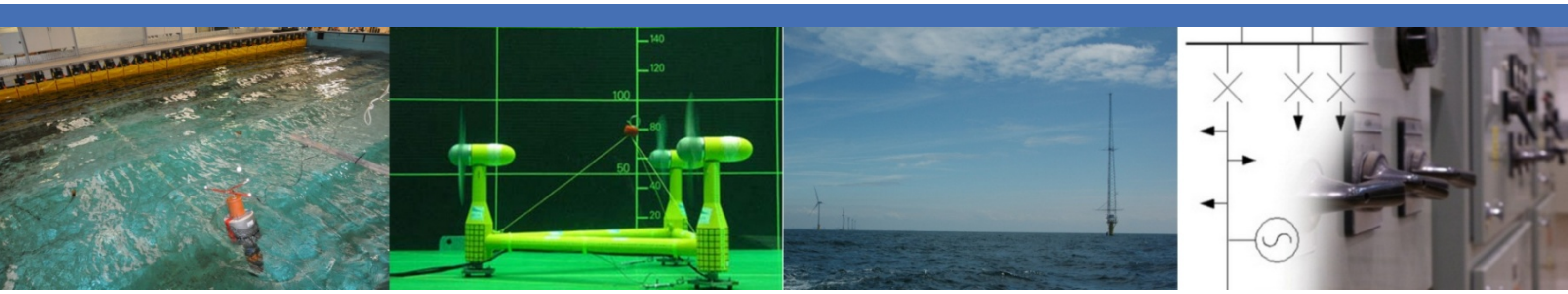
MARINET

Marine Renewables Infrastructure Network



Infrastructure Access Report

Infrastructure: UNEXE Dynamic Marine Component Test Facility

***User-Project*:FibreTaut2**

Fibre Ropes for Taut Mooring Lines for Marine Energy Converters

WireCoWorldGroup (Lankhorst-Euronete Portugal) & Fundación Centro Tecnológico de componentes (CTC)

Status: Final
Version: 02
Date: 19-Mar-2015

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 aimof the initiative isto 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)
DanmarksTekniskeUniversitet (RISOE)

France
Ecole Centrale de Nantes (ECN)
InstitutFrançais de RecherchePourl'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)
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Norway
SintefEnergi AS (SINTEF)
NorgesTeknisk-NaturvitenskapeligeUniversitet (NTNU)

DOCUMENT INFORMATION

Title	Fibre Ropes for Taut Mooring Lines for Marine Energy Converters
Distribution	**Public**
Document Reference	MARINET-TA1-FibreTaut2
User-Group Leader, Lead Author	JeroenDorenbusch WireCoWorldGroup JeroenDorenbusch@wirecoworldgroup.com
User-Group Members, Contributing Authors	Jose Canedo Lankhorst-Euronete Portugal Alberto Leao Lankhorst-Euronete Portugal Raúl Rodríguez Arias Centro Tecnológico de Componentes (CTC) Álvaro Rodríguez Ruíz Centro Tecnológico de Componentes (CTC) Verónica Glez. De Lena Centro Técnológicode Componentes (CTC) Lars Johanning University of Exeter (UoE) Philipp Thies University of Exeter (UoE) David Parish University of Exeter (UoE) Sam Weller University of Exeter (UoE)
Infrastructure Accessed:	UNEXE Dynamic Marine Component Test Facility
Infrastructure Manager (or Main Contact)	Lars Johaning

REVISION HISTORY

Rev.	Date	Description	Prepared by (Name)	Approved By Infrastructure Manager	Status (Draft/Final)
01	17/02/2015	First Draft	Raúl Rodríguez, Álvaro Rodríguez and Verónica Glez. de Lena	-	Draft
02	19/03/2015	Final Report	Raúl Rodríguez, Álvaro Rodríguez and Verónica Glez. de Lena	Lars Johanning	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

The work described in this publication has received support from MARINET, a European Community - Research Infrastructure Action under the FP7 "Capacities" Specific Programme.

LEGAL DISCLAIMER

EXECUTIVE SUMMARY

One immediate challenge for the Marine Energy Converters (MECs) industry is solving the cost and weight problems of mooring lines in deepwater (>75m). Fibre rope taut mooring lines represent a new and interesting option for the mooring of MECs in deepwater (see Figure 1).

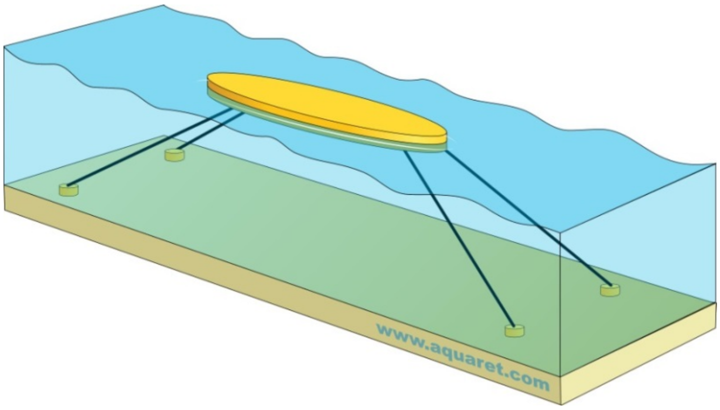

Figure 1: Taut mooring configuration.

Synthetic fibre ropes offer a solution to the weight problems of using steel lines in deepwater as they have a very low weight in water. 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 can be made into ropes using a number of constructions, some of which are suited to particular fibres (see Figure 2).

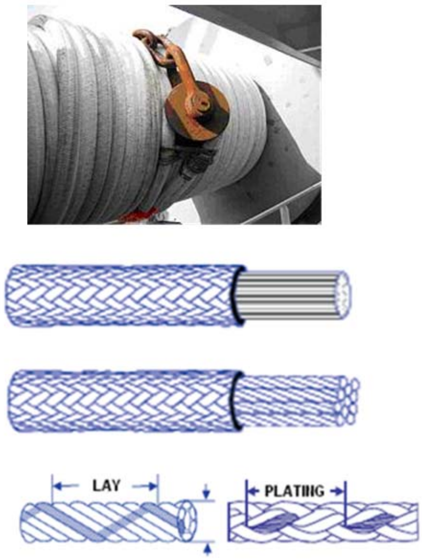

Figure 2: Different yarn configurations.

As with any new application, research must be conducted to determine how well the fibre ropes satisfy the performance requirements. The effects of aging of fibre ropes will be characterized in the proposed tests.

Test facilities at the University of Exeter are unique in the MARINET consortium, as they allow the extensive testing of mooring lines in water. Their testing infrastructure will help us to determine which prospective innovative fibre rope mooring line is best suited for deepwater MECs. Also, the technological and scientific support offered by the well experienced staff is another reason to propose the access to these two tests facilities.

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1 INTRODUCTION& BACKGROUND

1.1 INTRODUCTION

The company WireCoWorldGroup (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 that cost-effective fibre rope taut mooring lines in deep water applications will be developed for the emerging MREC industry. This will provide a new market for rope manufacturers and help advance the MREC industry further into deeper and more energetic wave environments.
- Contribute to the improvement of the correlation between accelerated laboratory tests and real offshore environment test.
- Promote communication and dissemination of findings among European centres and companies.

This report summarises the research activities developed within the proposal #219 (FibreTaut2), concerning the DMaC.

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 numericalmodels 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 earlymathematical models	
• Provide the empirical hydrodynamic co-efficient associated withthe device (for mathematical modelling tuning)	

STAGE GATE CRITERIA	Status
• Investigate physical process governing device response. May notbe well defined theoretically or 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 thedevices anticipated performance would be significantly affected bythem	
• 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	

STAGE GATE CRITERIA	Status
• Environmental impact issues	➲
• 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 was devoted to the specification of the mooring system and the detailed development of the Test Plan for the Dynamic Marine Component test facility (DMaC) at the University of Exeter facilities (UoE). The definition of the rope properties in terms of breaking load, stiffness and damping was addressed in this phase, as well as the development of the numerical model for the base line loads cases.
The Phase 2 was devoted to the preparation and fabrication of the test samples at the consortium premises to be tested at sea and finally, the last scientific part of the project was the comparison of the real field data with the accelerated tests in the lab.
During the Phase 3, 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 Plan (DMaC)
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 project 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).

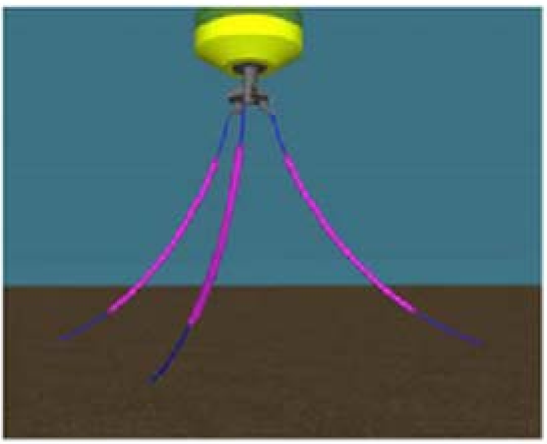


Figure 3: Example of a numerical model of the buoy and its mooring system

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

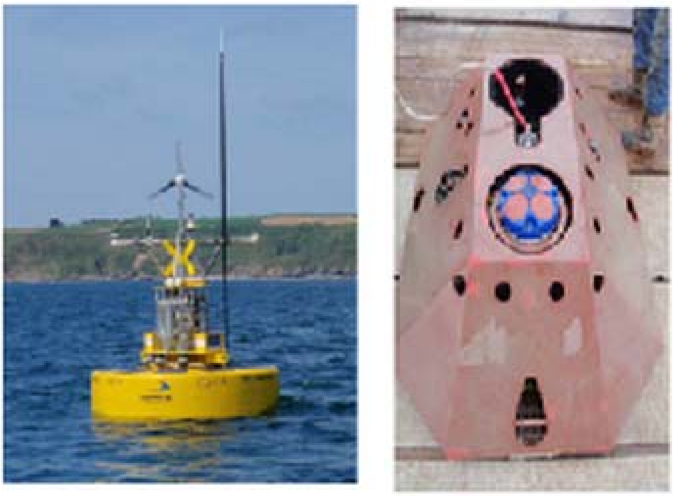


Figure 4: SWMTF buoy & Teledyne RDI ADCP

- 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).

2 OUTLINE OF WORK CARRIED OUT

2.1 SETUP

2.1.1 Preliminary work to deployment

The Phase 1 was devoted to the specification of mooring system and the detailed development of the Test Plan for the Dynamic Marine Component test facility (DMaC) and the South West Mooring Test Facility (SWMTF) at the University of Exeter. The definition of the rope properties in terms of breaking load, stiffness and damping was also addressed in this phase as well as the development of the numerical model for the base line loads cases.
Among all the fibre ropes offered by Lankhorst, Polyamide was the material chosen for the project. In the next figure the specification of the final mooring system for the SWMTF is shown:

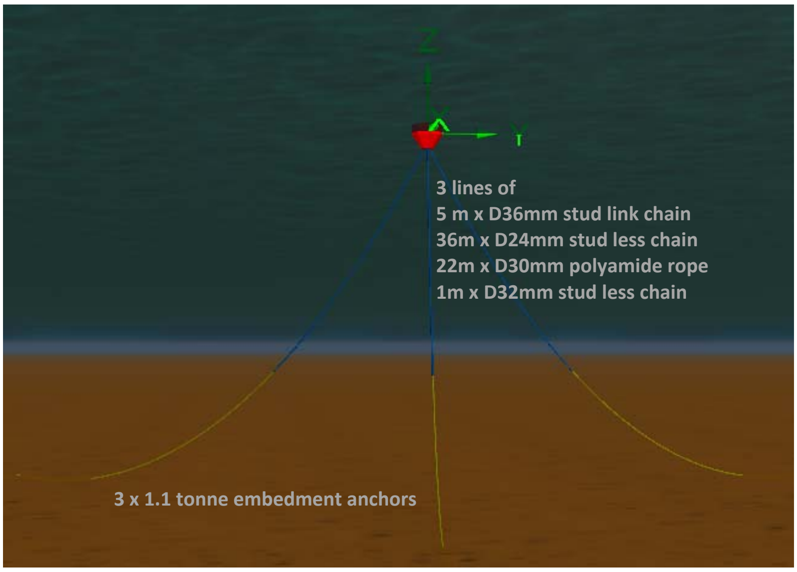


Figure 6: Final Mooring Configuration at SWMTF

The Phase 2 was devoted to the preparation and fabrication of the test samples at the client premises and finally to the real tests at sea in the SWMTF and accelerated tests in the lab with the DMaC.

The SWMTF was deployed on 12th June 2014 with the intention of recording line tensions for 30 days. Owing to the failure of inline load cells, UoE and CTC used available information to generate realistic line tension time series to use at DMaC using SWMTF motion data and numerical simulation.

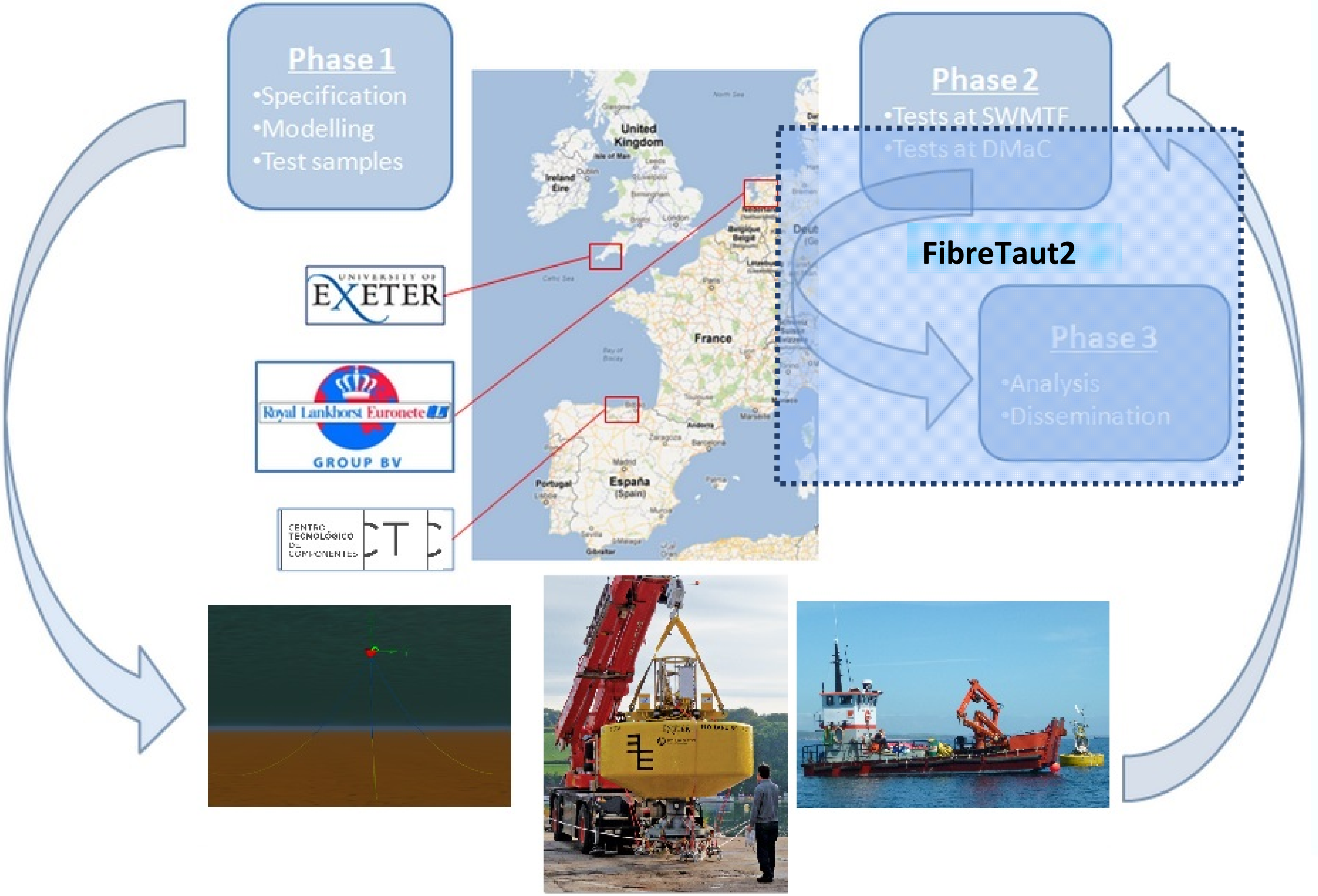
It is important to note that, despite the lack of tension data acquired from SWMTF, it was possible to generate realistic line tension data based on the SWMTF data that was available, but at extra effort mostly provided by the University of Exeter.

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 for the DMaC tests was carried out by Lankhorst.

Figure 7: 30 mm diameter polyamide rope

The final configuration of the samples required for the tests at the DMaC facility consisted of 5 samples of 30 mm diameter Polyamide rope of length 4 m between the galvanised eyes.


Phase 1
•Specification
•Modelling
•Test samples
Phase 2
•Tests at SWMTF
•Tests at DMaC
FibreTaut2
Phase 3
•Analysis
•Dissemination
UNIVERSITY OF EXETER
Royal Lankhorst Euronete
GROUP BV
CENTRO TECNOLÓGICO DE COMPONENTES
United Kingdom
Ireland
Éire
France
España
(Spain)
Portugal

2.2 TESTS

2.2.1 Test Plan

The test plan covers the next three types of tests:

- Calibration: Two samples for preliminary testing and calibration of DMaC.
- Real-time: Two samples for real-time testing. The most loaded line, from the fatigue point of view, was determined and subsequently a time series was applied to the samples.
- Accelerated-time: One sample for accelerated testing (the loads applied were the same as were used for the real-time tests).

In order to fulfil the 10 days of the facility access, UoE recommended CTC the final test scheduled as follows:

Day 1	Day 2	Day 3	Day 4	Day 5
Bedding cycles & Calibration works		Real-time dry testing		Set-up of DMaC for wet testing
Day 6	**Day 7**	**Day 8**	**Day 9**	**Day 10**
Final set-up (filling of DMaC) & Real-time wet testing			Calibration and one accelerated test	

Table 2: Test Schedule at DMaC

It was essential to implement preliminary tests prior to the accelerated testing to establish rope properties and to develop the relevant accelerated tests. The preliminary tests required a total of five days which reduced the time available for accelerated testing, which consequently affected the amount of data available for comparative assessment of fatigue damage.

Table 3 lists all of the tests conducted at DMaC:

Sample Number	Test number	Wet/dry	Date	Results file	L0 (m)[1]	Notes
1	**3**	Dry	03/12/14	Sample1Test3_PID_K0.0007.mat	1,62	5x bedding-in cycles and 5 repetitions of time-series
	4	Dry	04/12/14	Sample1Test4_PID_K0.0007.mat	1,694	
2	**9**	Wet	09/12/14	Sample2Test9_PID_K0.001.mat	1,506	
	10	Wet	10/12/14	Sample2Test10_PID_K0.001.mat	1,631[2]	
	13	Wet	11/12/14	SampleBTest13_PID_K0.001.mat	Not measured	Calibration
	14	Wet	11/12/14	SampleBTest14_PID_K0.001.mat	Not measured	Calibration
	15	Wet	11/12/14	SampleBTest15_PID_K0.0012.mat	Not measured	
	16	Wet	11/12/14	SampleBTest16_PID_K0.0015.mat	Not measured	
3	**17**	Wet	12/12/14	Sample3Test17_PID_K0.0015.mat	1,565	Accelerated (x1,2) time-series

Table 3: DMaC Tests

[1] Includes 0,106m length of transducer body.
[2] Spurious transducer measurements were observed during the bedding-in cycles of this test. The fault did not reoccur during subsequent tests.

In turn, each test carried out at DMaC consisted of some bedding in cycles and a time series of tension, as follows:

Step	Start Load (N)	End Load (N)	Duration (s)
Bedding in ramp up	2000	46200	150
Bedding in hold	46200	46200	300
Bedding in ramp down	46200	2000	150
Bedding in hold	2000	2000	300
Repeated 5x…			
Ramp to first time-series	2000	First value of TS	5
Time-series	First value of TS	Last value of TS	1 hour approx.
Ramp to hold	Last value of TS	2000	10
Hold	2000	2000	100
Repeated 5x…			

Table 4: Test Schedule at DMaC

2.3 RESULTS

2.3.1 Test Results

During the scheduled time of 10 days, the sample ropes were tested at DMaC according to the Test Plan described in the previous section. The input data for DMaC were the time series of tension obtained from the OrcaFlex models. The next figure shows the assembly of one rope tested at DMaC during the first days of December 2014.

Figure 8: Dynamic Marine Component test facility (DMaC)

The results obtained from DMaC were tension and displacement time series. The information of the three samples was processed with Matlab in order to generate figures that show the behaviour of each sample. As an example the following figures for Sample 1 are shown:

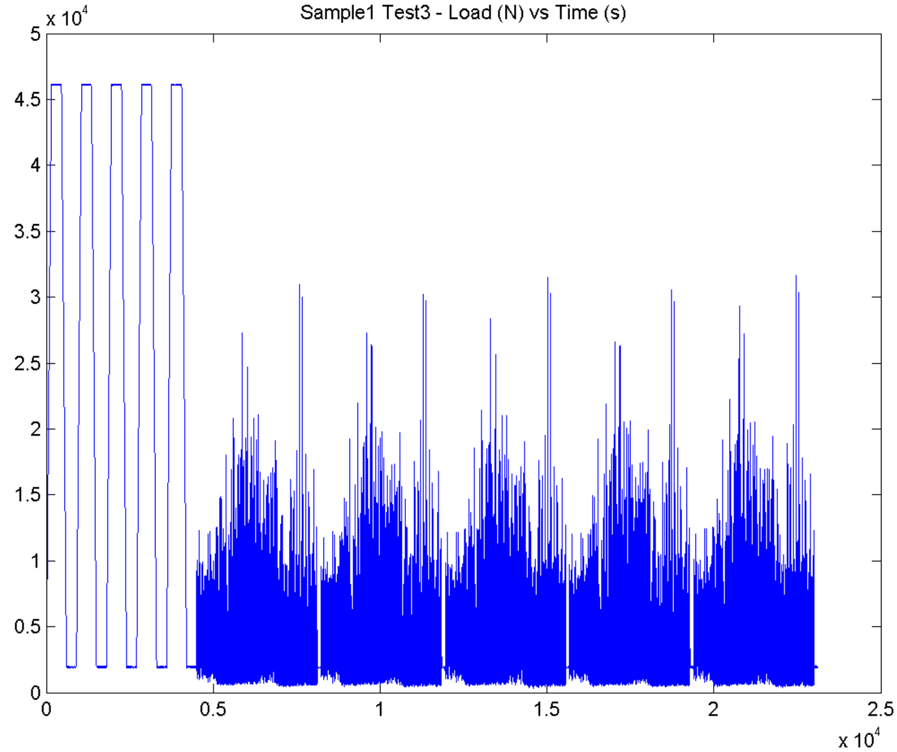


Figure 9: Sample 1 Test 3 – Load (N) vs Time (s)

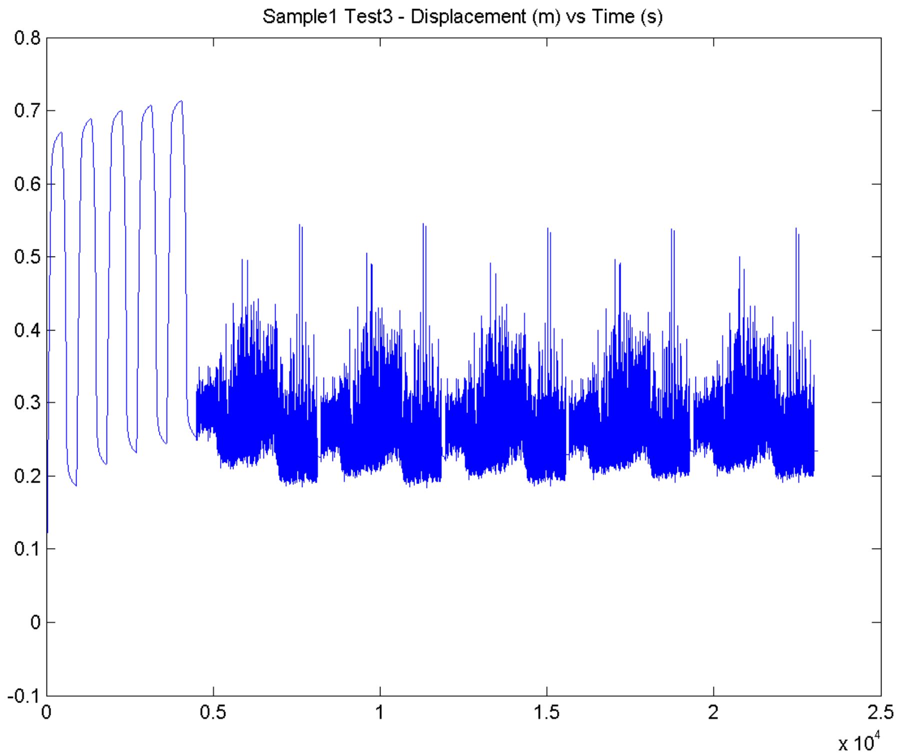


Figure 10: Sample 1 Test 3 – Displacement (m) vs Time (s)

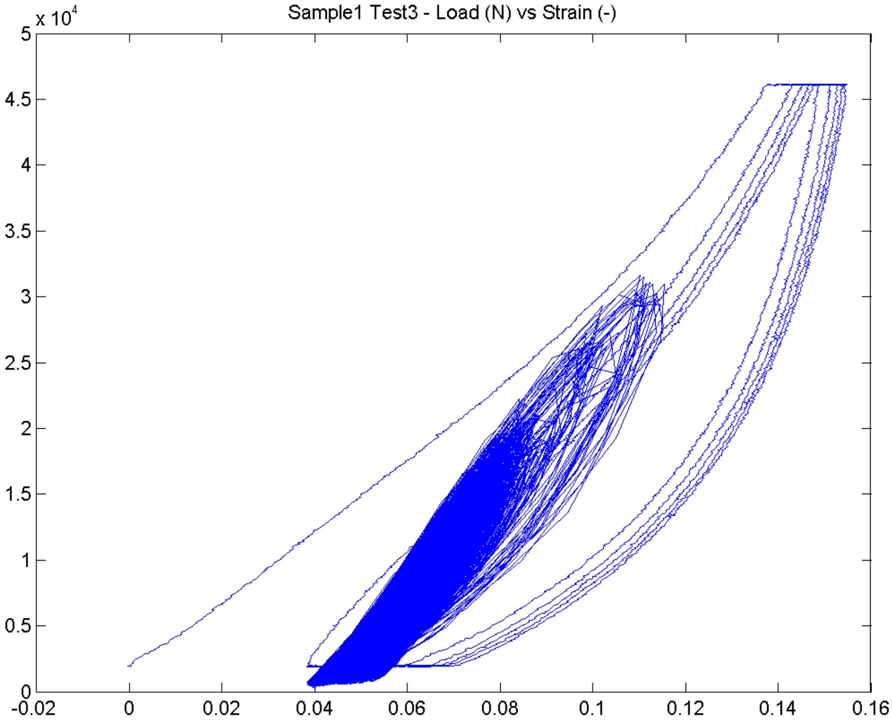


Figure 11: Sample 1 Test 3 – Load (N) vs Strain (-)

Preliminary tests identified variations in tension input and tension output data which can be seen in the following figure:

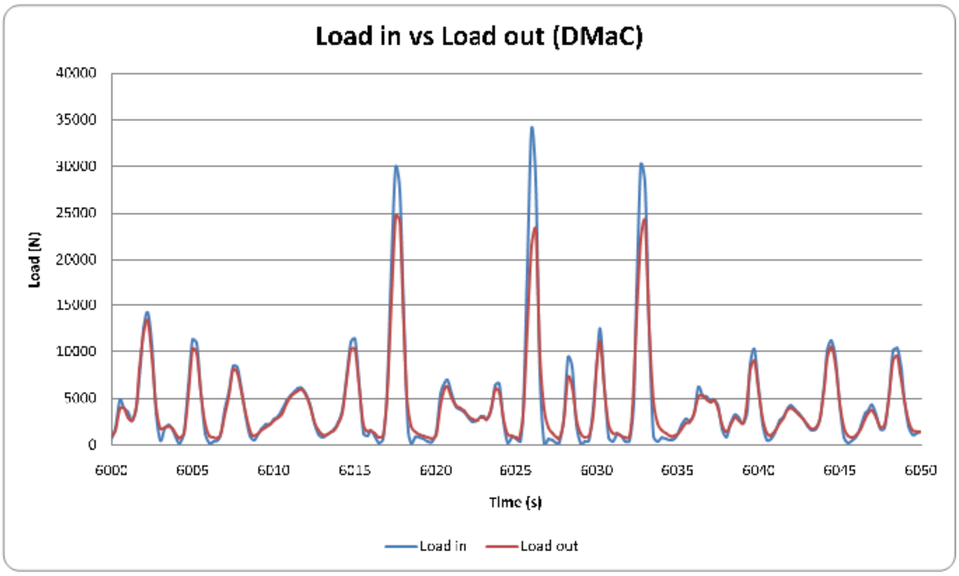


Figure 12: Load in vs Load out (DMaC)

These information was used to calibrate the control system in order to reduce these discrepancies. This was implemented through calibration of the DMaC's control system.

2.3.2 Test Results Analysis

In order to validate the obtained results, the output displacements from DMaC were implemented in the OrcaFlex models to obtain a comparison in terms of tension. A good correlation between the DMaC and OrcaFlex output was obtained. The following figures show this correlation for each sample:

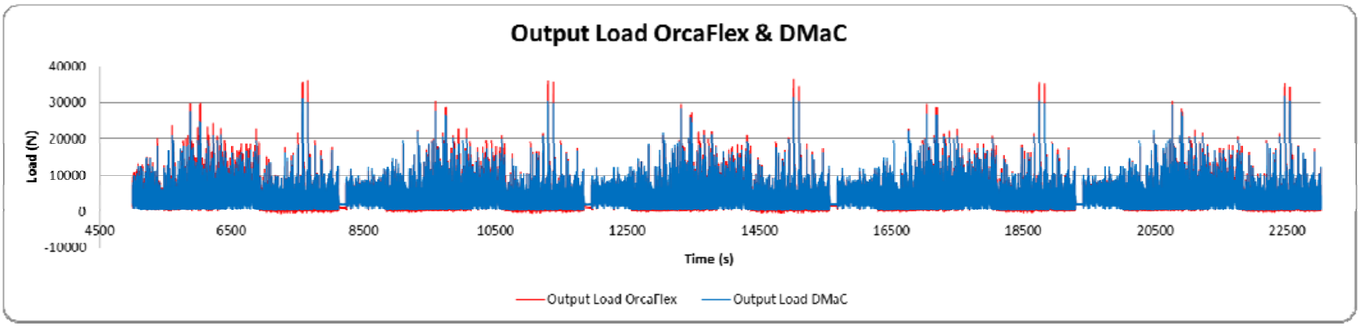


Figure 13: Sample1Test3. Output Load DMaC vs. Output Load OrcaFlex

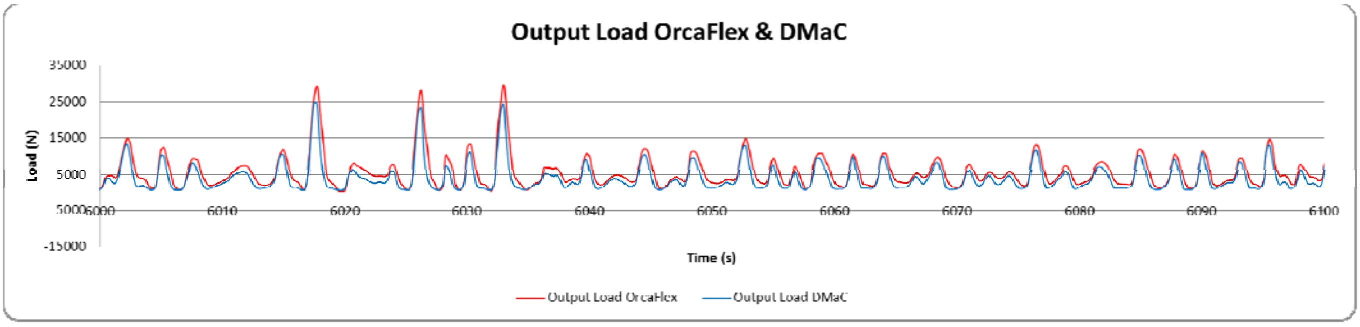


Figure 14: Sample1Test3. Detail of Output Load DMaC vs. Output Load OrcaFlex

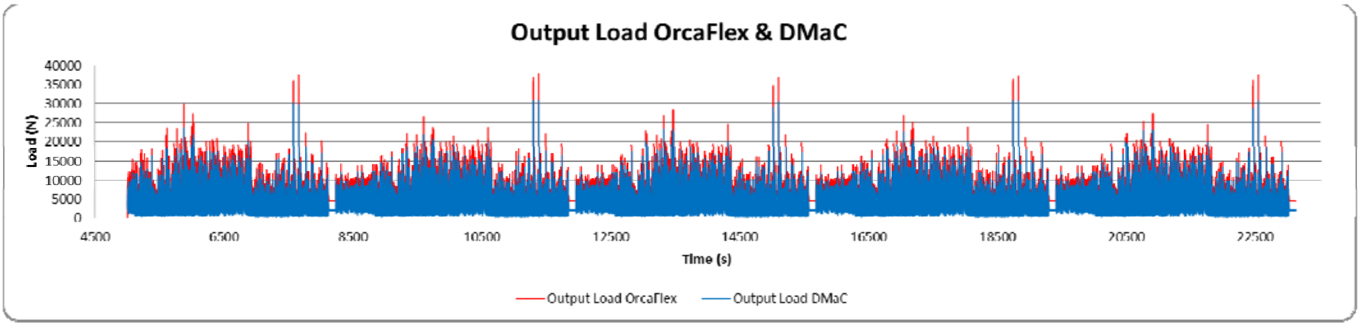


Figure 15: Sample2Test9. Output Load DMaC vs. Output Load OrcaFlex

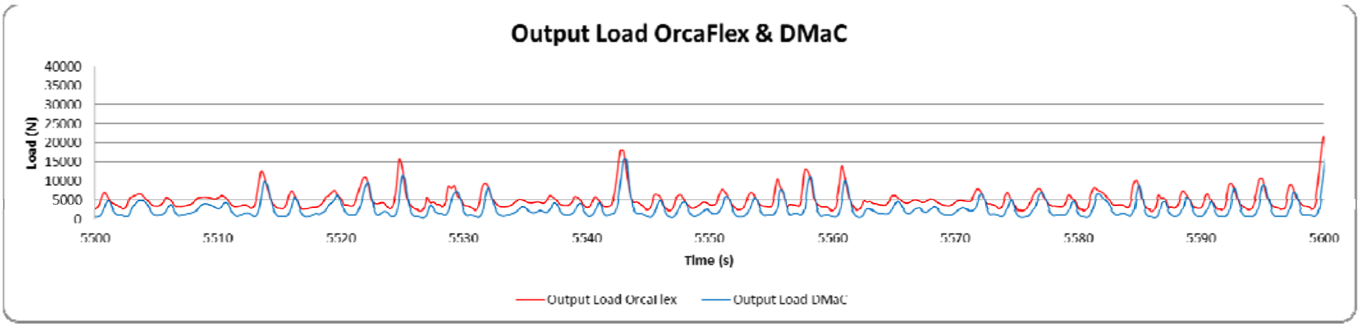


Figure 16: Sample2Test4. Zoom of Output Load DMaC vs. Output Load OrcaFlex

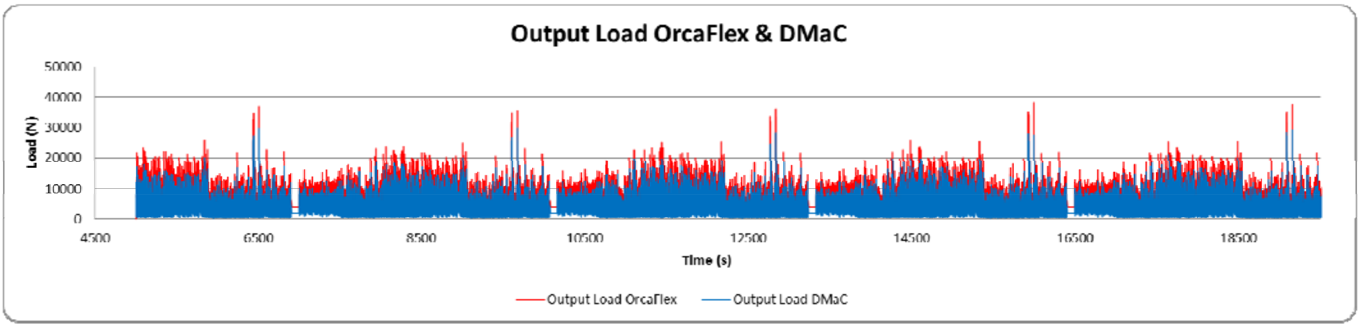


Figure 17: Sample3Test17. Output Load DMaC vs. Output Load OrcaFlex

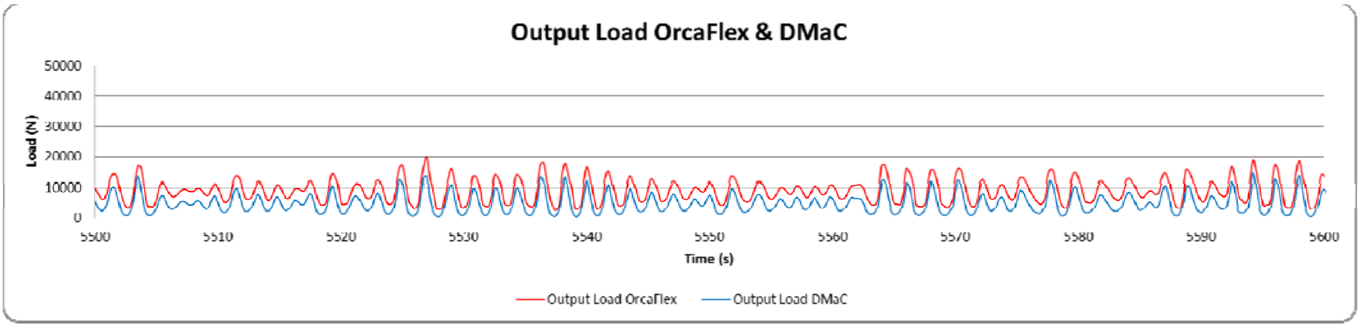


Figure 18: Sample3Test17. Zoom of Output Load DMaC vs. Output Load OrcaFlex

Finally, fatigue analysis using the Rainflow method was conducted in OrcaFlex in order to determine the fatigue damage resulting from the DMaC tension tests, as demonstrated in the following results:

Sample & Test number	Max Damage
Sample1_Test3	0,010
Sample1_Test4	0,011
Sample2_Test9	0,007
Sample2_Test10	0,009
Sample3_Test17	0,008

Table 5: Fatigue Damage

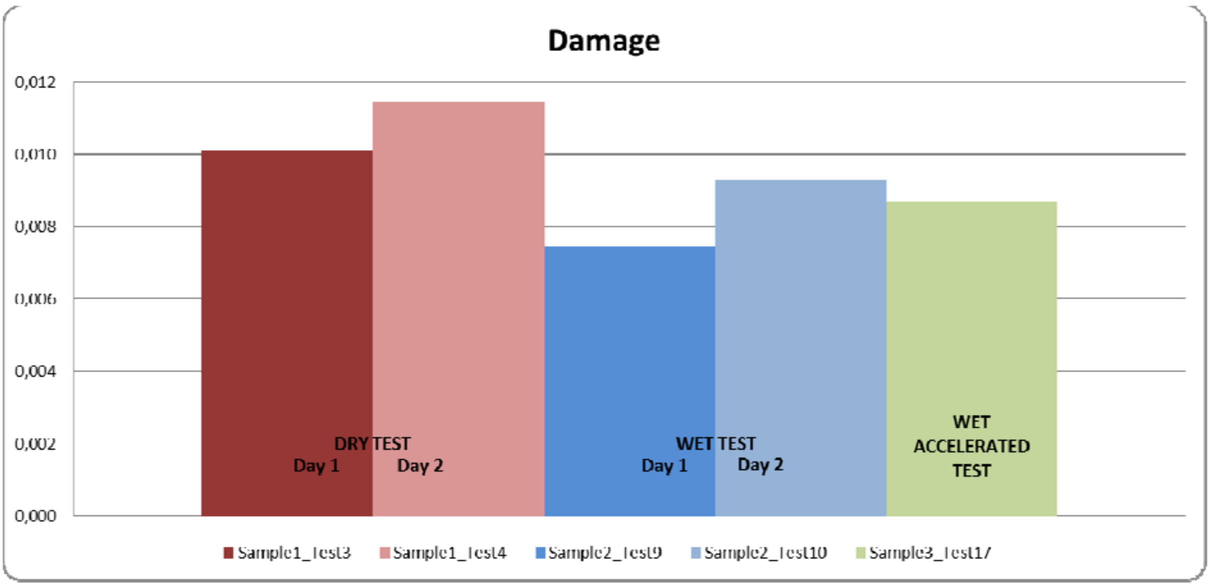


Figure 19: Damage obtained in Fatigue Analysis

Similar levels of damage between all the samples were expected. The difference between dry and wet test is a 24% in terms of fatigue damage. This discrepancy may have arisen due to the fact that the same S-N curve was used for this analysis (wet and dry conditions), the counting cycle algorithm or the differences of the two time series.

2.4 Analysis & conclusions

During the post-processing of the data, different behaviour in the same samples was observed. There are large differences between the results obtained during the first and second days of testing for each sample. In day 1, there is roughly a 4 – 5% of elongation without tension applied; however, in day 2 the behaviour is more or less linear with increases of stress and small deformations. This effect can be observed in the next figures:

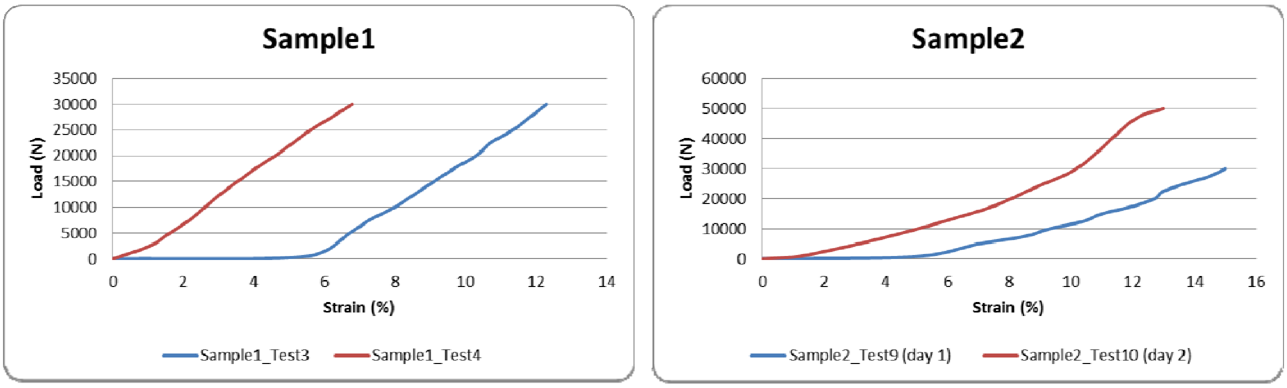


Figure 20: Strain – Stress curves for Sample 1 and Sample 2 in day 1 and day 2

These differences are due to the previous loading experienced by each sample (bedding-in cycles and day-1 loads). It is standard practice to apply bedding in cycles prior to testing to enable the rope to be conditioned from its manufactured state to one to which is known. The end result of this realignment is residual strain. Therefore, when applying bedding-in cycles to samples for the first time, it is expected some "pull-out" or constructional rearrangement of the rope and hence permanent extension. From the DMaC test results it can be concluded that whilst 5 bedding-in cycles were selected due to the length of test time available, the samples were not fully bedded-in.

In a study of larger nylon ropes, an increment of strain of around 6% after bedding-in was noted ("Synthetic rope responses in the context of load history: Operational performance". S.D. Weller, P. Davies, A.W. Vickers, L. Johanning).

Another conclusion achieved from the analysis of the information provided by DMaC is related to the influence of the testing environment. The next figure shows the behaviour of the 3 identical samples which only differs in the testing environment and the speed of load application:

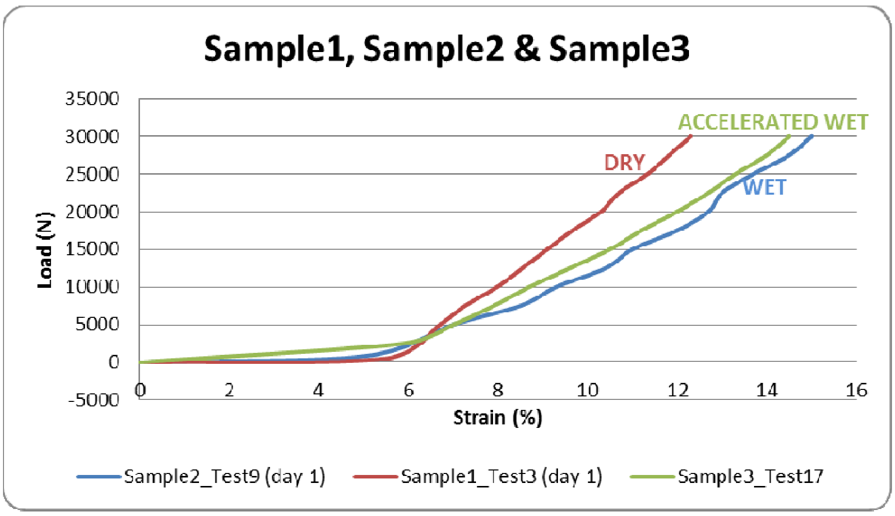


Figure 21: Behaviour of the 3 samples

It can be concluded that the use of water in the tests is a determining factor, even though the samples were not fully saturated prior to testing; however a notable decrease in axial stiffness was observed which is typical of wet nylon ("Synthetic rope responses in the context of load history: The influence of aging". S.D. Weller, P. Davies, A. W. Vickers, L. Johanning).

On the other hand, it was deducted that accelerating that application of loads causes a small increase in the axial stiffness of the rope. Whilst it has been noted that a mild effect of load rate on axial stiffness before in previous tests conducted by the UoE, further testing would be required before firm conclusions could be drawn. Intuitively it makes sense; the sample has less time to recover between cycles.

The main conclusions of the tests carried out in the Dynamic Marine Component Test Facility (DMaC) are:

- The behaviour of the ropes has been obtained for random loads, what is not easy to obtain for rope manufacturers.
- A good correlation between the measured DMaC output and OrcaFlex time-series was observed.
- The numerical model of the rope behaviour has been validated and (after further validated) could be used in commercial projects.
- Prior load history is very important. The standard bedding-in cycles didn't achieve full conditioning of the samples.
- Different behaviour of the ropes in dry and wet conditions was demonstrated. The use of water is very important in this type of tests, necessitating samples to be fully saturated prior to testing.
- A decrease in axial stiffness was noted for the samples tested in wet conditions in comparison to those tested in dry conditions.

3 MAIN LEARNING OUTCOMES

3.1 PROGRESS MADE

3.1.1 Progress Made: For This User-Group or Technology

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 tests at DMaC and the analysis of the data.
The tests have raised some questions about the effect of marine ageing on the material properties of the synthetic fibre ropes.

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

The next step in the project will be the submission of the samples tested at DMAC to the Lankhorst facilities, in order to continue with fatigue tests until failure to see the differences of the three samples.

The application of fiber taut moorings continues to a challenge for MREC, but this project can be assumed as a pillar for the creation of a new line of research between the partners of the project and the creation of a new market.

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 Lankhorst, 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

- Although in the test plan was taken into account some time to carry out the calibration of DMaC extra time was needed to have an adequate control system. This should be considered for another proposal when generating the test schedule.
- 10 days of infrastructure access is not enough due to the previous point.
- Photo and video documentation is vital when re-viewing and sharing data.
- The attendance of the personnel who is going to perform the post processing of the data is very positive and helpful to achieve the best results for the project.

4 FURTHER INFORMATION

4.1 Scientific Publications

List of any scientific publications made (already or planned) as a result of this work:

- 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 - Dynamic Marine Component Test Facility, (DMaC):
http://www.fp7-marinet.eu/UNEXE_Dynamic_Marine_Component_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 Characteristic 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 Perfm. Failure Rates Grid EIA reviews	Service, Maintenance & Production Monitor, Telemetry for Periodic checks & Evaluation
Primary Scale (λ)	$\lambda = 1 : 25 - 100$ ($\therefore \lambda_t = 1 : 5 - 10$)			$\lambda = 1 : 10 - 25$	$\lambda = 1 : 2 - 10$		$\lambda = 1 : 1 - 2$		$\lambda = 1:1$, 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