Fibre Rope Mooring for Floating Wind Turbines

EERA DeepWind 2021 - Digital conference

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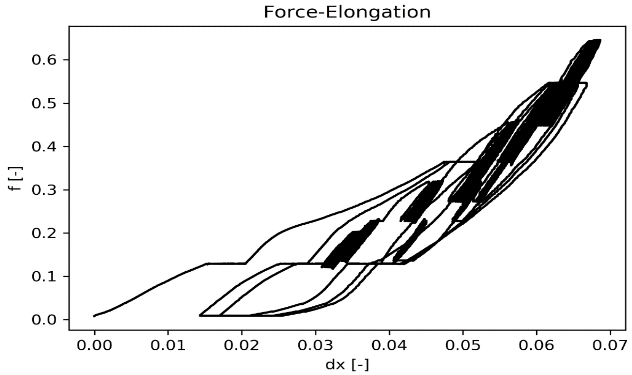
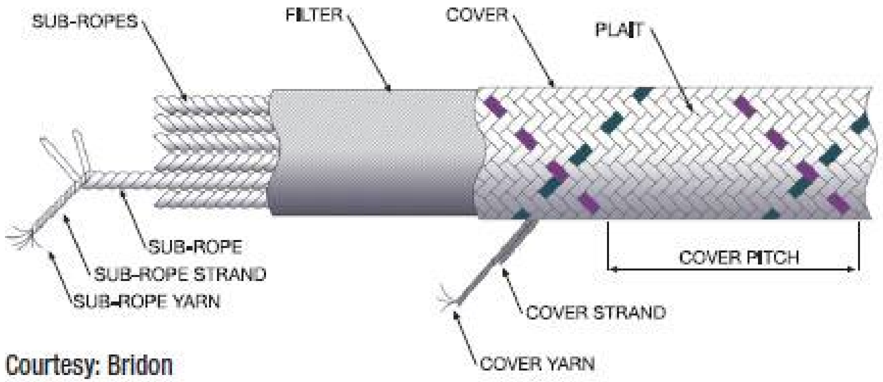


Outline

- Introduction: Why fibre ropes ?
- Fibre rope properties, typical test data
- The SYROPE model and implementation in 3DFloat
- Testing of nylon ropes at DNV GL
- Summary
- Extra slides not covered by the oral presentation
  - Overview of the FIRM project
  - Design examples; steel chain, polyester and nylon systems



Courtesy: Bridon

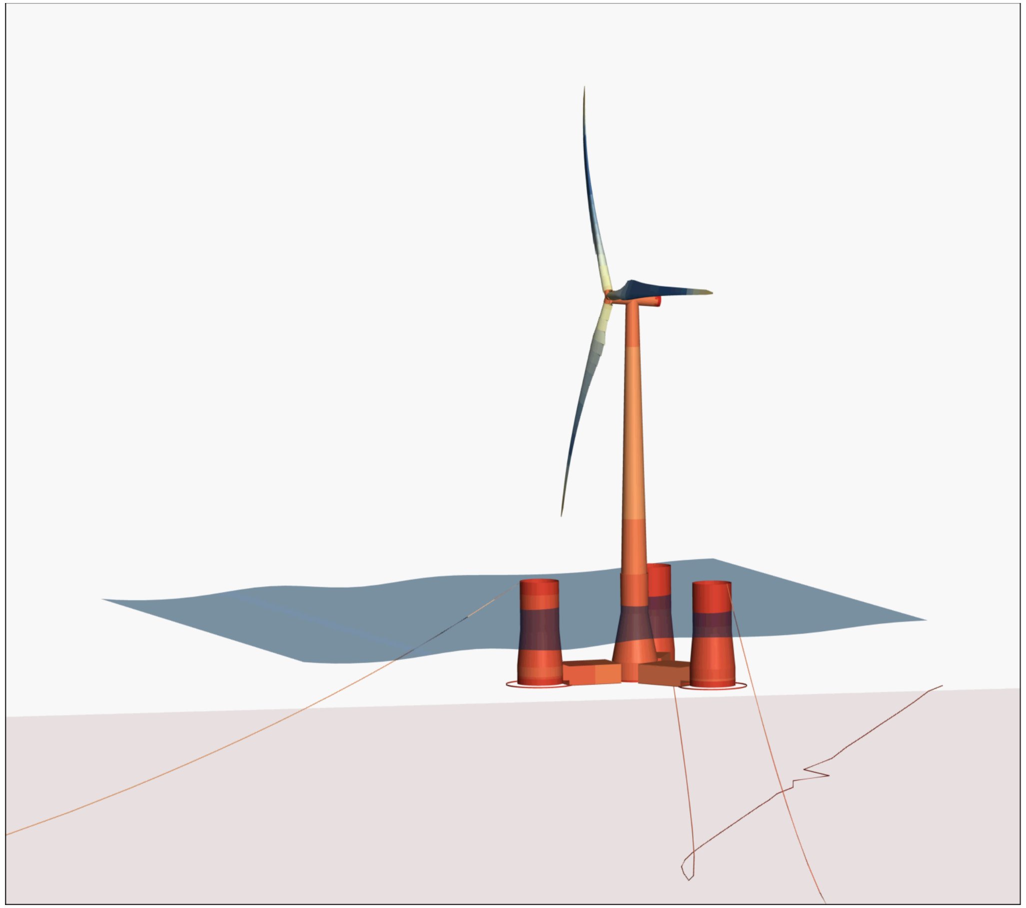
Why fibre ropes instead of steel wires and chains ?

- Lighter weight
- Better fatigue performance
- Smaller platform offsets
- Potential cost reductions of more than 40% compared to chain mooring systems
- Issues: Micro-plastics ?

Mooring chain for Ichtys field

Installation of polyester mooring line (Bozorgmehrian, et al., 2013)

Analysis and optimization of offshore wind turbines

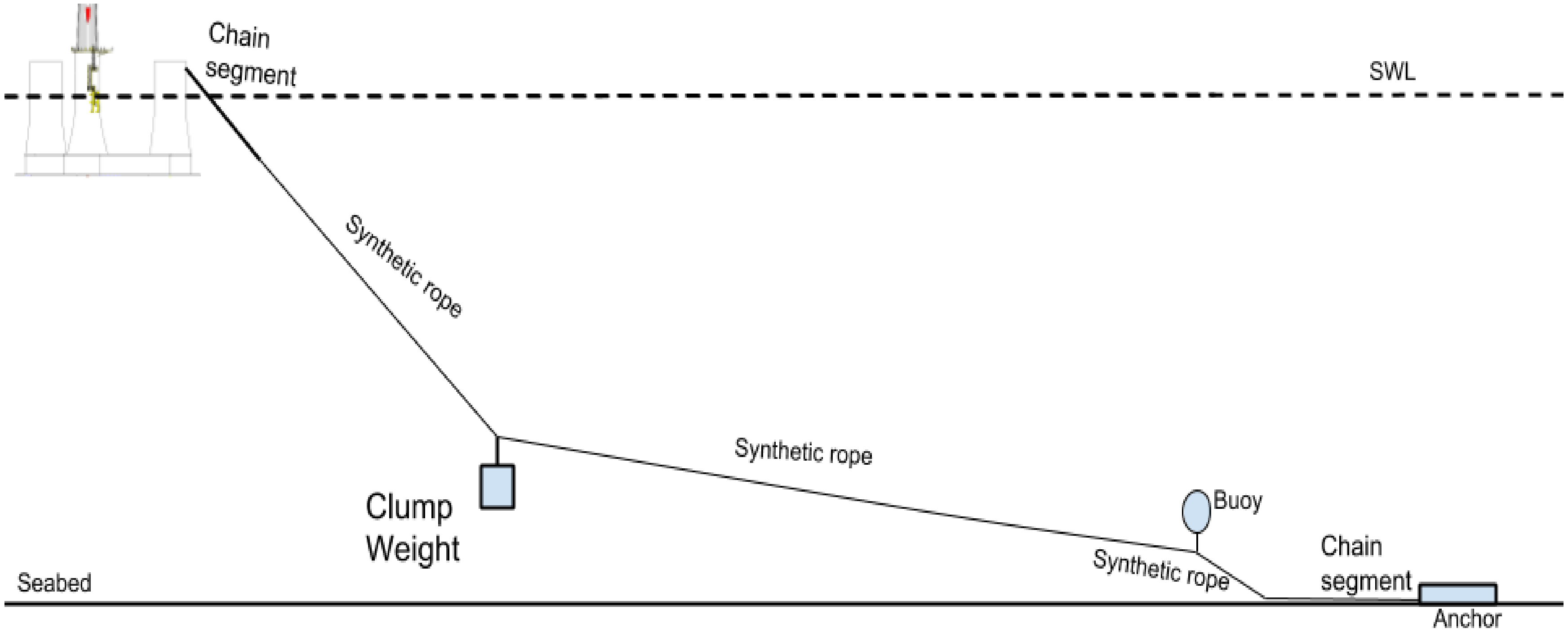


Example:

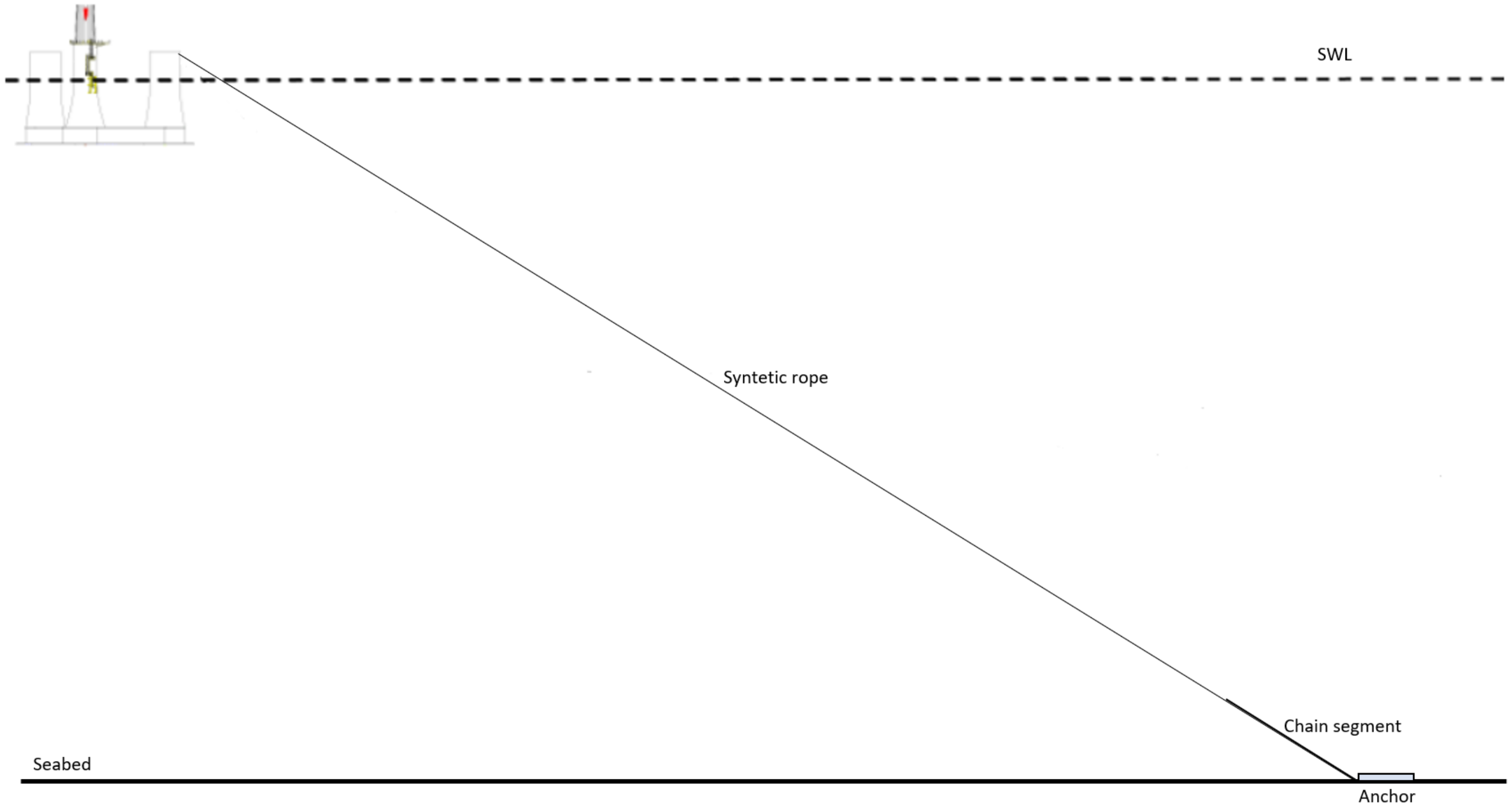
- OO Star Wind Floater
- DTU 10MW Rotor
- Catenary chain system
- Suction anchors

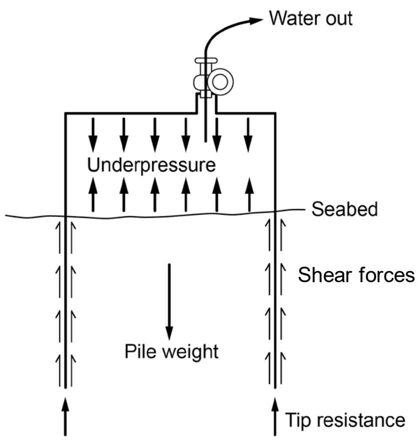
Nygaard, T. A., De Vaal, J., Pierella, F., Oggiano, L. and Stenbro, R. (2016). *Development, Verification and Validation of 3DFloat; Aero-Servo-Hydro-Elastic Computations of Offshore Structures.* Energy procedia 2016, Vol. 94, pg. 425-433

Baseline Polyester Fibre Rope System, 150m depth



Taut Leg Systems, Polyester and Nylon, 800m depth



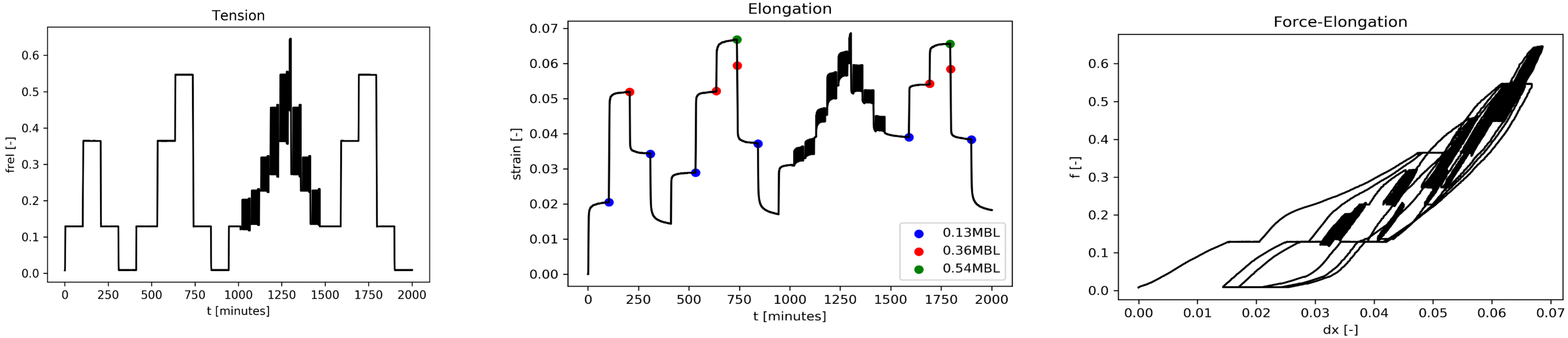


Suction anchors

Polyester Test Data Example

Courtesy of Lankhorst Euronete Portugal

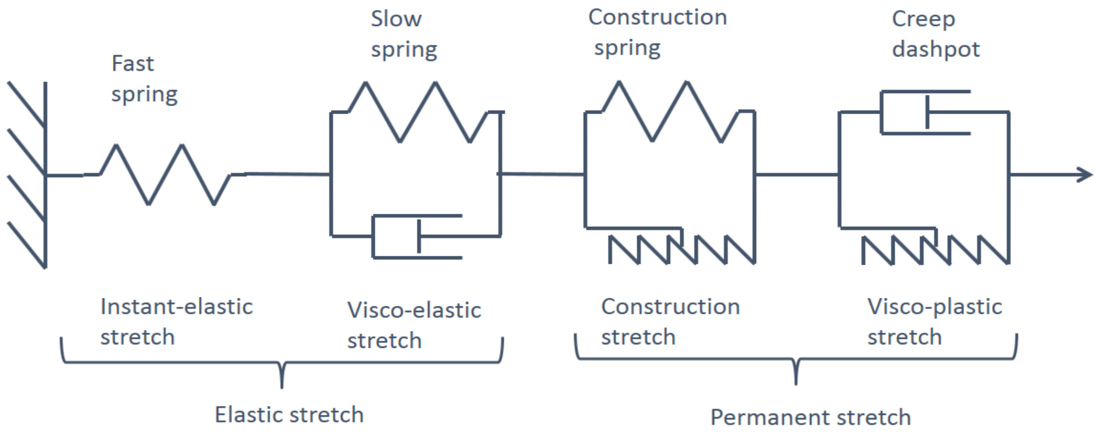
The axes have been normalized to obscure competition sensitive data.



1. Bedding in: Change tension in steps over 2 minutes, hold for 100 minutes
2. Dynamic stiffness test: Cycle with frequencies of 1/120s (surge) and 1/15s (wave frequency)
3. Quasi-static stiffness evaluation between equilibrium points before and after dynamic stiffness test

- For each step change in tension, we get an instant-elastic response, followed by a slower visco-elastic response with main time constant around 20 minutes.
- The axial stiffness of the rope can be seen as the slopes in the right graph. The quasi-static stiffness observed during bedding in, is less than half the stiffness observed during the dynamic stiffness test.
- The colored dots in the strain graph correspond to equal tension levels. The rope gets a permanent elongation due to construction- and visco-plastic stretch

Overview of the SYROPE element



The implementation of the SYROPE element in 3DFloat follows the work of Falkenberg et al. at DNV GL:

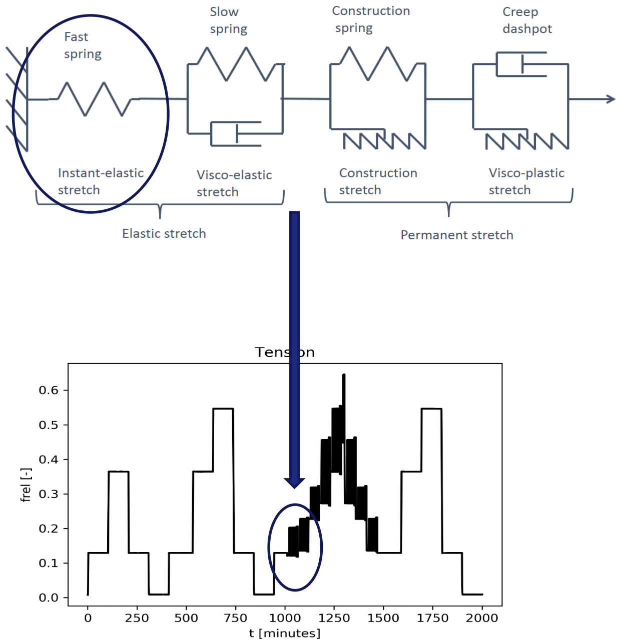
Falkenberg, E., Åhjem, V. and Yang, L. (2017). *Best Practice for Analysis of Polyester Rope Mooring Systems*. Offshore Technology Conference, Houston, Texas, USA, 1–4 May 2017.

Falkenberg, E., Yang, L. and Åhjem, V. (2018). *The syrope method for stiffness testing of polyester ropes*. Proceedings of the ASME 2018 37th International Conference on Ocean, Offshore and Arctic Engineering, OMAE2018

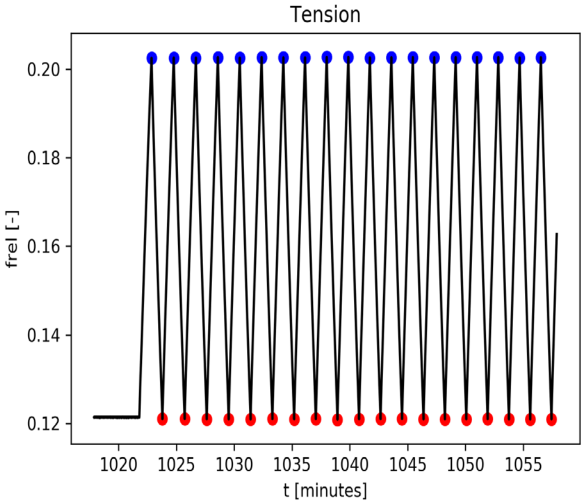
More recommended reading for modelers of offshore wind turbine dynamics:

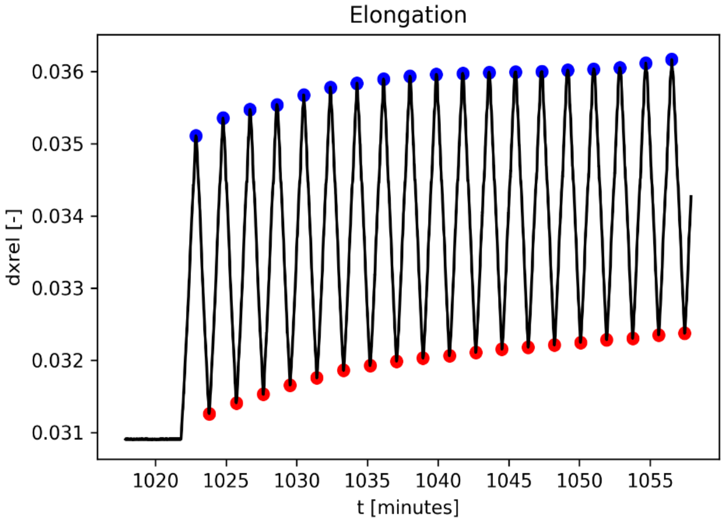
Flory, J.F., Banfield, S.P and Petruska, D.J (2004). *Defining, Measuring, and Calculating the Properties of Fiber Rope Deepwater Mooring Lines.* Offshore Technology Conference, Houston, Texas, USA, 3-6 May 2004.

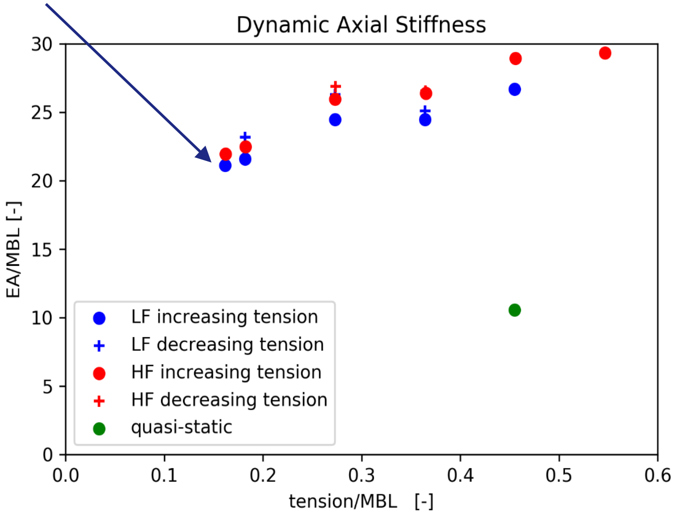
Instant-elastic stretch



- Axial stiffness in response to «rapid» changes in tension (wave and surge frequencies, periods 15s and 120s)
- Modeled as linear function of mean tension. To a lesser degree function of frequency and amplitude.
- When modelling fibre rope systems with standard linear-elastic cable elements, the axial stiffness must be chosen for each load case
- The stiffness plot below, right is generated from the dynamic stiffness test. Closeups for one tension level and frequency are shown on the left and middle graphs

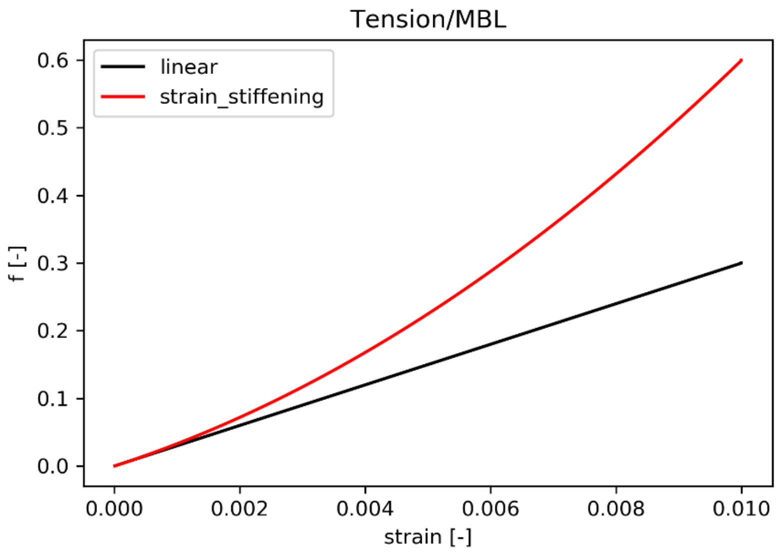






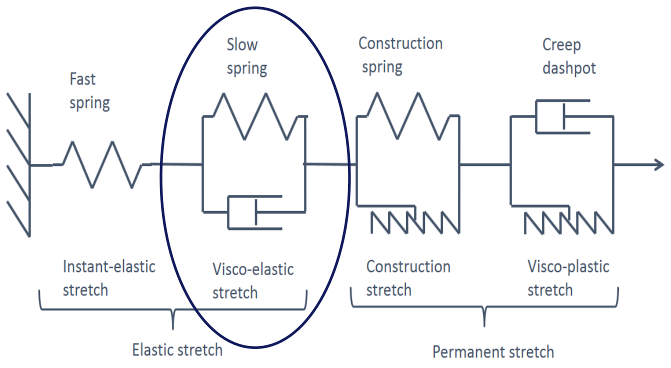
Instant-elastic stiffness vs. mean tension

- The increase of instant-elastic stiffness with mean tension is implemented in 3DFloat as material-specific secant strain-stiffening. This method is robust in the Finite-Element formulation in 3DFloat.
- User input:
  - Material name
  - Time constant used for computation of time-filtered strain
  - Reference strain
  - Strain stiffening slope for each of the components in the stiffness matrix that are to be adjusted.

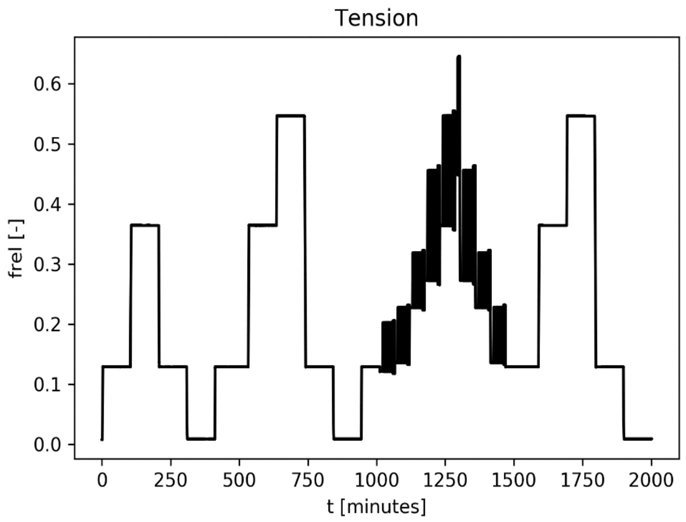


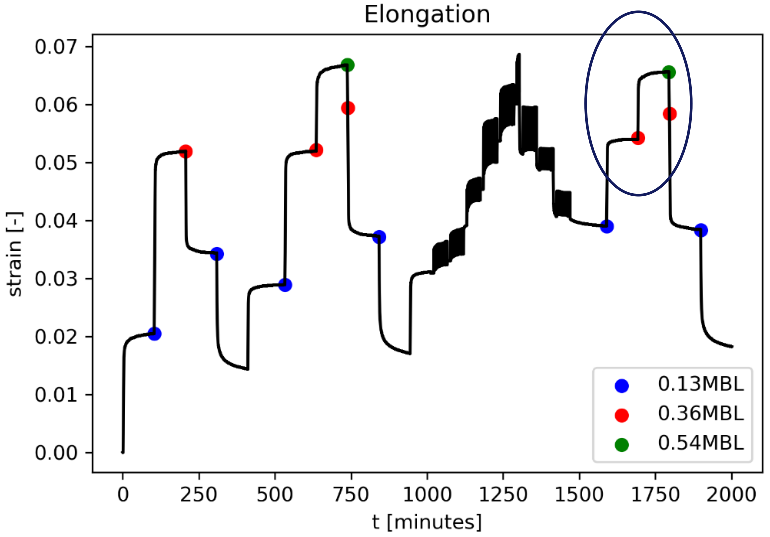
Visco-elastic stretch

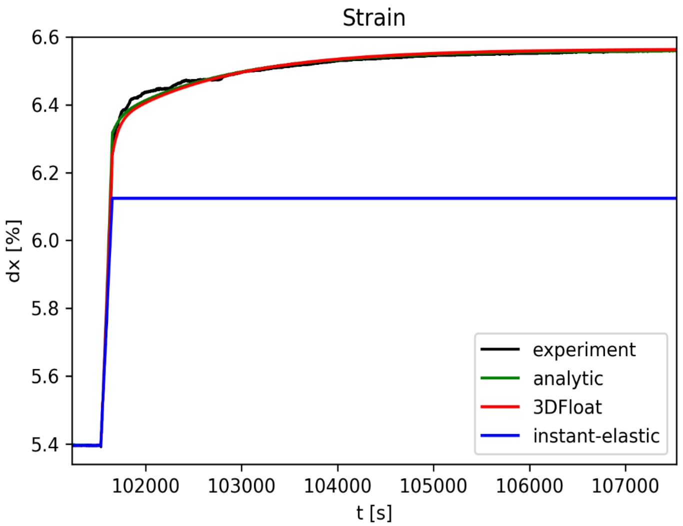
Two sets used here



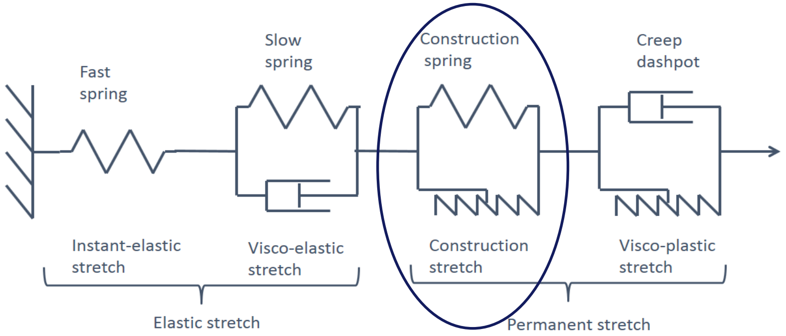
- Elasticity is usually the result of bond stretching along crystallographic planes in an ordered solid. Elastic materials strain under stress and immediately return to their original state once the stress is removed.
- Viscosity is the result of the diffusion of atoms or molecules inside the material. The material responds to stress with a time-dependent strain rate
- The figure shows 3DFloat simulation and experiment response to one of the tension steps in the test shown earlier. Two spring/damper sets with time constants of 80s and 20 minutes were used

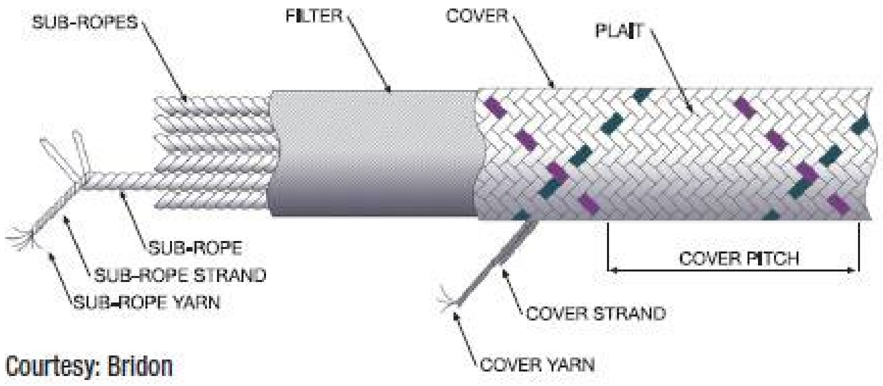






Construction stretch

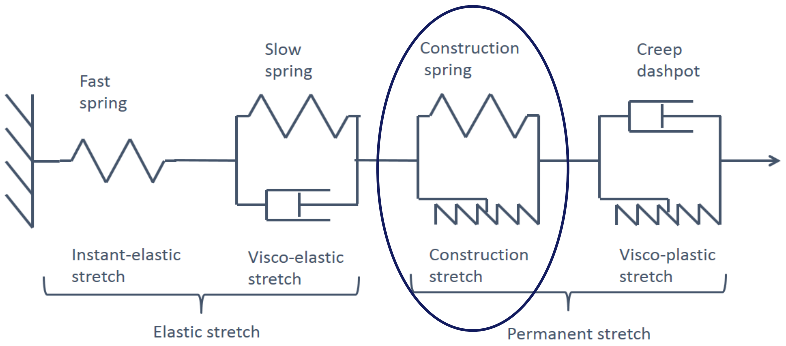


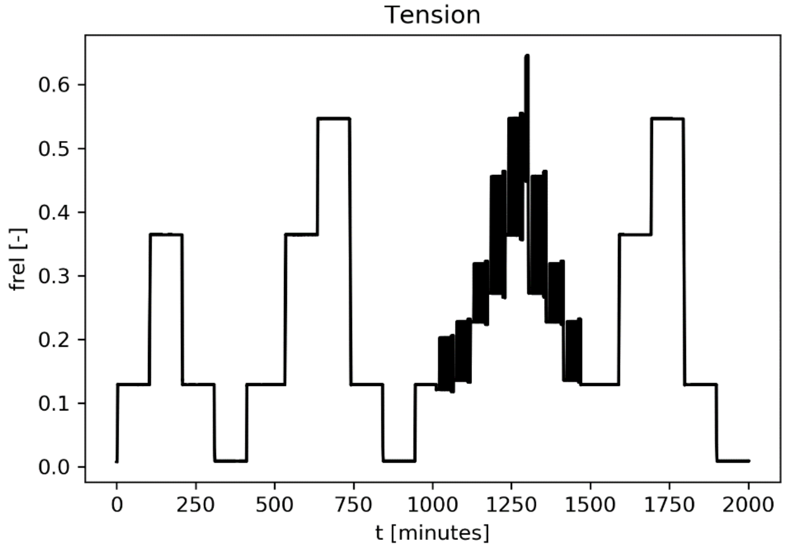


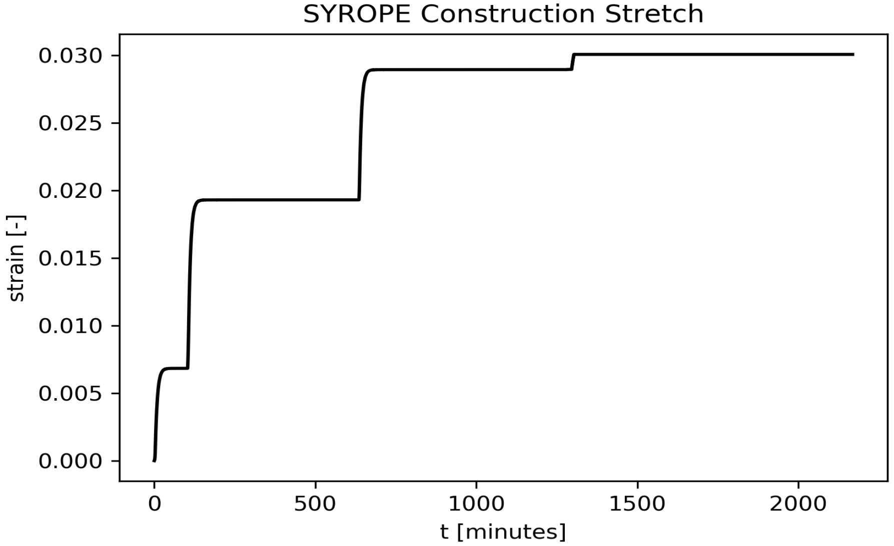
- Individual fibers are twisted into yarns
- The yarns are twisted into strands
- Strands are laid or braided to form the rope.
- When the rope is first tensioned, the various yarns and strands compact and realign, and the lay length of the yarns and strands in the laid or braided rope increases. These actions cause the rope length to increase. This process is sometimes called bedding in (Flory et al., 2004)
- The increase in length is the construction stretch.
- Unless tension is completely removed and the rope bent, the construction stretch is permanent, often nearly linear vs. tension, and reacts relatively quickly to tension exceeding previous tension history.
- A simple and intuitive model is a spring and ratchet in parallel.

Flory, J.F., Banfield, S.P and Petruska, D.J (2004). *Defining, Measuring, and Calculating the Properties of Fiber Rope Deepwater Mooring Lines.* Offshore Technology Conference, Houston, Texas, USA, 3-6 May 2004.

SYROPE Model of Construction Stretch
3DFloat Simulation

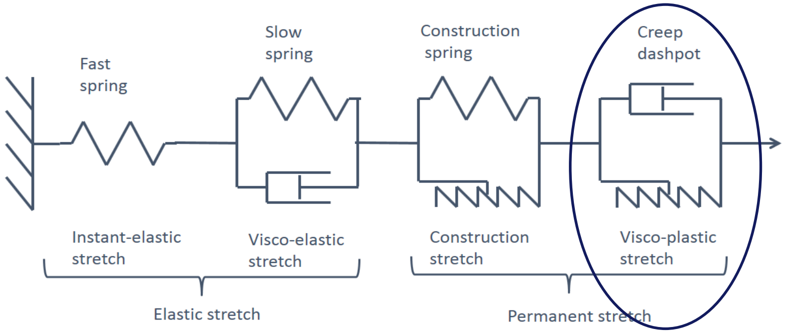




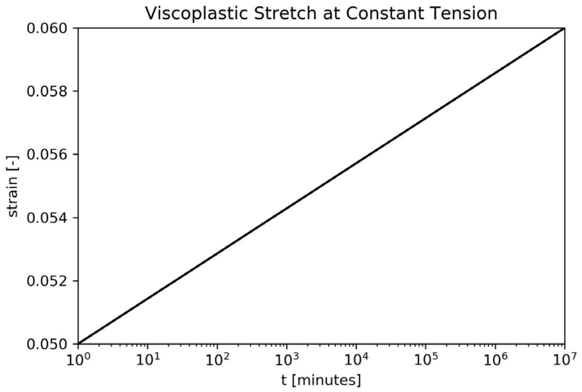


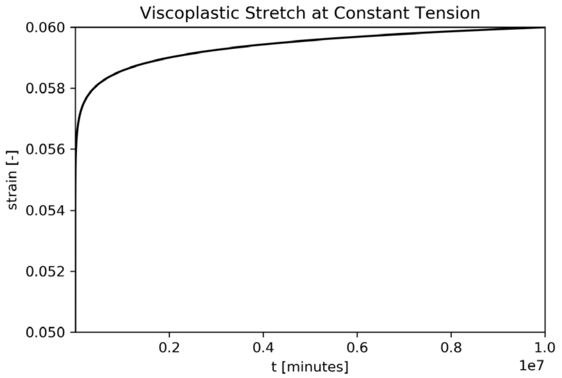
Each time the tension exceeds the previous max tension, the ratchet expands, and cannot compress again. This is a permanent elongation of the rope. The scale is arbitrary

Visco-plastic stretch

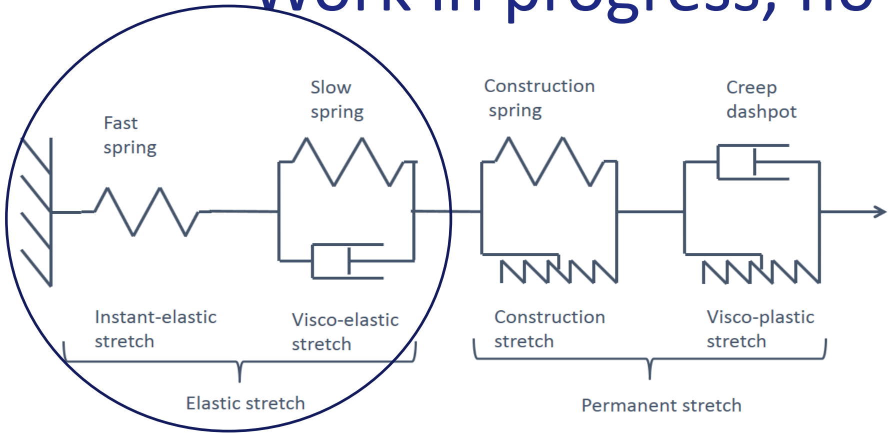


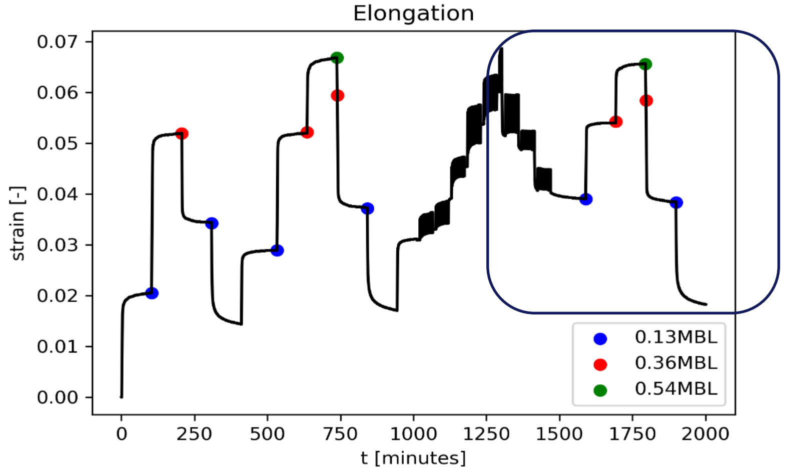
- Permanent elongation after prolonged application of loads.
- Continue to undergo a creep flow as a function of time under the influence of the applied load.
- Example of simple model is creep dashpot (damper) in parallel with ratchet.
- Tests for polyester yarns (Flory et al., 2004) show that for constant tension, strain is proportional to the logarithm of elapsed time. Yarns and complete ropes behave in a similar fashion regarding creep. The two figures below with semilog and linear time axes show typical shapes of test results for creep tests of polyester ropes.
- Work is in progress to implement a damping constant in the creep dashpot changing according to the load history.

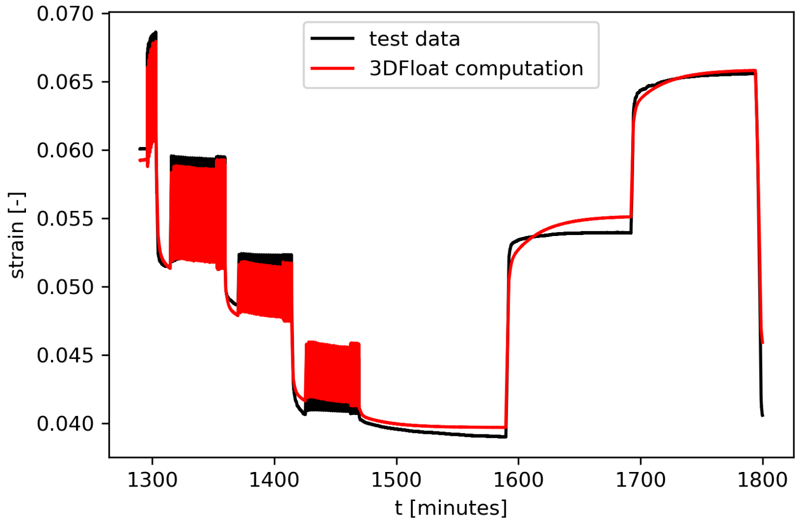


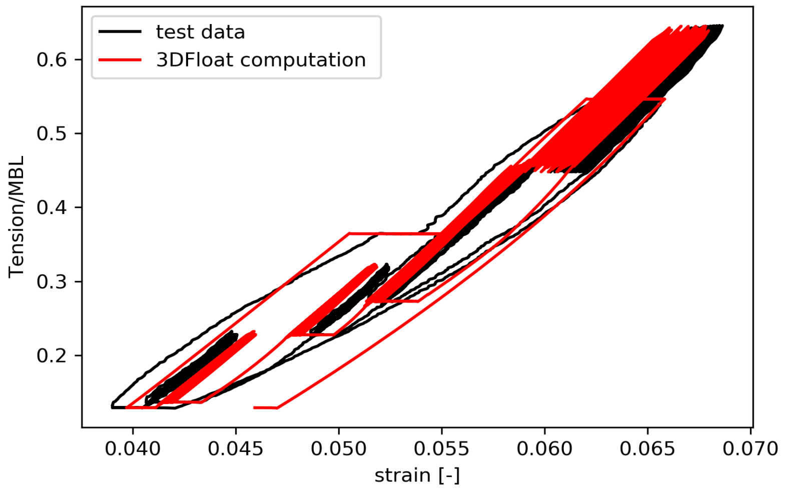


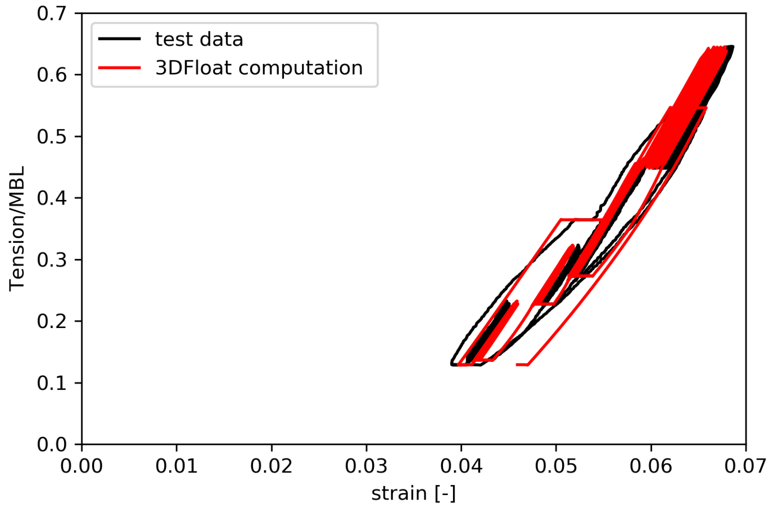
Preliminary results: Dynamic and quasi-static stiffness simulation
Work in progress, no construction- or visco-plastic stretch





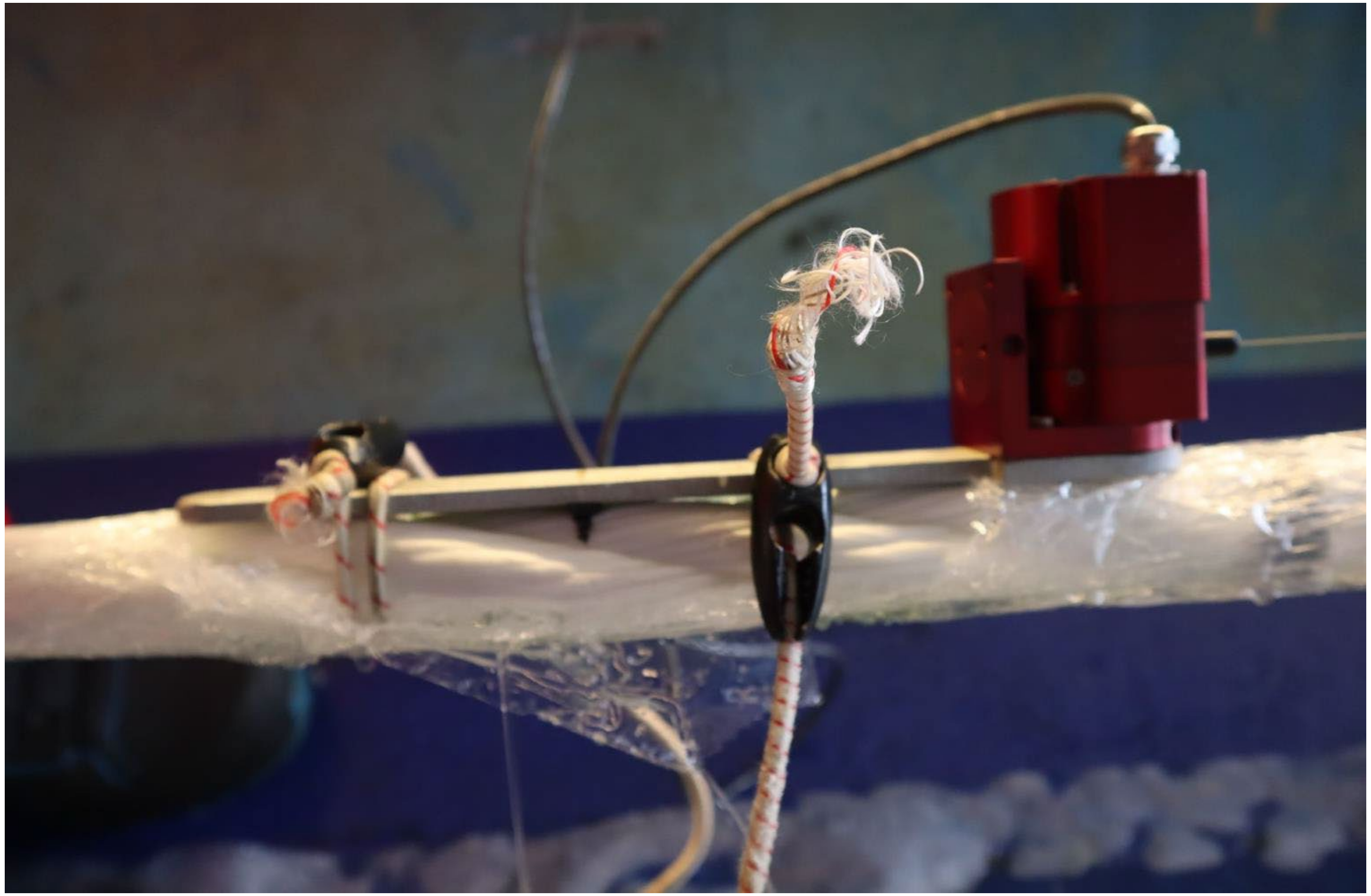






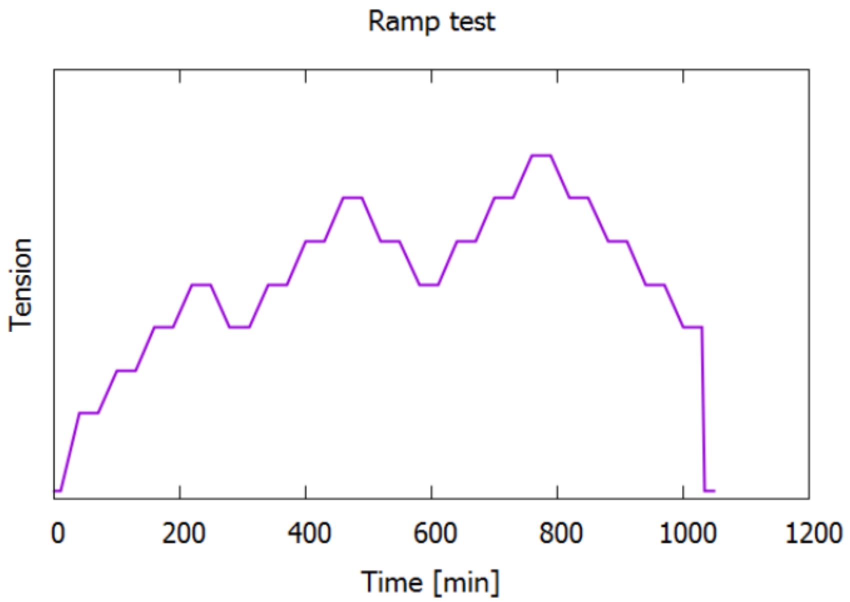
Nylon Rope test at DNV GL, Bergen

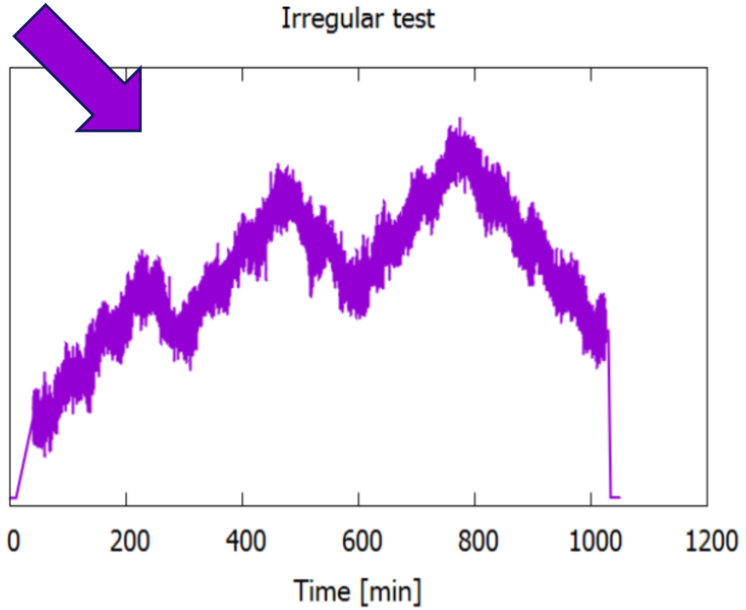
- For a given Minimum Breaking Load (MBL), nylon ropes have lower axial stiffness than polyester ropes. This is attractive for taut leg systems.
- We need more knowledge about properties
- Tests at DNV GL early 2021
  - Ropes from 3 rope supplier project partners
  - Creep test
  - Dynamic stiffness test



DNV GL Technology centre for offshore mooring and lifting, Bergen, Norway

Measuring dynamic stiffness





DNV GL Technology centre for offshore mooring and lifting, Bergen, Norway

Summary

- Fibre rope mooring systems for floating wind turbines can potentially cut mooring costs in half compared to chain systems.
- Utilization is hampered by lack of data for long term properties, in particular for nylon, lack of detailed Finite-Element representations of fibre ropes in software for design an analyses, and lack of experience with fibre ropes for wind energy engineers.
- The SYROPE model for fibre ropes have been implemented in the simulation tool 3DFloat, except for the visco-plastic model for long-term evolution of creep, which is ongoing.
- Preliminary simulations of a dynamic stiffness test for a polyester rope show fair agreement between experiment and simulation. A full validation will be performed when the implementation is finished, and the nylon rope test is finished.
- Creep and dynamic stiffness tests on nylon ropes from 3 suppliers are just about to start at DNV GL Technology centre for offshore mooring and lifting, Bergen, Norway.

Acknowledgements

- The FIRM project has been funded by the Norwegian Research Council and the Industry partners Equinor, Aibel, Bridon-Bekaert, DSR Corp Europe and Lankhorst Euronete Portugal.
- The following group of suppliers deliver in-kind contributions on equipment, costs, procedures for installation, maintenance, condition monitoring and decommsissioning: Bridon-Bekaert, DSR Corp Europe, Lankhorst Euronete Portugal, Hendrik Veder Group, Kongsberg Maritime, Seasystems (former Scana Offshore), H. Henriksen, Energy Valley NCE Energy Technology and SEMAR.
- The fibre rope suppliers Bridon-Bekaert, DSR Corp Europe and Lankhorst Euronete Portugal deliver rope samples for the testing and detailed data on fibre ropes.

Extra Slides

Norwegian Research Council IPN Project
Fibre Rope Mooring (FIRM)
Participants

- **Project management**: Aibel
- **Research partners** : IFE, Dr.techn Olav Olsen, NORCE and NGI
- **Funding, equipment and in-kind efforts**: Norwegian Research Council, Equinor, Aibel, Bridon-Bekaert, DSR Corp Europe, Lankhorst Euronete Portugal, Hendrik Veder Group, Kongsberg Maritime, Seasystems (former Scana Offshore), H. Henriksen, Energy Valley NCE Energy Technology and SEMAR.

FIRM Goals

- **Primary objective:** Develop fibre rope mooring systems for floating wind turbines, that compared to chain-based systems reduce the mooring costs with more than 50%.
- **Secondary objectives**:
  - Implementation of detailed material models in simulation tools for design and analysis of floating wind turbines
  - Testing of ropes to obtain material model parameters
  - Design and optimization of mooring systems including anchors
  - Develop innovative solutions through the value chain from design, fabrication, installation, condition monitoring, maintenance and decommissioning.
  - Contribute to qualification and standards

Overview of the FIRM work packages

Work package	Main activity, objective and delivery	Cost (NOK 1000)	Responsible Participant	Contributors
H1	Establish and update rope properties database	675	F1 (IFE)	O1, O2, O3
H2	Rope properties data, experiments and testing	710	F3 (NORCE)	F1, O1, O2, O3
H3	Implementation and validation of detailed fibre rope Finite Element Methods in 3DFloat	950	F1 (IFE)	
H4	Baseline fibre rope system development	1950	B3 (OO)	F1,B4,B5,B6,B7,B8,B1, O1, O2, O3
H5	Taut leg mooring system development	2010	B1 (AIBEL)	F1,B3,B4,B5,B6,B7,B8, O1, O2, O3
H6	Innovative mooring system development	2025	B1 (AIBEL)	F1,B4,B5,B6,B7,B8,B9, O1, O2, O3
H7	Condition monitoring and maintenance	460	F3 (NORCE)	O1, O2, O3
H8	Anchors and soil/structure interaction	1155	F2 (NGI)	B1, F1
H9	Power cable aspects	500	F1 (IFE)	B1,B3
H10	Project management	440	B1 (AIBEL)	

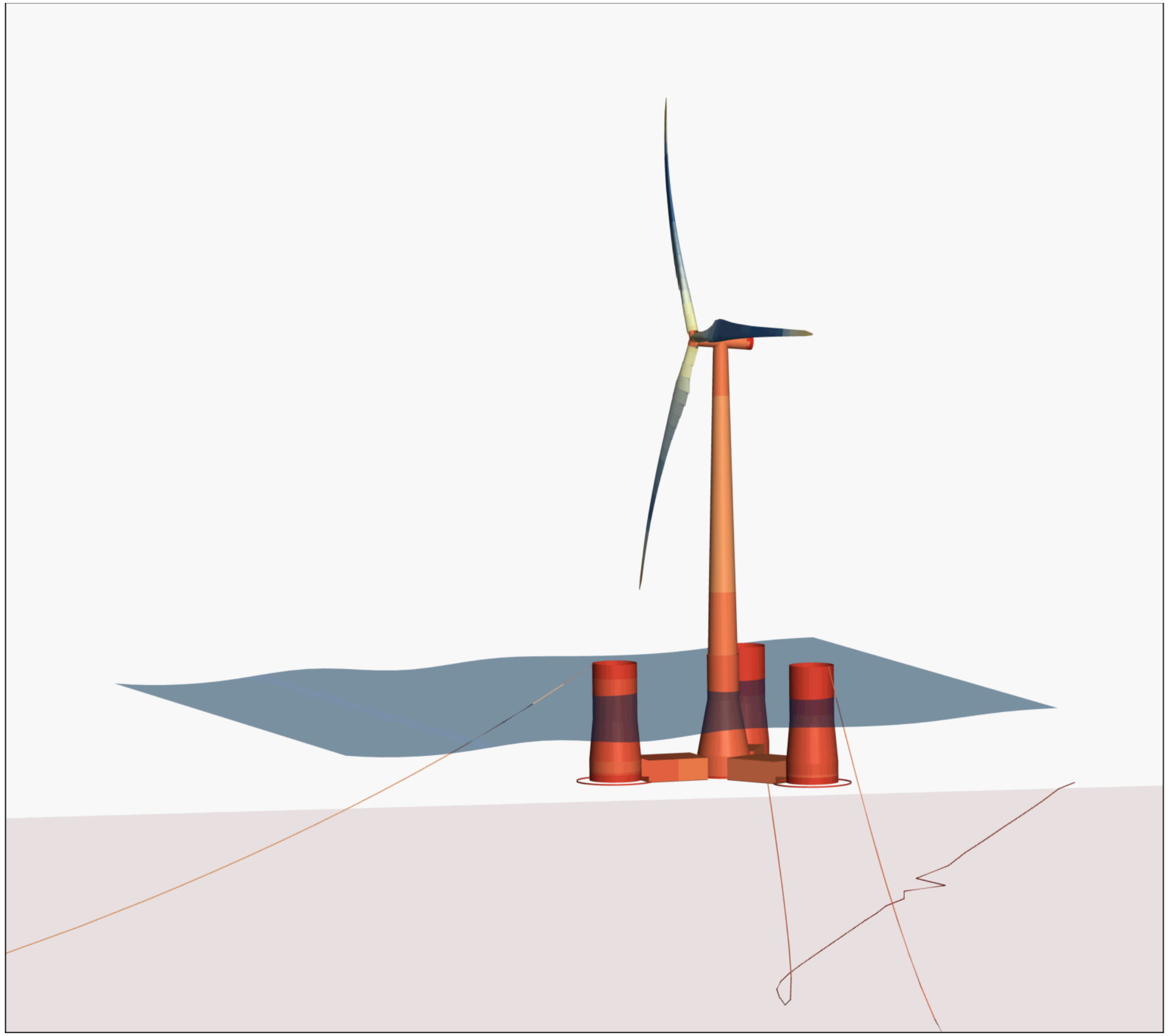
Participant	Name of Participant
B1	Aibel
B2	Equinor
B3	Dr.techn. Olav Olsen
B4	Energy Valley NCE Energy Technology
B5	Henrik Veder Group Norge
B6	Kongsberg Maritime CM AS
B7	Scana Offshore
B8	H. Henriksen AS
B9	Semar AS
F1	IFE
F2	NGI
F3	NORCE
O1	Lankhorst Euronete Portugal SA
O2	Bridon Wire Ropes Industries
O3	DSR CORP

Design Examples

- OO Star Floater with 10MW DTU rotor
- Sites: Buchan Deep; Scotland and Donghae, South Korea, water depths 150m and 800m.
- Reference: Chain system
- Baseline polyester system with clump weights and buoyancy elements
- Taut leg nylon system (in progress)
- Innovative systems (in progress)
- Load analysis and design optimizations with aero-servo-hydro-elastic time-domain computations with 3DFloat.

Nygaard, T. A., De Vaal, J., Pierella, F., Oggiano, L. and Stenbro, R. (2016). *Development, Verification and Validation of 3DFloat; Aero-Servo-Hydro-Elastic Computations of Offshore Structures.* Energy procedia 2016, Vol. 94, pg. 425-433

Reference Chain System



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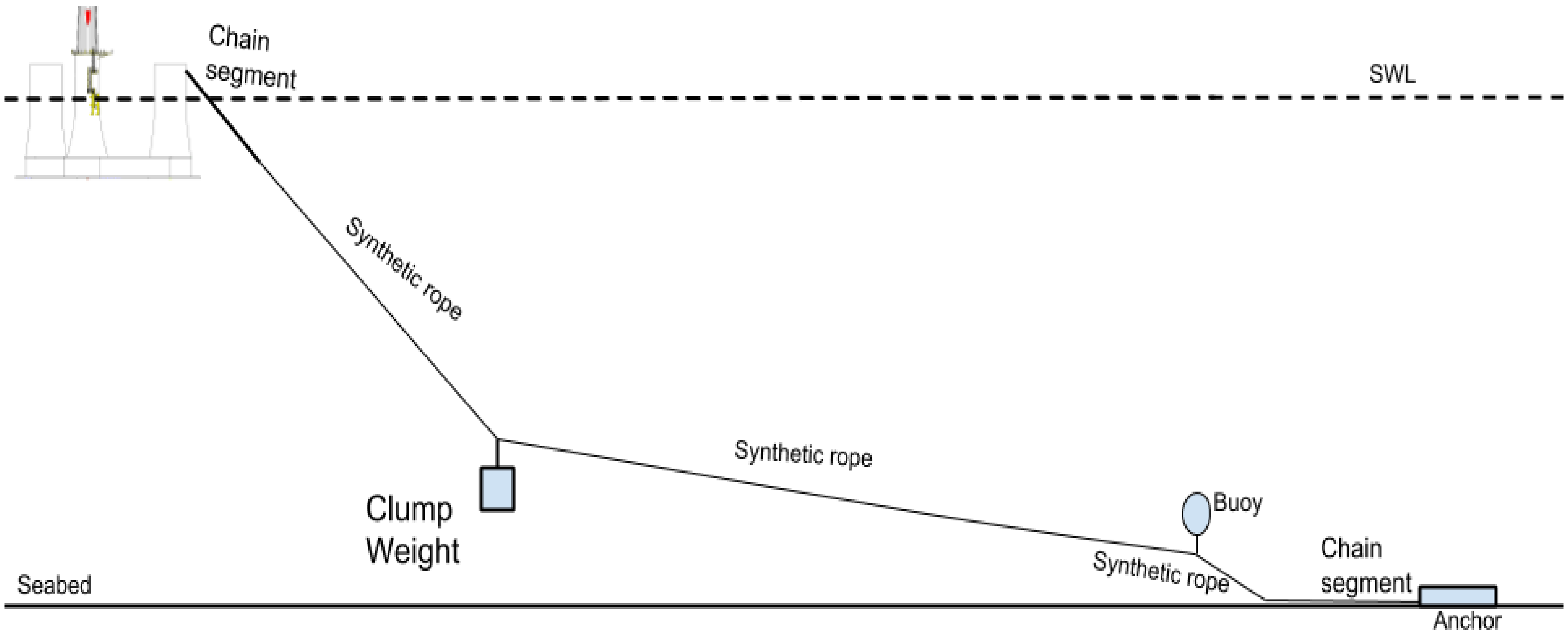
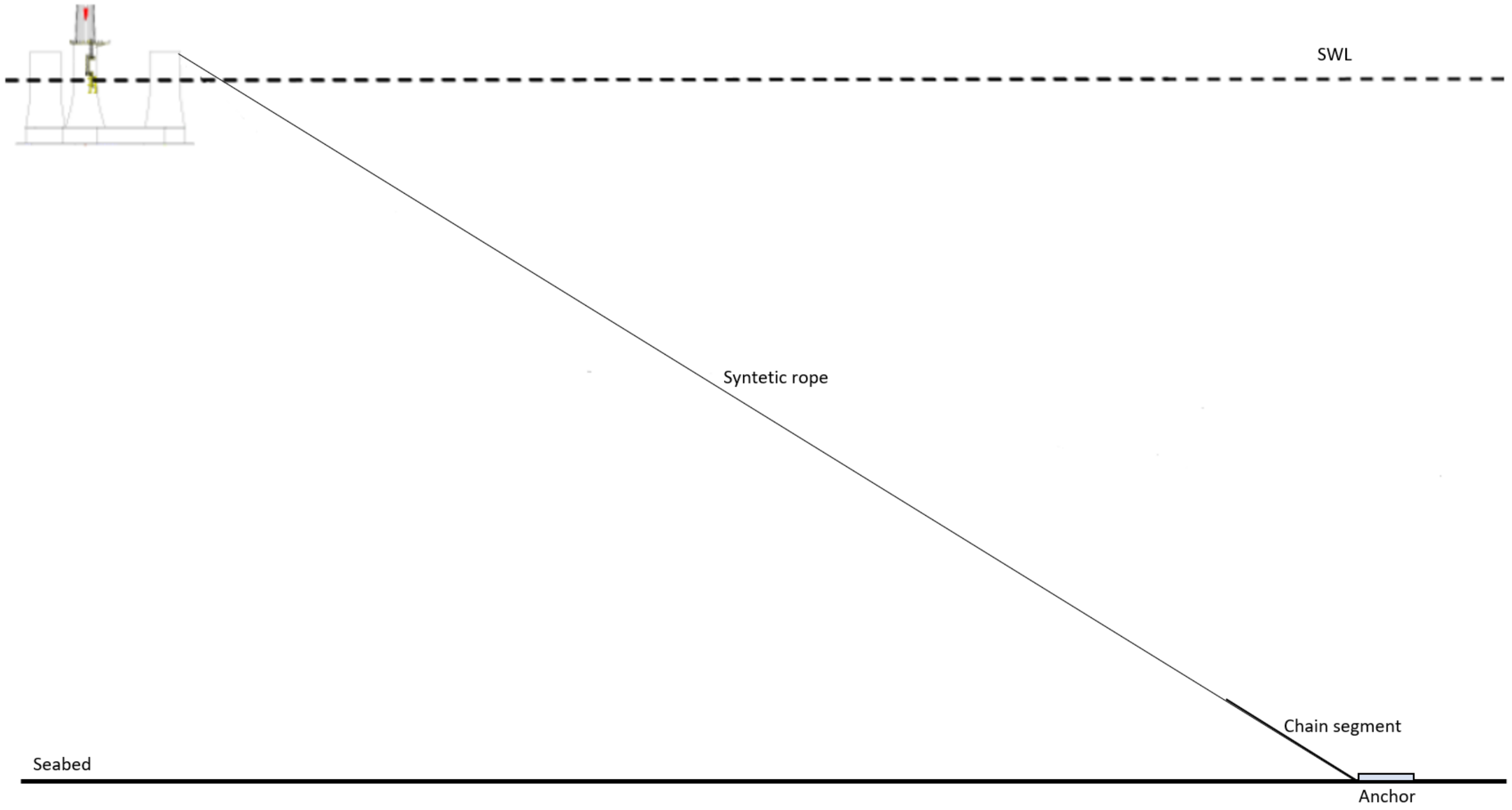
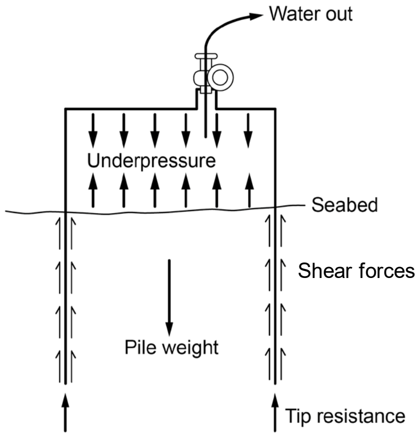


Taut Leg Systems, Polyester and Nylon, 800m depth





Suction anchors