: Milestone 2 Orcaflex report. Technical report, University of Exeter, Penryn.
5. Harnois V, Parish D and Johanning L (2012) Physical measurement of a slow drag of a drag embedment anchor during sea trials. In: International Conference on Ocean Energy. pp. 1–6.
6. International Standards Organisation, 2007. *Fibre ropes for offshore station keeping - polyester*, ISO 18692:2007(E).