Fibre rope selection for offshore renewable energy: Current status and future needs

Dr Sam Weller

Tension Technology International Ltd

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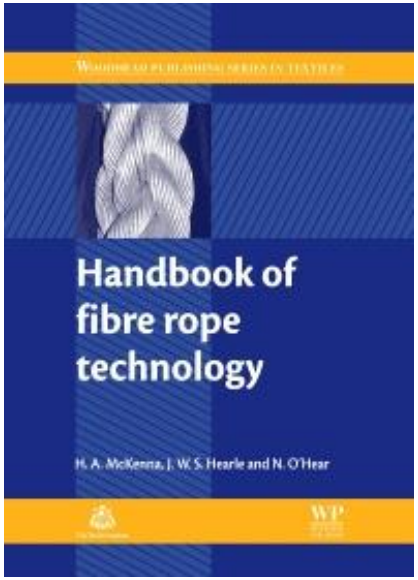
Primer

Tension Technology International (TTI) is a group of independent consultants who are experts in the **design, development, procurement, installation and testing** of mooring and anchoring systems for the offshore and renewable energy sectors

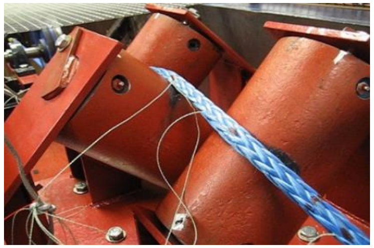
With a technology-neutral ethos, TTI consultants have led key mooring projects since the 1980s

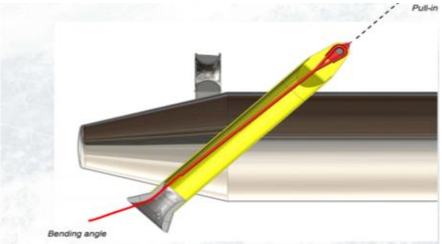
TTI Ltd (Eastbourne) – Mooring component / system R&D and analysis

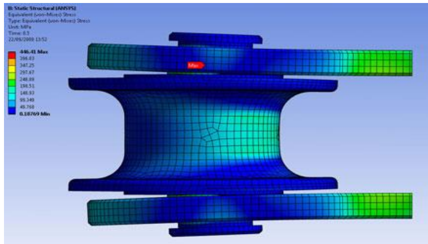


TTI Marine Renewables Ltd (Inverness) – design services from conception through to detailed engineering of the mooring system and its components. Physical and numerical hydrodynamic testing and analysis.

TTI Testing Ltd (Wallingford) - R&D and forensic testing on a wide range of mooring components, electro-mechanical cables and pipes.

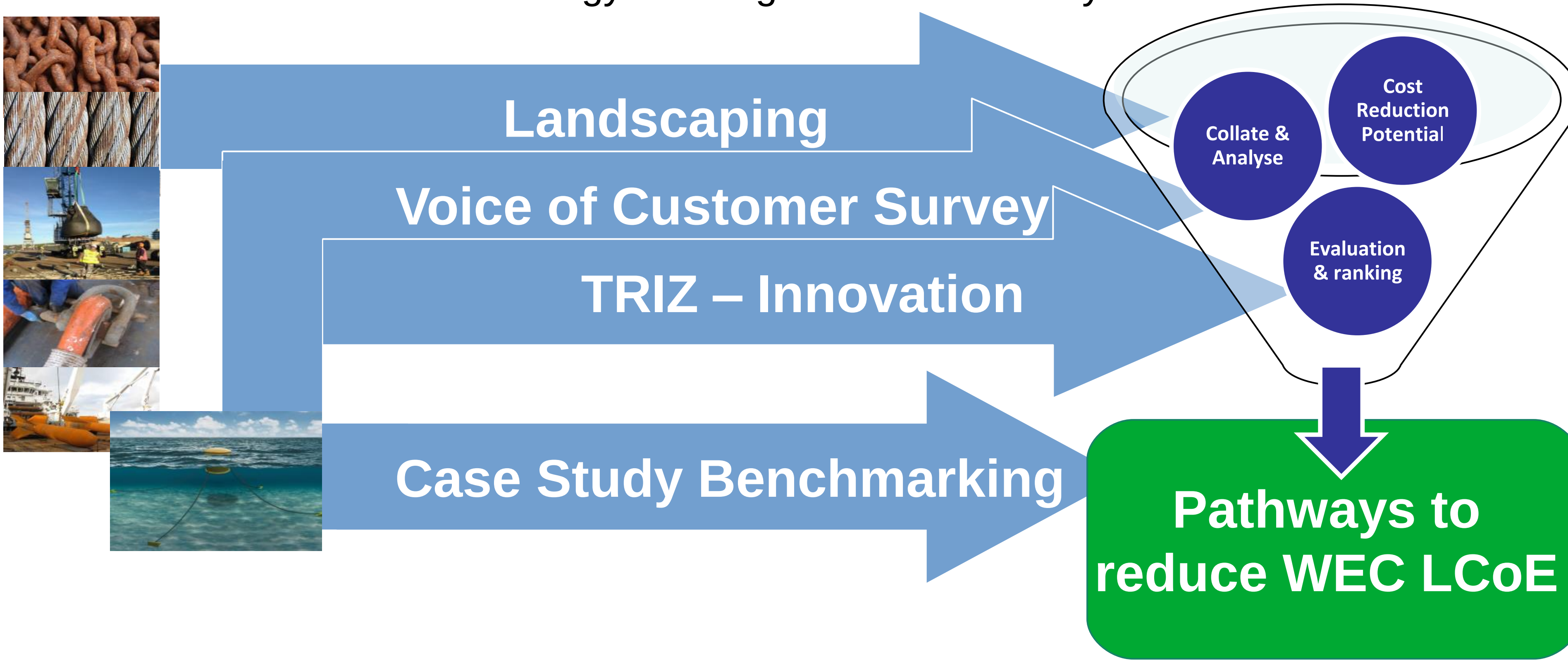






Mapping the landscape

TTI was recently commissioned by **Wave Energy Scotland** to investigate ways to reduce the LCoE of wave energy mooring and foundation systems



Cost Reduction in Supporting Infrastructure – Moorings and Foundations accessible from the Wave Energy Scotland knowledge library
https://library.waveenergyscotland.co.uk/

University of Exeter Black & Veatch wave energy Scotland

Fibre ropes

Extensive offshore use

Lankhorst Gama98®

Steel vs. Synthetic

	Material	Density (g/cm³)	Melting /charring point (°C)	Moisture (%)[1]	Modulus (N/tex, GPa)	Tenacity (mN/tex)	Strength (MPa)	Break extension (%)
	Steel	7.85	1600	0	20, 160	330	2600	2[4]
Synthetic	HMPE	0.97	150	0	100, 100	3500	3400	3.5
	Aramid	1.45	500	1-7	60, 90	2000	2900	3.5
	PET	1.38	258	<1	11, 15	820	1130	12
	PP	0.91	165	0	7, 6	620	560	20
	PA6[2]	1.14	218	5	7[3], 8[3]	840[6]	960	20

Low density

Low modulus

High strength

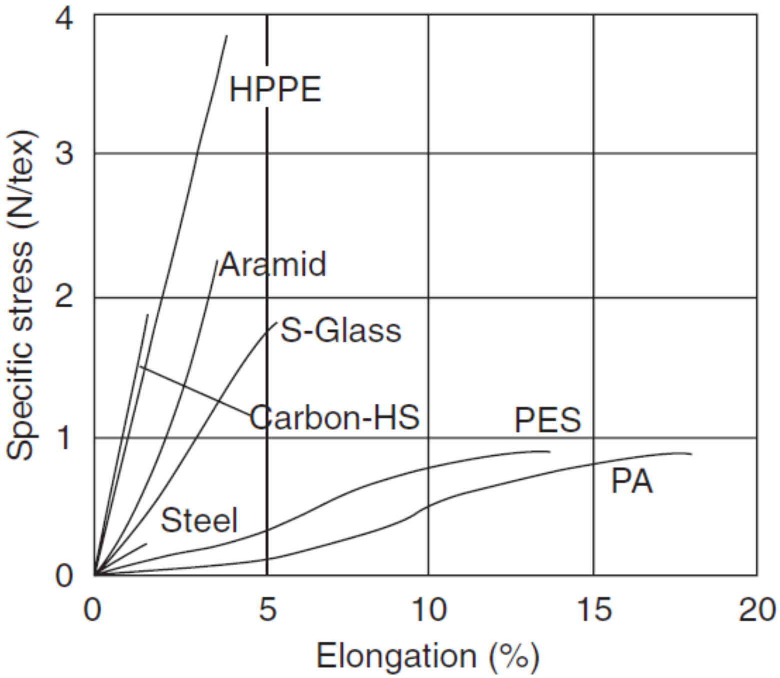
Compliant

Low cost and weight: 146mm diameter parallel strand polyester rope (MBL: 6,000kN) versus 76mm R4 studlink chain (MBL: 6,001kN) => Cost of rope is 42.2% of chain, and 10.4% of linear mass[5]

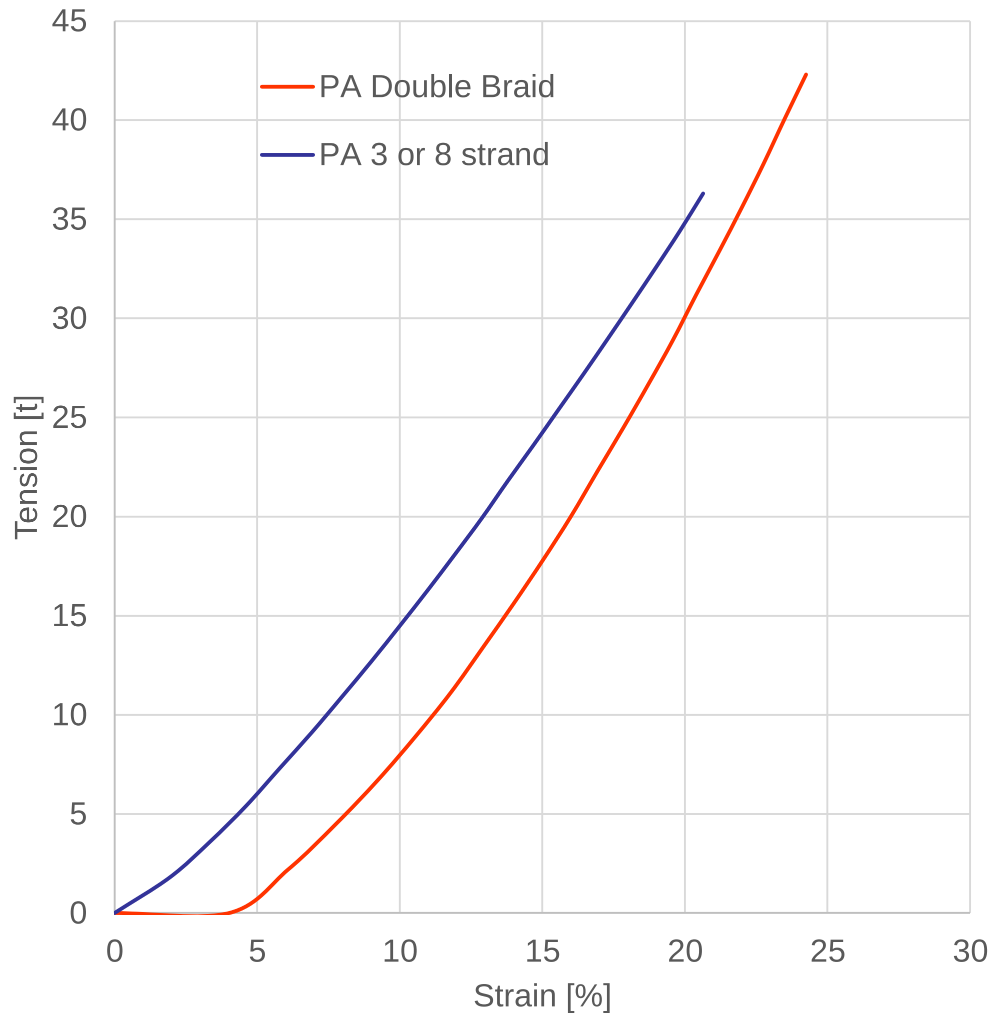
[1] At 65% rh and 20° C.
[2] PA6.6 has a higher melting point (258° C) than PA6.
[3] The modulus and strength of nylon is approximately 15% lower when wet (McKenna et al.)
[4] Yield point of steel.
[5] Per 100m length. Rope cost includes end terminations and protection.

(values from McKenna et al. 2004)

Fibre type and rope construction



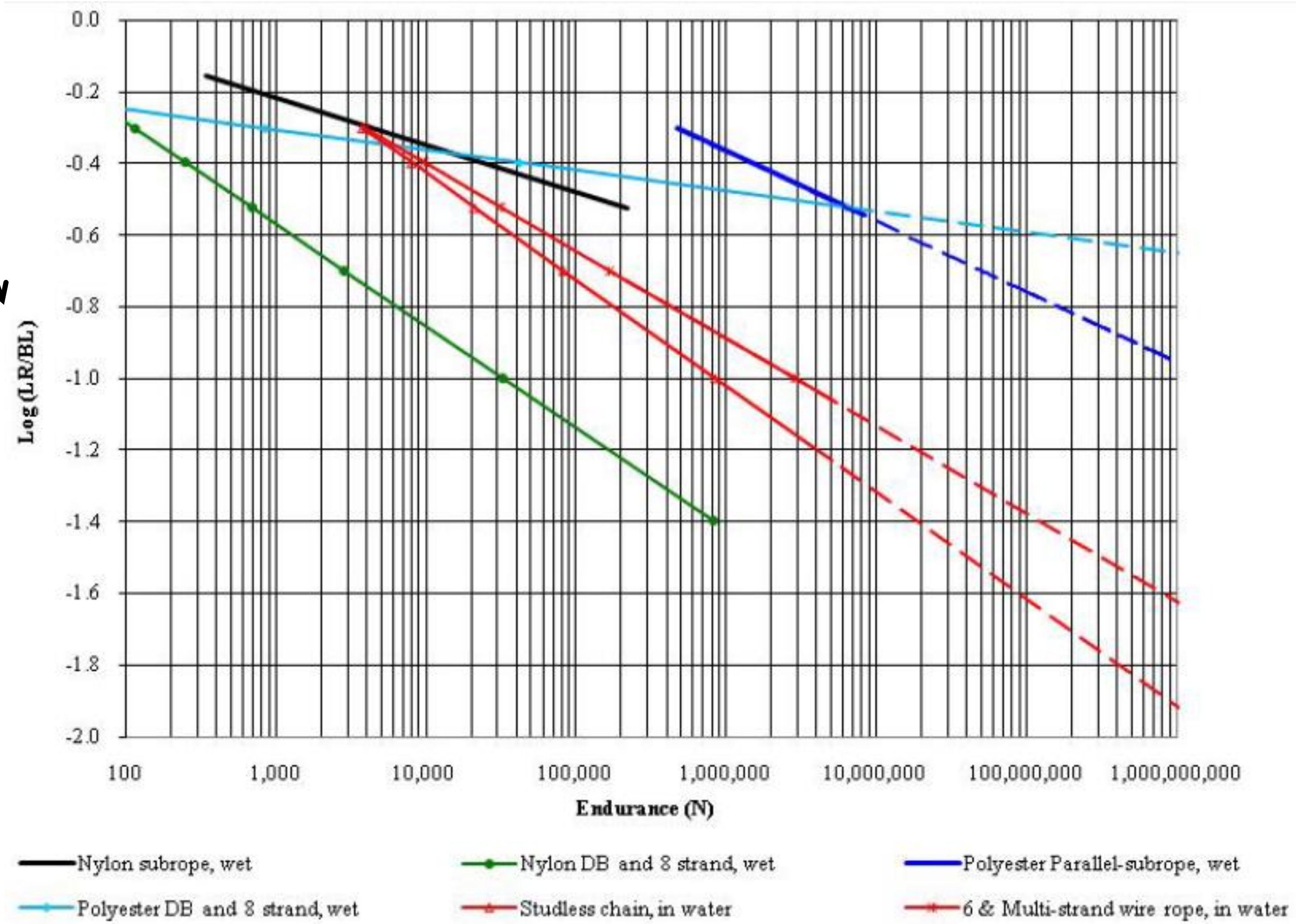
(from Dingenen, 2001)



Effect of construction on nylon ropes (*OPTIMOOR, 2019*)

Comparative fatigue performance

LR: Load range
BL: Break load



(from Ridge, Banfield et al. 2010)

Permanent mooring failures

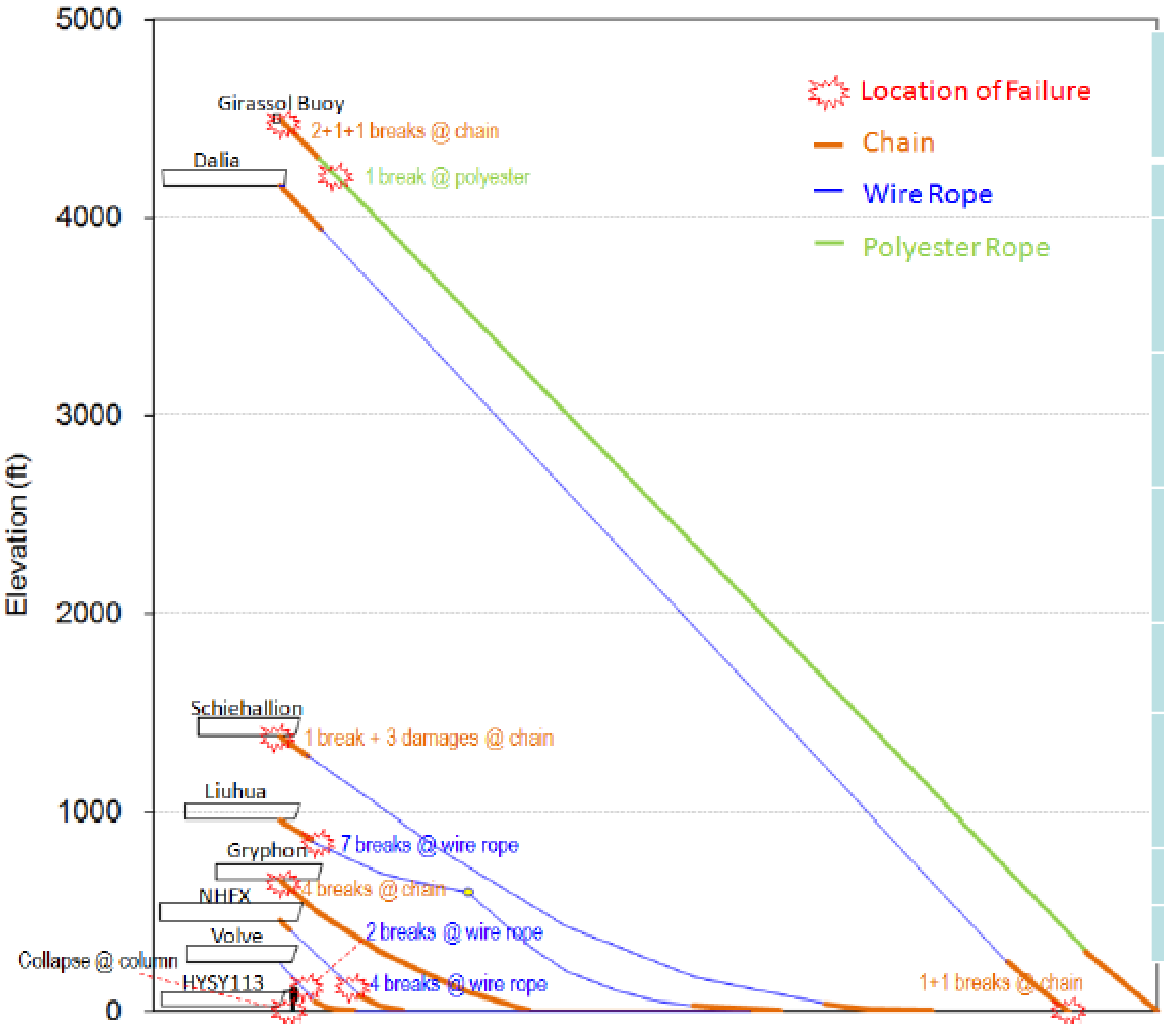


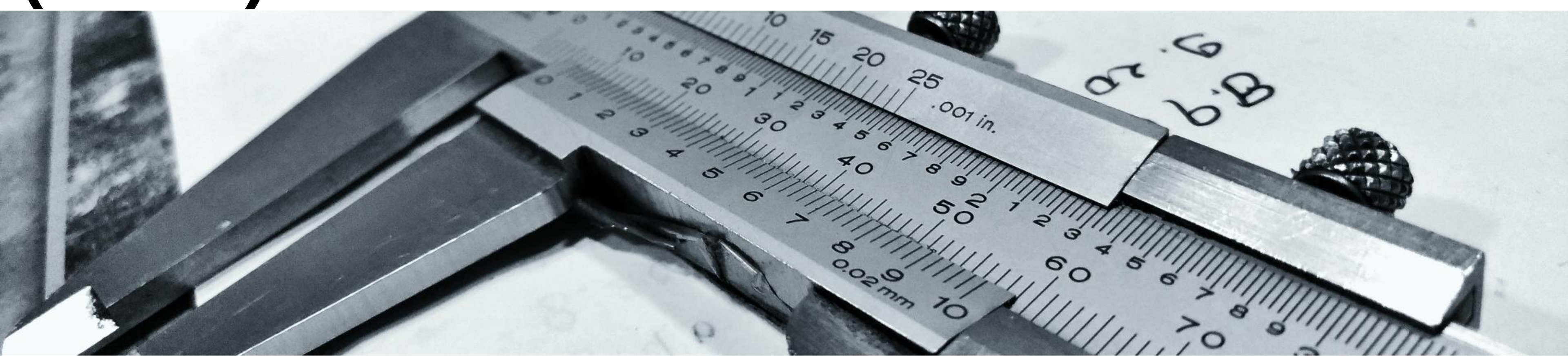
Figure 1: Examples of Break Locations along Mooring Profiles

Date	Name	Result
2002	Girassol buoy	3 (+2) of 9 lines
2006	Liuhua	7 of 10 lines parted. vessel drift, riser broken
2009	Hai Yang Shi You	Entire system collapse, vessel drift, riser broken
2009	Nan Hai Fa Xian	4 of 8 lines parted, vessel drift, riser broken
2010	Jubarte	3 lines parted (2008-2010)
2011	Gryphon Alpha	4 of 8 lines parted, vessel drift, riser broken
2011	Volve	2 of 9 lines parted
2011	Banff	5 of 10 lines parted

Ma, K-t et al. (2013)

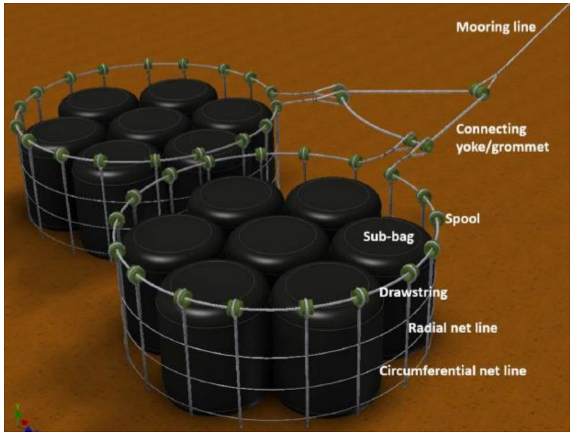
Typical floating platform lifespan ~25 years -> there is greater than 60% chance of failure during lifetime

Marine Renewables Commercialisation Fund (MRCF)



MRCF objectives

- To develop and qualify **enabling** technology and mooring products suitable for station-keeping of a wide range of floating wave and tidal array based technologies.
- To **build on** related mooring subsystem qualification programmes funded by Carbon Trust and TSB.
- To advance qualification of a **novel anchor bag** in accordance with DNV Recommended Practice for new technology (**DNV-RP-A203**)
- To advance **qualification of Nylon rope** in accordance with Lloyd's Register Technology Pathway
- To develop **methodologies and guidance** for the design of Nylon based mooring systems
- To demonstrate **step changes in cost reduction** while increasing mooring array density.
- To demonstrate technology viability through open water testing



The Scottish Government

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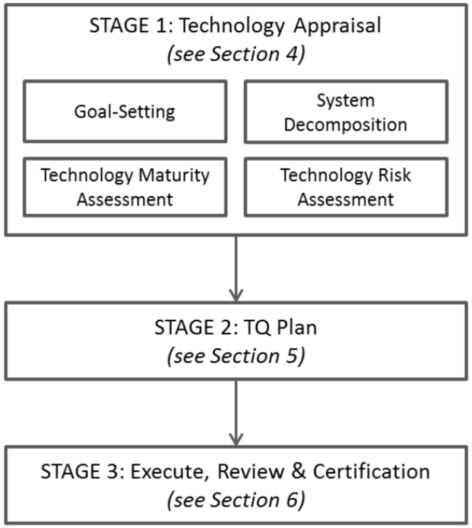
LR Technology Qualification (TQ)



Situation:
Novel technologies or new applications may not be covered by existing rules and standards

TQ Aim:
To identify, create and review the evidence that technology will function reliably within specified limits

- Goals may related to: i) safety, ii) environmental, iii) functionality, iv) performance, v) reliability and vi) availability
- Process typically applied during the early stages of technology development
- Usually cost of assurance and development of qualified technology is high due to requirements for testing

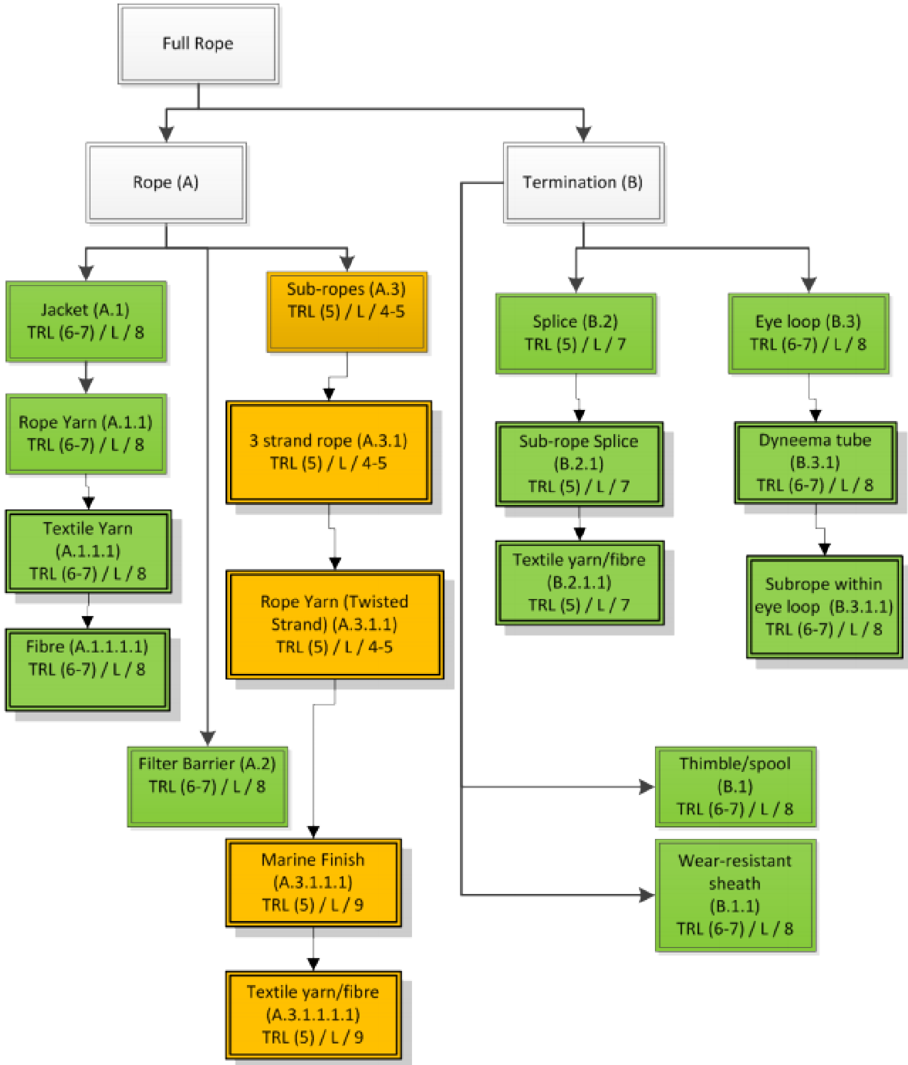
TQ Stage 1

Stage 1: Goals

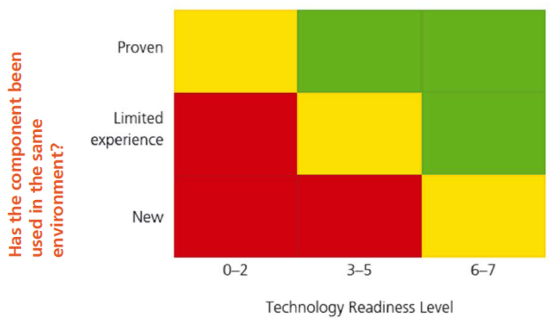
- Ensure mooring line integrity
- Acceptable probability of failure
- Characterizable performance throughout component lifetime
- Accommodate standardised end connections
- Be inspectable
- Block ingress of hard marine organisms into load bearing core
- Limit weight and drag increases due to marine growth
- Not leach materials into the sea

TQ Stage 1

Stage 1: System decomposition and technology maturity assessment



Process involves signposting to codes and standards for proven components



		Technology Qualification Plan Scope
	No new technical uncertainties	No qualification required
	Technology Qualification review medium	Moderate qualification activities
	Technology Qualification review high	More intensive qualification activities

TQ Stage 1

Stage 1: Risk assessment

Potential failures identified using FMEA (i.e. design and operational risks and hazards)

ID (Threat Number)	Component	Function	Failure mode	Failure mechanism or cause	Pre-MRCF Risk Ranking			Start/mid/end life	Comments	MRCF Project contribution	Recommended Actions
					Cons.	Prob.	Risk				
1	Main Line										
2	Nylon 3 strand subrope	Load Transfer	Line Breaking	Excessive load applied	R3	P2	green	100% MBL/95%/90% which reduces safety factor, so initila SF must be higher to compensate		Change in Length Stiffness Tests, break load tests	Mooring design and tank testing to ensure loads within limits, sub-rope and rope break tests
3				Tension-tension fatigue	R3	P3	yellow	As so long small loss life not effect	Excessively long life, not an issue (MOSAIC 10 Million cycle testing)	20 million cycle Tension- Tension fatigue tests	Ensure proper finish and sample test fatigue life
4				Abrasion due to small particle ingress	R3	P2	green	Increase strength loss at linear rate through life	Well tested and developed, filter keeps out all particles		Fit particle filter
5				Creep failure	R3	P3	yellow	1% strain start, 2% mid, 3% end of life. Reduces creep life, but as so long no significant effect	Creep life excessively long, this is more for testing residual life for field specimens #(Evidence is required to support statement)# Evidence is two years and 20 million cycles fatigue testing at 30% mean load, that is equivalent to 100's years at typical pretension 10% See also section 6.3.3 of API 2SM and factor of safety applicable to Nylon Rope from LR OU rules.	Creep testing	Check creep life on yarns and subrope
6				Axial compression	R3	P1	green	Any strength loss will be additive to other effects	Not considered problem for nylon as API2SM states		Model number low tension cycles as check
7				External abrasion seabed	R3	P3	yellow	Any strength loss will be additive to other effects, this is considering prelay of the rope on seabead but not under tension			Apply extra coatings or buoyancy to keep line off seabed

TQ Stage 2

Stage 2: TQ plan development

Novel components -> Determine why technology is immature/risks high -> Specify risk mitigation activities/methods -> Assess against acceptance criteria

System	Description of failure mode	Failure causes	Results of initial screening (RR)	Threat #	QA ID	Qualification activity	Mitigation / Qualification methods and activities	Acceptance criteria for each qualification activity	Track to goals	Test procedures and plans (Reference to detailed test plan document -document reference number)	Other Studies & Tests		
1.Nylon 3 strand subrope	1.Line Breaking	Excessive load applied	green	2	1	rope break tests	Mooring design and tank testing to ensure loads within limits, sub-rope and rope break tests	Conduct rope break tests to ensure meets minimum strength criteria - RKS - What are the minimum strength criteria? - 1000tonnes? For the expected temperature range (3-30deg in goals) SJB agree those parameters and applies to rope only	Survive loads of up to 1000Te	BL and Stiffness testing on nylon sub-rope			
					2	response modelling	Mooring design and tank testing to determine loads	Confidence in mooring loads in expected design sea states for the weight and dynamics of the floating structures (50year wave and tidal condition with a maximum 20tonne structure)		Modelling report required			
		Tension-tension fatigue	yellow	3	3	Fatigue tests	Ensure proper finish and sample test fatigue life	Conduct short and long term fatigue tests	Residual strength is high and S/N curve gives long fatigue life	Fatigue testing on nylon sub-rope FINAL REPORT FOR WP2.1	The suitability of nylon rope for moorings M3 report for WP1	The suitability of nylon rope for moorings Report for WP1 M4	
		Abrasion due to small particle ingress	green	4	4	Particle test	Fit particle filter	Must keep out particles down to 5 micron	Block particles	API 2SM and ISO			
		Creep failure	yellow	5	5	Creep strain and stress relaxation test	Check creep life on yarns and subrope	Conduct creep tests to measure elongation	Predict creep performance	Creep not conducted in this or previous studies for nylon. Implicit in short and long term fatigue tests, if creep rupture were an issue failures would have occurred in the extreme high load tests			
		Axial compression	green	6	6	Low minimum load Fatigue tests	Model number low tension cycles as check	Fatigue test to low minimum loads	No major degradation	Effect of mean load & low min load on fatigue endurance of nylon fibre ropes WP1 Milestone 3 Report			
		External abrasion seabed	yellow	7	7	Abrasion tests, buoyancy design	Apply extra coatings or bouyancy to keep line off seabed	Wear not to go through protective cover and /or sufficient buoyancy	Ensure mooring line integrity	Not conducted in this or previous studies for nylon			
		Hysteresis heating	green	8	8	Cyclic load test	Test load ranges and cycles and measure temperature	Temperature rise limited to material and strain range	Ensure mooring line integrity	Fatigue tests conducted at very high load range well beyond expected in any mooring and no heating found. TTI also has confidential data.	Fatigue testing on nylon sub-rope FINAL REPORT FOR WP2.1	The suitability of nylon rope for moorings M3 report for WP1	The suitability of nylon rope for moorings Report for WP1 M4

TQ Stage 3

Stage 3: Qualification activities

- QA3 Nylon 3 strand sub rope: Tension-tension fatigue
- QA5 Nylon 3 strand sub rope: Excessive creep
- QA7 Abrasion on sea-bed
- QA10 Rope yarn tension-tension fatigue
- QA15 Yarn imbalance
- QA16 Inter-strand abrasion
- QA17 Loss of marine finish due to sea water washing

Output: List of Recommendations for Certification

TQ Stage 3

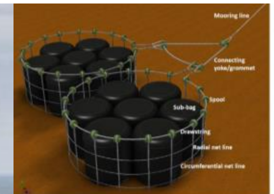
Stage 3: QA3 Nylon 3 strand sub rope: Tension-tension fatigue

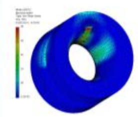
- Rope supplied by Bridon for 20M fatigue tests
- Rope tubular sleeve “over braid” by Culzean
- Rope splices designed and splices made by TTI
- 8 break tests (5 Bridon 3 TTI)
- 1 x fatigue test
- Test completed March 2016 and witnessed by LR

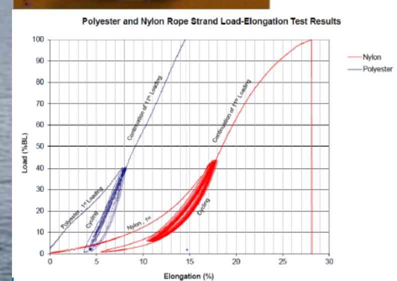
Wet nylon subropes subjected to 20,000,000 load cycles had a residual strength level of 108% (based on average new breaking strength).

Ideol Floatgen case study

(2014-2016) Testing, Qualification & Commercialisation of Synthetic Mooring System







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FaB Test
Lloyd's Register
DNV·GL
TENCATE materials that make a difference
BRIDON
UNIVERSITY OF EXETER
Orion Energy Centre

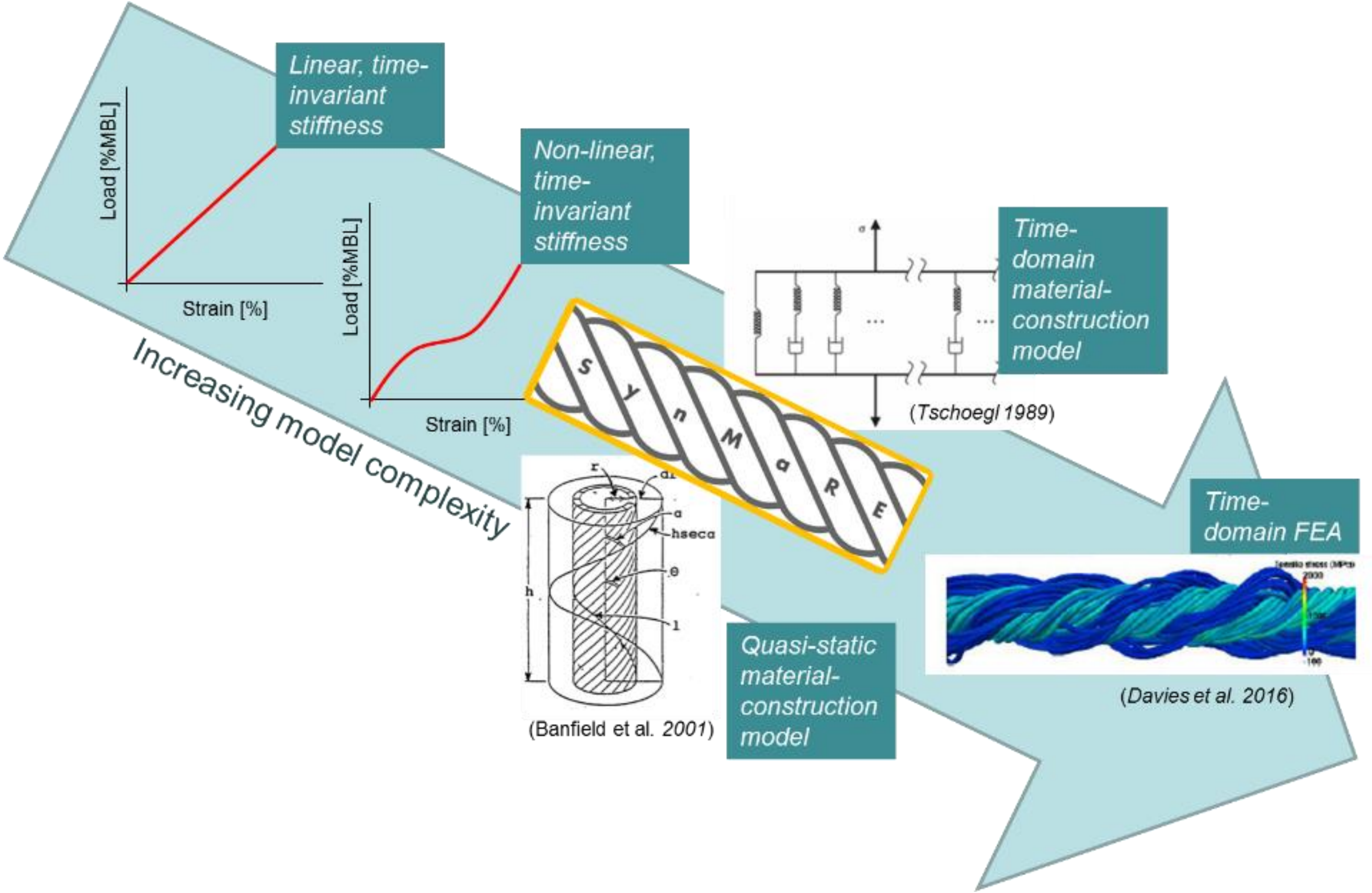
FLOATGEN displacement ~6000T
Water depth = 32m
Extreme design Hs = 9m

Peak line tensions using nylon mooring limbs (~3500kN, 30% to 50% lower than other options considered).

Hardware cost which was 20% lower than the polyester solution and <50% lower than an all-chain system

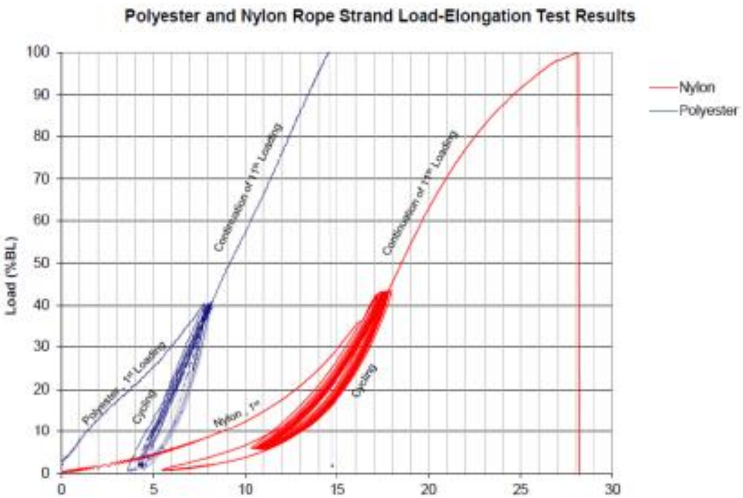
The installation time of synthetic semi-taut system was estimated to be 17% lower than for a chain system.

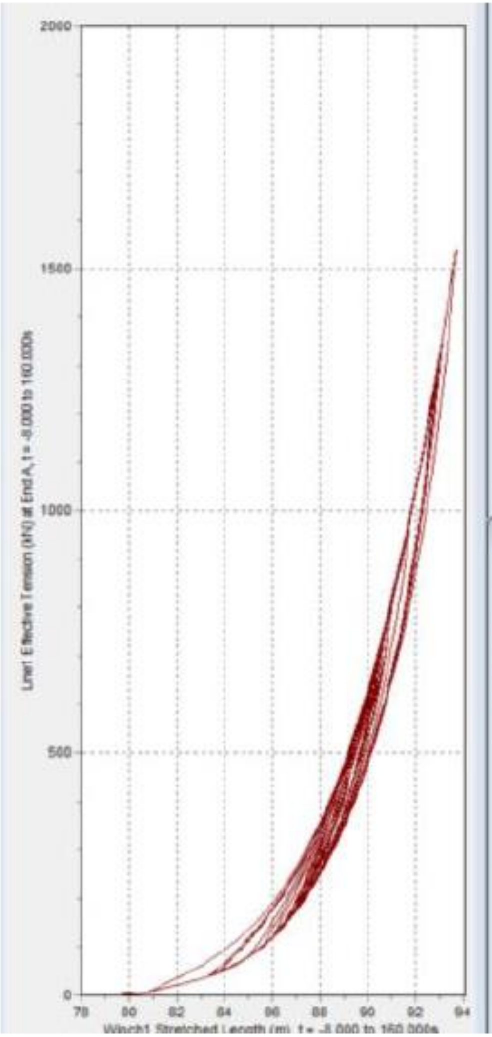
A high level view of synthetic rope modelling

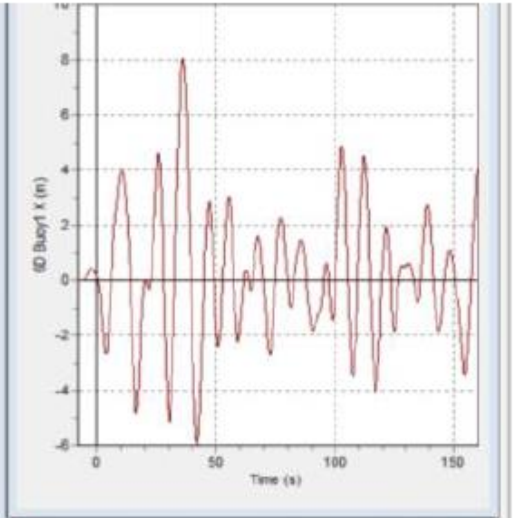


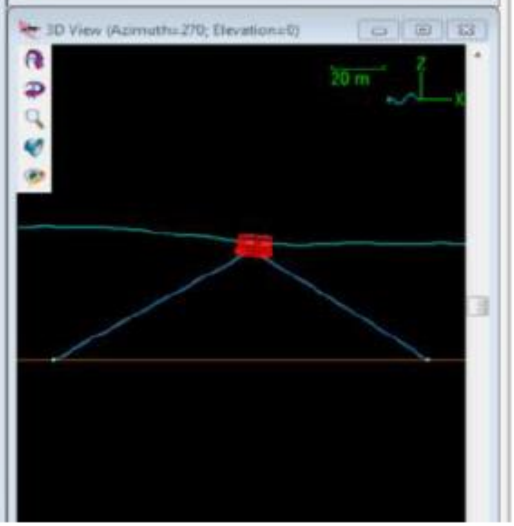
Rope modelling in the MRCF project

Focus on modelling nylon rope stiffness and developing guidelines







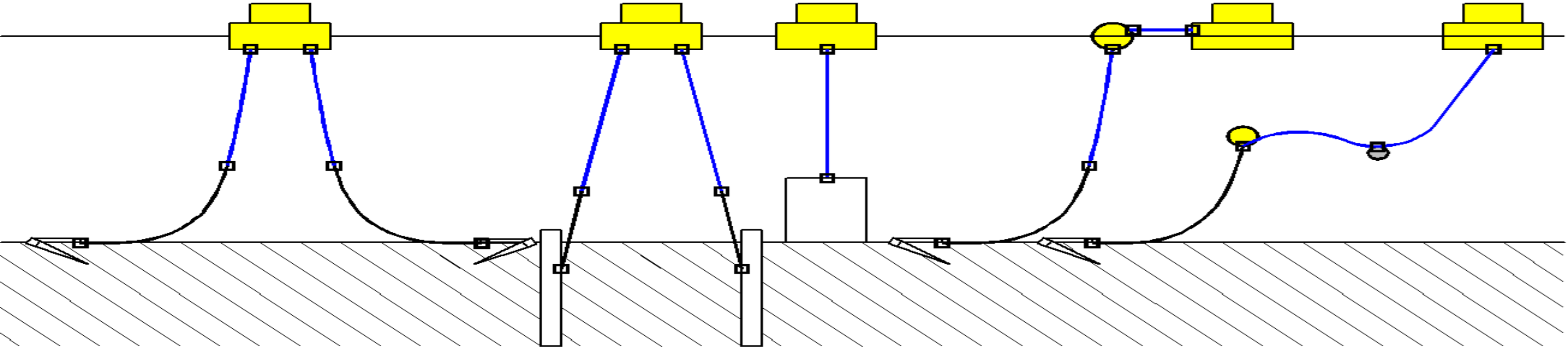


Marine Renewables Commercialisation Fund (MRCF) key outcomes

Key Outcomes

- **Completed extensive rope testing programme for nylon. Key tests witnessed by Lloyd's Register**
- Lloyd's Register facilitated **FMEA approach to qualification of nylon** with input from all project stakeholders (High TRL)
- **Lloyd's Register Statement of Compliance Nylon Qualification**
- Developed new technique **for modelling non-linear and hysteresis stiffness of nylon and guidelines**
- Completed **validation trials of Orcaflex** via tank tests of dummy buoy
- Completed **qualification plan for anchor bag design** (DNV-RP-203)
- **Design & manufacture of 10 x 50T capacity gravity bags**
- **Deployment and recovery trials of single anchor bag**
- Completed **cost benefit assessment of technology** for range of generic device sizes, environments and water depths, also partner devices
- **Chain costs can be an order of magnitude bigger than nylon, as chain needs a bigger break load to satisfy Min FOS.**
- **Array densities in MW/km2 are significantly improved.**

Other relevant projects

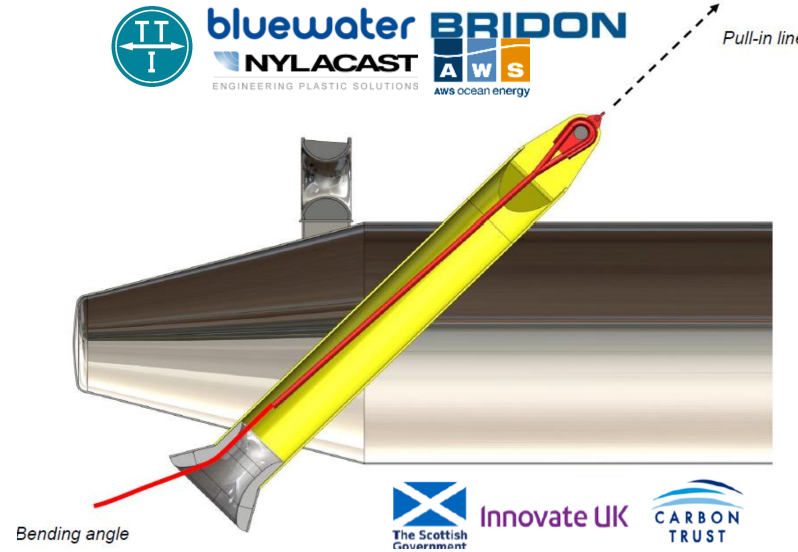


Marine Energy: Supporting Array Technologies (MESAT)

2013-2016

Synthetic Fibre Rope Polymer Line Fairleads

- Light weight, no heavy chain or handling equipment
- Reduced maintenance
- No fatigue issues, unlike many bending fatigue failures in chain
- Fast and easy hook-up/disconnect using light rope



Line bend testing (18° wrap angle)

Development and testing of fairleads and jackets

H2020 ERA-NET Cofund DemoWind

2016-2019

Simulate, implement and demonstrate the technical and economic viability of a twin-turbine floating solution by testing a 1:6 scale platform at a sea testing site (PLOCAN, Canary Islands) in order to achieve a TRL of 6.

- Development & correlation of hydrodynamic models with tank tests.
- Benchmarking conventional steel moorings with synthetic based moorings
- 6th scale mooring design & analysis to specify mooring
- Site selection at PLOCAN
- Procurement and supply of 6th scale mooring
- Commercial scale mooring FEED
- Market & Economic studies

Department for Business, Energy and Industrial Strategy

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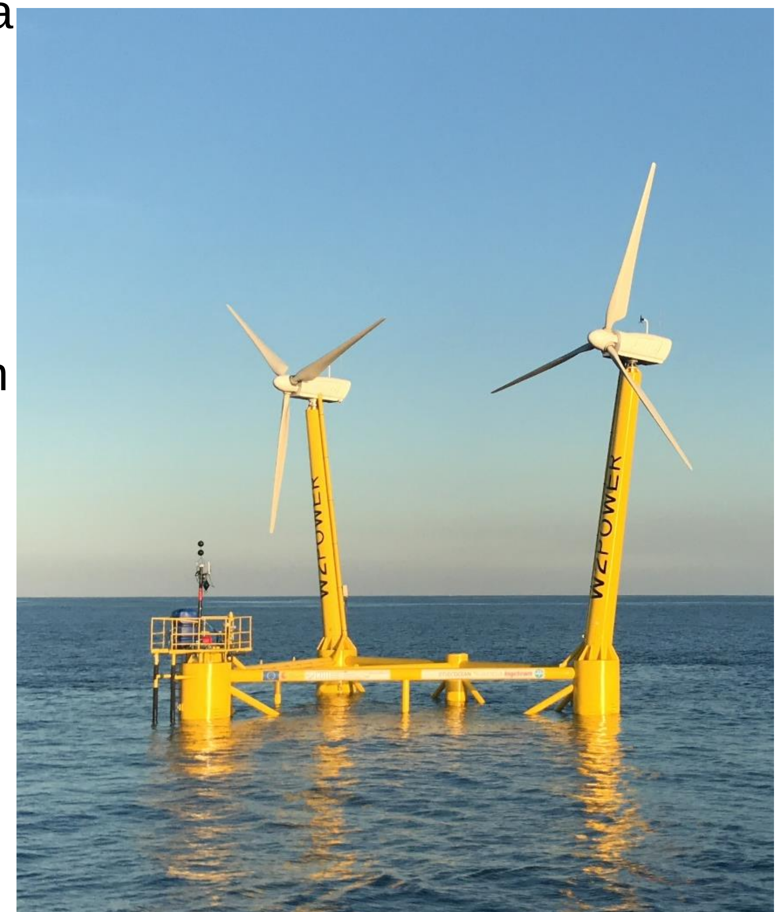
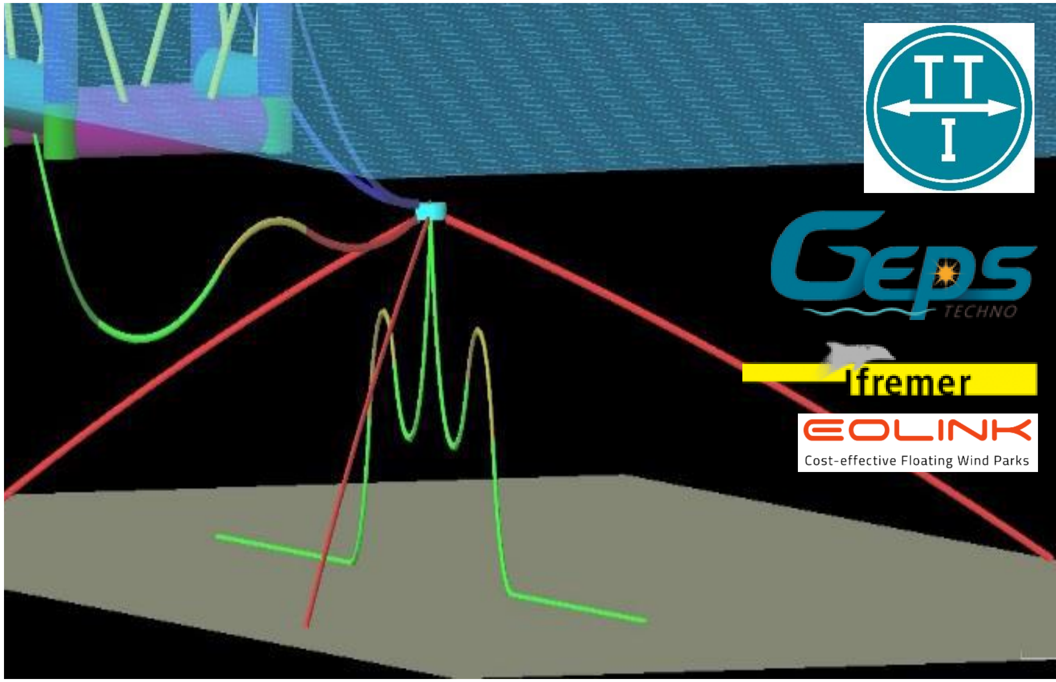


TIM- Towards an Industrialized single point Mooring system

2018-2020

To develop fit-for-purpose, standardized single point mooring subsystem which would cover the needs of most floating MRE converters and FWTs and their associated output power range.

- Experimental testing campaign at 1/10 scale
- Design of a single point mooring system for a multi MW device (based on the EOLINK prototype) and for a multi-kW device developed by GEPS TECHNO.
- Associated benchmarking on logistics, cost-benefits and environmental impact



Future Needs

Requirements

- **No approved supplier of nylon yarn currently exists worldwide** (for example approval to DNV TAP 322)

- **Current guidance may not be the best fit, commercially or technically, for the ORE sector**, for example, the scope and extent of the ‘3-T’ (tension, time and temperature) approach to testing

- **Concern (from rope manufacturers and developers) about the costs associated with extensive testing and certification.** These costs would be easily absorbed by rope orders for the first large commercial ORE farms.

- **Larger scale commercial ORE systems are expected to require lines which have an MBL well in excess of 1000T**. The impact of this on testing, qualification and certification requirements should be explored

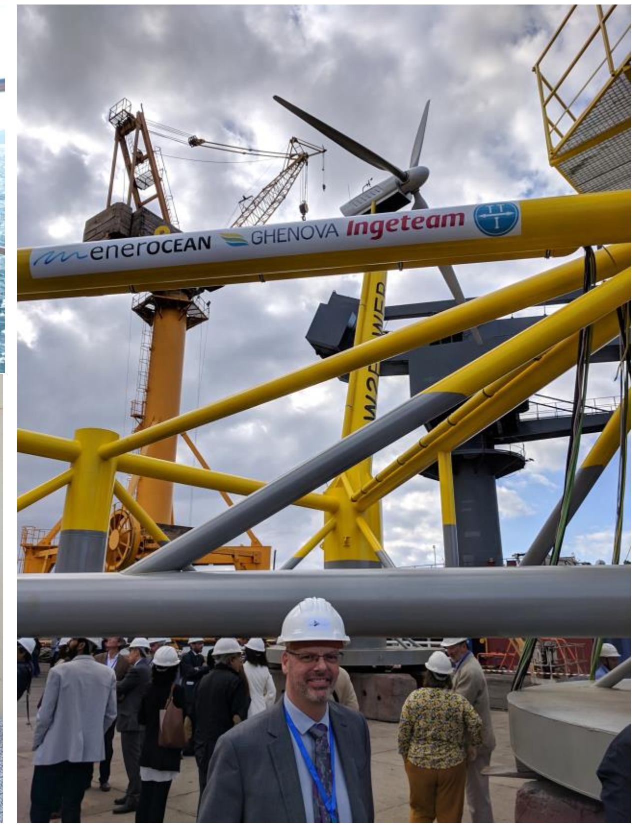
- **Robust modelling techniques are required** to represent short- and long-term performance of fibre ropes in this application

Contact

Sam Weller
weller@tensiontech.com

Ben Yeats
yeats@tensiontech.com

Stephen Banfield
banfield@tensiontech.com



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