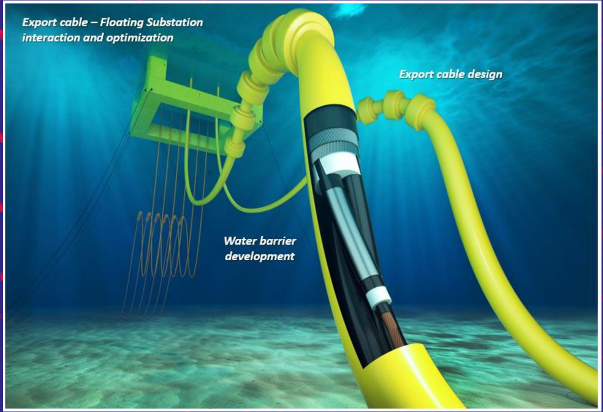
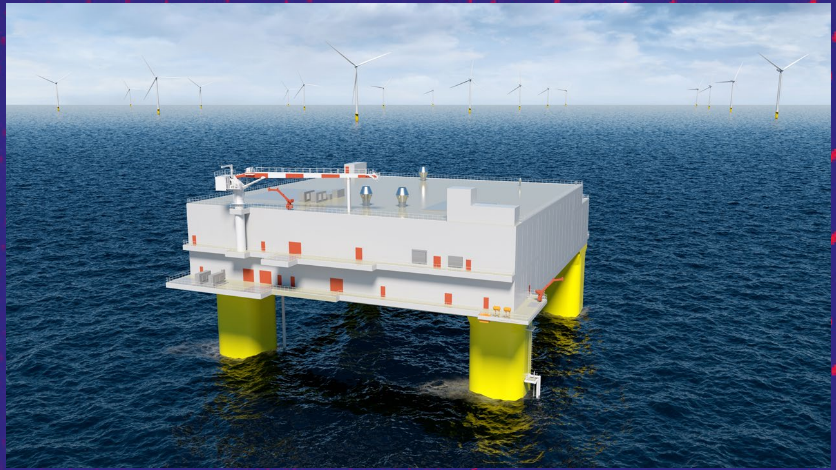


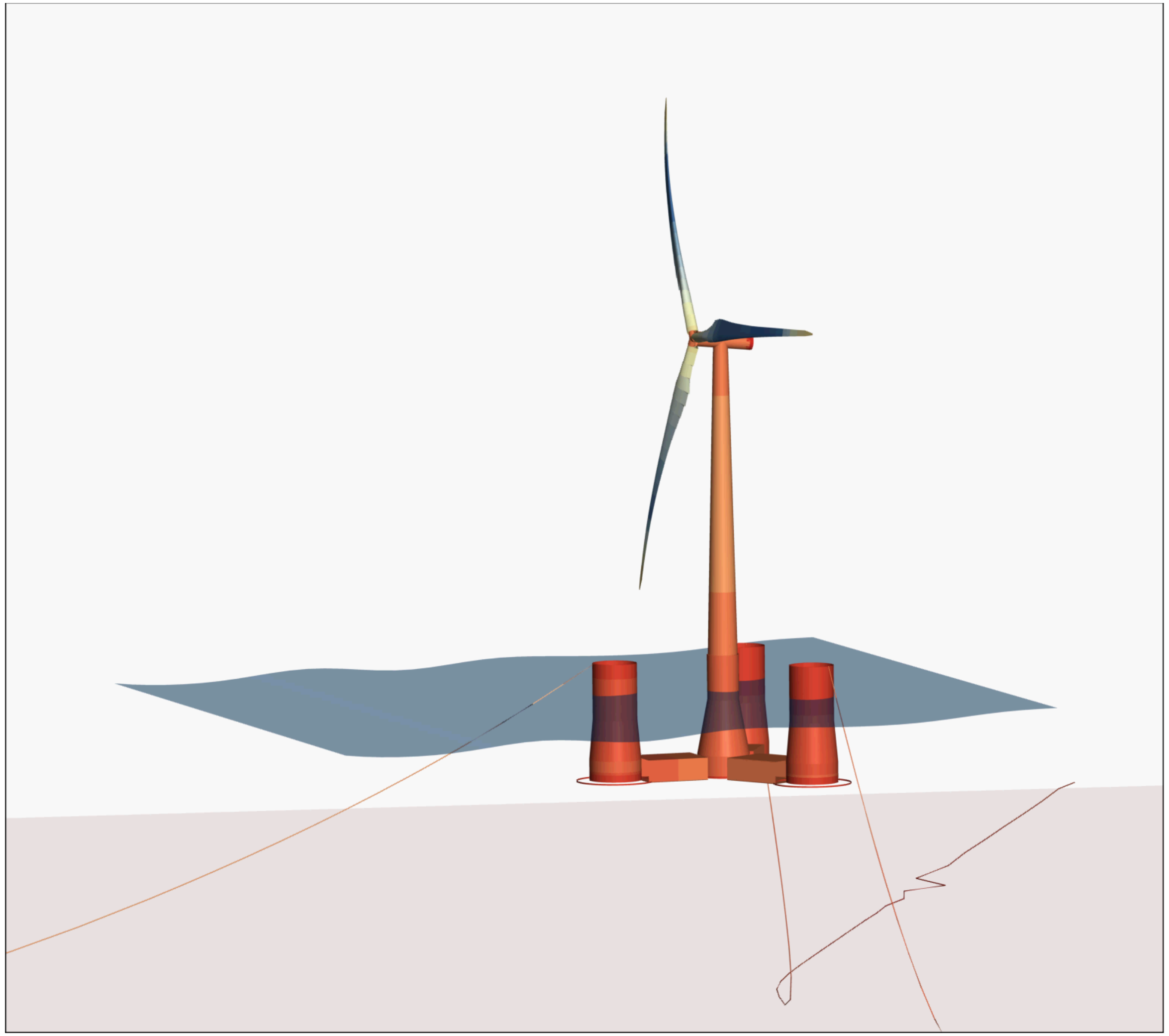


Integration of dynamic cables and mooring in floating substation analysis

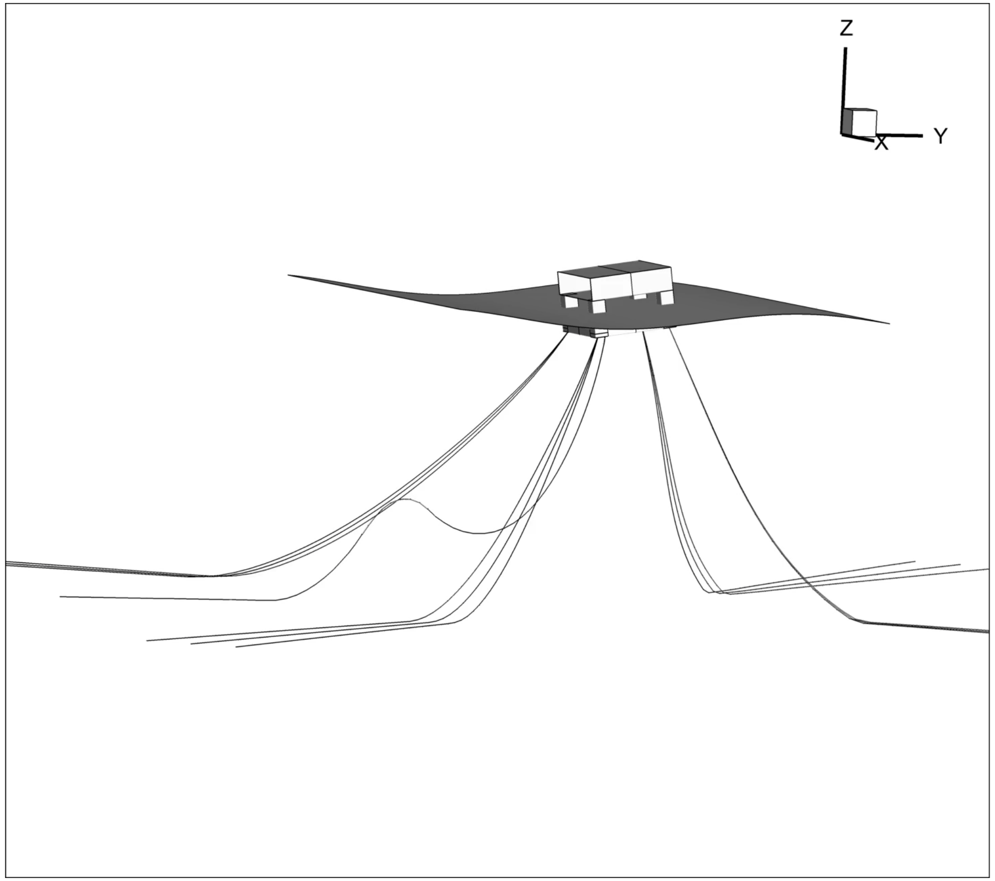
DeepWind Conference 2025, Trondheim, Norway

Tor Anders Nygaard, IFE (tor.anders.nygaard@ife.no)
Tedy Asyikin, Nexans
Elisabeth Gjolmesli, Nexans
Dagfinn Ulvestad, Aibel
Gaute Aasen Slinde, Aibel
Audun Johanson, Nexans

What is the purpose of this thing ?
What is missing ?



Floating substations



Balancing different design goals:

- Soft mooring is desired to give low mooring loads, but this can lead to large platform offsets
- Large platform offsets can be a problem for the dynamic power cable (DPC).
- This leads to design iterations between mooring and DPC designers
- More knowledge about the cable for the platform and mooring designers could cut down the number of iterations and speed up the design process

In this project we use 3DFloat and OrcaFlex. Both models have undergone verification and validation in the IEA OC3-OC7 projects.

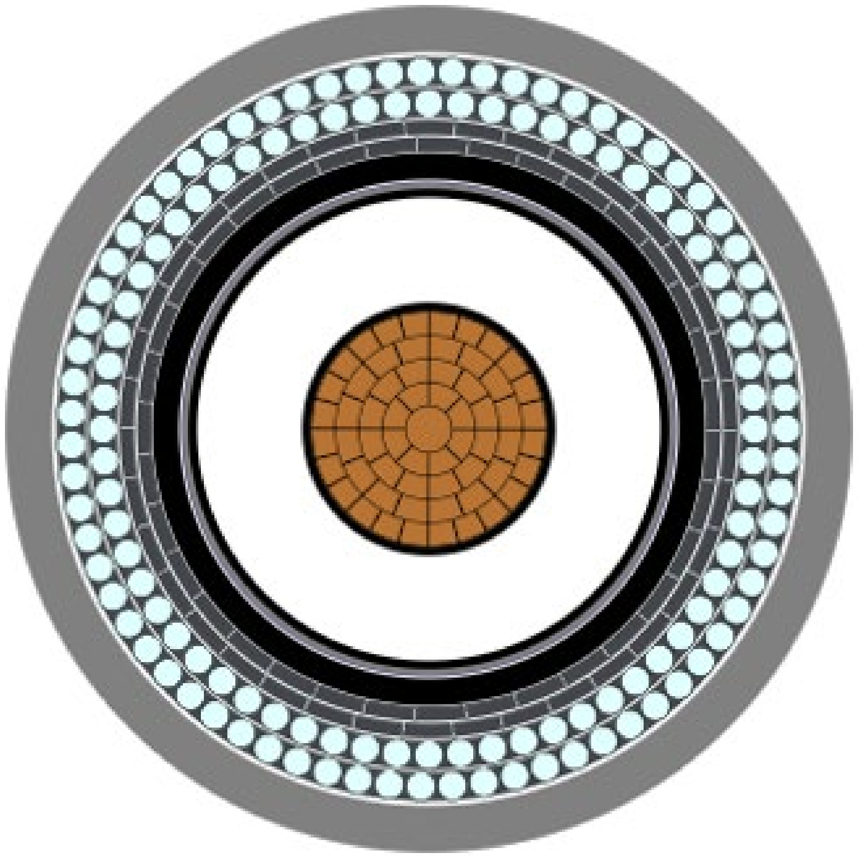
Agenda

- Overview of Connect Floating Offshore Wind (Connect-FOW)
- DPC cross section and lazy wave layout
- Mechanical properties specific to DPC
  - Stick-slip hysteresis of cable bending moment
  - Bend Stiffener (BS) function and modeling
- Case study: Floating substation at Utsira Nord
  - Comparison of 3DFloat and OrcaFlex equilibrium configuration
  - Ultimate Limit State (ULS)
    - Sensitivity of results to BS modeling

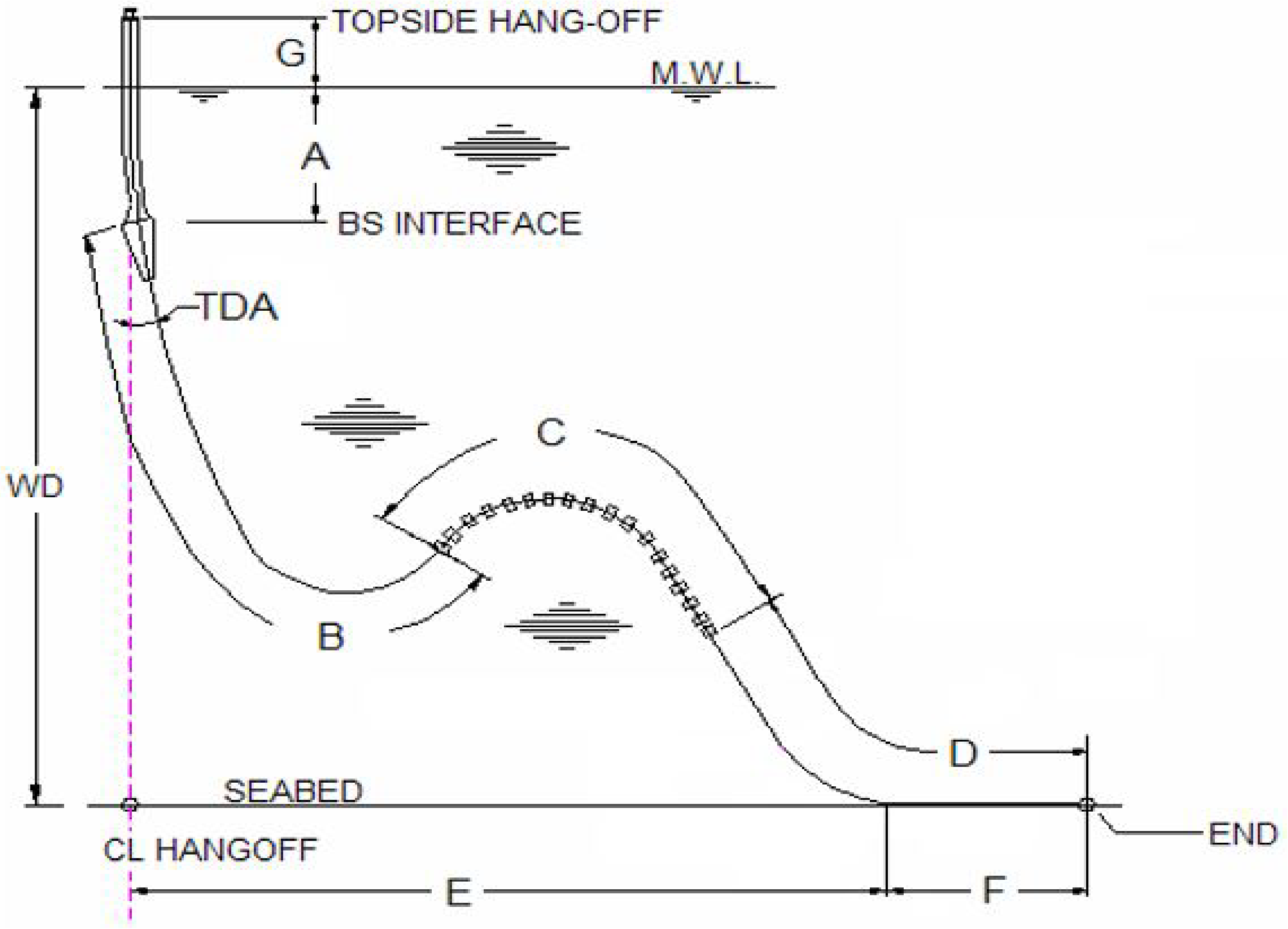
Connect-Floating Offshore Wind (Connect-FOW)

1. Development of dynamic high voltage subsea cables (>220 kV AC and >320 kV DC) with particular focus on fatigue resistance of the water barrier.
2. Development of an integrated modelling tool to accurately address the effect on the cable system of the floating platform and mooring line designs (the focus of this presentation).
3. The optimization of the platform and cable integration to maximize the export cable fatigue life.
4. Design of top-side substation lay-outs consistent with the design constraints added as a consequence of the export cable hang-off location given by (1)- (3).

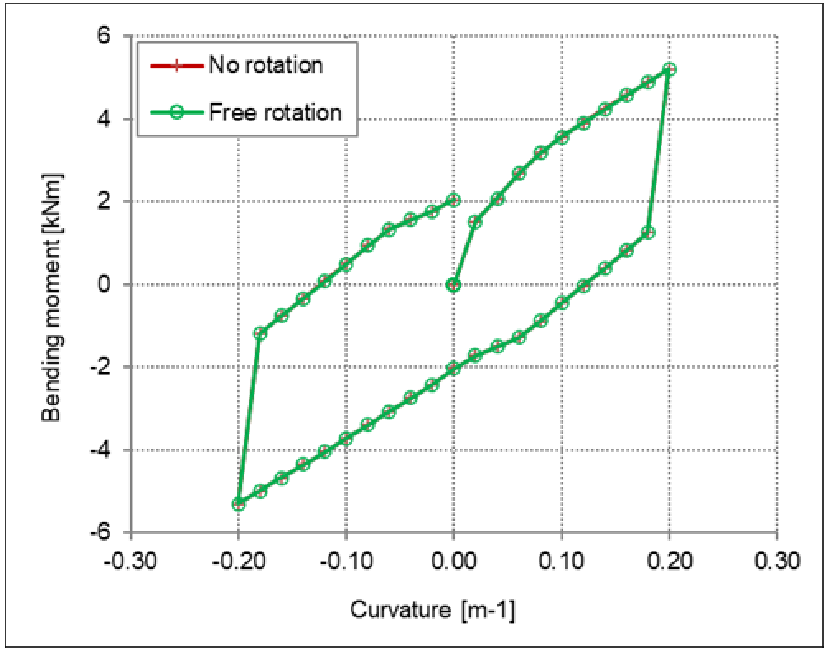
Dynamic Power Cable (DPC) cross section and "lazy-wave"layout



320 kV 1x1200 mm² DC



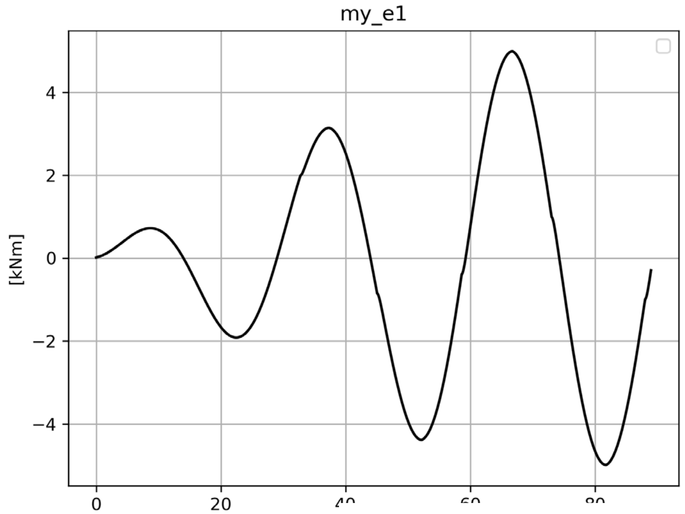
Stick-slip hysteresis of section bending moment

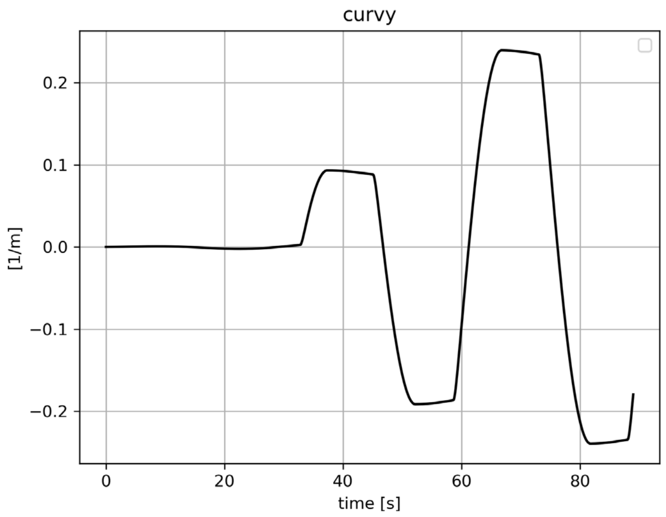


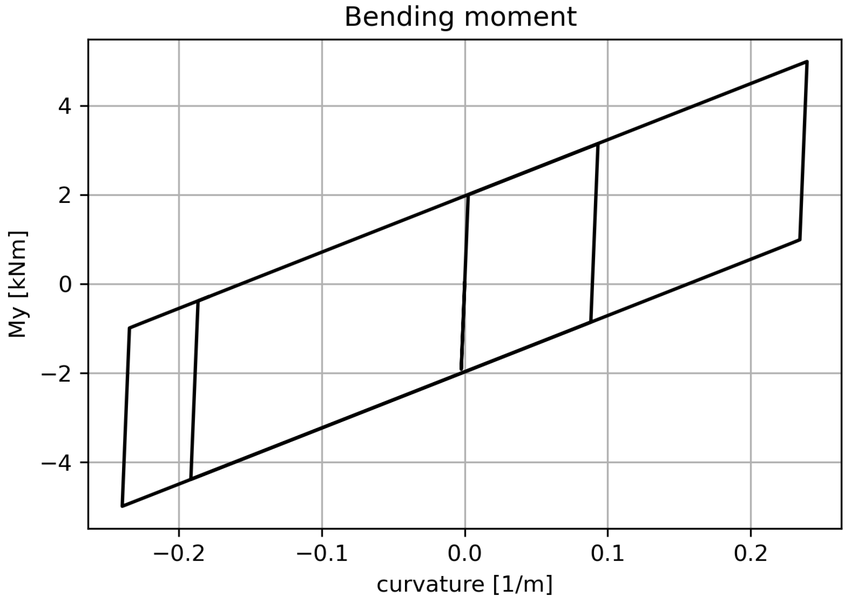
- For a dynamic export cable, with several layers of armor wires, water barriers, insulation and conductors, the mechanical properties are complex. Several layers stick together up to a limiting bending moment, then the cable bending stiffness is reduced as the different layers slip relative to each other.

- The stick and slip effects give the cable a non-linear bending stiffness typically described by a hysteresis, as shown below. The figure is generated by a detailed model of the cable cross section.

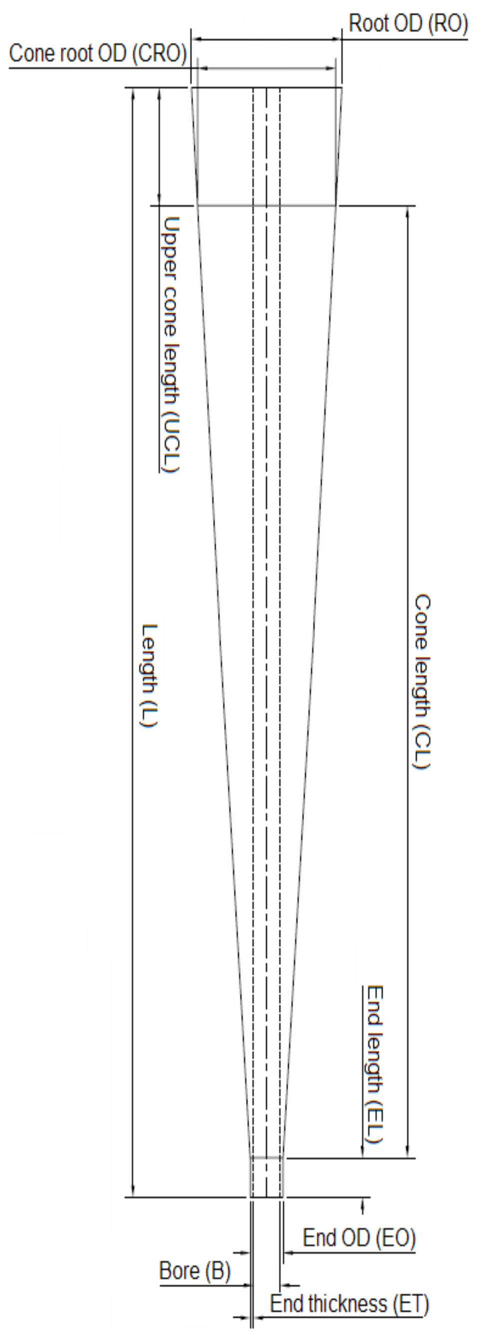
3DFloat forced bending moment and resulting curvature with stick-slip hysteresis





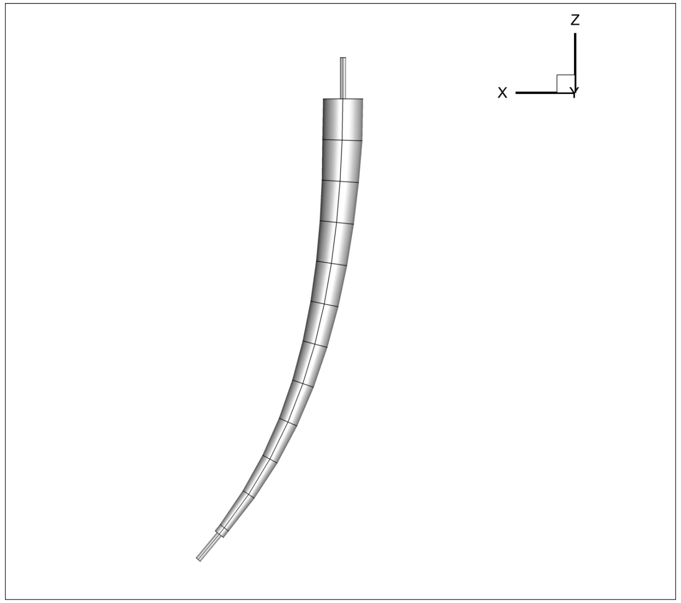


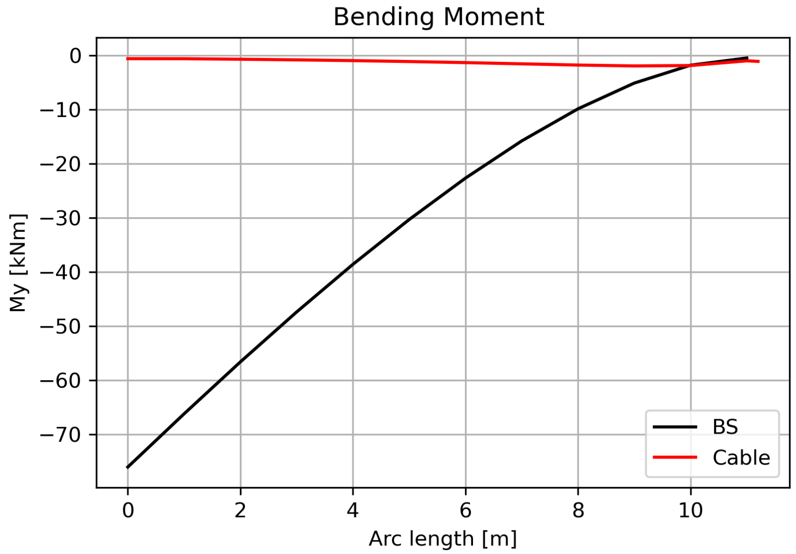
Bend Stiffener (BS)

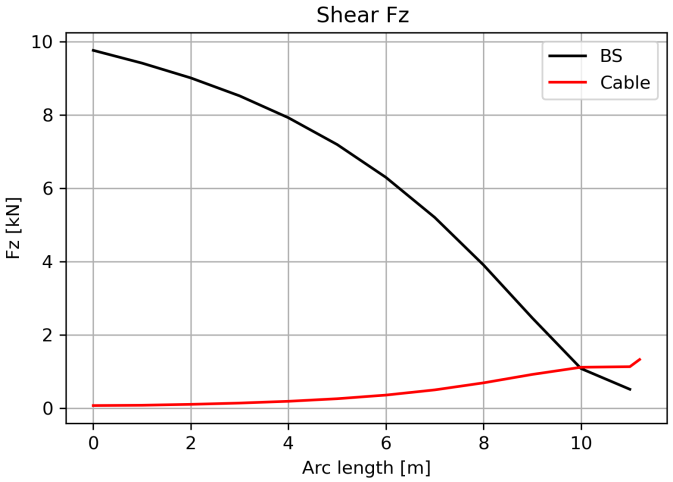


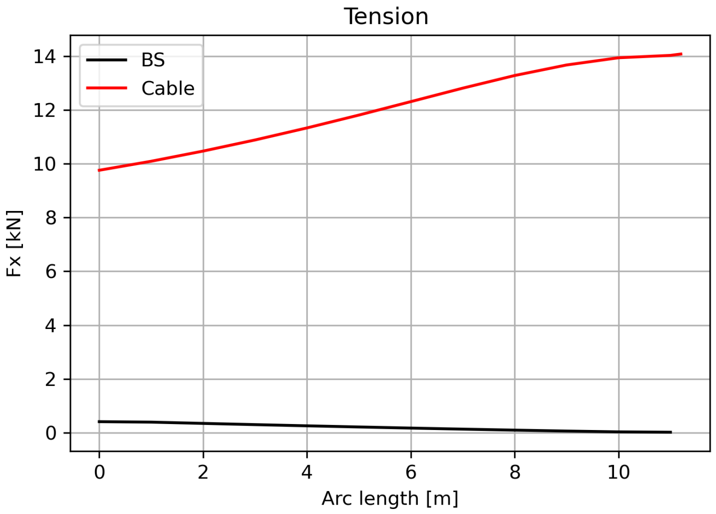
- At the platform interface, DPC runs inside a flexible cone, relieving the DPC of bending moment
- DPC is not restricted in elongation or torsion inside the BS.
- In the 3DFloat finite-element model, BS is modeled as a series of cone beam elements with nonlinear material properties
- The DPC elements run inside the BS cone elements, with the same axial resolution
- For this example, the axial stiffness of the BS is only a small fraction of the axial stiffness in the DPC.
- It is therefore a good approximation to let the DPC and BS elements have common nodes, eliminating the need for a contact/friction model.
- The torsional stiffness of the BS was reduced to accommodate torsion of the DPC without interference from BS.

Isolated bend stiffener and cable example





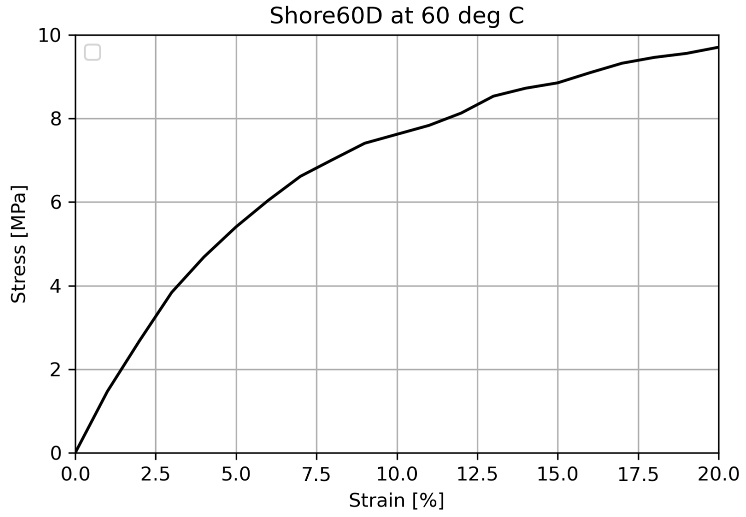


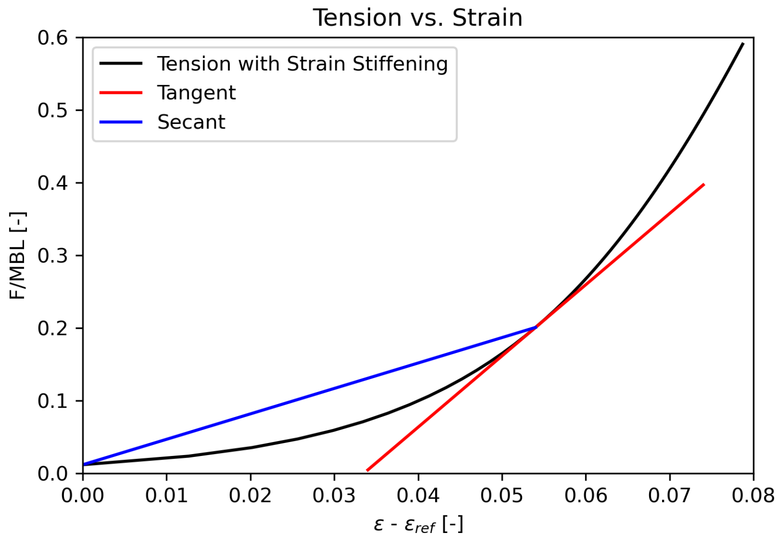


- BS is clamped at top of BS
- Upper end of the cable is fixed
- Lower end of cable is pulled at 45 deg angle
- BS takes the entire bending moment towards the interface.
- Withous BS, this moment would have to be taken by the cable
- The cable takes the major part of the tension, despite the approximation of common nodes for BS and cable.
- Modeling of the BS is essential for understanding the cable internal forces/moments towards the platform.

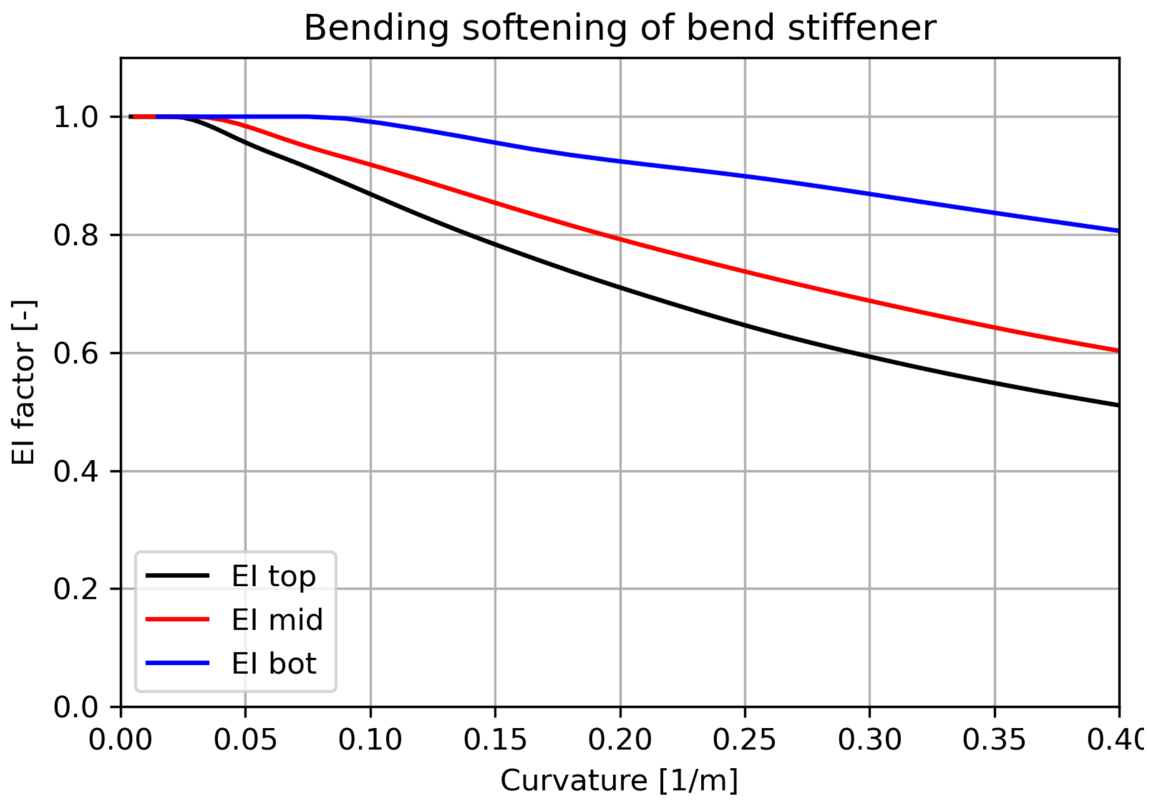
Bend stiffener material model

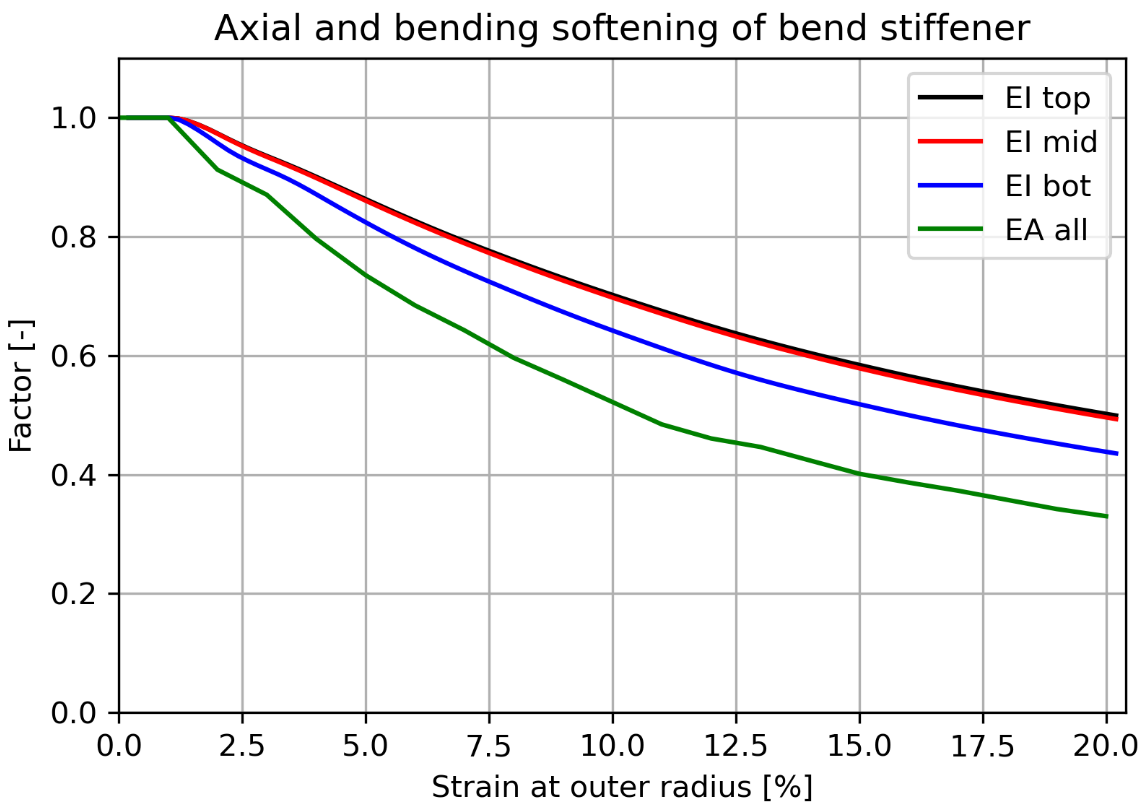
- The stress-strain relationship would be a straight line for a linear-elastic material.
- For the plastic material in this example, the stiffness (slope of the curve) is reduced for higher strain
- This relationship translates directly to axial stiffness
- For bending stiffness, the stress-strain relationship is integrated across the different cross-sections. This is done only once for each cross-section in a simulation
- The result is a nonlinear relationship between bending moment and curvature.
- Secant stiffness (see figure from another context) is used throughout this presentation



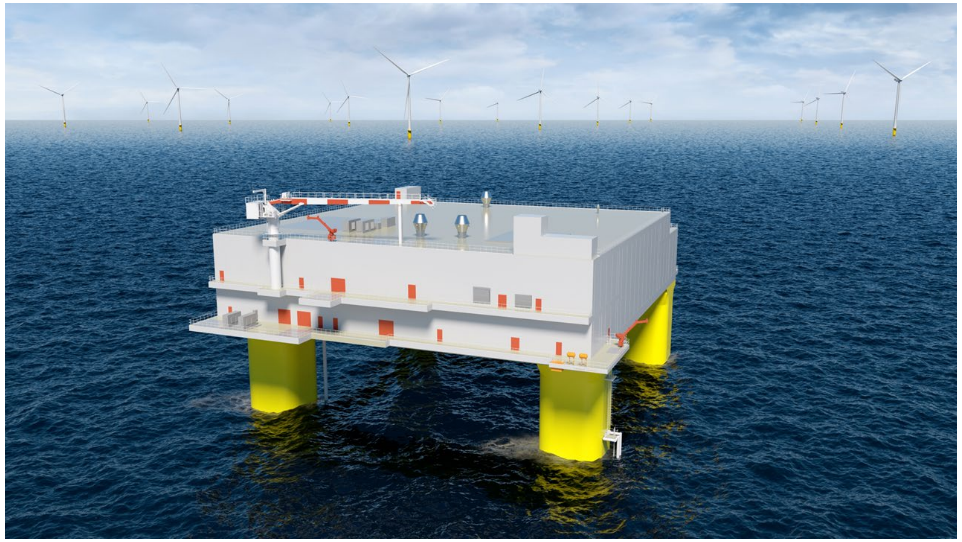


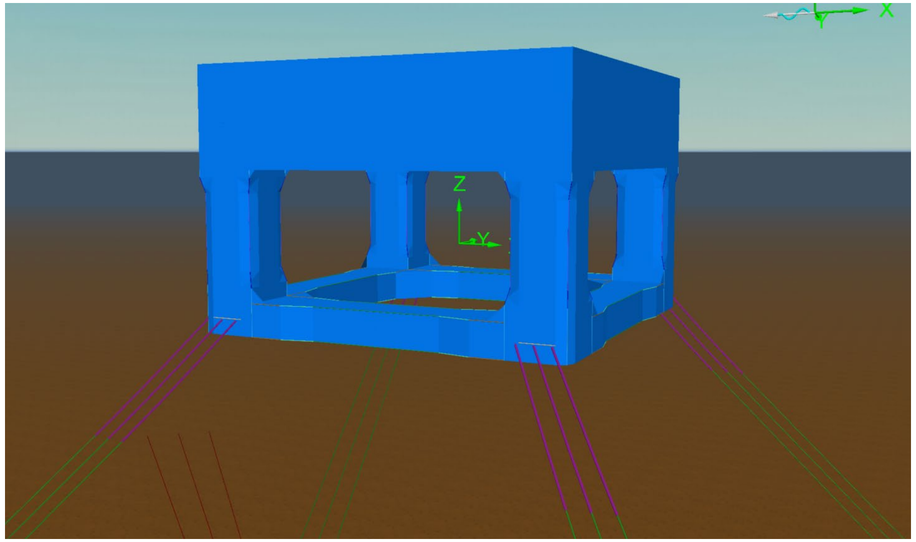
Bend stiffener axial and bending stiffness corrections

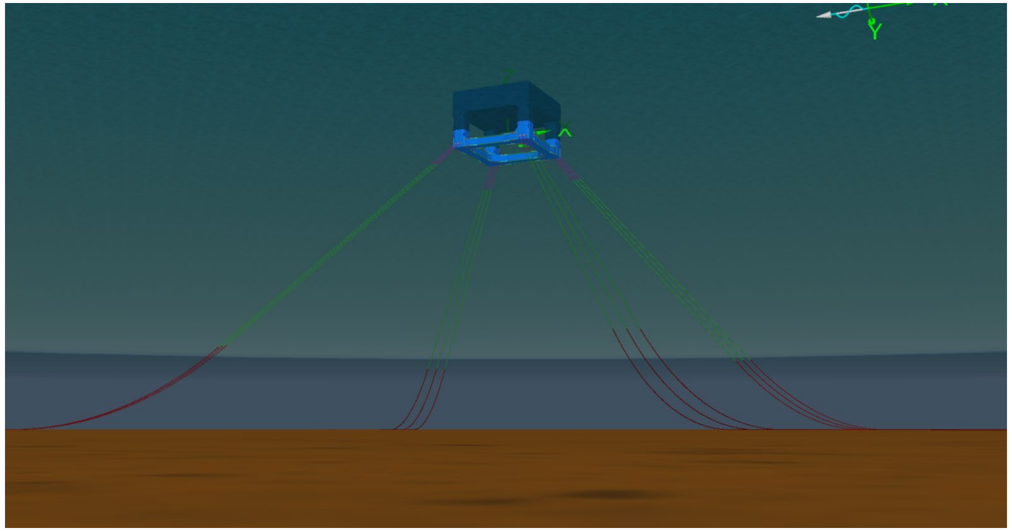




Case study: Utsira Nord at 260m water depth

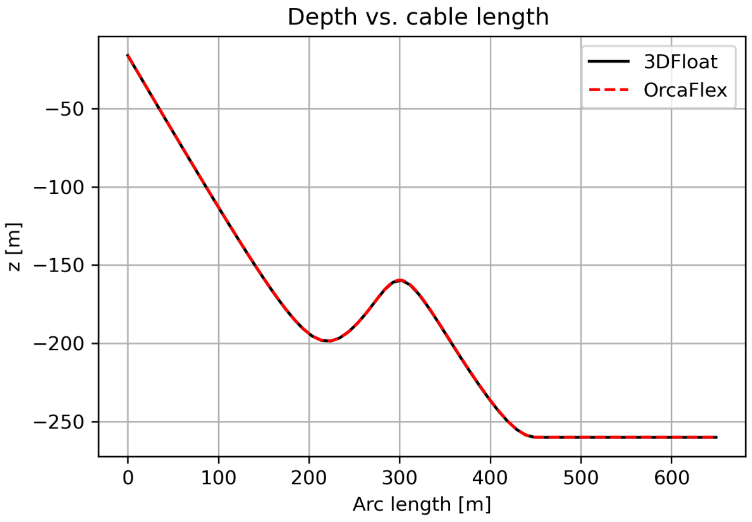


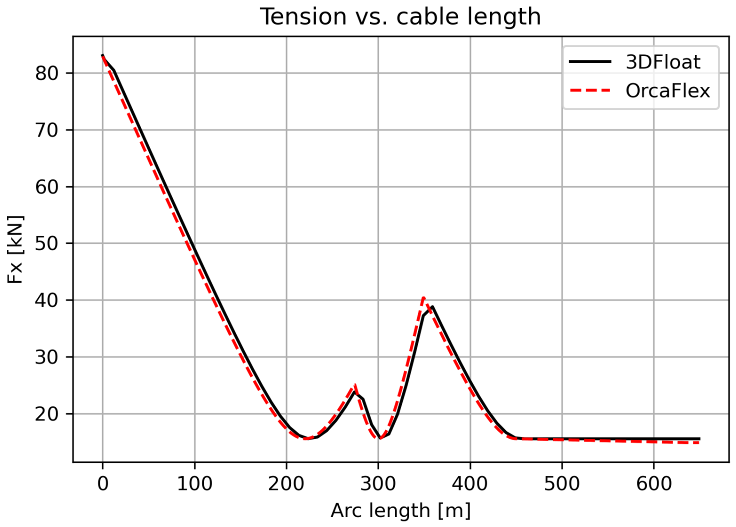


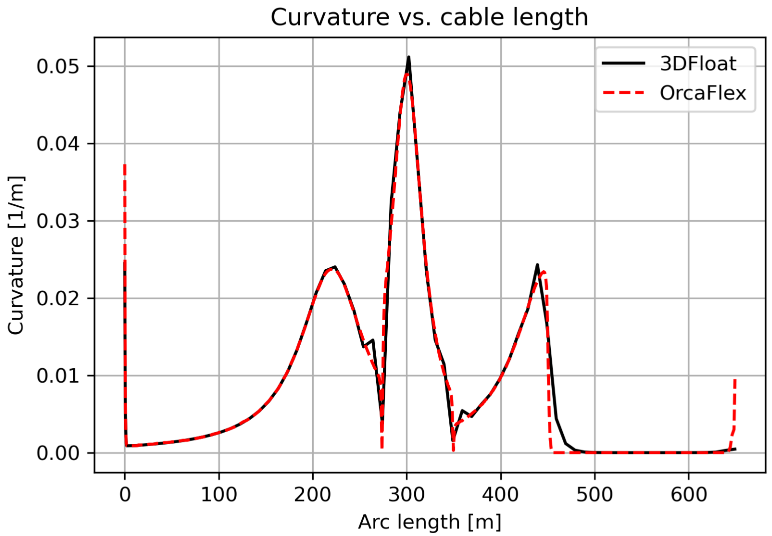


- HVDC 1.4GW
- Unmanned
- 8-15 inter-array cables
- 3 export cables
- 16m draft
- 75.4 m x 75.4m

DPC equilibrium configuration, no platform offset

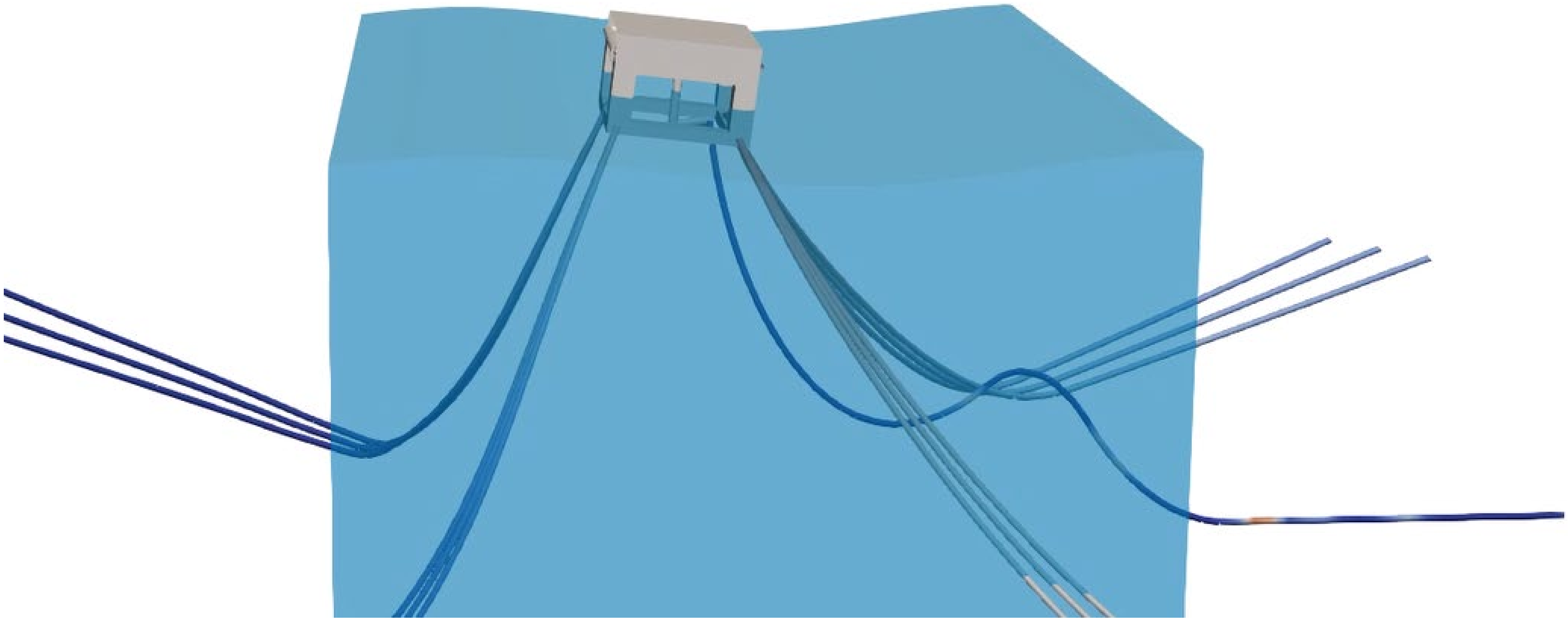




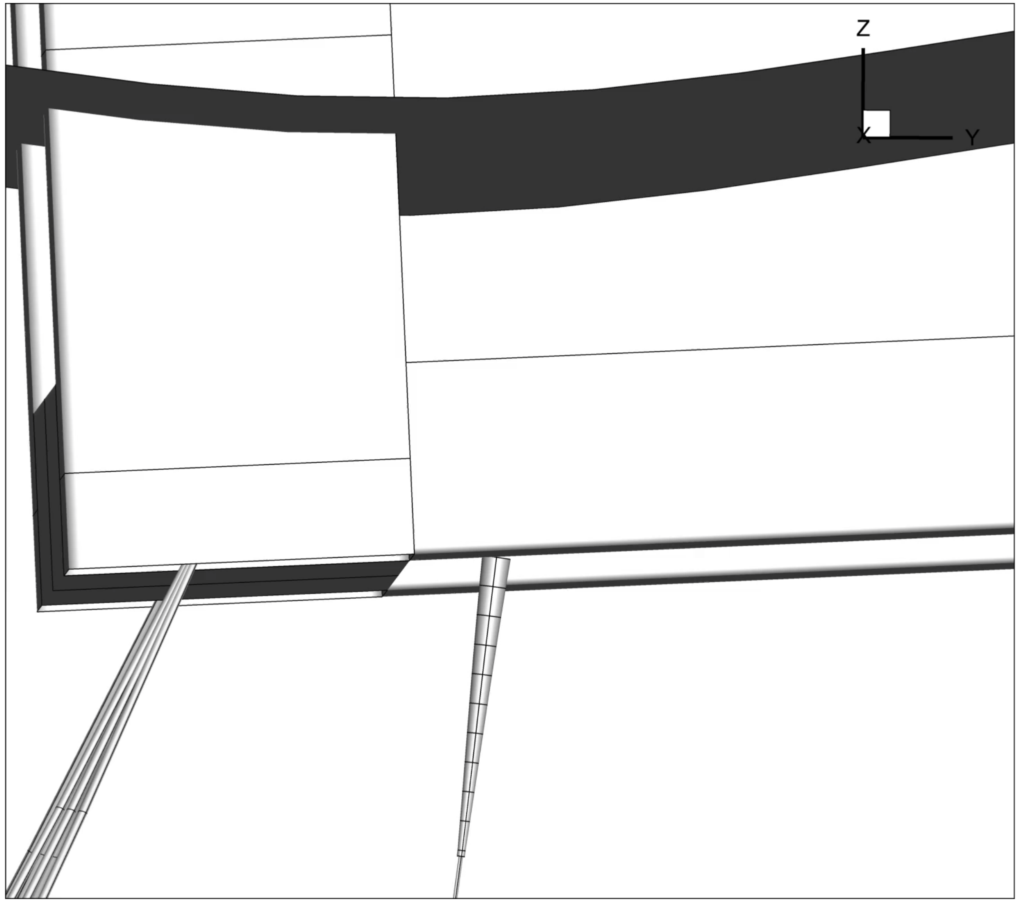


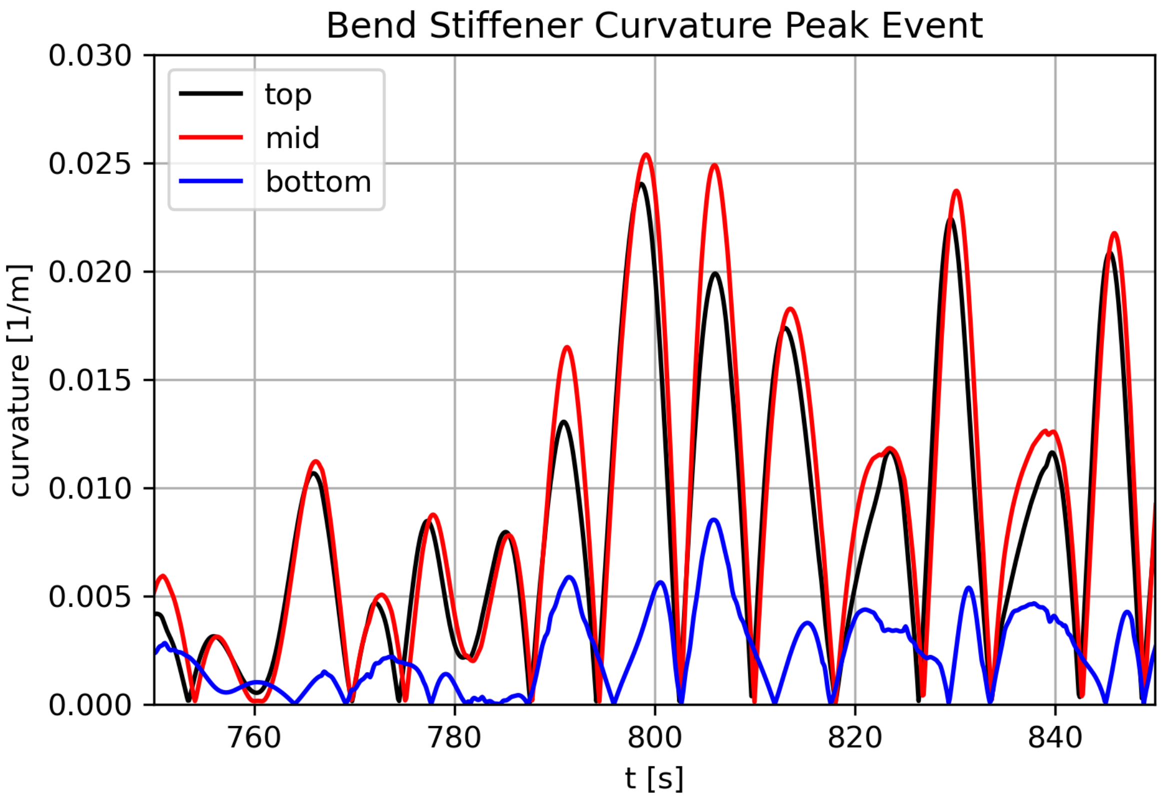
The differences between 3DFloat and OrcaFlex are small and may be due to differences in seabed friction and damping modeling, and the procedure for initiating the simulation

ULS example in progress, Utsira Nord



Bend stiffener, ULS

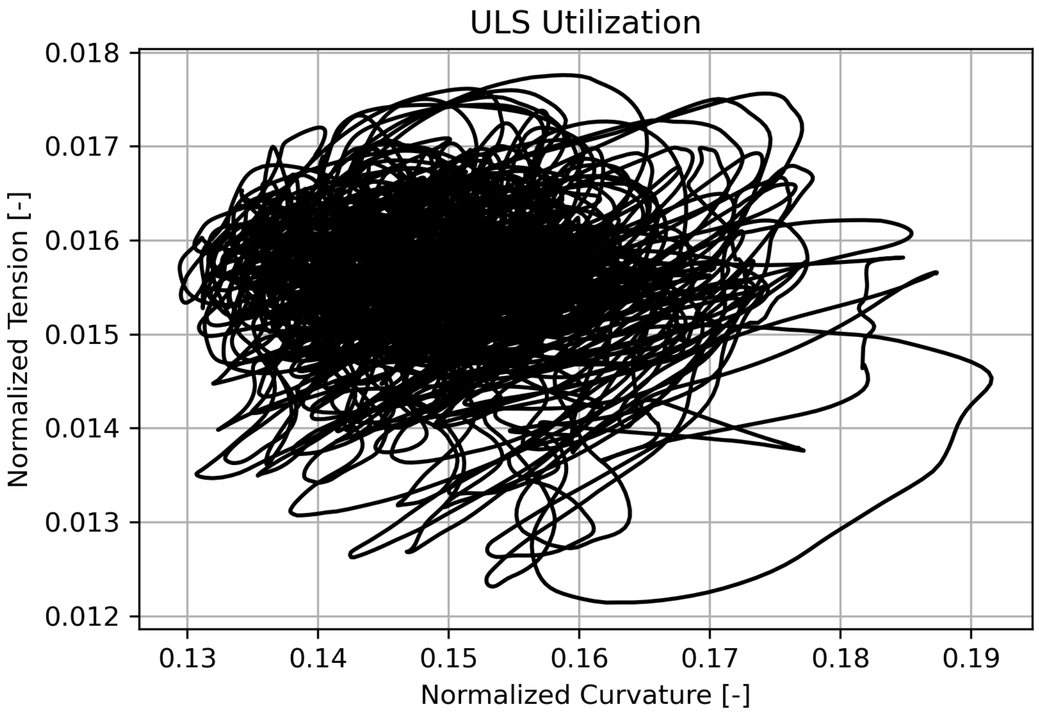


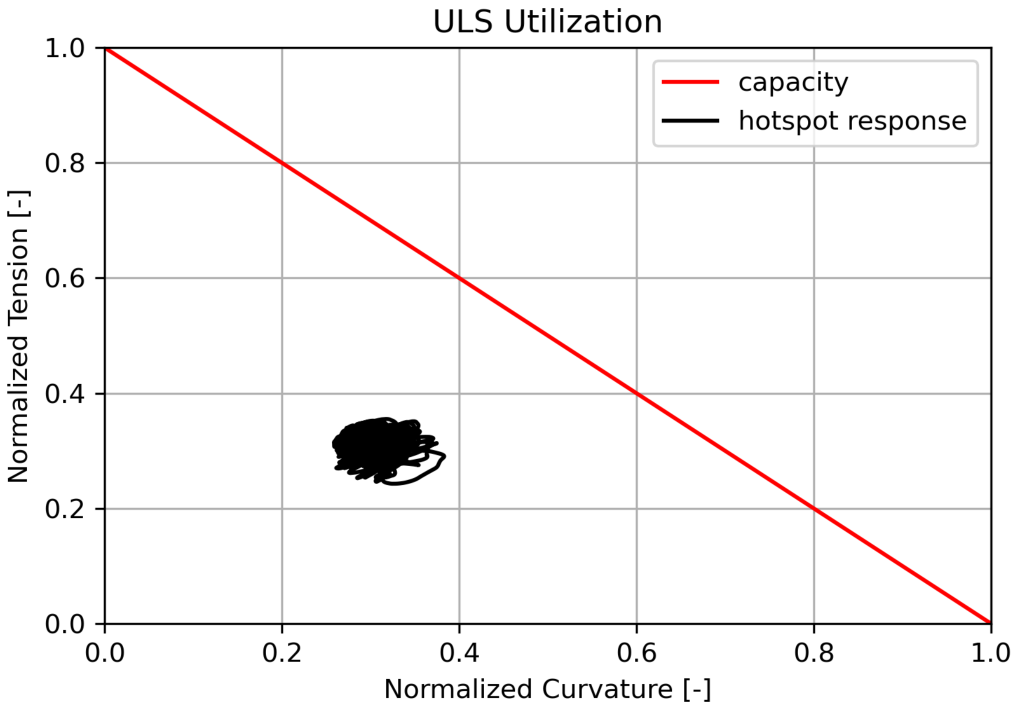


The nonlinear material for BS model is not critical for this particular case, see the bending stiffness corrections

ULS capacity

- Capacity curves for ULS are often given in curvature-tension diagrams, not necessarily as straight lines as in the illustration below
- Hotspots along the cable are plotted in this diagram for all the ULS cases. Here one hot-spot for one wind/wave direction





Summary and conclusions

- For modeling of dynamic power cables, aero-servo-hydro-elastic time domain codes should be supplemented with a model for the bend stiffener.
- The bend stiffener material has a nonlinear stress-strain relationship.
- The load cases so far in this study did, however, not load the bend stiffener much beyond the linear region in the stress-strain relationship.
- The ULS-cases computed so far for Utsira Nord are well with the cable capacity.
- The effect of bending stick-slip hysteresis is being examined with a case with more severe conditions.
- Next up is development of a methodology for approximate fatigue calculations that can be used by the mooring system designers. It is a challenge to balance the need for accuracy, and protection of competition-sensitive information.

Acknowledgements

- This work has been supported through grant # 332325 from the Norwegian Research Council and the industry partners Nexans, Aibel, Ørsted and RWE in the project Connect- Floating Offshore Wind
- Lars Einar Sørensen Stieng, IFE helped out with the 3DFloat animation