4subsea

Planning for re-tensioning?
A probabilistic take on post-installation fibre rope elongation

Lars Frøyd | 4Subsea

EERA DeepWind 2025 | Trondheim 2025-01-16

Why focus on rope elongation?

And why consider this right now?

- **Industry (in general) don't really understand fibre ropes**
- By Industry I mean:
  - Developers, Operators, EPC contractors,
  - T&I contractors, Insurance, Certification,
  - Design engineers and consultants,
  - Rope manufacturers
- There are of course exceptions…
- **Industry really should understand fibre ropes quite well**
- Fibre rope behavior and characteristics are imperative to mooring system integrity and redundancy, and thus short- and long-term operating cost for floating wind.
- **Personally, I also don't really understand fibre ropes**
  But as design engineer I have been, and will be, asked for advice on this topic, and design and analyze fibre rope mooring systems for upcoming floating wind projects.
- The time to improve our understanding (industry and myself) is **right now**, to be well prepared for the next generation of floating wind projects (Utsira Nord, GoliatVIND, ++)

Topic of this work:

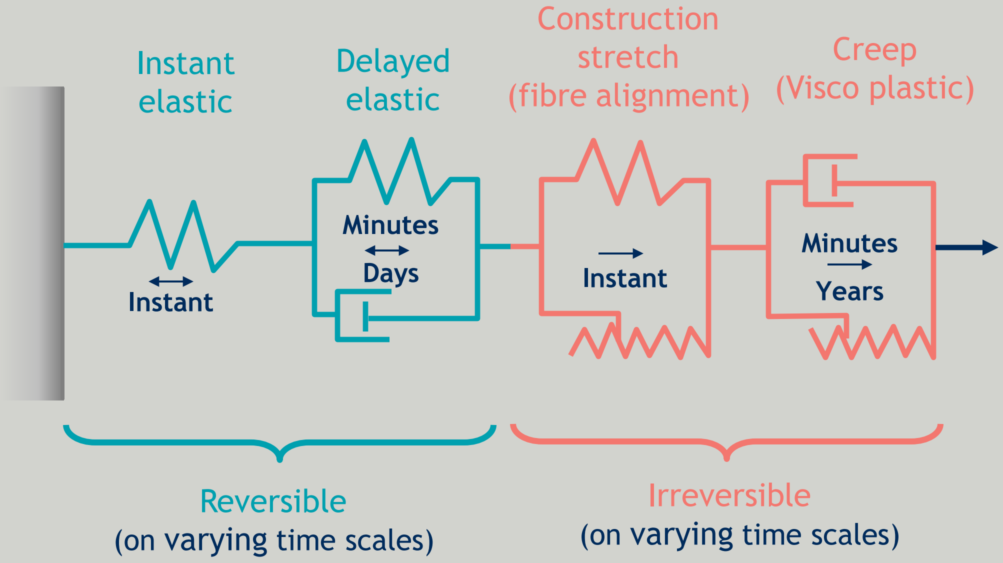
1. How much will polyester mooring ropes elongate during the 1st storm season?
2. How are loads and responses affected?
3. What is the effect of re-tensioning?

Polyester rope characteristics

High-level summary

Polyester rope behaviour is:

- Highly non-linear
- Time and history dependent



Focus of this work is irreversible elongation from installation through 1st storm season

Irreversible elongation largely caused by **mean tension** in the rope

Mean tension dominated by **wind (turbine thrust)** and **current**

Mean loads approximated by **quasi-static** analysis

Figure adapted from Falkenberg et al., 2017

What are the effects of rope elongation?

And what to do about it

- **Rope elongation** leads to:
    - Reduced pre-tension → Risk of fibre rope contact with seabed
    - Change of natural periods
    - Reduced yaw stiffness
    - Increased floater offset → Impact power cable design loads

  (Change of natural periods, Reduced yaw stiffness → Impact controller behavior, power production, fatigue)
- If **asymmetric**, also:
    - Nominal position offset → Impact power cable design loads
    - Uneven loading between mooring lines → Impact mooring fatigue
- **Possible mitigations**, which all come at **additional cost**:
    - Using different material than fibre rope → Chain more expensive, production capacity limited
    - Increased start-of-life pre-tension → Impact mooring fatigue
    - Re-tensioning during lifetime → Expensive, corrective action not possible during winter season
    - In-line buoyancy to ensure rope seabed clearance → Cost and maturity concerns

The **better option** is to design mooring systems that can tolerate the elongation, but this requires a good understanding of fibre rope to avoid excessive conservatism (or non-conservatism!) in design.

Polyester rope characteristics

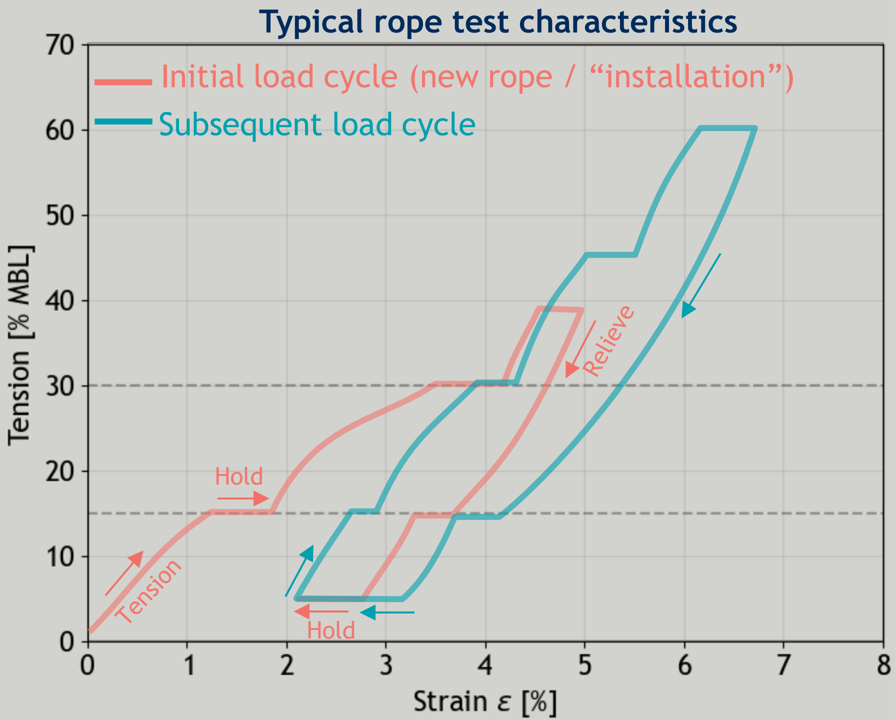
Modelling

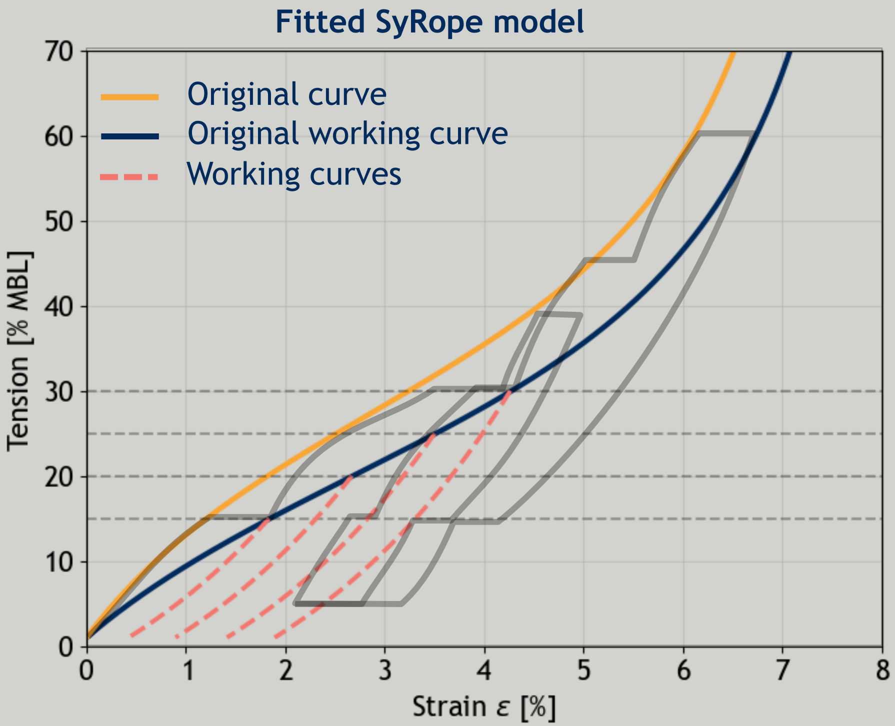
Parametrized stiffness (slope):

$k_{OC}(T) = 16.5 - 0.70T + 0.0127T^2$

$k_{OWC}(T) = 10.5 - 0.46T + 0.0115T^2$

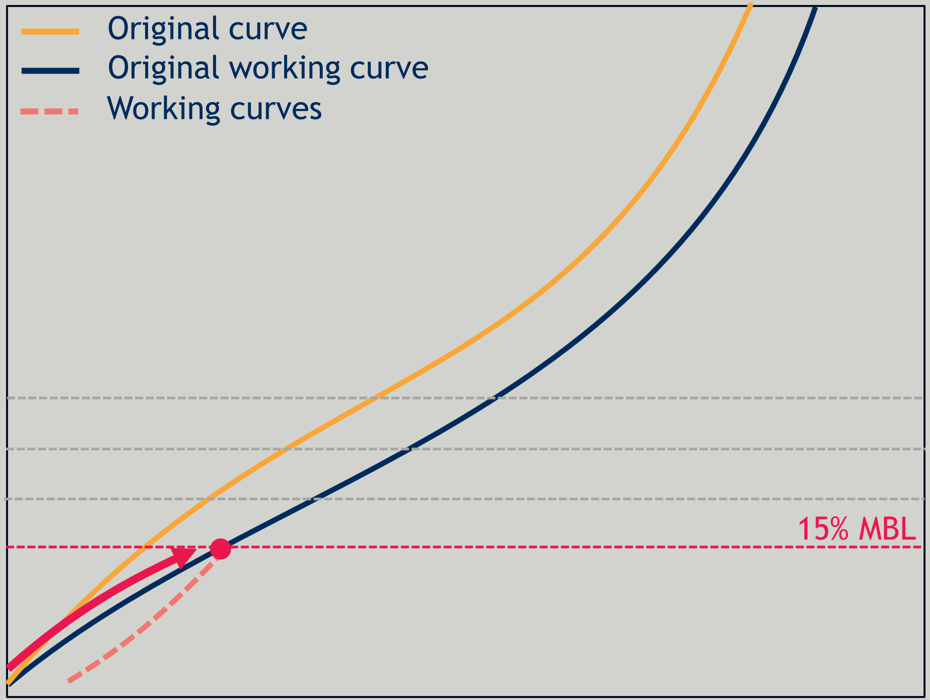
$k_{WC}(T) = 7 + 0.40T$





Polyester rope characteristics

Example installation and loading cycle

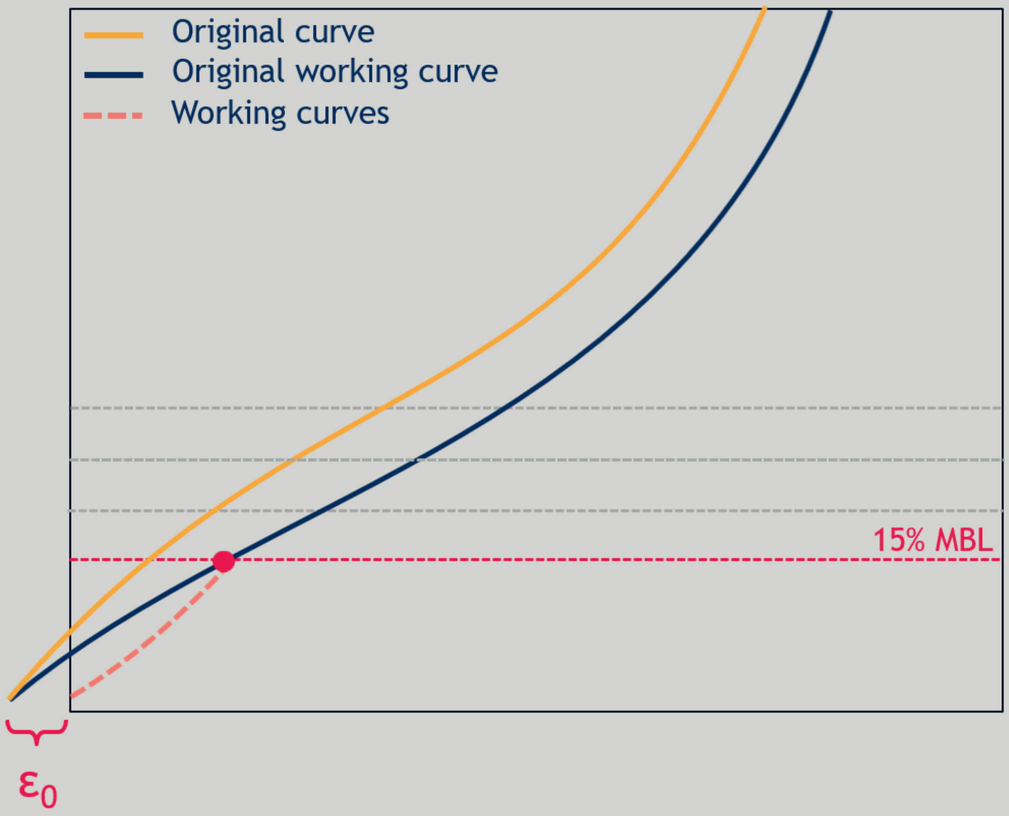


Example 1 – No pre-stretching

1. Rope tensioned to target post-installation tension of 15% MBL.

Polyester rope characteristics

Example installation and loading cycle

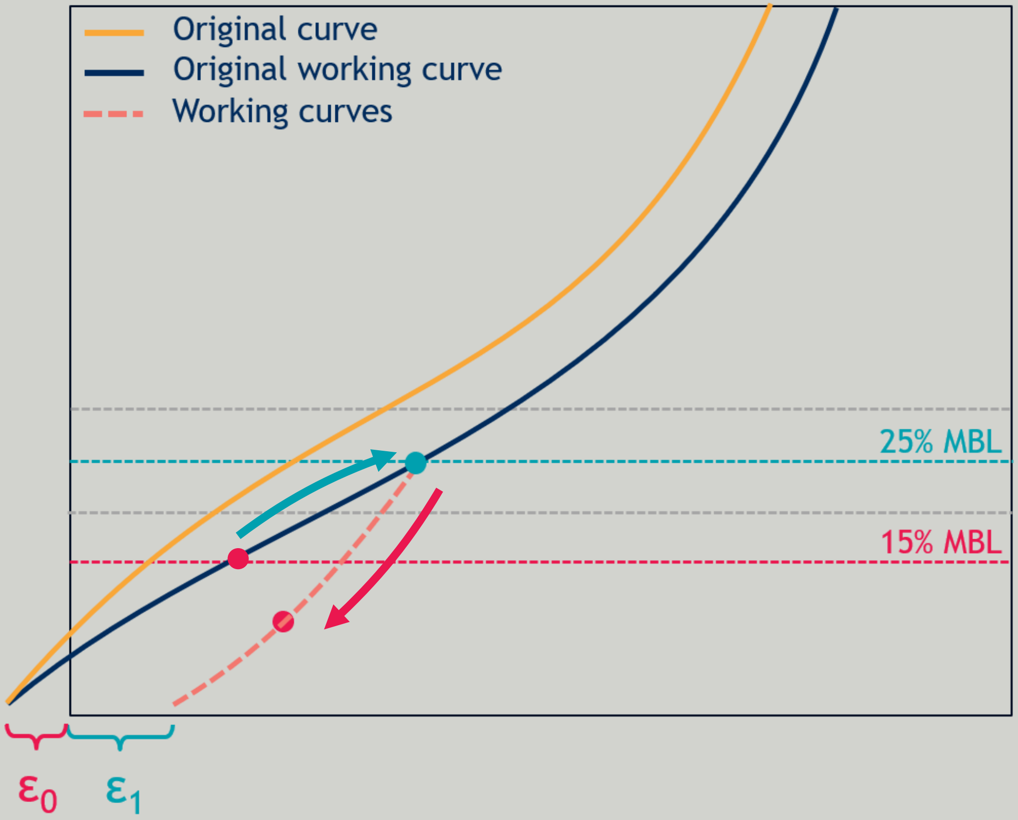


Example 1 – No pre-stretching

1. Rope tensioned to target post-installation tension of 15% MBL.
2. When installing to target tension with a chain tensioner the overlength ε_0 from rope stretching is effectively cancelled (the same length of chain is removed)

Polyester rope characteristics

Example installation and loading cycle

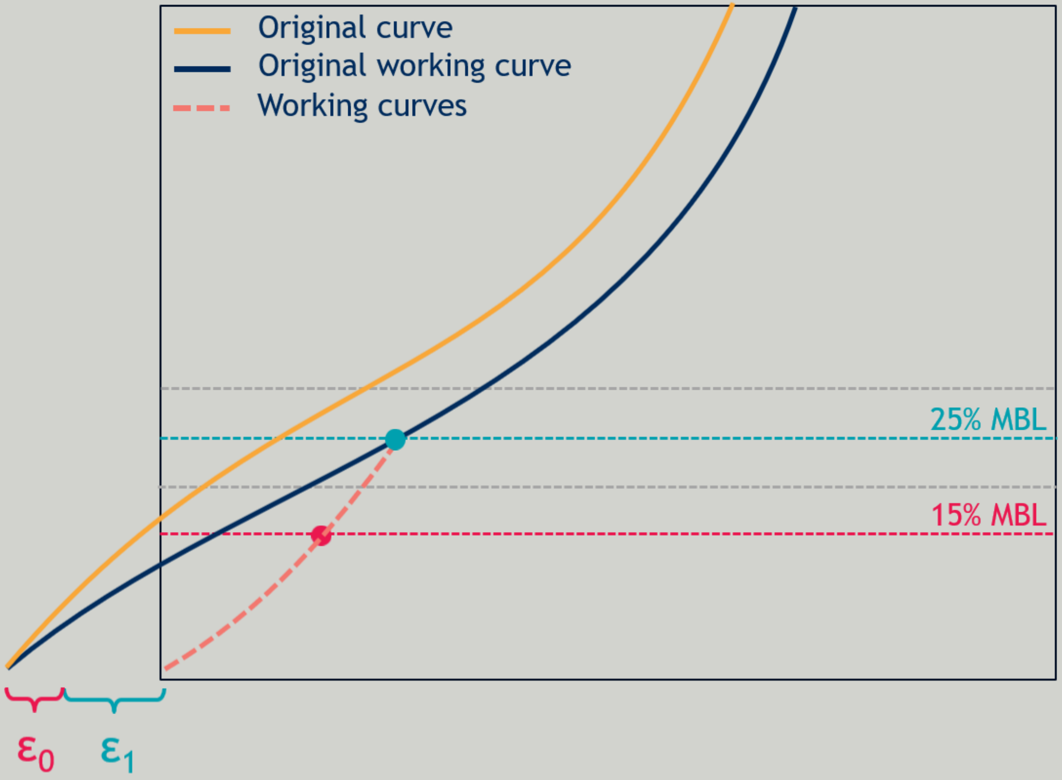


Example 1 – No pre-stretching

1. Rope tensioned to target post-installation tension of 15% MBL.
2. When installing to target tension with a chain tensioner the overlength ε_0 from rope stretching is effectively cancelled (the same length of chain is removed)
3. Later during service life the rope experiences higher mean tension levels. Maximum 25% MBL
4. This leads to a permanent elongation ε_1. The rope is now on a new working curve and has reduced pre-tension

Polyester rope characteristics

Example installation and loading cycle



Example 1 – No pre-stretching

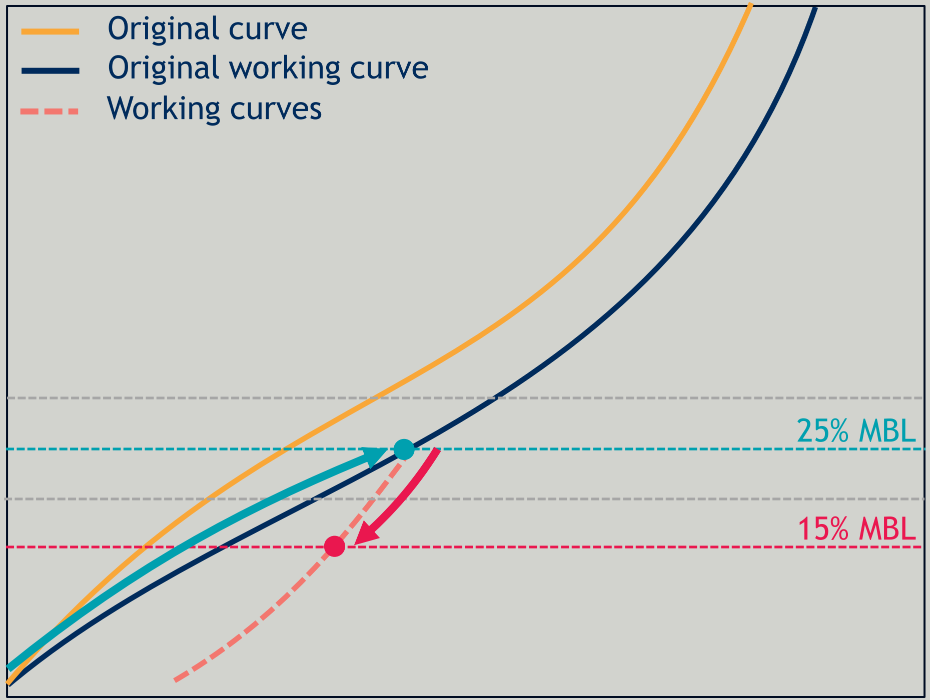
1. Rope tensioned to target post-installation tension of 15% MBL.
2. When installing to target tension with a chain tensioner the overlength ε_0 from rope stretching is effectively cancelled (the same length of chain is removed)
3. Later during service life the rope experiences higher mean tension levels. Maximum 25% MBL
4. This leads to a permanent elongation ε_1. The rope is now on a new working curve and has reduced pre-tension

Example 2 – Re-tensioning

5. When re-tensioning to (to 15% MBL) with a chain tensioner the overlength ε_1 from in-service rope stretching is effectively cancelled (the same length of chain is removed)
6. After this, no further elongation unless tension above 25% MBL is experienced

Polyester rope characteristics

Example installation and loading cycle

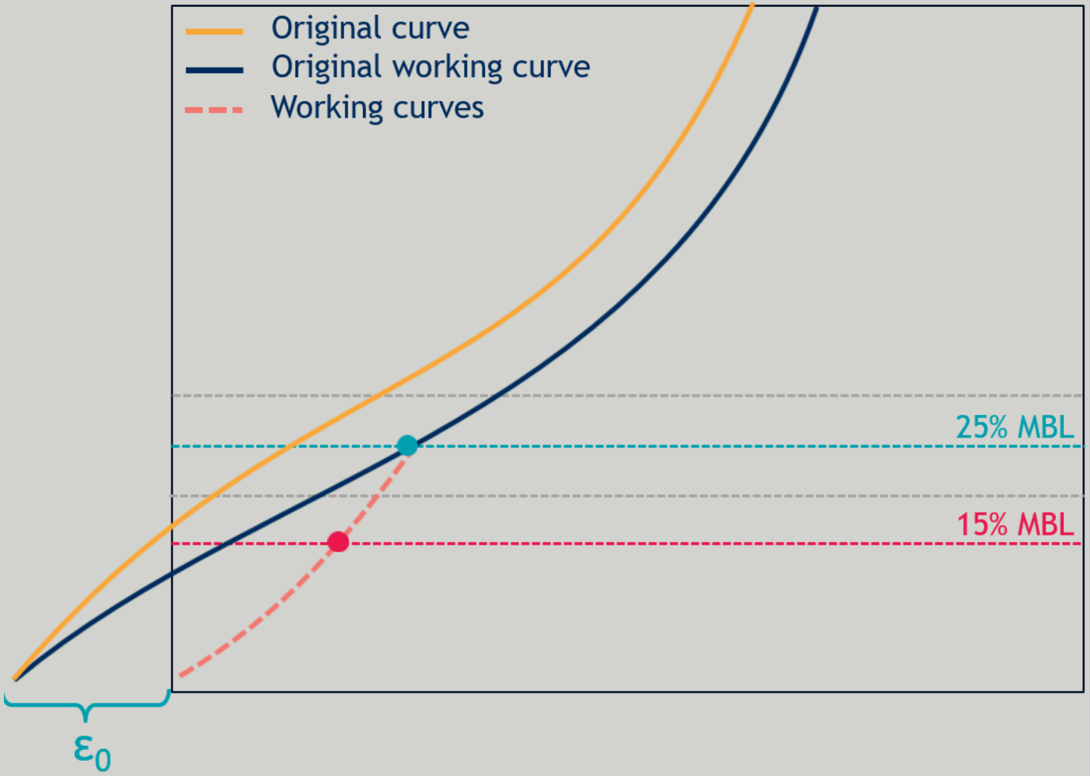


Example 3 – Pre-stretching

1. Rope pre-stretched to 25% MBL before reducing to target post-installation tension of 15% MBL.

Polyester rope characteristics

Example installation and loading cycle



Example 3 – Pre-stretching

1. Rope pre-stretched to 25% MBL before reducing to target post-installation tension of 15% MBL.
2. When installing to target tension with a chain tensioner the overlength ε_0 from rope stretching is effectively cancelled (the same length of chain is removed)
3. No further elongation occurs unless tension later increases above 25% MBL

Rope elongation case study

Summary

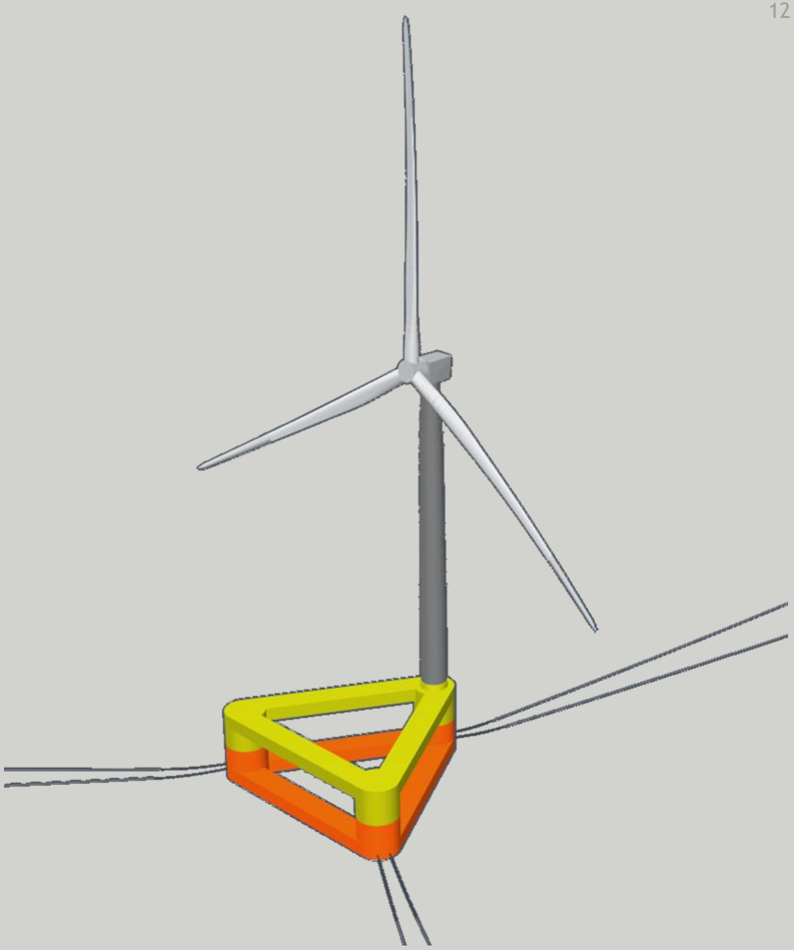
Floating wind turbine model:
- 15 MW 3-column semisubmersible floater, offset turbine
- 15 MW IEA turbine (mean rotor load according to thrust curve)

Mooring system:
- 6-line (3x2 clustered) mooring configuration.
- Chain/polyester semi-taut mooring
- Post-installation pre-tension 15% of rope MBL

Environment and metocean:
- North Sea wind, wave & current conditions
- Utsira Nord selected for case study at water depth 270m

Polyester rope modelling:
- Generic SyRope model for polyester mooring ropes (as shown)
- 3 levels of installation pre-stretching (15%, 20%, 25% MBL)

Simulation:
- Stepwise sequential static analysis throughout the 1st winter season after installation, tracking the state (tension history and elongation) of each mooring rope
- Repeat for several years to get statistics
- Analyses performed in OrcaFlex 11.5



Mooring configuration

System overview

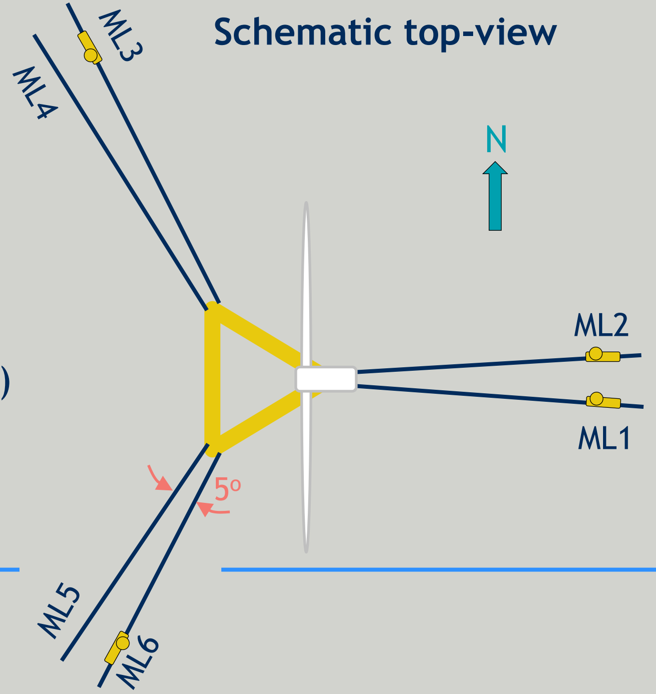
6-line configuration: Semi-taut, 2x3 clustered, 5º cluster angle

Anchor radius: 6.5 x WD = 1750 m

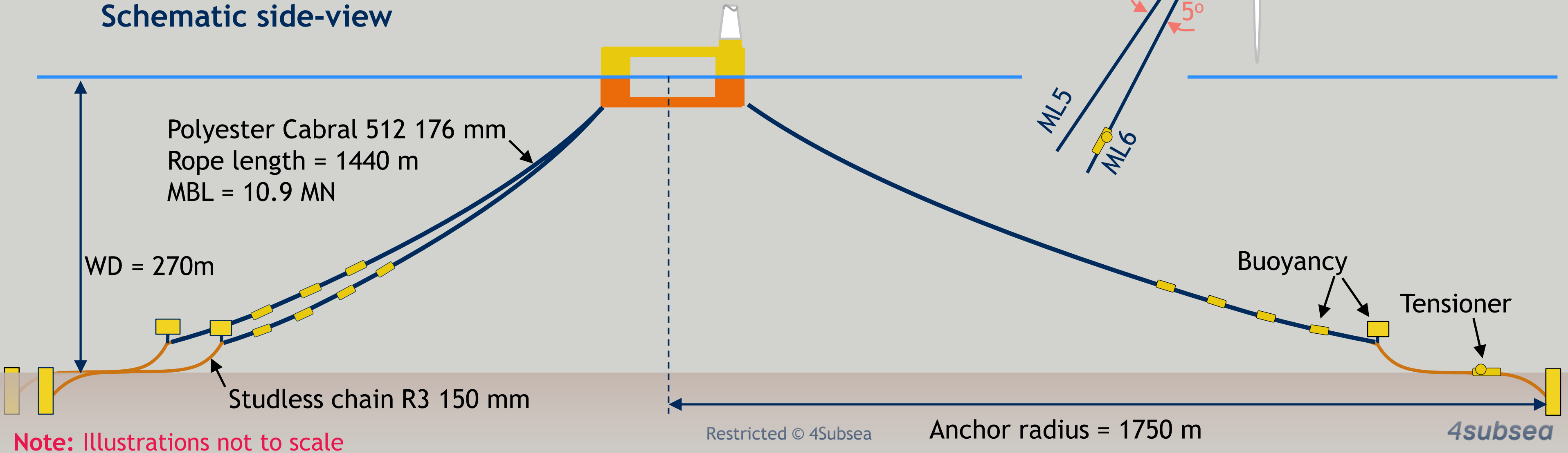
Post-installation pre-tension: 15% of MBL = 1636 kN

Tensioners: ILT's for system tensioning (2x per cluster in 1 cluster)
and equalizing cluster tension (1x per cluster in 2 clusters)

Schematic top-view



Schematic side-view

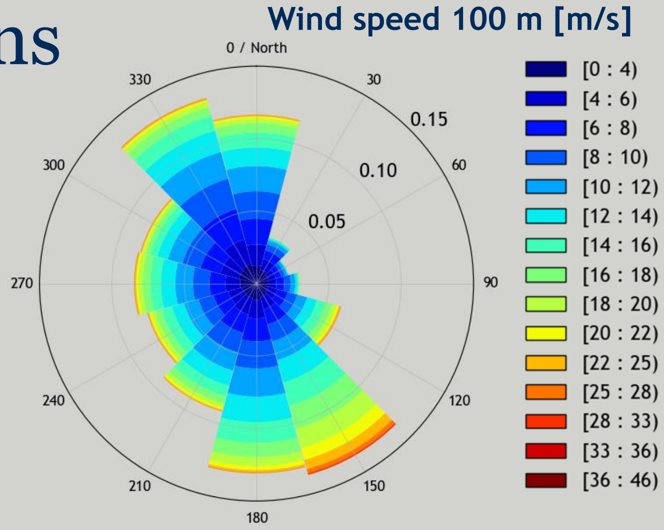


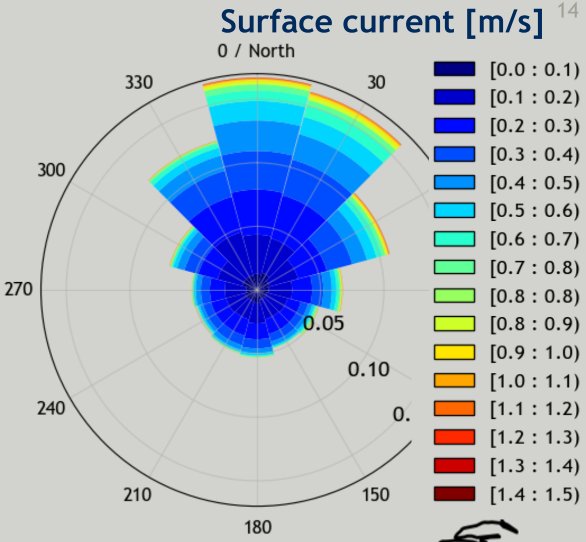
Note: Illustrations not to scale

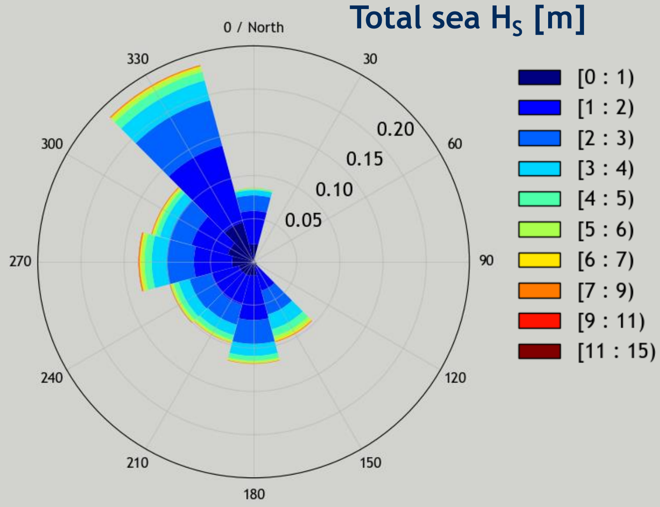
Metocean conditions

At Utsira Nord (Norwegian North Sea)

- Analysis based on:
  - 48 years wind/wave hindcast (**NORA3**)
  - 8 years current hindcast (**NorKyst**)
- **Every 1-hour** environmental state considered in **each year** from **Oct. 1st to April 1st** the following year
  - 48 years => 47 full winter seasons
  - Years without current randomly assigned a current history (with minor random/stochastic adjustments) from the 7 full current histories
- The **NORA3** hindcast includes:
  - Wind speed and direction
  - Wind-sea H_S, T_P and direction
  - Swell H_S, T_P and direction
- The **NorKyst** hindcast includes:
  - Current speed and direction through water depth





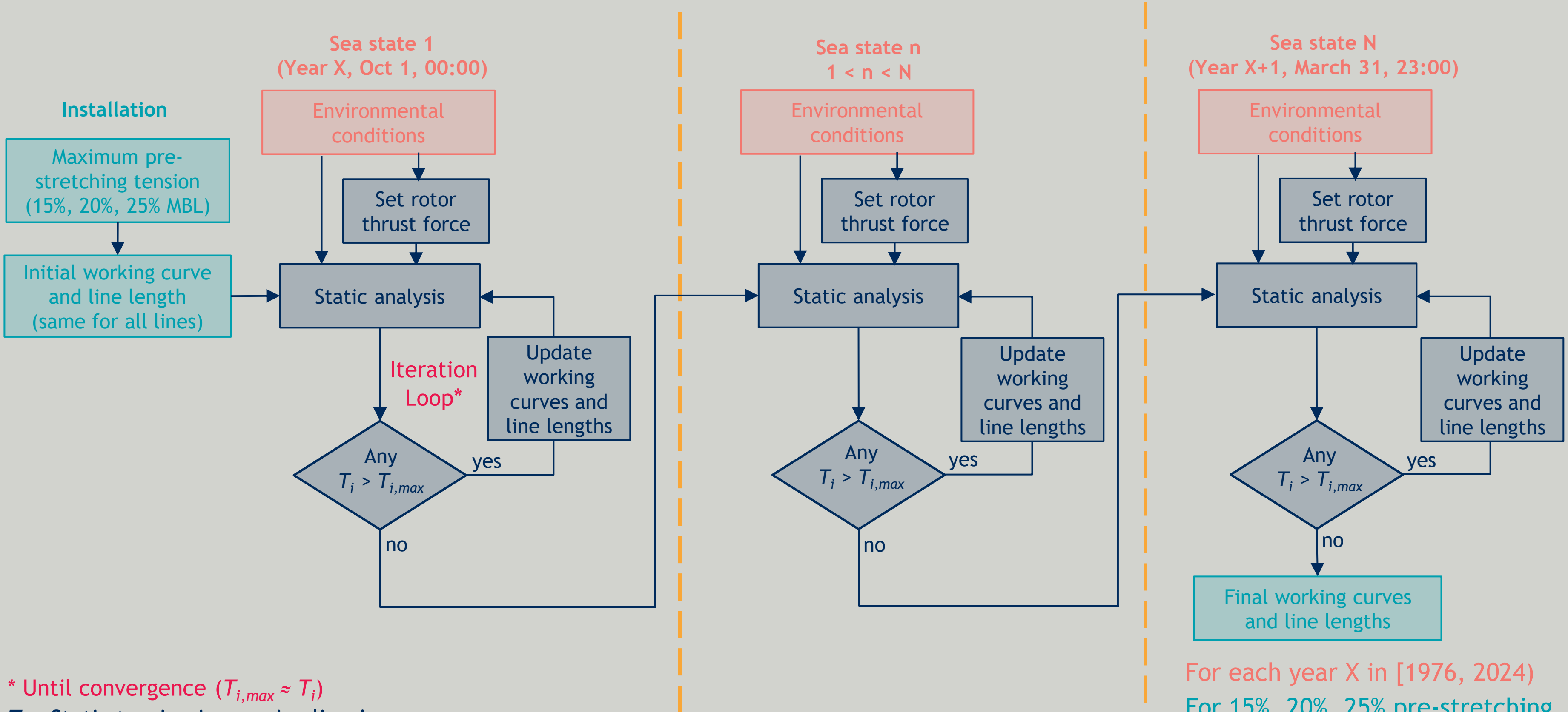


4subsea

Simulation – Part I

Sequential static simulation

1 How much will polyester mooring ropes elongate during the 1st storm season?



For each year X in [1976, 2024]

For 15%, 20%, 25% pre-stretching

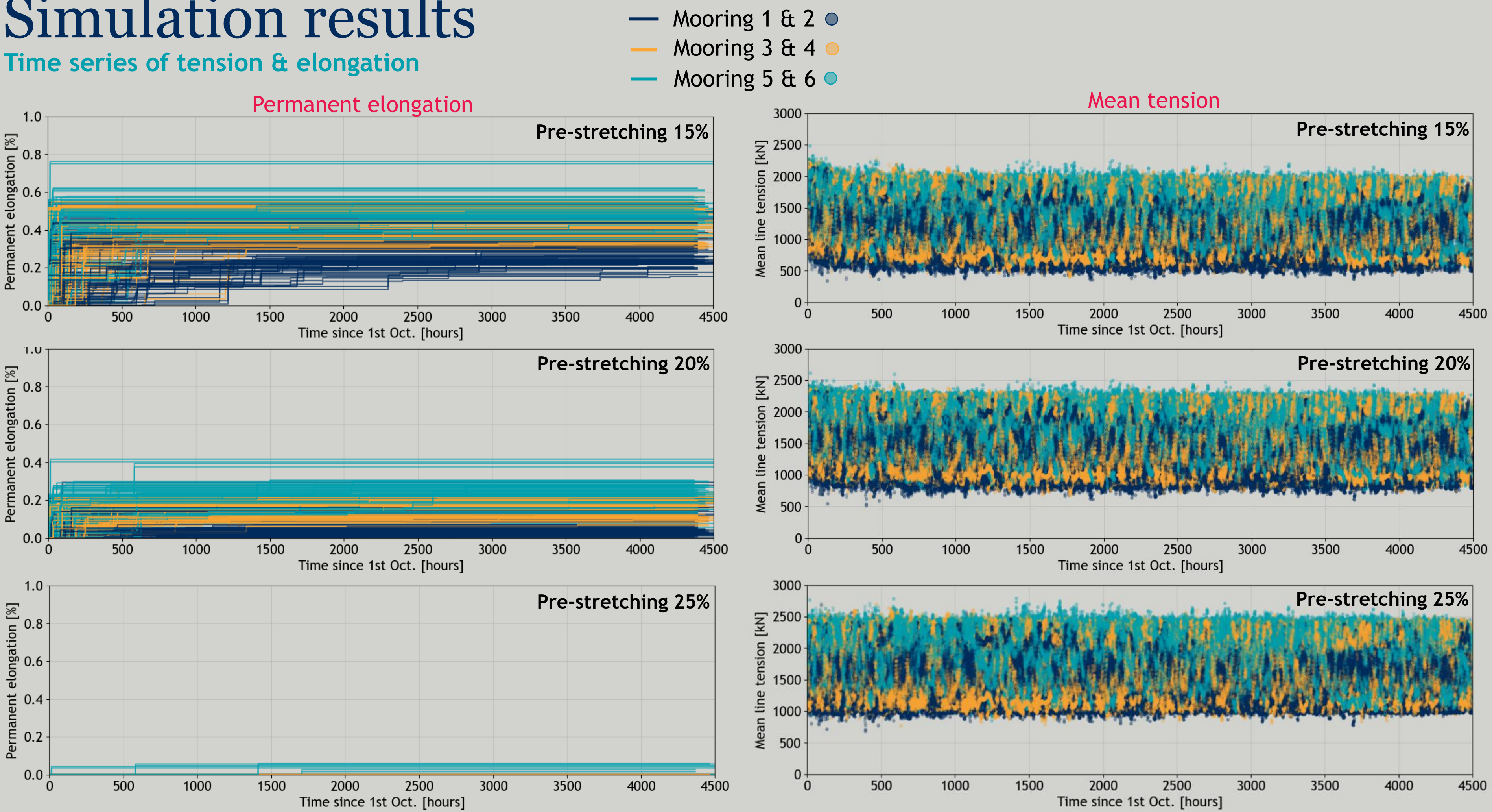
* Until convergence ($T_{i,max} \approx T_i$)

T_i = Static tension in mooring line i

$T_{i,max}$ = Max. static tension in mooring line i

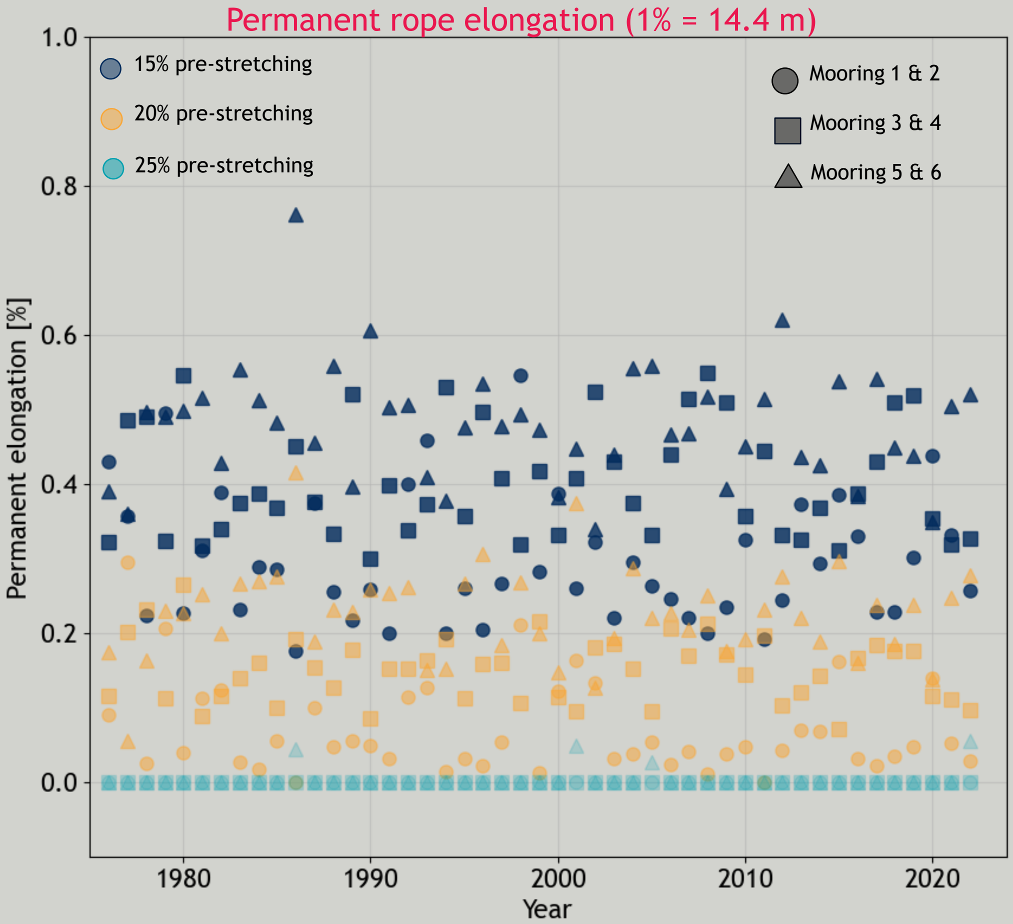
Simulation results

Time series of tension & elongation



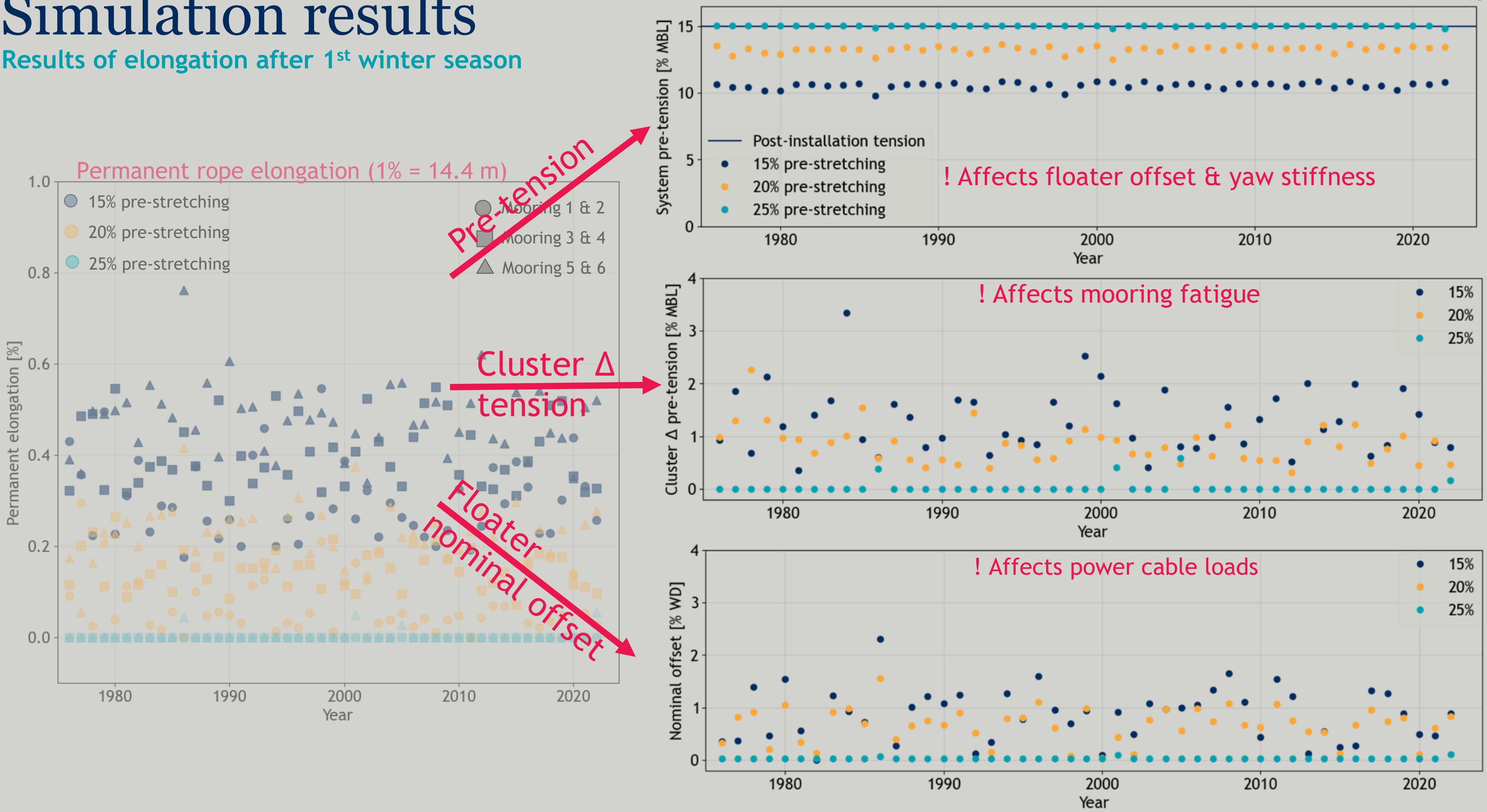
Simulation results

Results of elongation after 1st winter season



Simulation results

Results of elongation after 1st winter season

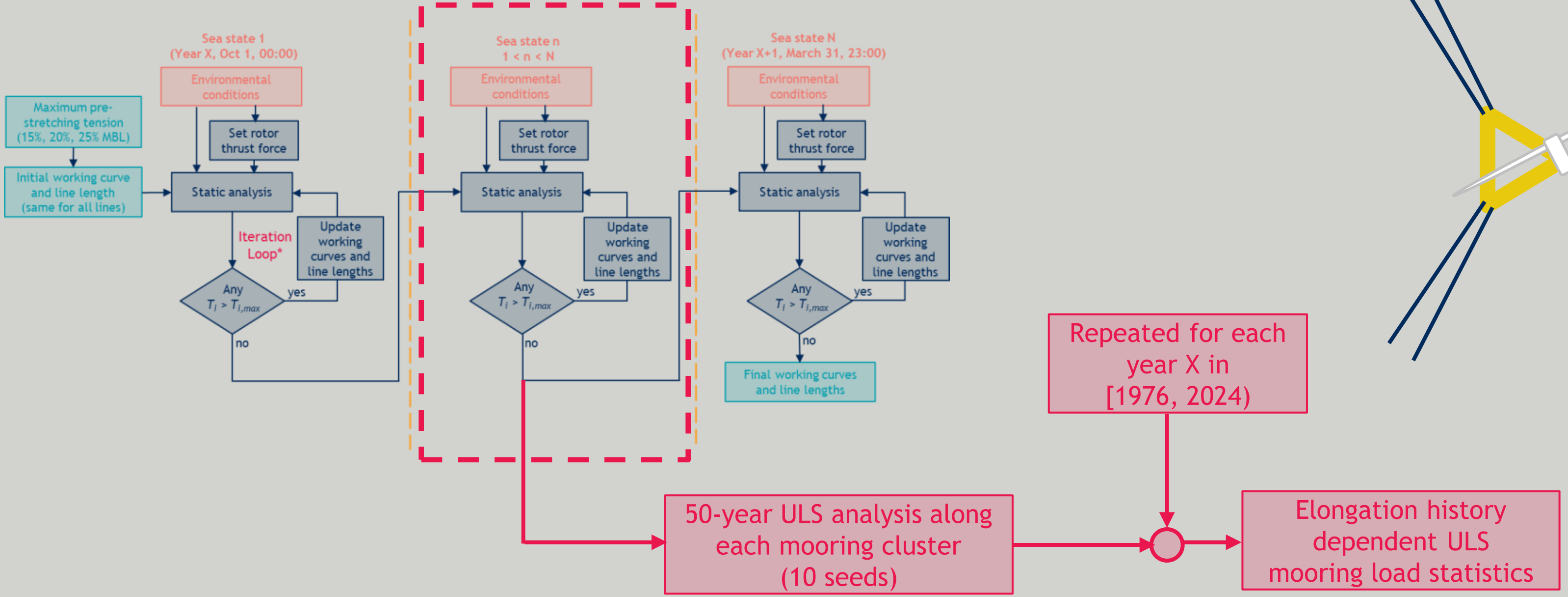


Simulation – Part II

Insert 50-year ULS sea state for dynamic analysis

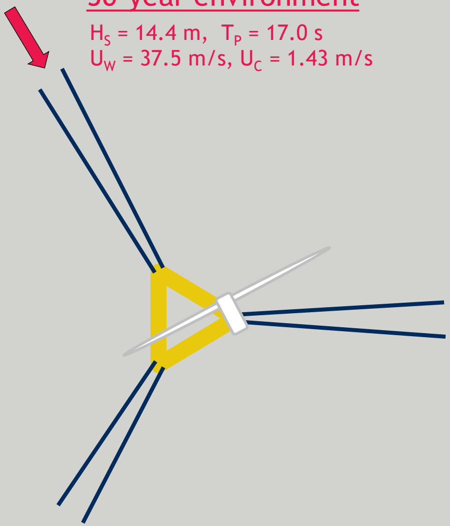
2 How are loads and responses affected?

For sea state with
$H_S = \max(H_S)|_{\text{year X}}$



50-year environment

H_S = 14.4 m, T_P = 17.0 s
U_W = 37.5 m/s, U_C = 1.43 m/s

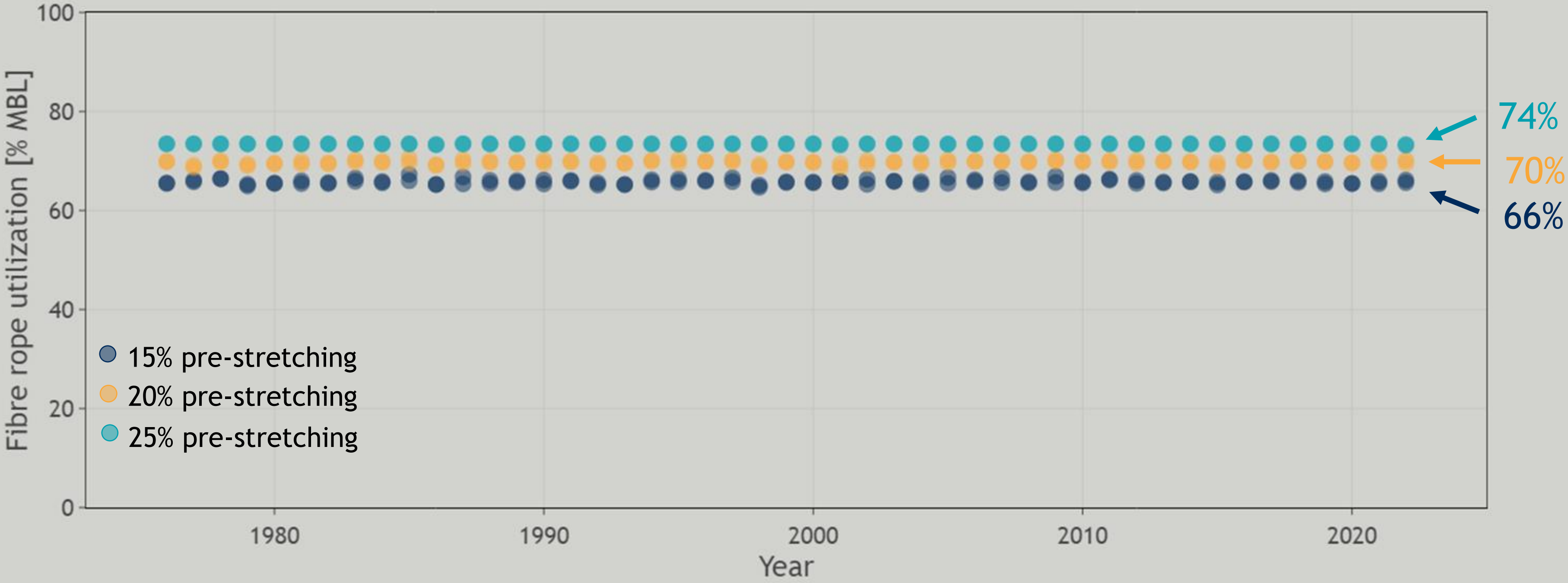


4subsea

Simulation results - Part II

Elongation history dependent ULS mooring utilization

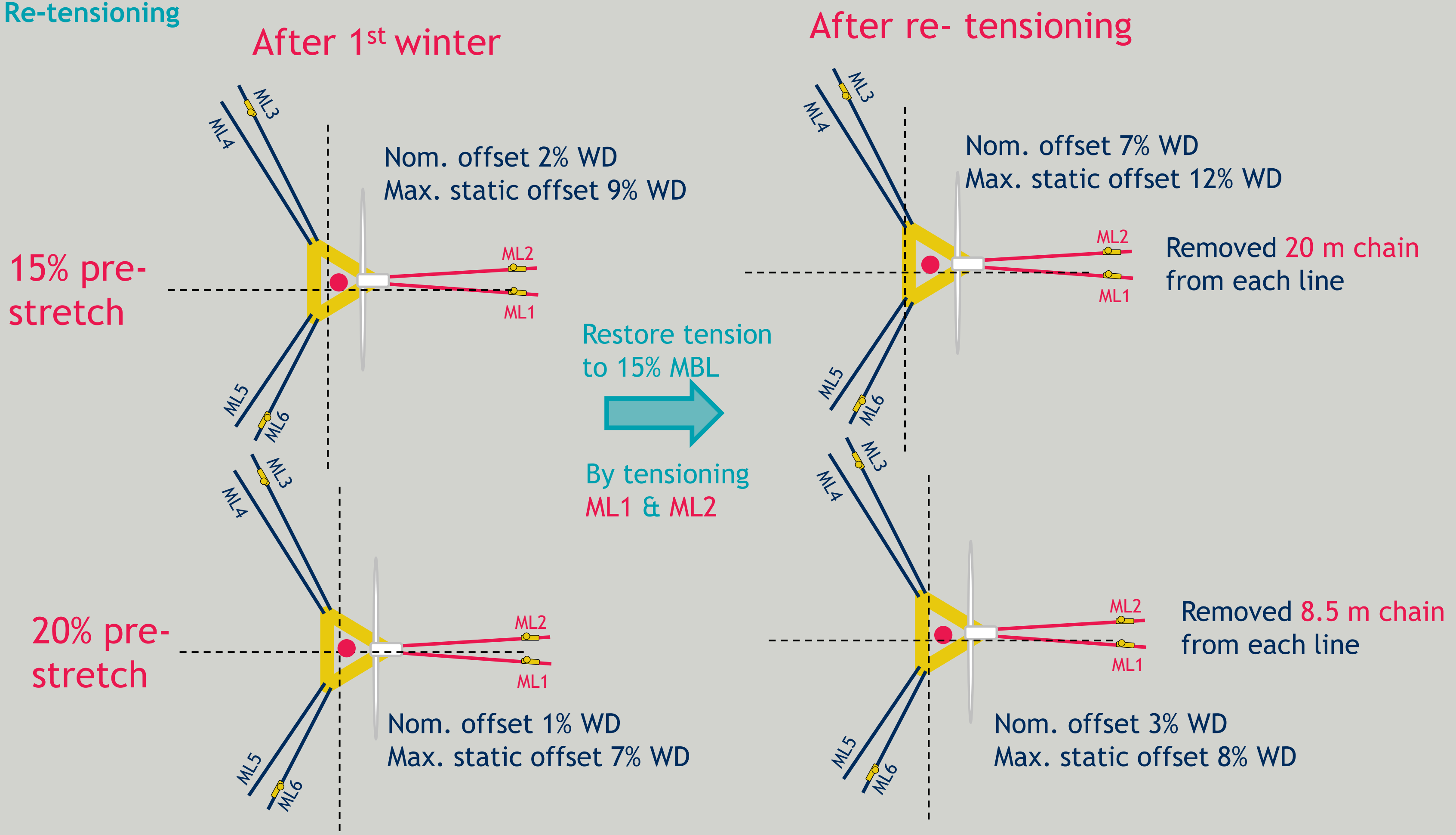
- Mooring loads sensitive to system pre-tension (which depends on pre-stretching)
- Inter-year variability is minimal (less than seed to seed variation in ULS)



Simulation – Part III

Re-tensioning

3 What is the effect of re-tensioning?



4subsea

Summary and conclusions

Contact: Lars Frøyd, Lead Engineer Wind Energy at 4Subsea - lars.froyd@4subsea.com

1. How much will polyester mooring ropes elongate during the 1st winter season?

- Rope elongation varies significantly from year to year, including which cluster elongates most.
- Rope elongation depends significantly on the amount of pre-stretching during installation
- Rope elongation between lines in a cluster can vary significantly.
  (A common assumption is that initial fibre rope length variations/tolerances will equalize due to the shorter rope elongating more, but this cannot be universally true based on the observed)

2. How are loads and responses affected?

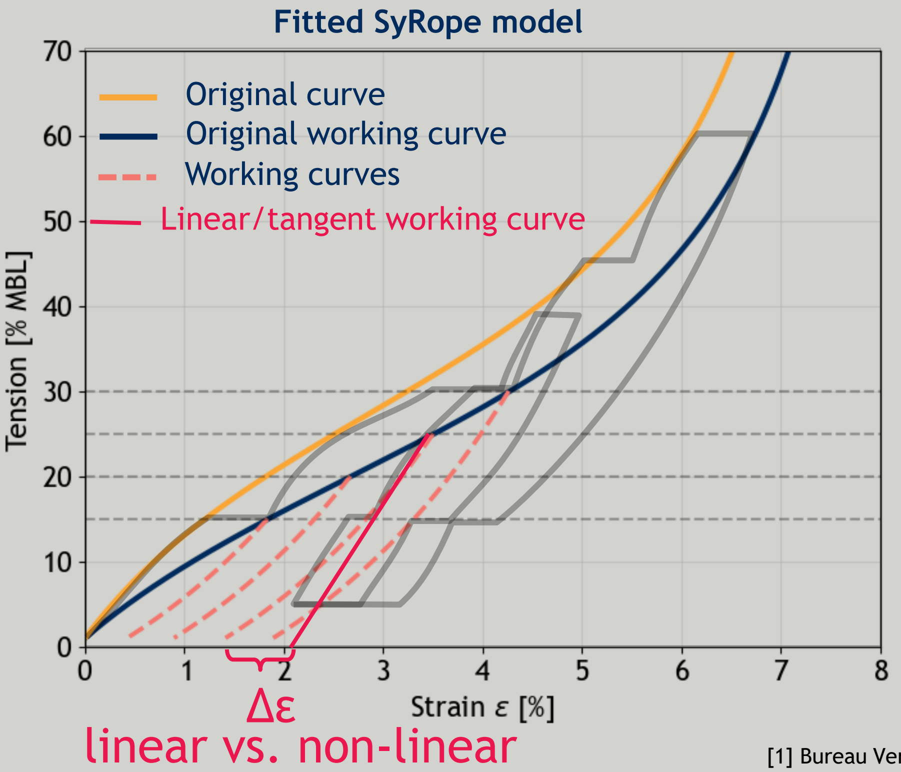
- Although rope elongation varies significantly from year to year, the resulting variation in system pre-tension is small. Mooring ULS loads depend mostly on system pre-tension.
- Most of the elongation develops early in the lifetime such that at the time when the yearly maxima occurs the elongation is largely stabilized.
- Thus, mooring ULS loads vary little between years (less than variations between random seeds)
- As loads depend on pre-tension and pretension reduces over time there is a potential cost saving of considering (in a probabilistic manner) the time until the likely earliest occurrence of the ULS load. (Polyester ropes are ULS governed, as opposed to chains that are FLS governed!)

3. What is the effect of re-tensioning?

- Re-tensioning in a single cluster can cause significant nominal floater offsets with impact on cable system design loads and require significant chain overlength. Can be mitigated by pre-stretching

Post-presentation note

Non-linear vs. linear working curve models



I received some comments after the presentation that the levels of permanent elongation shown were smaller than expected.

This can be partly explained by the use of a non-linear working curve model. ABS [2] and BV [1] for example both describe a linear quasi-satatic stiffness. A linear stiffness curve tangential to the working curve at the intercept of the original working curve would result in a larger permanent elongation as shown to the riight. However, the system characteristics/response of the system with linear static stiffness and increased permanent elongation Δε would be comparable to the non-linear base case. This difference/effect was not sufficiently explained in the presentation.

Other reasons for “smaller than expected” permanent elongation is likely that this work does not consider long-term creep directly, although some creep is built into the original working curve. Also, this work does not include elongation following a “design load condition”, which would certainly exceed the elongation from the probabilistic load combination considered here.

Lars Frøyd
20/01/2025

[1] Bureau Veritas BV-NI-432, Certification of Fibre Ropes for Deepwater Offshore Services, 2018-12
[2] American Bureau of Shipping (ABS), Requirements for the application of fiber rope for offshore mooring, 2024

4subsea

15 years in floating wind engineering

- Floater sizing
- Mooring system
- Cable configuration
- Installability ++

Dynamic cable engineering (for Nexans)

Marine ops.

Engineering partner E
- Coupled analysis
- Global loads
- Mooring system desi
- WTG OEM interface/
- Cable 3rd party ++

- Methodology
- Software & tools
- Standards adaption

Company's Engineer

Several Concept, Pre-FEED, FEED studies with fibre rope. (Korea, North Sea, Celtic Sea, West of Shetland, France ++)

Company founded 2007

2009 Floating wind begins (Hywind Demo)

1st FOWT project with Statoil 2010

2012 Start work on "Hywind II" 6MW

Pre-FEED 2014

FEED 2015

Detailed 2016

Installation 2017

Hywind Scotland

Concept 2018

FEED 2019

Detailed 2020

Hywind Tampen

Subsea 7 acquires 4Subsea

2021

2022

2023

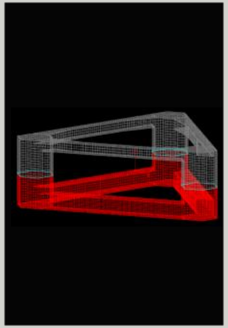
2024

"FOWT Program" with SS7. Technologies for cost efficient FOWT EPCI (PET ropes++)

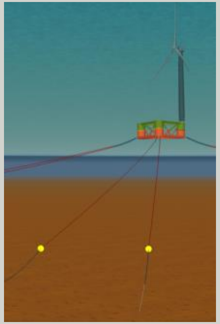
Specialized in advanced analyses

Coupled analysis

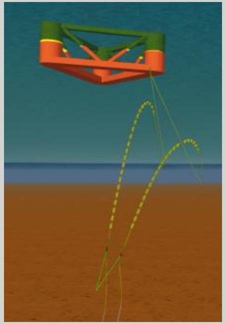
Hydrodynamics



Mooring system



Dynamic cables



WTG and controller