EERA DeepWind’2021: “Dynamic cable model for layout optimisation purposes in Floating Offshore Wind Farms”

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Part 1: Introduction

Part 2: Cables

Part 3: Cable model

Part 4: Algorithm

Part 5: Results

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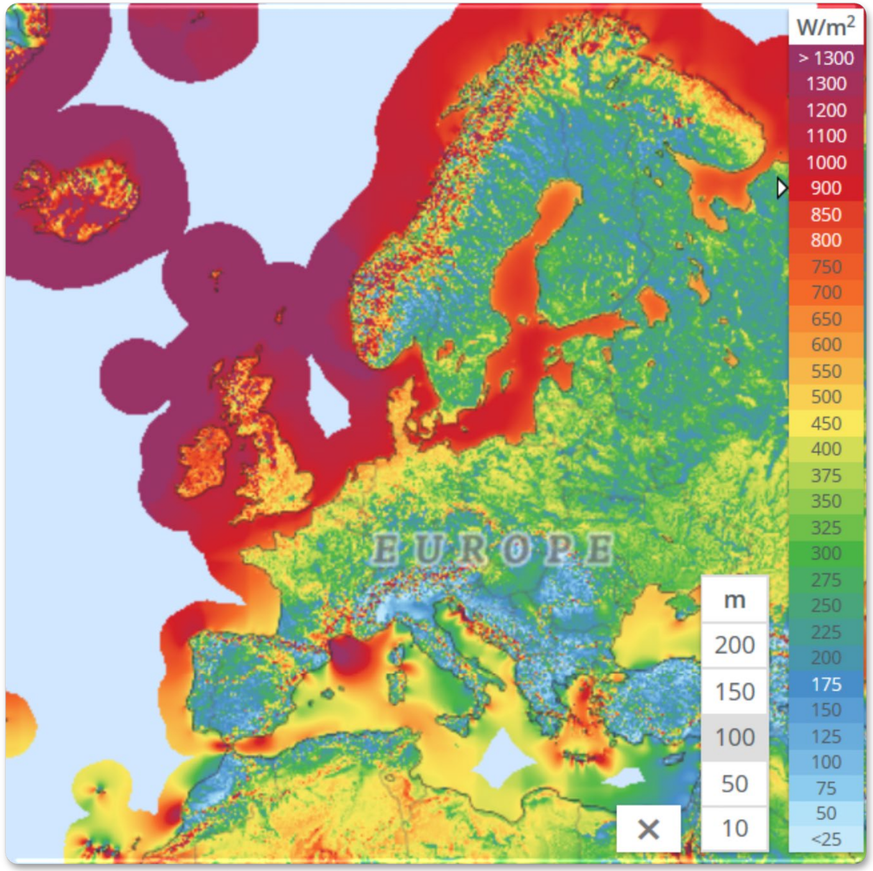
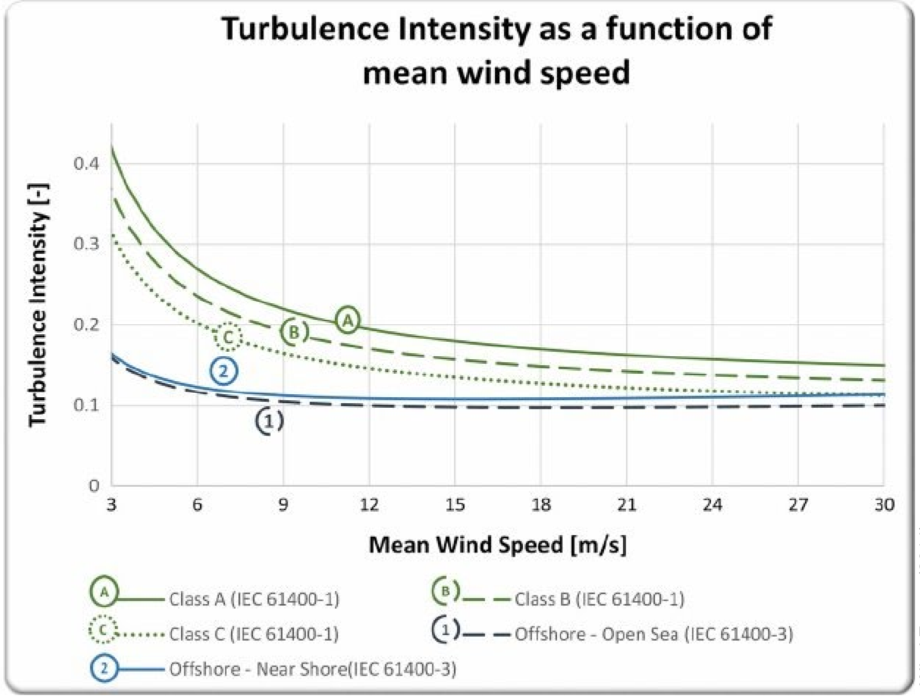
GOING OFFSHORE 1



https://globalwindatlas.info/



Wind Energ. (2014)

The best locations are far from the coast but…

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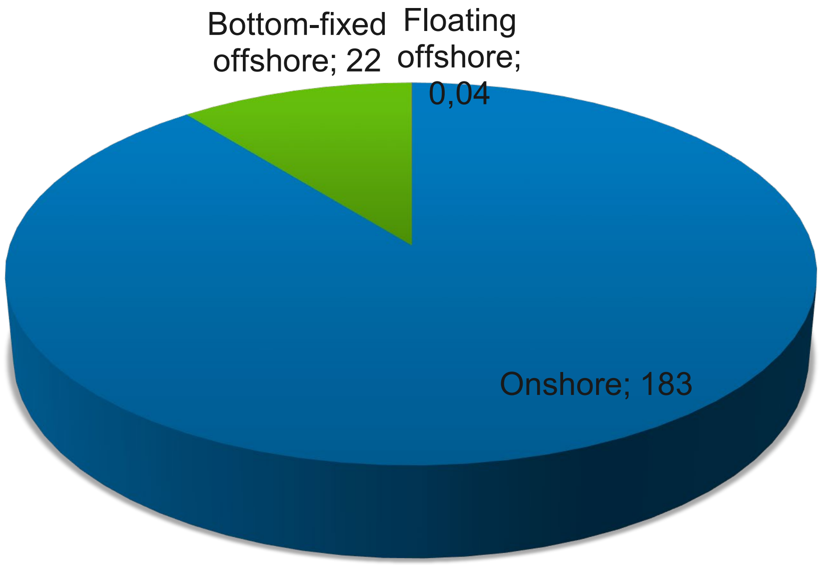
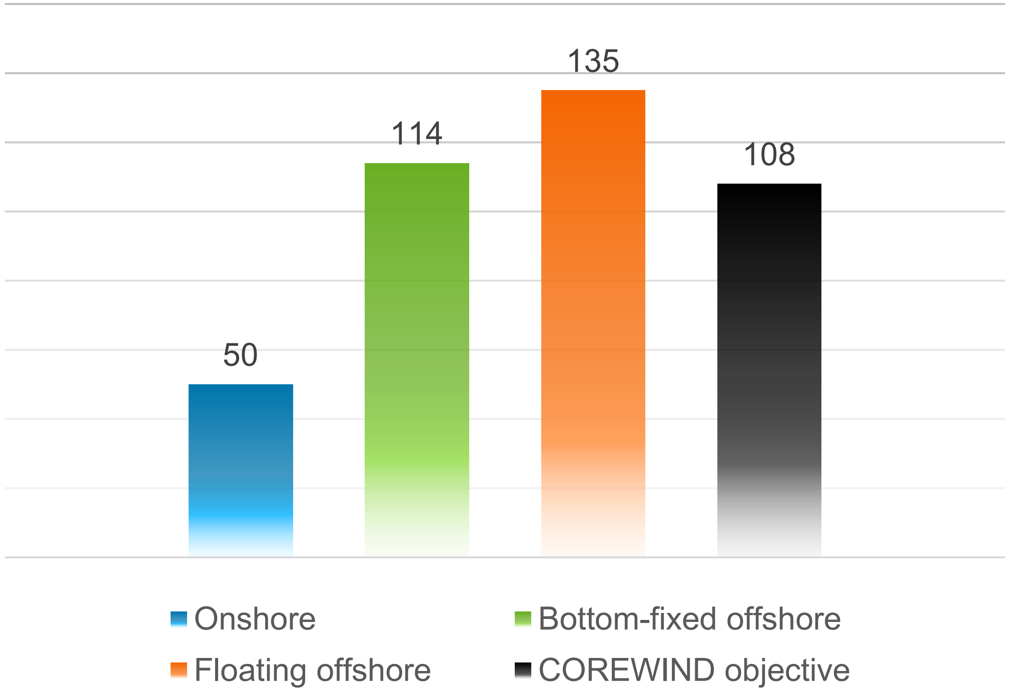
GOING OFFSHORE 2

… it is all about costs.

Installed capacity in Europe 2019 [GW]



LCOE 2020 [€/MWh]



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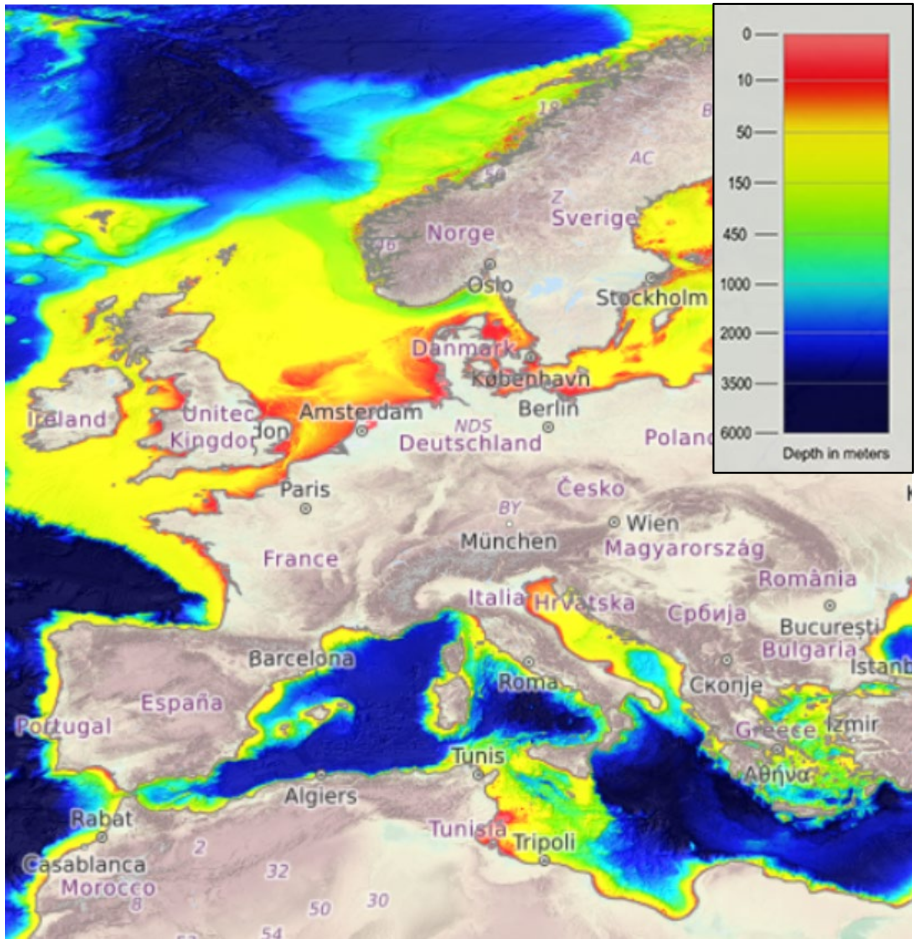
GOING OFFSHORE 3



https://portal.emodnet-bathymetry.eu/

However:

- In Europe, the best locations for onshore wind farms are already exploited. Remaining locations present winds with lower quality, are remote areas or are just protected.
- Bottom-fixed offshore wind farms are now a consolidated technology, but their costs make it unviable at depths greater than 50 m.
- Floating offshore wind has a great potential: combining Europe, US and Japan, around 7.000 GW are available!!

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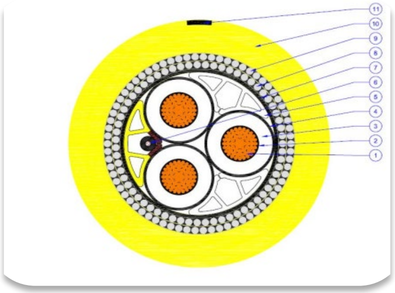
SOME FOWFS CHALLENGES

Standardisation

Logistics & assembly

Repair & maintenance



Dynamic cables

Costs

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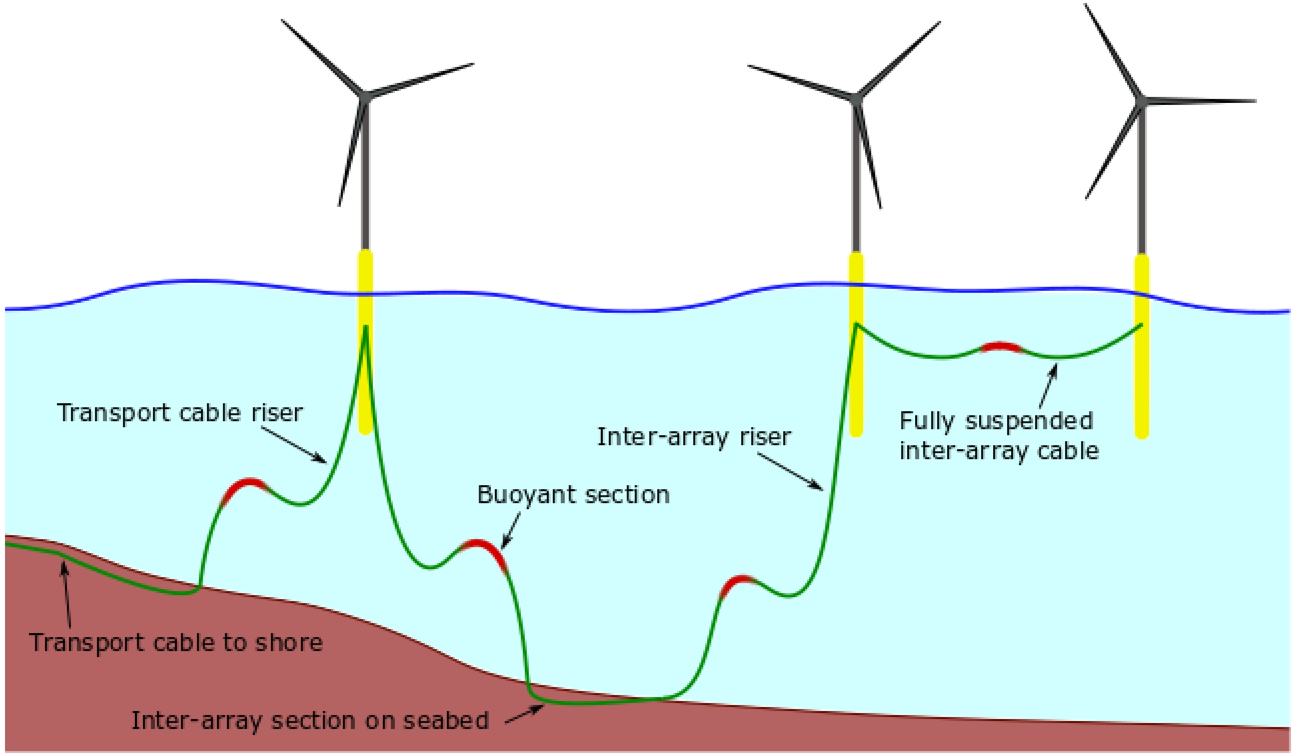
FOWF CABLING OVERVIEW

Cable classification

- Function
  - *Transmission*
  - *Inter-array*
- Structure
  - *Static*
  - *Dynamic*
- Position
  - *Fixed*
  - *Suspended*



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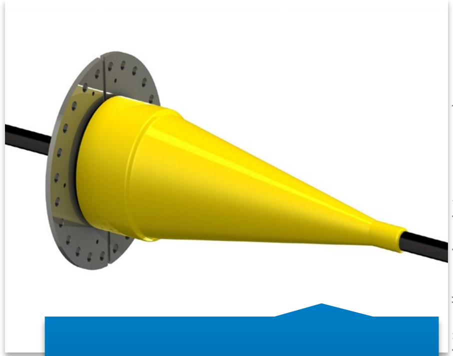
ANCILLARY EQUIPMENT FOR DYNAMIC CABLES



https://www.bardotgroup.com/

Bend stiffeners

https://www.renewableconstructions.com/

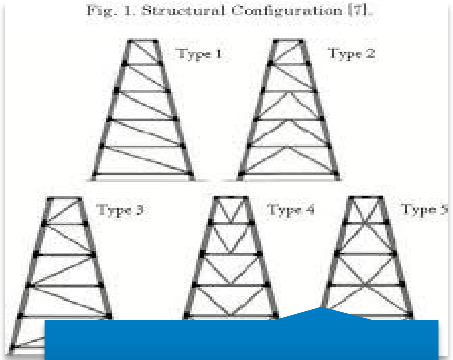
Bell mouths

https://www.bardotgroup.com/

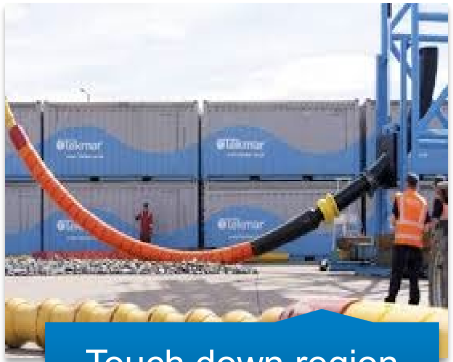
Buoyant modules

https://www.trelleborg.com/

Buoyant arches



Rigid structures

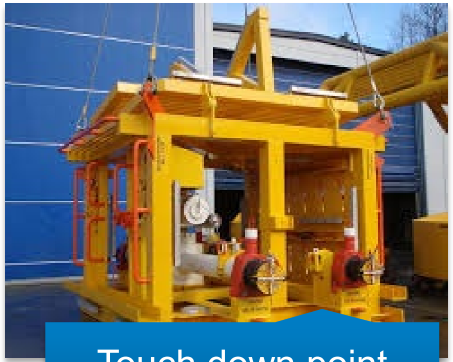


http://subsea-equipment.com/

Touch down region protection

http://www.blueoceanprojects.com/

Clamps tethered to the seabed



Touch down point base

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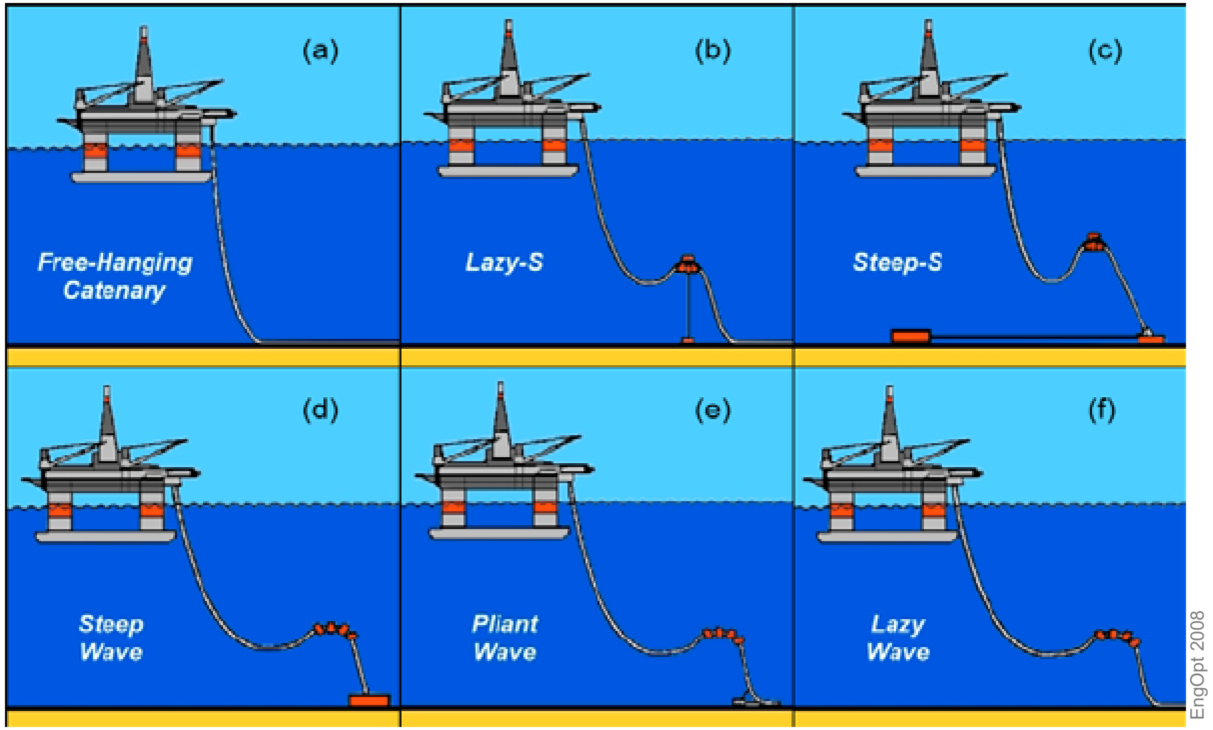
SUSPENDED CABLE CONFIGURATIONS



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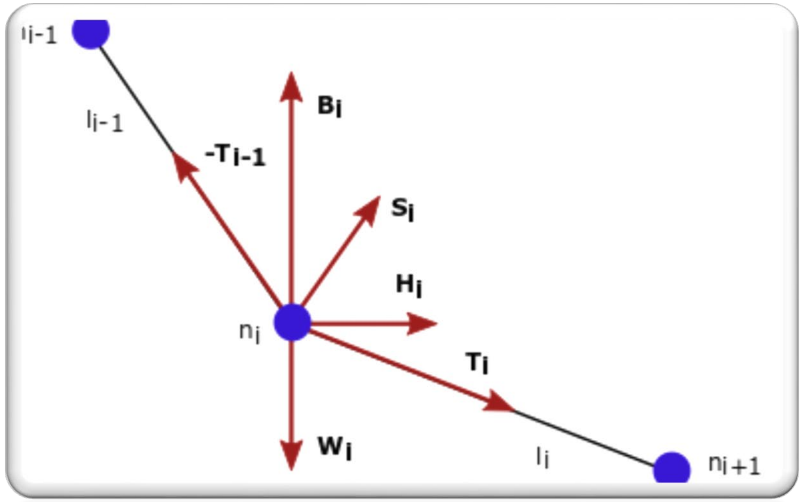

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EXISTING MODELS

Advantages

- *Some existing programs can perform accurate dynamic analysis of dynamic cables (e.g., OrcaFlex)*

Disadvantages

- *Lacking or limited optimising capabilities (e.g., only 2D optimisation)*
- *Long simulations*
- *Difficult integration for expanded optimisation or additional evaluations*
- *Complex tasks even for early stages of projects*

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OBJECTIVE

The aim is to develop a model of the suspended cables with several degrees of freedom and including the main ancillary equipment as well as the relevant loads, finding a balance between realistic behaviour and moderated computation times when it comes to optimising.

The existing cable configurations are assessed, plus additional configurations that may be feasible and viable for FOWFs.

The model is developed to meet the requirements of the next steps.

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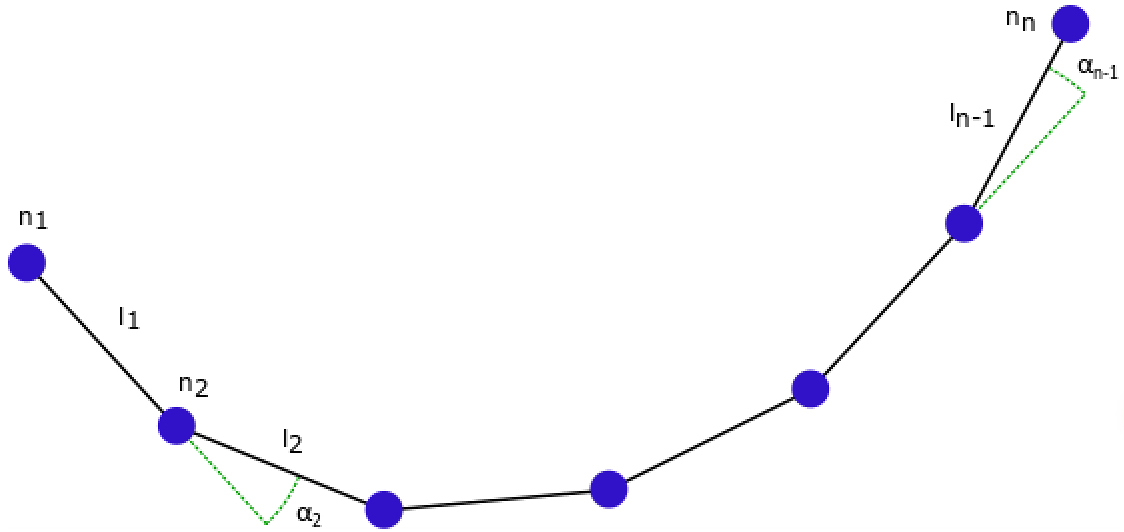
MODEL OVERVIEW

The position of a suspended cable, even in static conditions, can’t be determined analytically in most of cases

Lumped mass model: all cable properties are transferred to the nodes (except its length)

The position and tensions are determined imposing equilibrium conditions at each node



Maximum angle between segments

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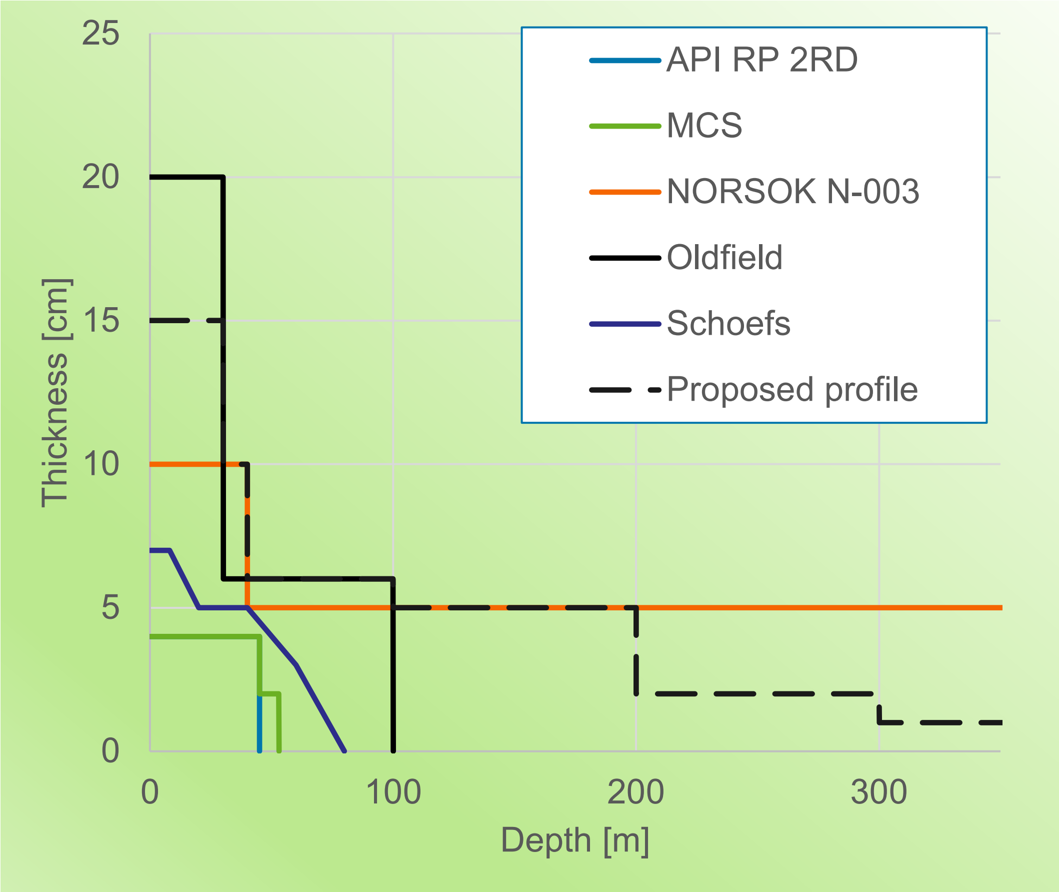
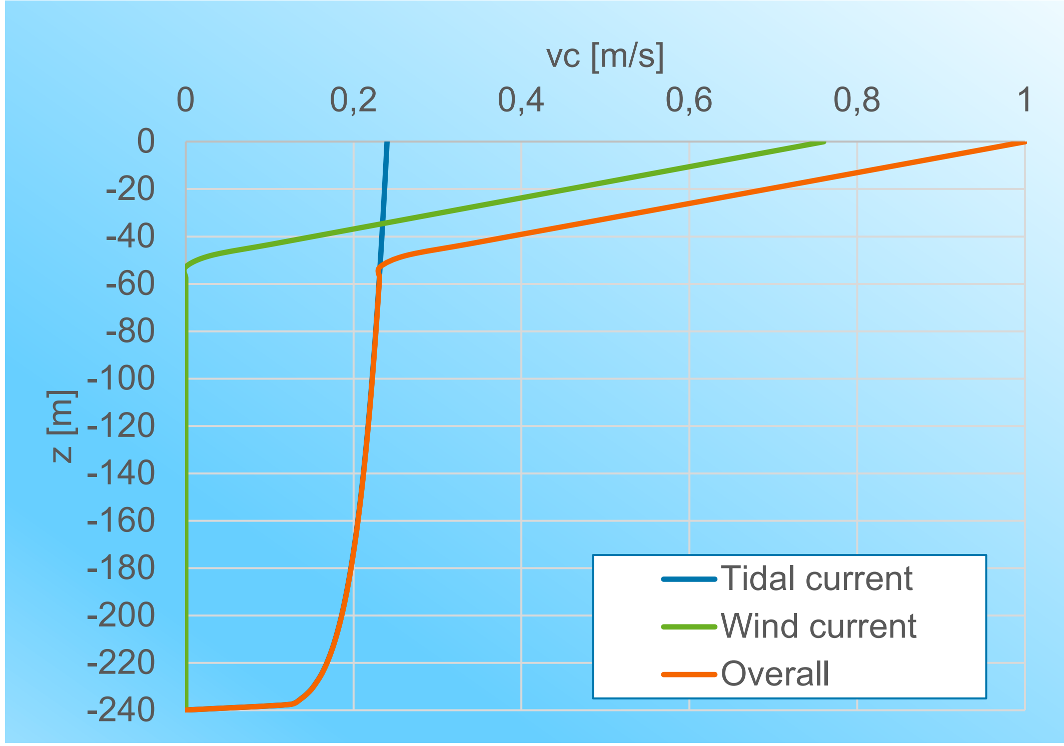
EXTERNAL ACTIONS

Marine growth



Currents



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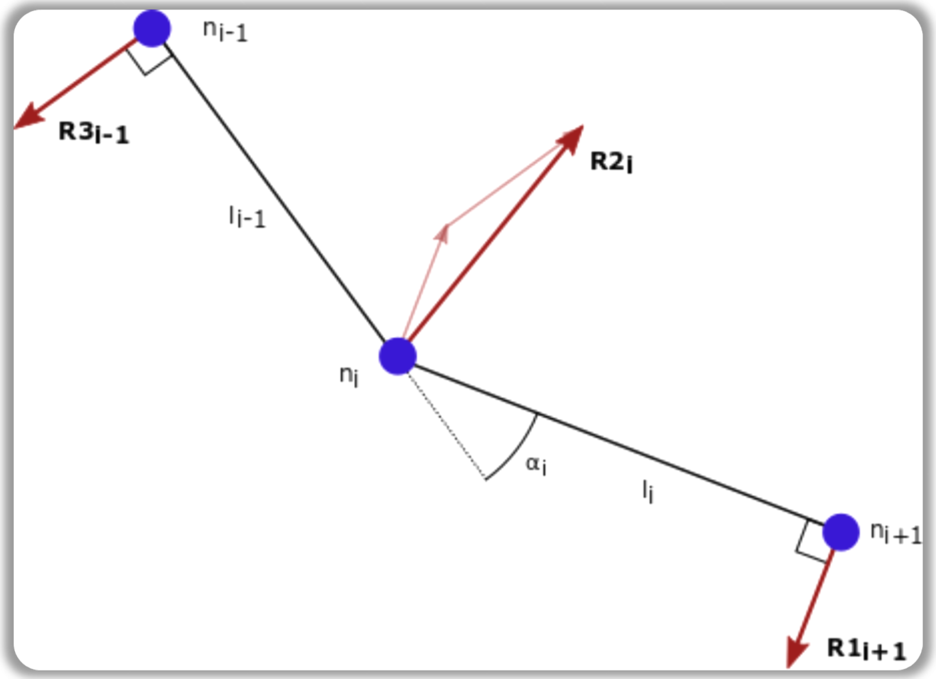
FORCE MODELS

- Force applied to each node
  - Seabed reaction
  - Weight
    - Cable
    - Marine growth
    - Clamp
  - Buoyancy
  - Tensions
  - Moments
    - Cable bend stiffness
    - Bend stiffeners
  - Drag
    - Cable diameter
    - Marine growth thickness



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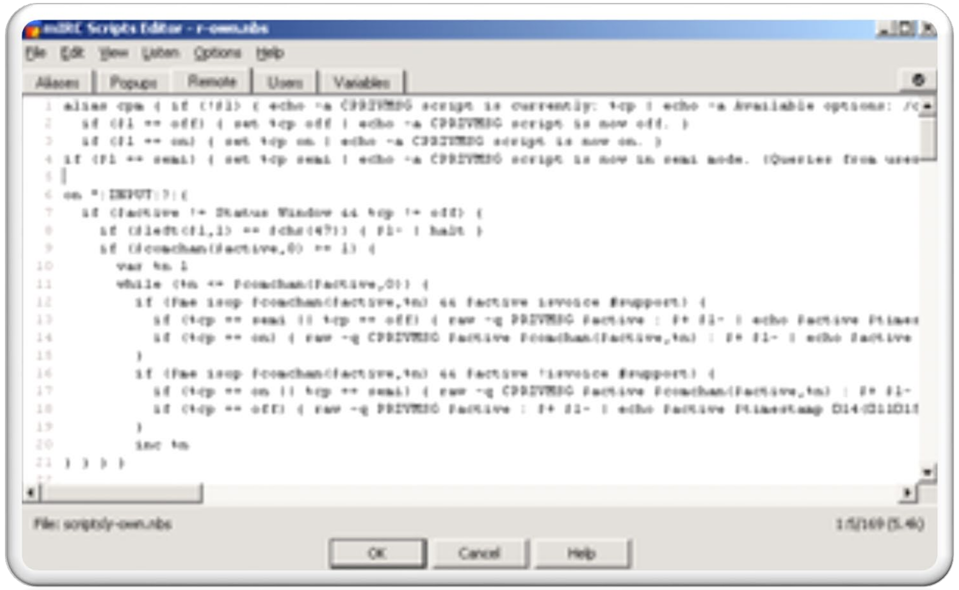

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THE CATENARY

Mathematical definition and properties

- Equation

$$\frac{d^2z}{dx^2} = \frac{\lambda}{T_H}\sqrt{1+\left(\frac{dz}{dx}\right)^2}$$

- Integrated equation

$$z - z_0 = a \cdot \cosh\left(\frac{x - x_0}{a}\right)$$

- Arc length

$$L = a \cdot \sinh\left(\frac{x_0 - x_A}{a}\right) + a \cdot \sinh\left(\frac{x_B - x_0}{a}\right)$$

Physical properties

- Horizontal tension

$$T_H = a \cdot \lambda$$

- Vertical tension

$$T_V = T_H \cdot z' = a \cdot \lambda \cdot \sinh\left(\frac{x - x_0}{a}\right)$$

- Tension

$$T = T_H \cdot \cosh\left(\frac{x - x_0}{a}\right) = \lambda(z - z_0)$$

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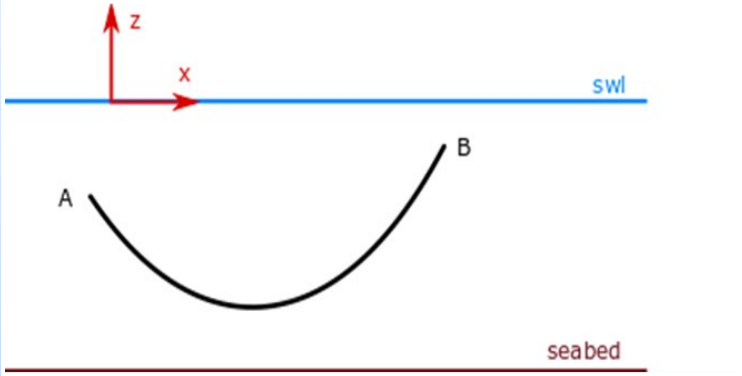
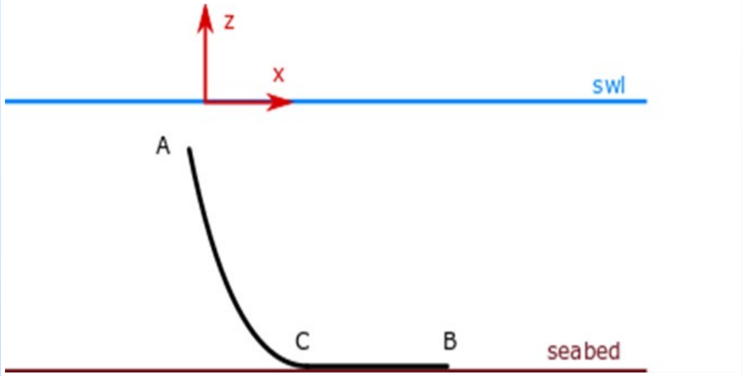
INITIAL GUESSES

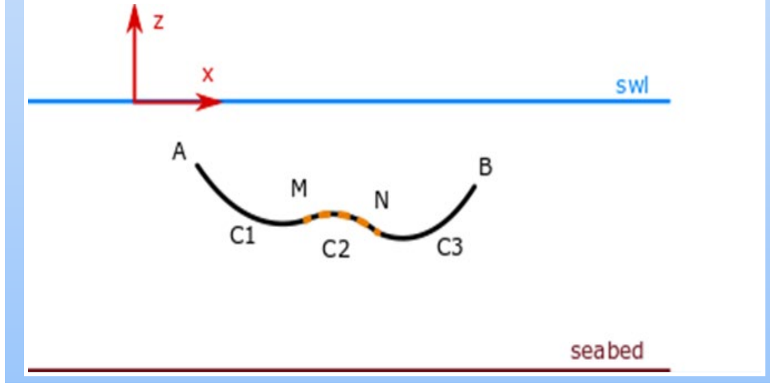
Double hanging catenary



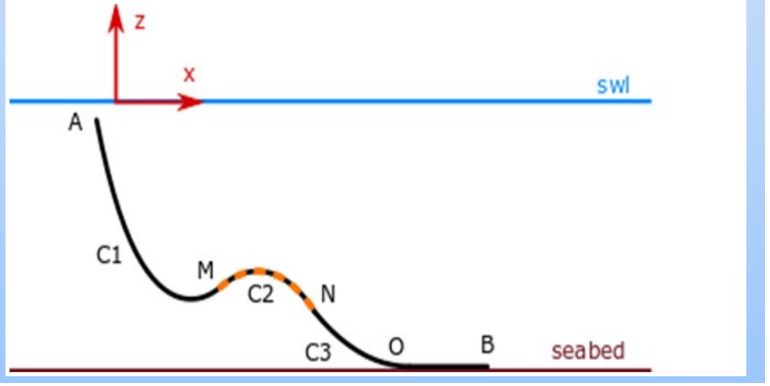
Single hanging catenary



Triple catenary



Lazy wave



CABLE POSITION CALCULATION

- Step 1 – Initial guess
- Step 2 – Initial position
- Step 3 – + bend stiffness
- Step 4 – + tether
- Step 5 – + marine growth
- Step 6 – + currents
- Step 7 – + axial strain

```
Loaded cable: Nexans V333x80035
Loaded marine growth profile: Default

Step   Iter   Flag   Cable T [kN]   Curv [m-1]   Alpha [deg]   Lengths [m]   Tether T   Check
                      Min     Max       Max          Max        Laid   Susp     [kN]
  1     14      1    Guess3Caten
  1     37      1    GuessLW
  2      3      1     7.3    68.4     0.058          3.1         10     370        -        OK
  3      5      1     7.3    67.8     0.177          9.6         10     370        -        OK
  4     27      1     7.1    69.0     0.178          9.7         18     362       3.5       OK
  5     12      1     7.4    76.6     0.190         10.4         18     362       2.6       OK
  6     16      1     6.9    76.3     0.177          9.7         19     361       2.8       OK
  7     Cable strain of 0.013% (5 cm) neglected.

Elapsed time is 6.656814 seconds.
```

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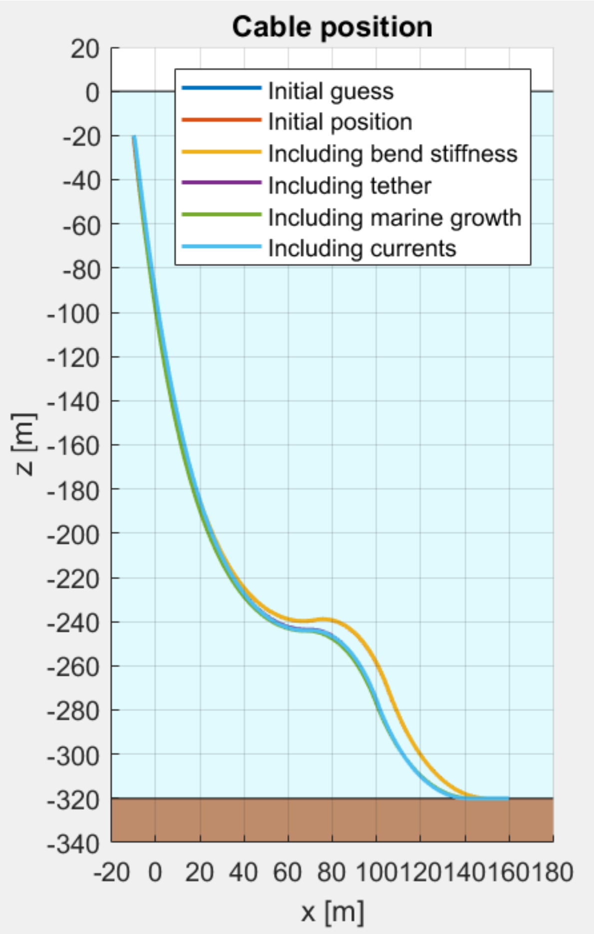
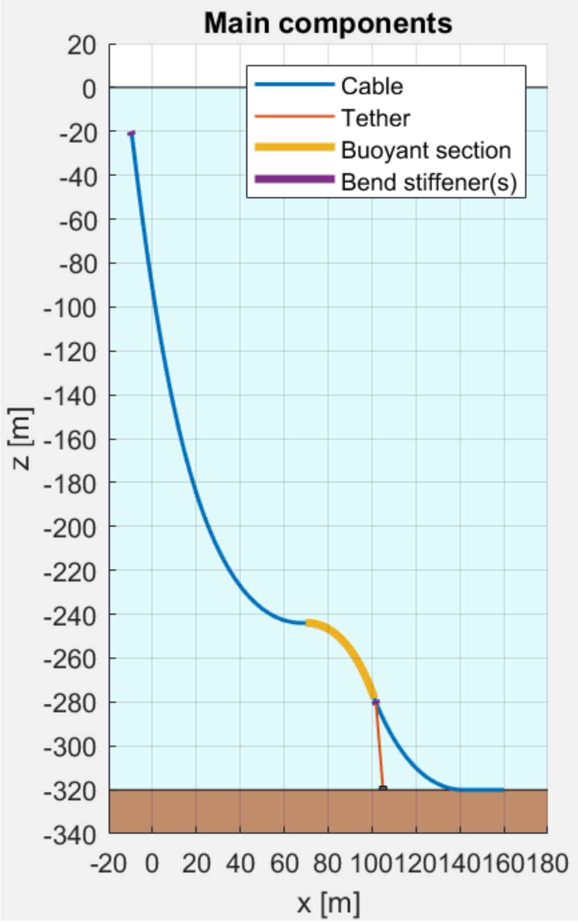
GRAPHIC RESULTS 1





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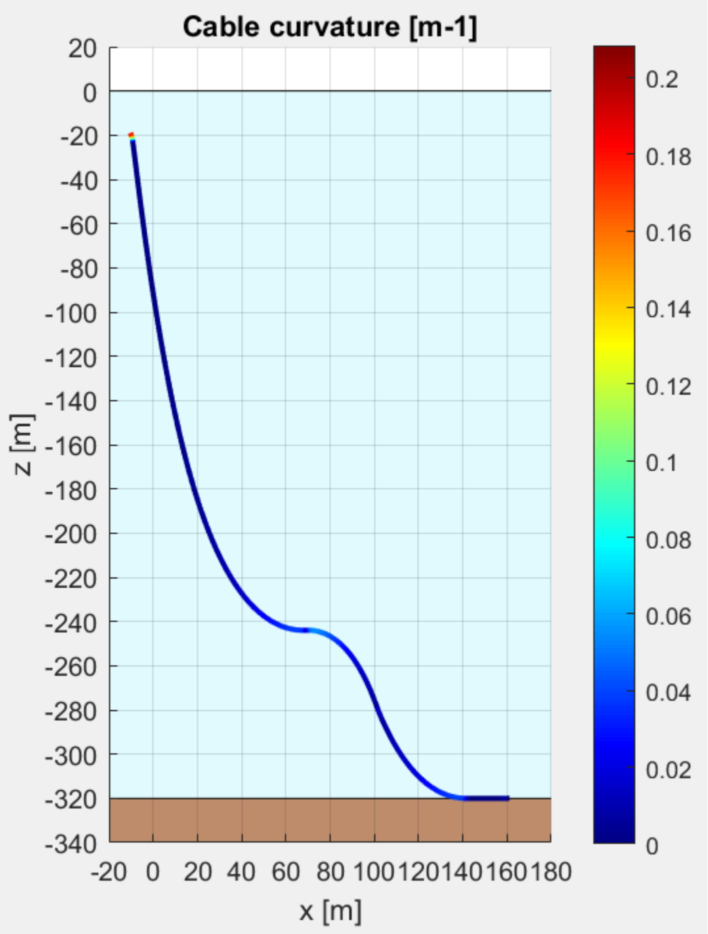
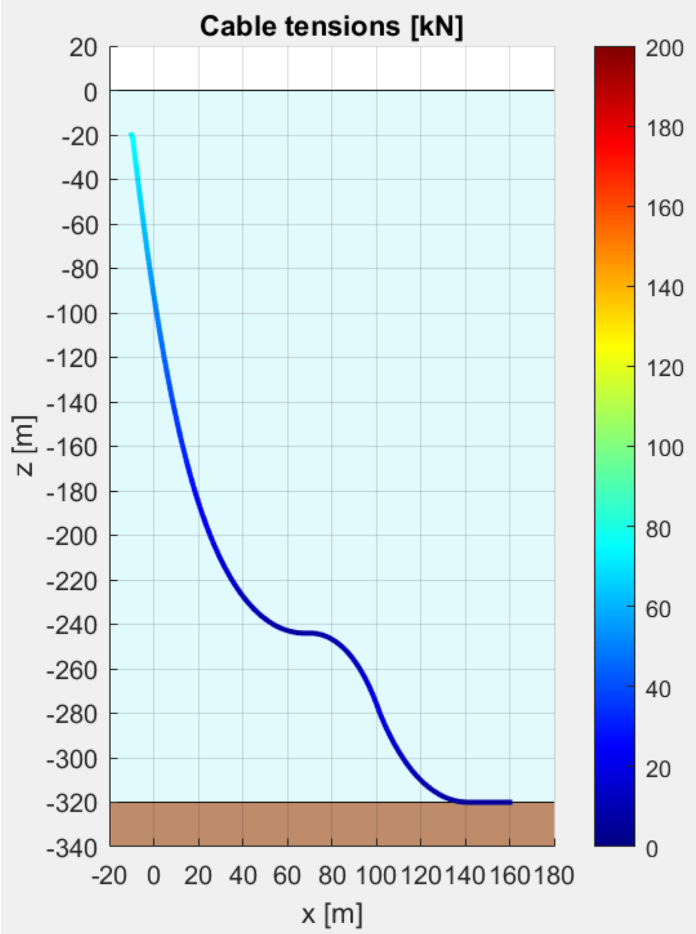
GRAPHIC RESULTS 2





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FINAL REMARKS

- Floating offshore wind is an available technology but requires optimisation to lower its costs
- The dynamic cables play a relevant role in the technology progress as they are being developed specifically for this task
- A good initial guess saves time and prevents the algorithm from reaching wrong solutions (or not finding any solution), and variable scaling is important
- Buoyant sections should be below the euphotic zone
- Bend stiffness is usually negligible due to the low cable bending
- Site-specific marine growth and current profiles are important to avoid additional uncertainty, as their effect is relevant
- Axial stiffness can be neglected almost always

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