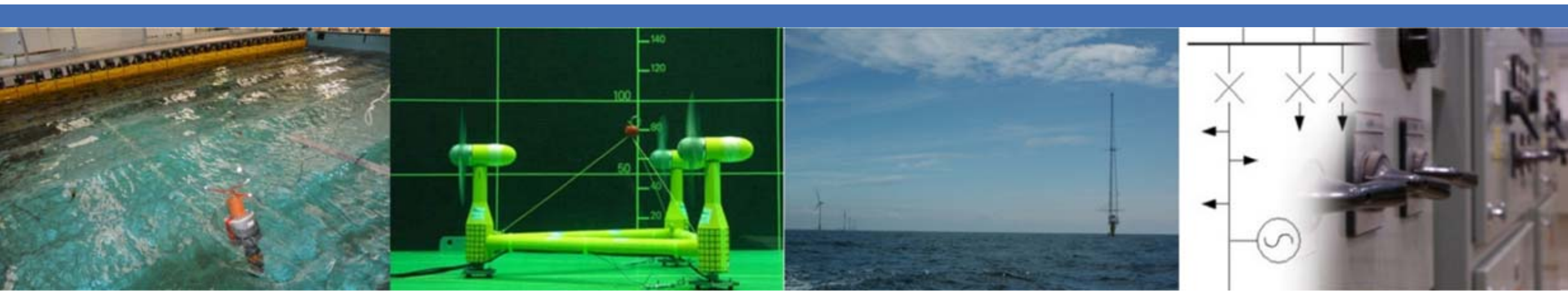
MARINET

Marine Renewables Infrastructure Network



Infrastructure Access Report

Infrastructure: UNEXE South West Mooring Test Facility

***User-Project*: FibreTaut 1**

Fibre Ropes for Taut Mooring Lines for Marine Energy Converters

WireCo WorldGroup (Lankhorst-Euronete Portugal) & Fundación Centro Tecnológico de Componentes (CTC)

Status: Draft
Version: 01
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EC FP7 "Capacities" Specific Programme
Research Infrastructure Action

ABOUT MARINET

MARINET (Marine Renewables Infrastructure Network for emerging Energy Technologies) is an EC-funded network of research centres and organisations that are working together to accelerate the development of marine renewable energy - wave, tidal & offshore-wind. The initiative is funded through the EC's Seventh Framework Programme (FP7) and runs for four years until 2015. The network of 29 partners with 42 specialist marine research facilities is spread across 11 EU countries and 1 International Cooperation Partner Country (Brazil).

MARINET offers periods of free-of-charge access to test facilities at a range of world-class research centres. Companies and research groups can avail of this Transnational Access (TA) to test devices at any scale in areas such as wave energy, tidal energy, offshore-wind energy and environmental data or to conduct tests on cross-cutting areas such as power take-off systems, grid integration, materials or moorings. In total, over 700 weeks of access is available to an estimated 300 projects and 800 external users, with at least four calls for access applications over the 4-year initiative.

MARINET partners are also working to implement common standards for testing in order to streamline the development process, conducting research to improve testing capabilities across the network, providing training at various facilities in the network in order to enhance personnel expertise and organising industry networking events in order to facilitate partnerships and knowledge exchange.

The aim of the initiative is to streamline the capabilities of test infrastructures in order to enhance their impact and accelerate the commercialisation of marine renewable energy. See www.fp7-marinet.eu for more details.

Partners

Ireland
University College Cork, HMRC (UCC_HMRC)
Coordinator
Sustainable Energy Authority of Ireland (SEAI_OEDU)

Denmark
Aalborg Universitet (AAU)
Danmarks Tekniske Universitet (RISOE)

France
Ecole Centrale de Nantes (ECN)
Institut Français de Recherche Pour l'Exploitation de la Mer (IFREMER)

United Kingdom
National Renewable Energy Centre Ltd. (NAREC)
The University of Exeter (UNEXE)
European Marine Energy Centre Ltd. (EMEC)
University of Strathclyde (UNI_STRATH)
The University of Edinburgh (UEDIN)
Queen's University Belfast (QUB)
Plymouth University(PU)

Spain
Ente Vasco de la Energía (EVE)
Tecnalia Research & Innovation Foundation (TECNALIA)

Belgium
1-Tech (1_TECH)

Netherlands
Stichting Tidal Testing Centre (TTC)
Stichting Energieonderzoek Centrum Nederland (ECNeth)

Germany
Fraunhofer-Gesellschaft Zur Foerderung Der Angewandten Forschung E.V (Fh_IWES)
Gottfried Wilhelm Leibniz Universität Hannover (LUH)
Universitaet Stuttgart (USTUTT)

Portugal
Wave Energy Centre – Centro de Energia das Ondas (WavEC)

Italy
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Università degli Studi della Tuscia (UNI_TUS)
Consiglio Nazionale delle Ricerche (CNR-INSEAN)

Brazil
Instituto de Pesquisas Tecnológicas do Estado de São Paulo S.A. (IPT)

Norway
Sintef Energi AS (SINTEF)
Norges Teknisk-Naturvitenskapelige Universitet (NTNU)

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Infrastructure Accessed:	UNEXE South West Mooring Test Facility
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01	15/12/2014	First Draft	Raúl Rodríguez, Álvaro Rodríguez and Verónica Glez. De Lena		Draft
02	18/12/2014	Final Report	Raúl Rodríguez, Álvaro Rodríguez and Verónica Glez. De Lena	Lars Johaning	Final

About This Report

One of the requirements of the EC in enabling a user group to benefit from free-of-charge access to an infrastructure is that the user group must be entitled to disseminate the foreground (information and results) that they have generated under the project in order to progress the state-of-the-art of the sector. Notwithstanding this, the EC also state that dissemination activities shall be compatible with the protection of intellectual property rights, confidentiality obligations and the legitimate interests of the owner(s) of the foreground.

The aim of this report is therefore to meet the first requirement of publicly disseminating the knowledge generated through this MARINET infrastructure access project in an accessible format in order to:

- progress the state-of-the-art
- publicise resulting progress made for the technology/industry
- provide evidence of progress made along the Structured Development Plan
- provide due diligence material for potential future investment and financing
- share lessons learned
- avoid potential future replication by others
- provide opportunities for future collaboration
- etc.

In some cases, the user group may wish to protect some of this information which they deem commercially sensitive, and so may choose to present results in a normalised (non-dimensional) format or withhold certain design data – this is acceptable and allowed for in the second requirement outlined above.

Acknowledgement

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Legal Disclaimer

EXECUTIVE SUMMARY

One immediate challenge for the Marine Renewable Energy Converters (MRECs) industry is solving the cost and weight problems of mooring lines in deep water (>75m). Synthetic fibre ropes already offer a solution to the weight problems of using steel lines in deep water offshore oil and gas installations as they have a very low weight in water (see Figure 1).

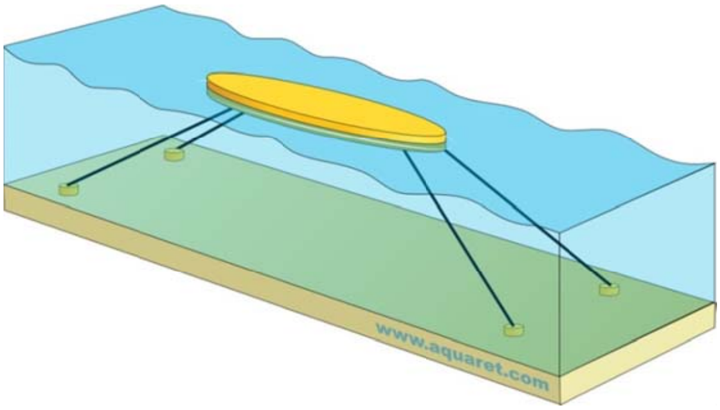


Figure 1: Taut mooring configuration.

Also, compared to steel, there are a large number of synthetic fibre material compositions with a wide range of material properties. A synthetic rope can therefore be designed to have properties that match the mooring requirements. Several materials have potential for mooring line application. Yarns of these synthetic materials may be built into ropes using a number of constructions, some of which are suited to particular fibres (see Figure 2).

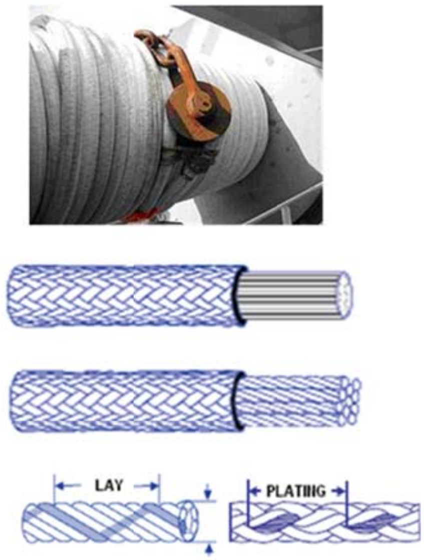


Figure 2: Different yarn configurations.

As with any new application, research must be conducted to determine how well the fibre ropes satisfy the performance requirements.

The testing infrastructures at the University of Exeter (UoE) are unique in the MARINET consortium, as it allows for extensive testing of mooring lines in sea water. Its testing infrastructure will help the consortium to determine which prospective innovative fibre rope mooring line is best suited for deep water MECs. Also, the technological and scientific support offered by the well experienced staff is another reason to propose the access to this kind of facilities.

The present study of international partners, WireCo WorldGroup (Lankhorst-Euronete Portugal), Fundación Centro Tecnológico de Componentes - CTC (Spain), and University of Exeter - UoE (UK) as facility provider, focuses on obtaining knowledge of the applicability of fibre ropes in Marine Energy Converters (MEC), both in laboratory and sea conditions.

CONTENTS

1 INTRODUCTION & BACKGROUND

1.1 INTRODUCTION

The company WireCo WorldGroup (Lankhorst-Euronete Portugal), a world leader in the manufacturing, engineering and distribution of steel cables, synthetic rope cables, cable assemblies, and electromechanical cables, along with the Fundación Centro Tecnológico de Componentes (CTC) have received support from MARINET to develop the project FIBRETAUT (Fibre Ropes for Taut Mooring Lines for Marine Energy Converters). The objective of this project was to obtain knowledge of the applicability of fibre ropes in Marine Renewable Energy Converters (MREC), both in laboratory and sea conditions. For this reason, the following two different proposals were presented:

Proposal #182 (FibreTaut1): UNEXE South West Mooring Test Facility (SWMTF).
Proposal #219 (FibreTaut2): UNEXE Dynamic Marine Component Test Facility (DMaC).

The overall idea was to acquire real load time series measured from load cells implemented in the mooring system of the buoy of the SWMTF and replicate similar loads at different rates at DMaC to compare the fatigue damage.

To achieve this, several project development objectives are described below.

- Perform tests of the fibre ropes in two environments, one in real open water conditions and other in a control environment at the laboratory.
- Determine strength limits and the stiffness and damping properties of fibre ropes with cycling at different loads.
- Develop a base line numerical model of the mooring system and rope behaviour based on the rope characteristics.
- Validate the model with real data: meta-ocean conditions and measured loads at sea.
- Verify the applicability of fibre ropes for marine energy converter applications.
- In the long-term, it is expected to develop cost-effective fibre rope taut mooring lines in deep water applications for the emerging MREC industry. This would provide a new market for rope manufacturers and help advance the MREC industry further into the deeper and more energetic wave environments.
- Contribution to the improvement of the correlation between accelerated laboratory tests and real offshore environment test.
- Promotion of communication and dissemination of findings among European centres and companies.

This report summarises the research activities developed within the proposal #182 (FibreTaut1), concerning the SWMTF.

1.2 DEVELOPMENT SO FAR

1.2.1 Stage Gate Progress

Previously completed: ✓
Planned for this project: ➲

STAGE GATE CRITERIA	Status
Stage 1 – Concept Validation	
• Linear monochromatic waves to validate or calibrate numerical models of the system (25 – 100 waves)	
• Finite monochromatic waves to include higher order effects (25 –100 waves)	
• Hull(s) sea worthiness in real seas (scaled duration at 3 hours)	
• Restricted degrees of freedom (DofF) if required by the early mathematical models	
• Provide the empirical hydrodynamic co-efficient associated with the device (for mathematical modelling tuning)	✓
• Investigate physical process governing device response. May not be well defined theoretically or	

STAGE GATE CRITERIA	Status
numerically solvable	
• Real seaway productivity (scaled duration at 20-30 minutes)	
• Initially 2-D (flume) test programme	
• Short crested seas need only be run at this early stage if the devices anticipated performance would be significantly affected by them	
• Evidence of the device seaworthiness	
• Initial indication of the full system load regimes	
Stage 2 – Design Validation	
• Accurately simulated PTO characteristics	
• Performance in real seaways (long and short crested)	
• Survival loading and extreme motion behaviour.	
• Active damping control (may be deferred to Stage 3)	
• Device design changes and modifications	
• Mooring arrangements and effects on motion	➲
• Data for proposed PTO design and bench testing (Stage 3)	
• Engineering Design (Prototype), feasibility and costing	
• Site Review for Stage 3 and Stage 4 deployments	
• Over topping rates	
Stage 3 – Sub-Systems Validation	
• To investigate physical properties not well scaled & validate performance figures	
• To employ a realistic/actual PTO and generating system & develop control strategies	
• To qualify environmental factors (i.e. the device on the environment and vice versa) e.g. marine growth, corrosion, windage and current drag	
• To validate electrical supply quality and power electronic requirements.	
• To quantify survival conditions, mooring behaviour and hull seaworthiness	➲
• Manufacturing, deployment, recovery and O&M (component reliability)	➲
• Project planning and management, including licensing, certification, insurance etc.	
Stage 4 – Solo Device Validation	
• Hull seaworthiness and survival strategies	
• Mooring and cable connection issues, including failure modes	➲
• PTO performance and reliability	
• Component and assembly longevity	➲
• Electricity supply quality (absorbed/pneumatic power-converted/electrical power)	
• Application in local wave climate conditions	➲
• Project management, manufacturing, deployment, recovery, etc	➲
• Service, maintenance and operational experience [O&M]	
• Accepted EIA	
Stage 5 – Multi-Device Demonstration	
• Economic Feasibility/Profitability	
• Multiple units performance	
• Device array interactions	
• Power supply interaction & quality	
• Environmental impact issues	➲

STAGE GATE CRITERIA	Status
• Full technical and economic due diligence	
• Compliance of all operations with existing legal requirements	

1.2.2 Plan For This Access

The complete project was planned to be developed over eleven months, divided into three consecutive phases:
The Phase 1 is devoted to the specification of the mooring system and the detailed development of the Test Plans for the South West Mooring Test Facility (SWMTF) at the University of Exeter facilities (UoE). The definition of the rope properties in terms of breaking load, stiffness and damping is addressed in this Phase as well as the development of the numerical model for the base line loads cases.
The Phase 2 will be devoted to the preparation and fabrication of the test samples at the Lankhorst premises and finally testing at sea in the SWMTF.
Finally, during four months, the corresponding analysis, correlations and conclusions were addressed. The dissemination activities are ongoing.

According to the above, the tasks for this project are:

PHASE 1. Specifications and modelling activities	
Task 1	T1. Specification of the mooring system and Test Plans (SWMTF)
Task 2	T2. Definition of the rope properties
Task 3	T3. Modelling activities (base line load cases)
PHASE 2. Development of the tests	
Task 4	T4. Preparation of the test samples (fabrication) and tests set-up
Task 5	T5. Tests at SWMTF
Task 6	T6. Accelerated test at DMaC (real load cases)
PHASE 3. Analysis, conclusions and dissemination	
Task 7	T7. Analysis of the tests, conclusions and further work
Task 8	T8. Dissemination activities

Table 1: Phases of the project

For the development of the tests plans within the project and further activities, the following Key Points (KP) have been considered:
- KP1: Definition of the base line load cases and the numerical model based on the rope properties (see Figure 3).

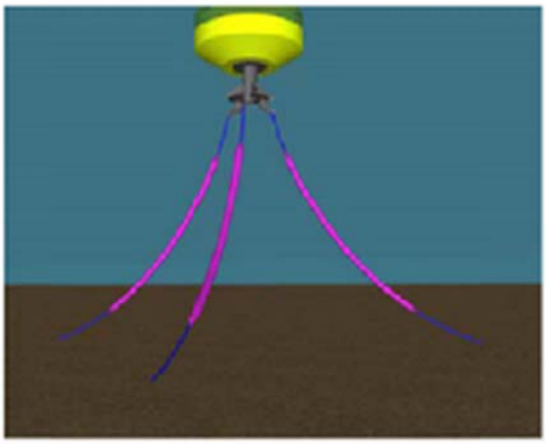


Figure 3: Example of a numerical model of the buoy and its mooring system

- KP2: Tests at the SWMTF and collection of the data for the real sea conditions with the ADCP (see Figure 4)

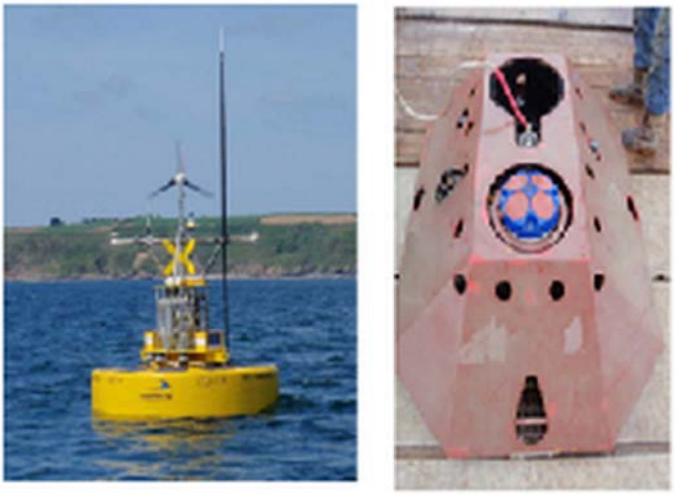


Figure 4: SWMTF buoy & Teledyne RDI ADCP

- KP3: Accelerated test at DMaC based on the real load cases obtained in the test site in open waters (see Figure 5).

Figure 5: DMaC

- KP4: Validate the numerical model and correlate the accelerated test in the Lab (DMaC) with the test at sea (SWMTF).

NOTE: Task 6 is out of the scope of the proposal #182 (FibreTaut1).

2 OUTLINE OF WORK CARRIED OUT

2.1 SETUP

2.1.1 Preliminary work to deployment

During the Phase 1 of the project, the main objective was the definition of the mooring system to the test plans for the test at SWMTF.
According to the design constraints and environment characteristics provided by the University of Exeter, and the fibre rope information provided by Lankhorst-Euronete Portugal, several configurations of the mooring system for the SWMTF were proposed and simulated, up to reach the final mooring design.

All the proposed mooring lines configurations were modelled in OrcaFlex and subjected to the real sea state conditions, up to reach the final mooring design. The final design was approved by UoE previously to construct/acquire any component.

The tension load in each line was measured at two points: end the point of the polyamide rope (close to the buoy) and the anchoring point. These values were compared with the admissible ones of the fibre rope and holding capacity of the anchor.

The final mooring configuration was:

1m length chain + 22m length of polyamide rope D30 + 36m length stud less chain + 5m length stud less chain. [1]

The final mooring design is shown in Figure 6:
and Table 2 respectively:

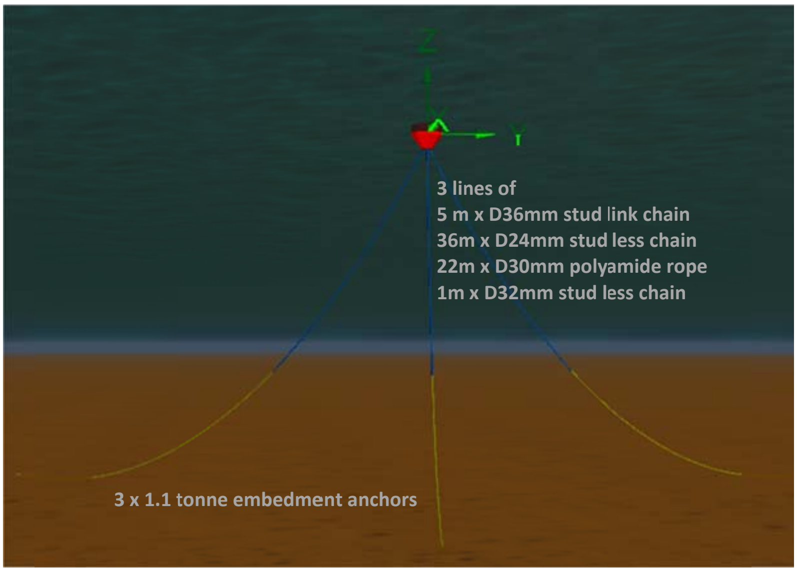


Figure 6: Final Mooring Configuration at SWMTF

Table 2 and Figure 7 show the properties of the rope used:

Type of rope	Diameter (mm)	Weight (g/m)	MBL (kN)	Design constraint
Polyamide	30	585	231	MBL > 207 kN

Table 2: Pre-selected ropes

[1] From the top to bottom

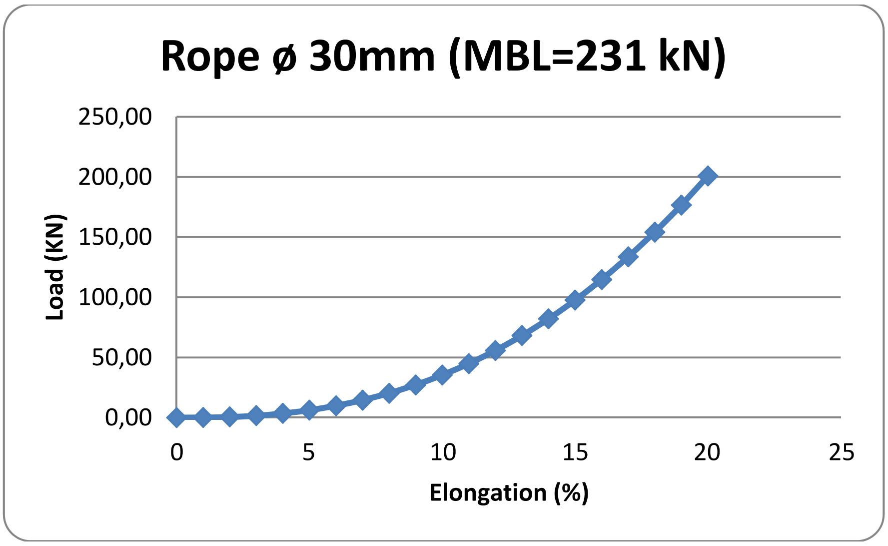


Figure 7: Stress-strain curve of 30mm diameter polyamide rope

2.1.2 Preparation of the test samples (fabrication) and tests set-up

During the Phase 2 of the project, the fabrication of the ropes was carried out.

Figure 8: 30 mm diameter polyamide rope

Based on the final mooring configuration, a detailed design was performed to be installed at SWMTF. Each line is composed by the following elements (from the top to bottom):

- SWMTF Buoy padeye
- Load Cells and swivels
- D shackle 9.5 tonnes
- D shackle 25 tonnes
- 30 mm Polyamide Rope spliced over galvanized eyes (21 m length eye to eye)
- D shackle 25 tonnes
- D shackle 9.5 tonnes
- Axial swivel 10 tonnes
- D shackle 9.5 tonnes
- DN 24 open link galvanized chain (36 m length)
- D shackle 9.5 tonnes (connected to the 5 m ground chain)
- Anchor

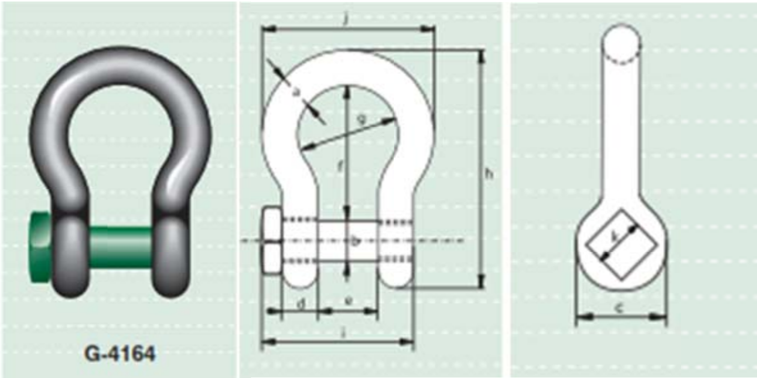
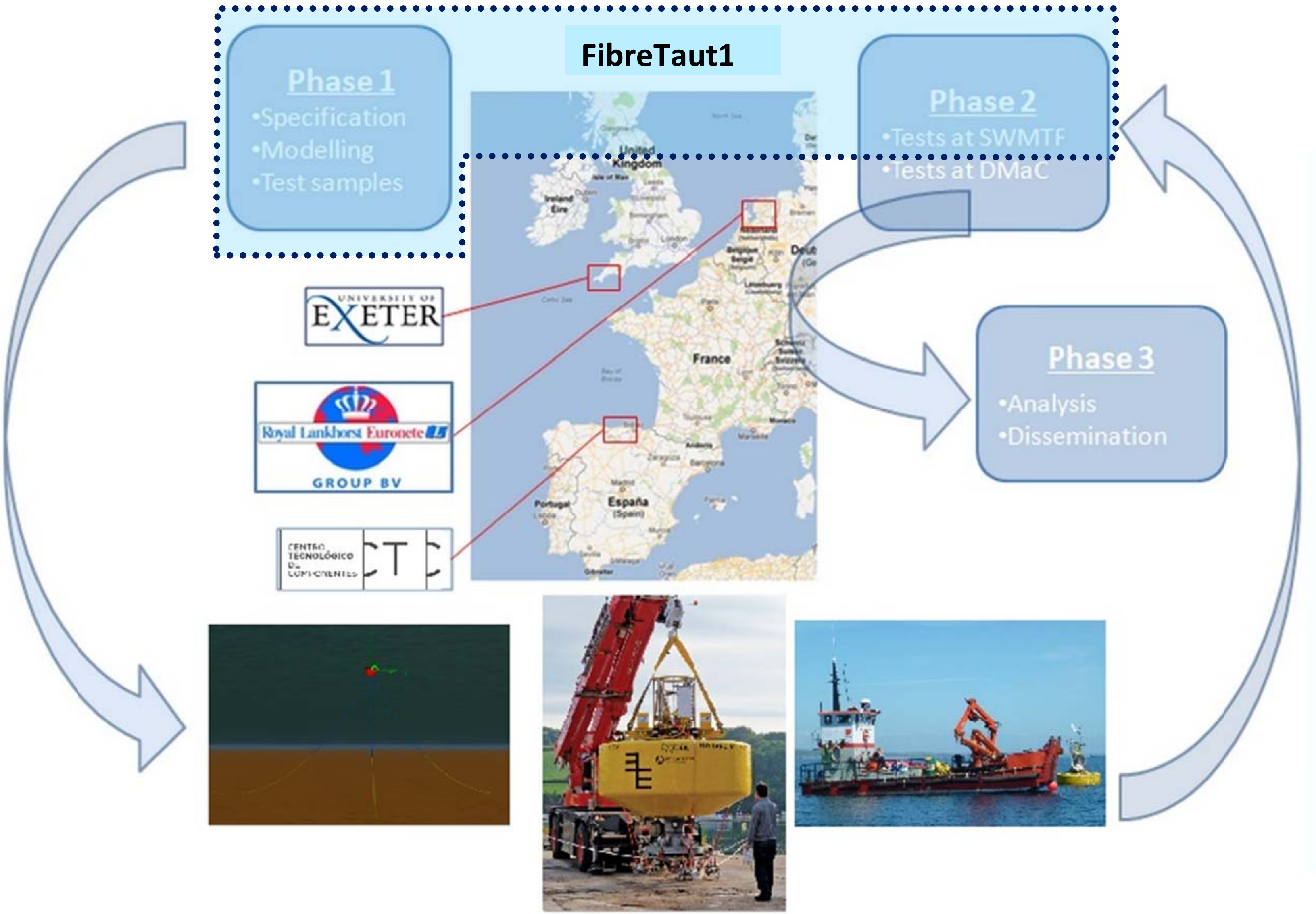


Figure 9: D Shackles

Noted that at the end of each line thimbles and encapsulation with an elastomer compound were installed for further protection.


FibreTaut1
Phase 1
•Specification
•Modelling
•Test samples
Phase 2
•Tests at SWMTF
•Tests at DMaC
Phase 3
•Analysis
•Dissemination
UNIVERSITY OF EXETER
Royal Lankhorst Euronete
GROUP BV
France
España

2.2 TESTS

2.2.1 Test Plan

The tests were carried out at the SWMTF. In the next table, the main characteristics of the test plan are shown:

Task	Test at	Objective	Duration	Number of ropes
Task 5	SWMTF	Measure environment information	30 days	3

Table 3: Test Plans

2.3 RESULTS

The SWMTF was deployed on 12th June 2014 with the intention of recording line tensions for at least 30 days.

Figure 10: Deployment of the SWMTF

The data was collected in the planned time, 30 days after. Previous to the deployment, two new load cells were installed at SWMTF. The load cells were calibrated at DMaC previously and during the deployment they were checked again, but after some days, one load cell failed. Therefore, the tension data were collected only for the first five days.

Owing to the failure of inline load cells, the UoE processed the MotionPak[2] information, thus it was possible to have the 6 DoF displacements of the buoy. This data was imported into OrcaFlex in order to estimate mooring line tensions during the deployment.
As an extra effort, UoE performed a qualitative validation of mooring line tensions using MotionPak-derived displacements:

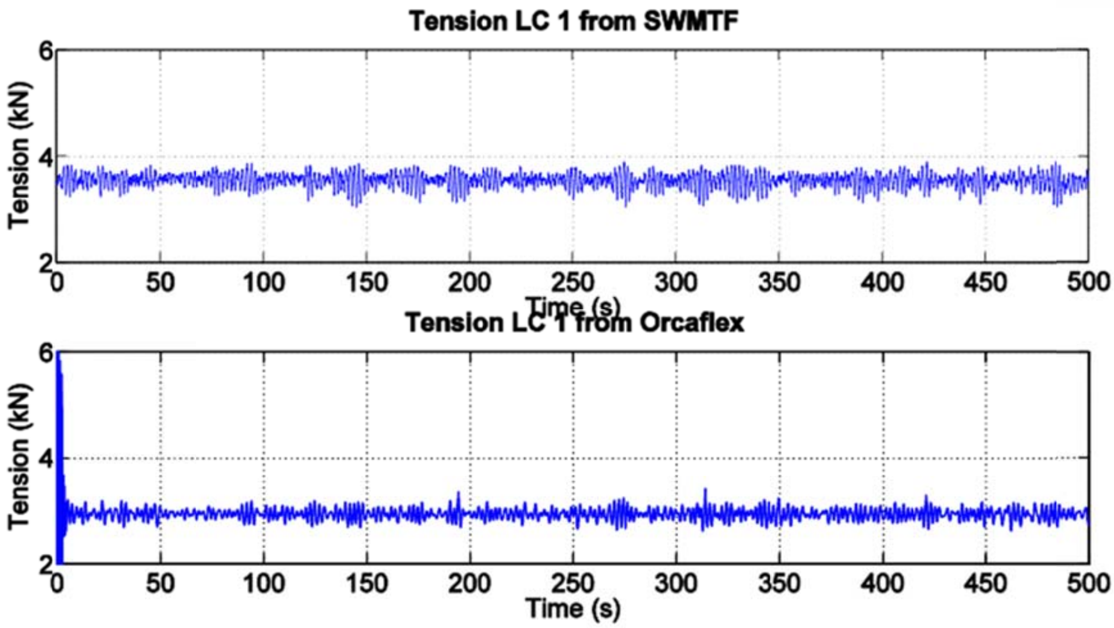


Figure 11: Validation of mooring line tensions using MotionPak-derived displacements provided by UoE

This figure shows the comparison between the measured SWMTF data (recorded when load cell 1 was initially working) with the Orcaflex simulation results based on displacements derived from MotionPak data.
The MotionPak-based displacements (in 6 DoF) were inputted into Orcaflex as a time-history of superimposed motion. The method with the MotionPak based-data inputted in Orcaflex gives sensible results and a good correlation is achievable.

Together with the recorded ADCP data (processed with WavesMon software) this allowed to assess the mooring line response during deployment (after firsts five days). The following data was supplied by UoE:

- ADCP data from 12th June 2014 – 12th August 2014
- Axial load cell 1 data from 12th June 2014 – 15th June 2014
- MotionPak-derived displacements from 12th June 2014 – 22nd July 2014 (and header file)

2.4 ANALYSIS & CONCLUSIONS

During the post-processing of the data, it was noted a 20% difference between the tensions measured data and the tension simulated data by OrcaFlex. Further analysis exposed that the data of the displacements had a mean value very close to zero (see Figure 12). This caused the differences between the measured and simulated values of tension.

[2] The MotionPak system comprises accelerometers and gyroscopes to measure accelerations and angular displacements in all 6 degrees-of-freedom.

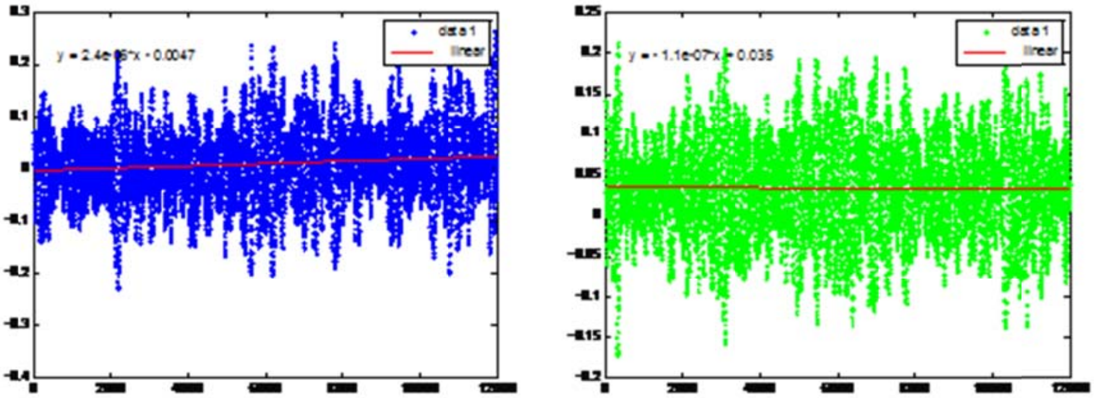


Figure 12: Mean values very close to zero

Due to those differences, the new approach to proceed was to run simulations to obtain a drift value more realistic, instead of zero, and add it to the amplitudes measured by the MotionPack.

For this purpose, there were selected the most relevant values of Hs, in order to perform simulations with a JONSWAP spectrum (Hs, Tp, depth, current and directions obtained from ADCP data) to obtain the mean values of displacement (X-Y movements). These simulations were selected among the data provided by UoE as the most representative of the deployment.
These mean values were added to the MotionPak displacements (6 DoF) in order to obtain a modified time history to impose in OrcaFlex.
New simulations with the modified time history were again performed in OrcaFlex, with superimposed motion method to obtain the missed tension values of the lines.

Finally, the decommissioning of the ropes is scheduled to be performed after the winter season. The ropes will be sent to Lankhorst-Euronete Portugal to be subjected to further testing and analysis (out of scope of MARINET proposal).

The main conclusions of the tests carried out in the South West Mooring Test Facility (SWMTF) are:

- Even with new load cells being installed prior deployment of SWMTF load cell failed occurred during test phase.
- The SWMTF has displacement sensors onboard so if this information is implemented in a software such as Orcaflex, the line tensions can be obtained with minor error, although this means an extra effort of data processing.
- There have been delays, but this is common when work at sea, due to dependence on the weather windows and availability of vessels.
- The design of the mooring system was subject to constraints, so its design was very conservative.
- Storm data were not obtained during deployment period.
- The loads of a MREC are faster than an Oil&Gas platform, so this must be taken into account carefully.
- Despite some drawbacks, the project objectives have been met in their great majority and the extra work performed by UoE was essential. The project has been able to overcome the drawbacks suffered during the deployment of the buoy and new strategies were applied successfully.

3 MAIN LEARNING OUTCOMES

3.1 PROGRESS MADE

These tests were intended as a first step to understanding the longer term considerations of the use of synthetic fibre ropes in MREC.
The key objectives for the testing have been mostly achieved. The work performed by UoE has been essential, during the deployment of the buoy and analysis the data.

3.1.1 Progress Made: For This User-Group or Technology

The tests have raised some questions about the effect of marine ageing on the material properties of the synthetic fibre ropes. Compression fatigue shouldn't be an issue for nylon, use in the offshore industry has highlighted that it can be an issue for stiffer materials such as HMPE and Aramids. Further analysis of the data is needed before conclusions are drawn on this.

3.1.1.1 Next Steps for Research or Staged Development Plan – Exit/Change & Retest/Proceed?

The results obtained through these tests will feed directly into the next steps of development for the FiberTaut project (FiberTaut2), in order to analyse the potential correlation between the tests at sea with the accelerated tests at the laboratory (DMaC).
Further data analysis of these results is required as the project moves on to the next stage of development.
With limited time available, many of these tests can be considered a first attempt at understanding loading and ageing implications on the material. The tests have indicated key areas for further test work to validate the results observed in the limited testing conducted here.

3.1.2 Progress Made: For Marine Renewable Energy Industry

The development of synthetic fibre mooring systems will be an asset to the industry as a whole, leading to improved mooring design with reduced weight and therefore reduced costs.

In the long-term it is expected to develop cost-effective fibre rope taut mooring lines for deep water applications for the emerging MREC industry. This would provide a new market for rope manufacturers and help advance the MREC industry further into the deeper and more energetic wave environments.
In the specific case of WireCo WorldGroup (Lankhorst-Euronete Portugal), this project represents an opening to a new market framework, and all the knowledge derived from this project will be applicable for future developments in the field of MREC.

3.2 Key Lessons Learned

- Installation windows provide some uncertainties to project time line which should be considered when generating the test schedule.
- It is important to extreme the reliability of the vital measurement components.
- The design of the mooring system was subject to many constraints, so its design was very conservative.
- Photo and Video documentation is vital when re-viewing and sharing data.
- 30 days of infrastructure access is not enough.

4 FURTHER INFORMATION

4.1 Scientific Publications

- Paper EWTEC 2015: Abstract accepted.

- Paper IJOME: An abstract was accepted to IJOME but due to the delays it wasn't possible to fulfil the full paper.
- THETIS 2015 (planned).
- Other journals in the field of Ocean Engineering (under discussion)

4.2 Website & Social Media

Fundación Centro Tecnológico de Componentes, (CTC):
http://ctcomponentes.es/lanzamiento-del-proyecto-fibre-taut/

University of Exeter, South West Mooring Test Facility (SWMTF):
http://www.fp7-marinet.eu/UNEXE-south-west-mooring-test-facility.html

5 APPENDICES

5.1 Stage Development Summary Table

The table following offers an overview of the test programmes recommended by IEA-OES for each Technology Readiness Level. This is only offered as a guide and is in no way extensive of the full test programme that should be committed to at each TRL.

DEVELOPMENT PROTOCOL	STAGE 1 CONCEPT VALIDATION			STAGE 2 DESIGN VALIDATION	STAGE 3 SYSTEMS VALIDATION		STAGE 4 DEVICE VALIDATION		STAGE 5 ECONOMICS VALIDATION
	TRL 1: **Confirmation of Operation**	**TRL 2:** **Performance Convergence**	**TRL 3:** **Device Optimisation**	**TRL 4:** **Sub-Systems Assessment**	**TRL5:** **Sub-Assembly Bench Tests**	**TRL 6:** **Full System Sea Trials**	**TRL 7:** **Solo, Sheltered, Grid Emulator**	**TRL 8:** **Solo, Exposed, Grid Connected**	**TRL 9:** **Multi-device Array (3-5)**
Objectives/ Investigations	Op. Verification Design Variables Physical Process Validate/Calibrate Maths Model Damping Effect Signal Phase	Real Generic Seas Design variables Damping PTO Natural Periods Power Absorption Wave to Devise Response Phase	Hull Geometry Components Configurations Power Take-Off Characteristics Design Eng. (Naval Architects)	Final Design Accurate PTO [Active Control] Mooring system Survival Options Power Production Added mass	PTO Method Options & Control Inst. Power Absorption Electricity Production & Quality	Scale effects of Overall Performance Characteristics Mooring & Anchorage Security Environmental Influences & Factors	Oper & Mains Procedures Electrical Output Quality Grid Supply, Stability & Security PTO Performance at all phases Control Strategy Seaworthiness, Survival & Lifecycle Analysis Device Array Interaction (Stages 1 & 2)		Grid Connection Array Interaction Maintenance Service Schedules Component Life Economics
Output/ Measurement	Vessel Motion Response Amplitude Operators & Stability Pressure / Force, Velocity RAOs with Phase Diagrams Power Conversion Charcteristic Time Histories Hull Seaworthiness; Excessive Rotations or Submergence Water Surface Elevation Abeam of Devices			Motion RAOs Phase Diagrams Power *v* Time Wave Climates @ *head, beam, follow*	PTO Forces & Power Conversion Control Strategies	Incident Wave Field 6 D of F Body Motion & Phase Seaworthiness of Hull & Mooring [Survival Strategies]	Full On-Board Monitoring Kit for Extended Physical Parameters Power Matrix Supply forecasting	Array Interaction Annual Power Prod. Elec. Power Perfrm. Failure Rates Grid EIA reviews	Service, Maintenance & Production Monitor, Telemetry for Periodic checks & Evaluation
Primary Scale (λ)	$\lambda = 1 : 25 - 100$ ($\therefore \lambda_e = 1 : 5 - 10$)			$\lambda = 1 : 10 - 25$	$\lambda = 1 : 2 - 10$		$\lambda = 1 : 1 - 2$		$\lambda = 1:1$, Full size
Facility	2D Flume or 3D Basin			3D Basin	Power Electronics Lab	Benign Site	Sheltered Full Scale Site	Exposed Full Scale Site	Open Location
Duration –*inc Analysis*	1-3months	1-3months	1 3 months	6 – 12 months	6 – 18 months		12 – 36 months		1 – 5 years
Typical No. Tests	250 - 750	250 - 500	100 - 250	100 - 250	50 - 250		Continuous		Statistical Sample
Budget (€,000)	1 – 5	25-75	25-50	50 - 250	1,000 – 2,500		10,000 – 20,000		2,500 – 7,500
Device	Idealised with Quick Change Options Simulated PTO (0-∞ Damping Range) Std Mooring & Mass Distribution		Distributed Mass Minimal Drag Design Dynamics	Final design (internal view) Mooring Layout	Advanced PTO Simulation Special Materials	Full Fabrication True PTO & Elec Generator	Grid Control Electronics or Emulator Emergency Response Strategies Pre-Production Pre-Commercial		Operational Multi-Device
Excitation / Waves	Monochromatic Linear (10-25Δ*f*) (25-100 waves)	Panchromatic Waves (20min scale) +ve 15 Classical Seaways Spectra Long crested Head Seas		Deployment -Pilot Site Sea Spectra Long, Short Crested Classical Seas Select Mean wave Approach Angle		Extended Test Period to Ensure all Seaways inc.	Full Scatter Diagram for initial Evaluation Continuous Thereafter Time & Frequency Domain Analysis		
Specials	DofF (heave only) 2-Dimentional Solo & Multi Hull	Short Crest Seas Angled Waves As Required	Storm Seas (3hr) Finite Regular As required	Power Take-Off Bench Test PTO & Generator	Device Output Repeatability Survival Forces	Salt Corrosion Marine Growth Permissions	Grid Emulator Quick Release Cable Service Ops	Stakeholder Consult. Health & Safety Issues	Small Array (Up-grade to Generating Station)?
Maths Methods (Computer)	Hydrodynamic, Numerical Frequency Domain to Solve the Model Undamped Linear Equations of Motion		Finite Waves Applied Damping Multi Freq Inputs	Time Domain Response Model & Control Strategy Naval Architects Design Codes for Hull, Mooring & Anchorage System. Economic & Business Plan			Economic Model Electrical Stab. Array Interaction	Grid Simulation Wave forecasting	Array Interaction Market Projection for Devise Sales
	EVALUATION [Stage Gates]								
Absorbed / Converted Power [kW]									
Weight, [tonnes]									
Manufacturing Cost [€]									
Capture [kW/tonne] or [kW/m^3]	[200-50 m^3]								
Production [c/kW]	< 25 €c / kW			≤ 15 €c / kW			≤ 10 €c / kW		≤ 5 €c / kW

SEVENTH FRAMEWORK PROGRAMME