BLUE MISSION BANOS

1st MISSION ARENA
14-16 November 2023 | Gothenburg, SE

MULTI-USE TECHNOLOGY ROADSHOW – Numerical Modelling

Ajie Pribadi – Ghent University

Maritime Technology Division – Faculty of Engineering & Architecture

THEME: **UNITED FINAL EVENT**

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UNITED

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#MissionArenaBANOS1

EU MISSIONS RESTORE OUR OCEAN & WATERS

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UNITED

Offshore aquaculture system design assessment utilising a numerical tool in the German and Belgian pilots

Ajie Pribadi – Ghent University

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30/11/2023

OUTLINE

1. *Introduction*
2. *Methodology*
3. *Results*
4. *Conclusions*

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1. ***Introduction***
   1.1 UNITED project
2. *Methodology*
3. *Results*
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1. Introduction

1.1 UNITED PROJECT

1.1.1 Research objectives

1.1.1.1 Demonstrate multi-use (MU) of offshore wind farms and aquaculture activities

1.1.2 Five pilots

1.1.2.1 Germany – Blue mussels and **Seaweed longline** in **FINO3**

1.1.2.2 The Netherlands – Seaweed and offshore floating solar panel

1.1.2.3 Belgium – **Offshore flat oysters** and seaweed cultivation in a wind Farm

1.1.2.4 Denmark – Tourism within offshore wind farm (OWF)

1.1.2.5 Greece – Aquaculture (fisheries) and tourism

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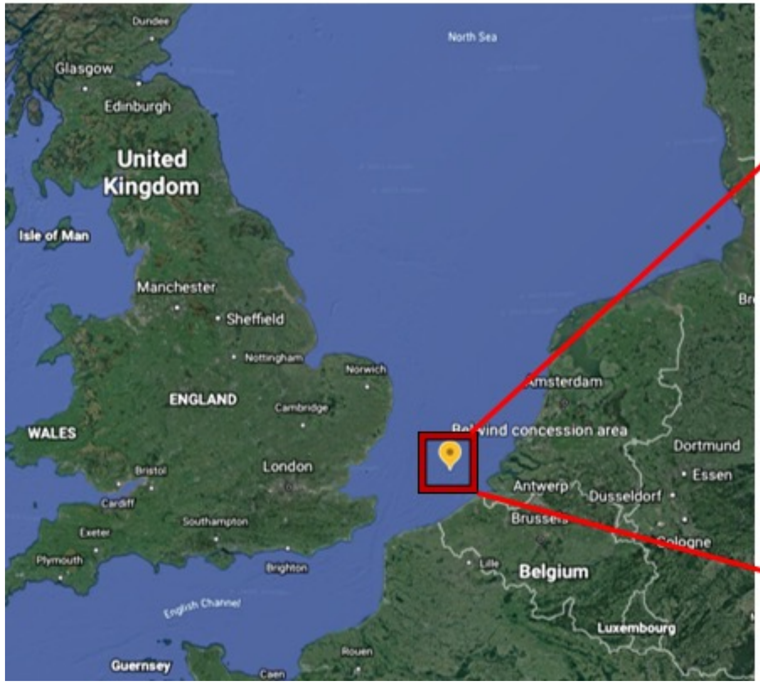
1. Introduction

1.2 Pilot site

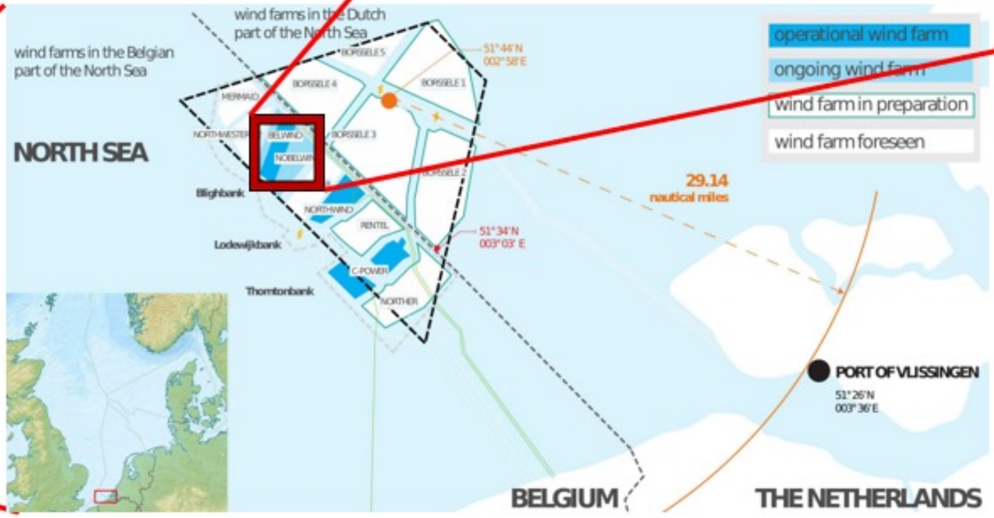
1.2.1 Belgium – **Belwind OWF**

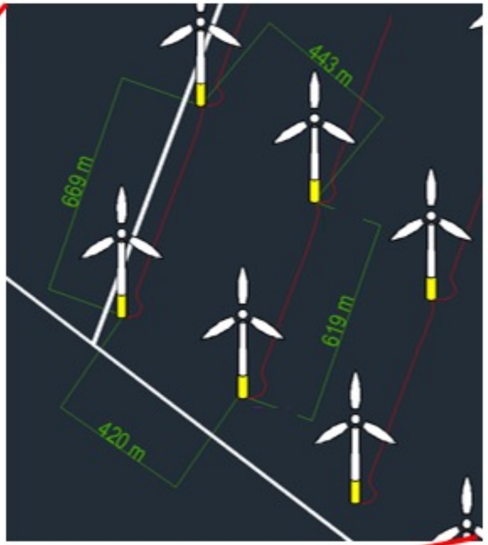
1.2.1.1 Oyster longline and seaweed cultivation system

1.2.1.2 40-50 km off the Belgian coast



Map data ©2021 Google





[1] Allaerts, D., Broucke, S. V., van Lipzig, N., & Meyers, J. (2018). Annual impact of wind-farm gravity waves on the Belgian–dutch offshore wind-farm cluster. *Journal of Physics: Conference Series*, *1037*, 072006. https://doi.org/10.1088/1742-6596/1037/7/072006

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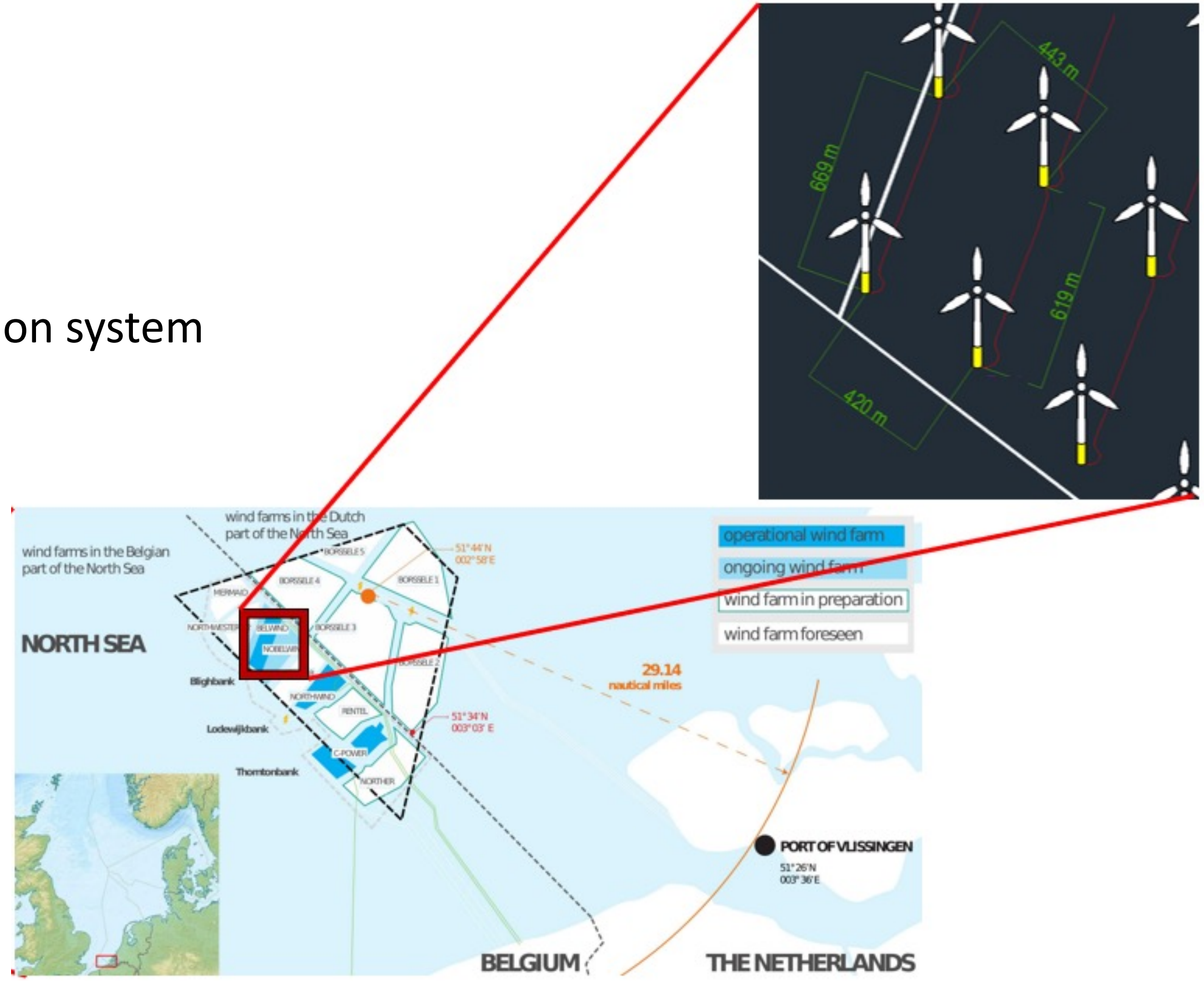
1.2 Pilot site

1.2.1 Belgium – **Belwind OWF**

- **1.2.1.1 Oyster longline** and seaweed cultivation system
- 1.2.1.2 40-50 km off the Belgian coast
- 1.2.1.3 Water depth: 28 – 29 m LAT
- 1.2.1.4 Tidal variation: +5 m from LAT
- 1.2.1.5 50-year return period
  - 1.2.1.5.1 Regular wave height: 11.6 m
  - 1.2.1.5.2 Regular wave period: 9 s
  - 1.2.1.5.3 Current (depth-avg): 1.38 m/s; 2.7 knots



[1] Allaerts, D., Broucke, S. V., van Lipzig, N., & Meyers, J. (2018). Annual impact of wind-farm gravity waves on the Belgian–dutch offshore wind-farm cluster. *Journal of Physics: Conference Series*, *1037*, 072006. https://doi.org/10.1088/1742-6596/1037/7/072006

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1. Introduction

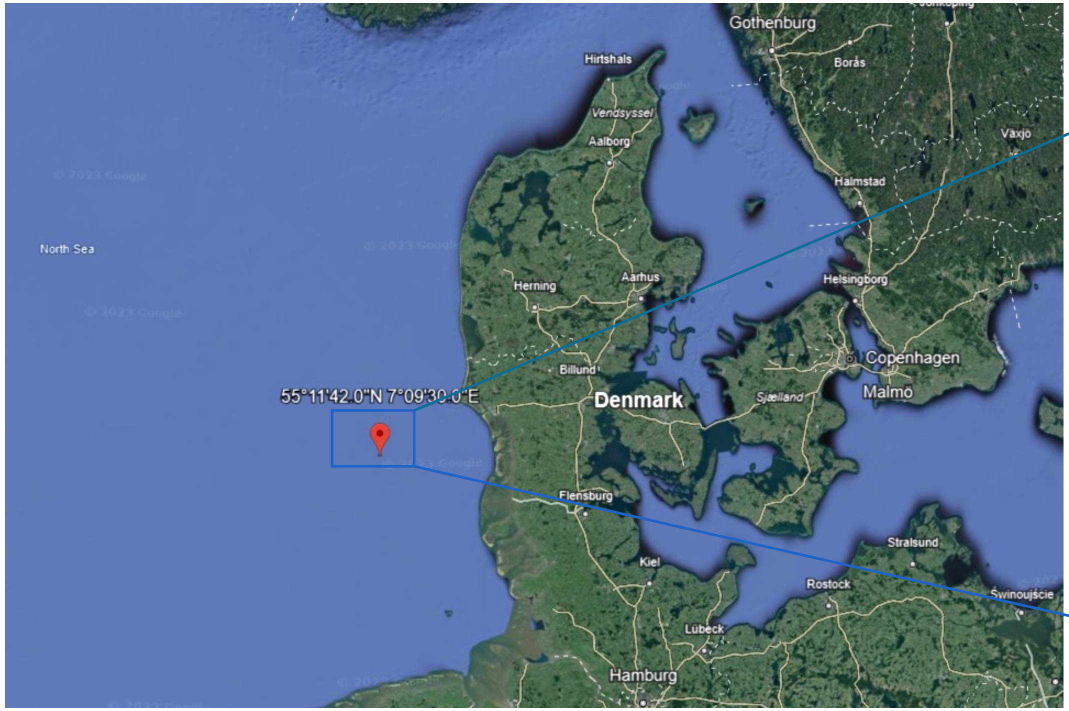
1.2 Pilot site

1.2.2 Germany – **FINO3**

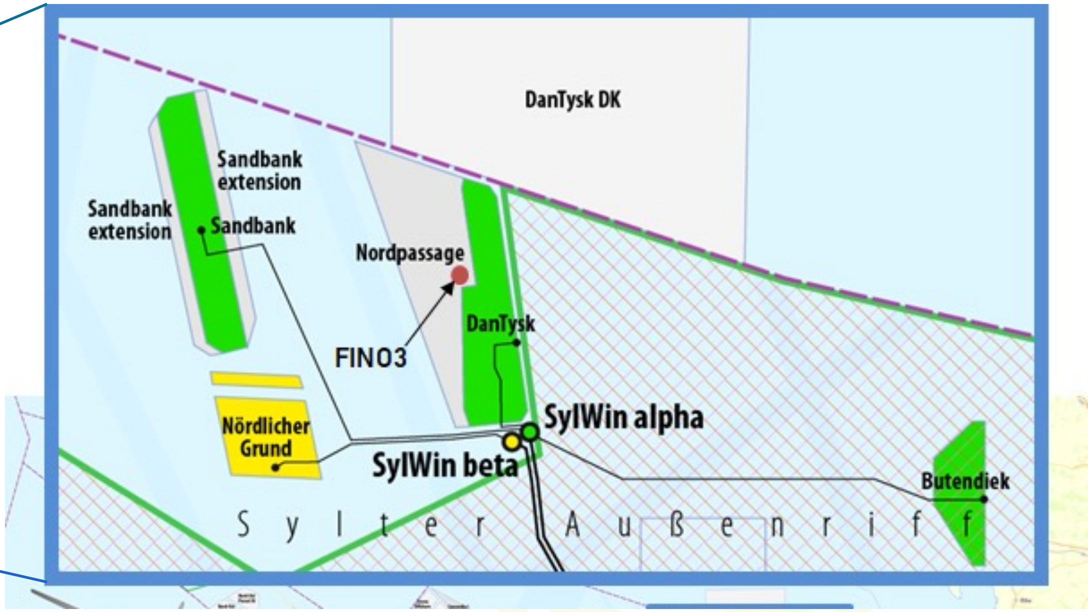
1.2.2.1 Blue mussels and **Seaweed longline**

1.2.2.2 Within OWFs, 80 km off Sylt

"Impressionen." FINO3. Accessed October 30, 2023. https://www.fino3.de/de/medien/fotos/impressionen.html.



Map data ©2023 Google



[1] "Location of FINO3." FINO3 - Research Platform in the North Sea and the Baltic No. 3. Accessed October 30, 2023. https://www.fino3.de/en/location.html.

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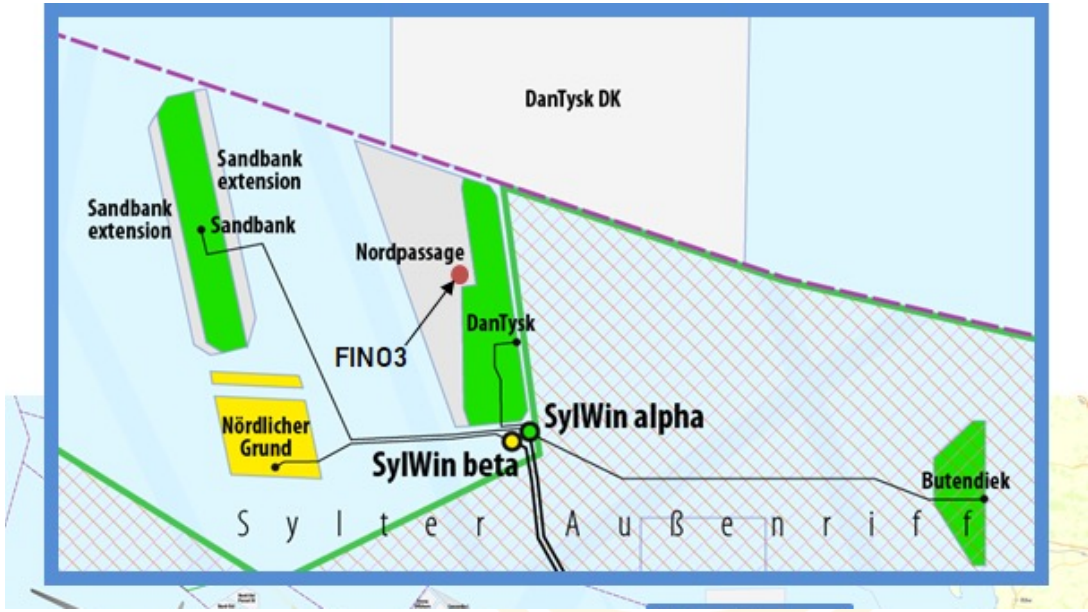
1. Introduction

1.2 Pilot site

1.2.2 Germany – **FINO3**

- 1.2.2.1 Blue mussels and **Seaweed longline**
- 1.2.2.2 Within OWFs, 80 km off Sylt
- 1.2.2.3 Water depth: 26 m
- 1.2.2.4 Tidal variation: +4.5 m from LAT
- 1.2.2.5 50-year return period
  - 1.2.2.5.1 Regular wave height: 17.9 m
  - 1.2.2.5.2 Regular wave period: 13.9 s
  - 1.2.2.5.3 Current (depth-avg): 1.40 m/s

"Impressionen." FINO3. Accessed October 30, 2023. https://www.fino3.de/de/medien/fotos/impressionen.html.



[1] "Location of FINO3." FINO3 - Research Platform in the North Sea and the Baltic No. 3. Accessed October 30, 2023. https://www.fino3.de/en/location.html.

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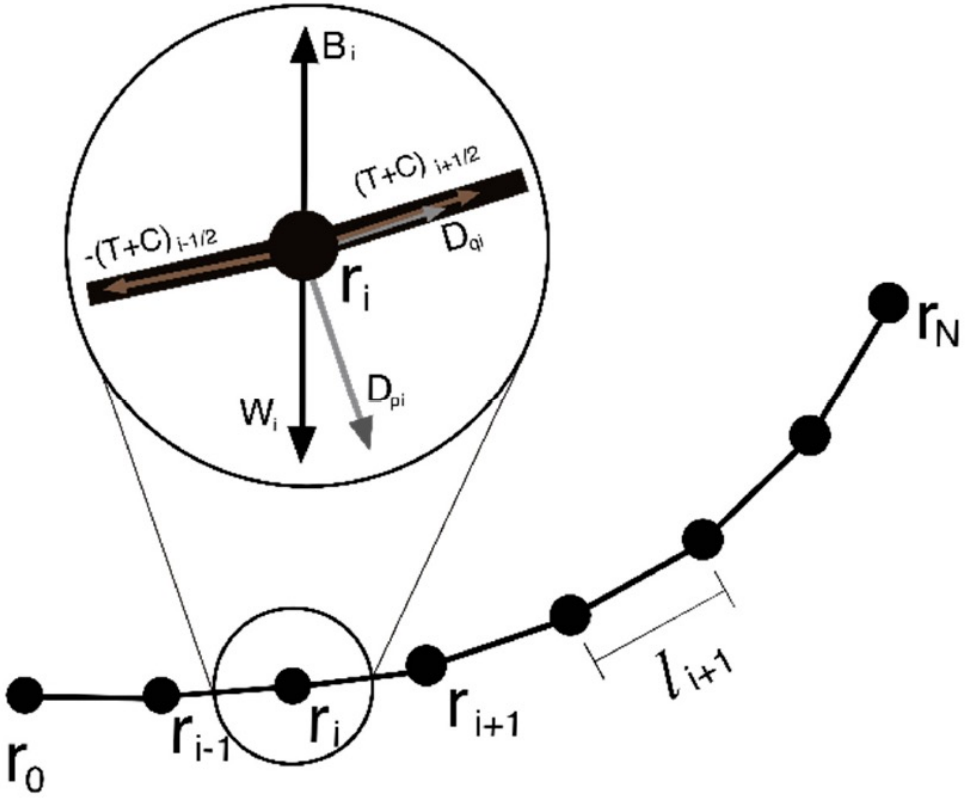
2. Methodology

2.1 Numerical simulation tool

2.1.1 MoorDyn: mooring dynamic solver [1-2]

- 2.1.1.1 Time-domain
- 2.1.1.2 Lumped-mass approach
- 2.1.1.3 Morison equation
- 2.1.1.4 Add-on in other numerical solvers

[1] Hall, M.; Goupee, A. Validation of a lumped-mass mooring line model with DeepCwind semisubmersible model test data. *Ocean Engineering* **2015**, Vol. 104, 590–603.
[2] Hall, M. MoorDyn user's guide. Tech. rep, University of Prince Edward Island, Canada, 2017.
[3] Pribadi, A. B. K., Donatini, L., Lataire, E. Numerical modelling of a mussel line system by means of lumped-mass approach. *Journal of Marine Science and Engineering* **2019** 7(9).



$$(m+a_i)\ddot{r}_i(t) = F_i(r_i(t), \dot{r}_i(t), v_i(t), \dot{v}_i(t))$$

Illustration of lumped-mass approach [3]

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2. Methodology

[1] Pribadi, A. B. K., Donatini, L., Lataire, E. Numerical modelling of a mussel line system by means of lumped-mass approach. *Journal of Marine Science and Engineering* **2019** 7(9).
[2] Fernandez, G., A. Pribadi, W. Minghao, V. Stratigaki, P. Troch, and E. Lataire. 2021. "Experimental Validation of a State Space Model of a Moored Cuboid in Waves." in 14th European Wave and Tidal Energy Conference (EWTEC 2021). Plymouth: 14th European Wave and Tidal Energy Conference.
[3] Pribadi ABK, Donatini L, Lataire E, et al. Validation of a computationally efficient time-domain numerical tool against DeepCwind experimental data. Trends Renew Energies Offshore [Internet]. London: CRC Press; 2022. p. 597–608. Available from: https://doi.org/10.1201/9781003360773-68.

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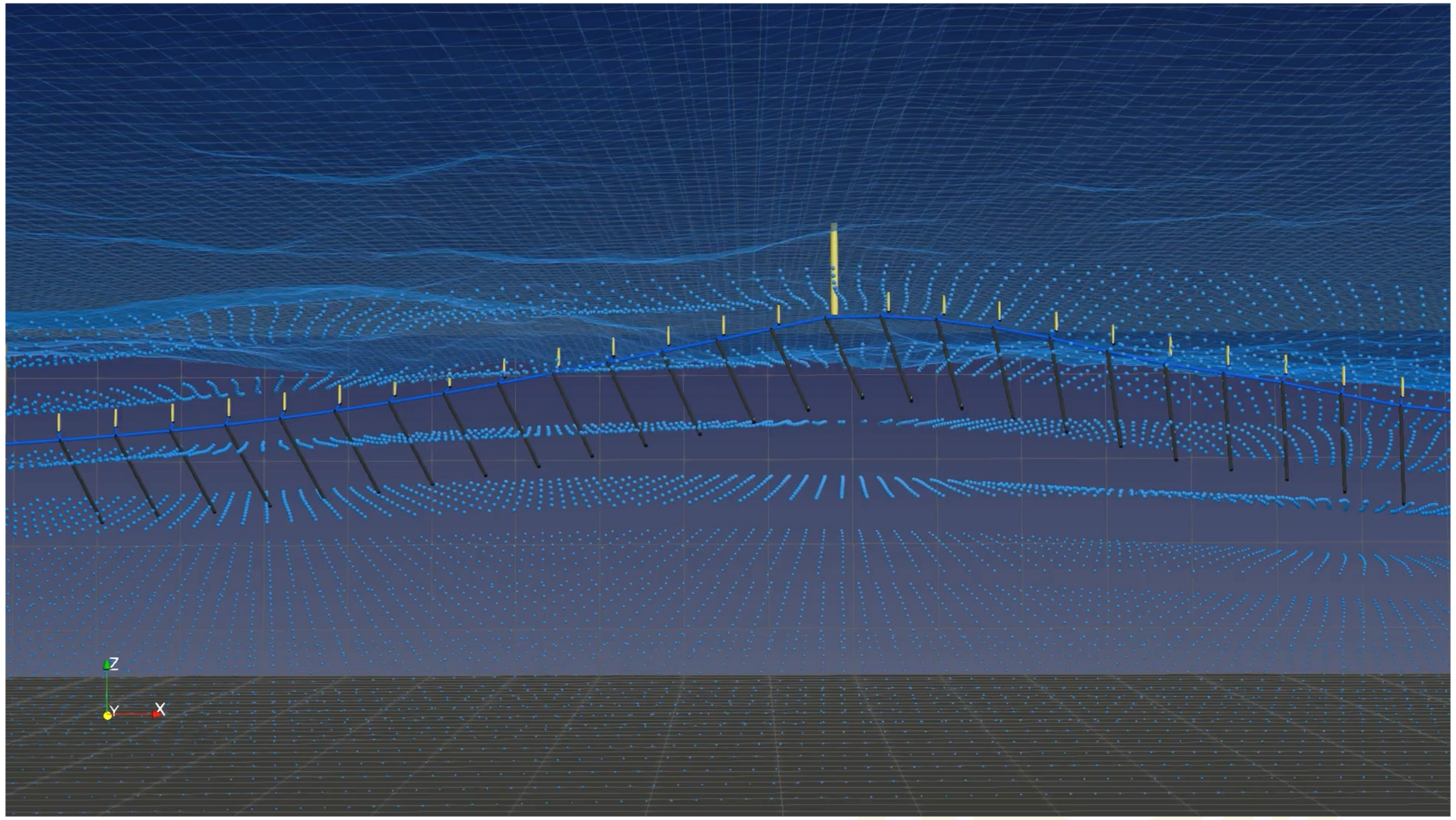
- 2.1.1.3 Morison equation
- 2.1.1.4 Add-on in other numerical solvers

2.1.2 Adapted by MTD Ugent [1-3]

- 2.1.2.1 Stand-alone tool
- 2.1.2.2 Wave and current loads
- 2.1.2.3 Seabed friction
- 2.1.2.4 Clump weight
- 2.1.2.5 3-dof buoy
- 2.1.2.6 Rigid body motion



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2.1 Numerical simulation tool

2.2 Design consideration

3. Results

4. Conclusions

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2. Methodology

2.2 Design consideration

2.2.1 Guidelines: DNV OS301, NS9415, DNV RPC205, NORSOK Standard N-003

2.2.1.1 Design waves

2.2.1.2 Safety factors

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2.2.1.1 Design waves

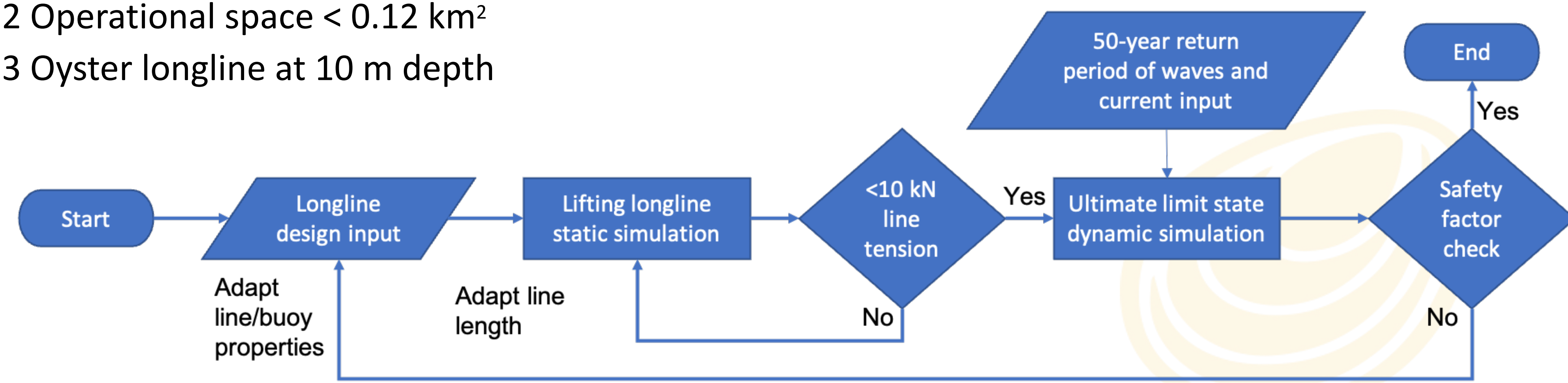
2.2.1.2 Safety factors

2.2.2 Other criteria – BE pilot

2.2.2.1 Lifting for maintenance/harvesting operation

2.2.2.2 Operational space < 0.12 km^2

2.2.2.3 Oyster longline at 10 m depth



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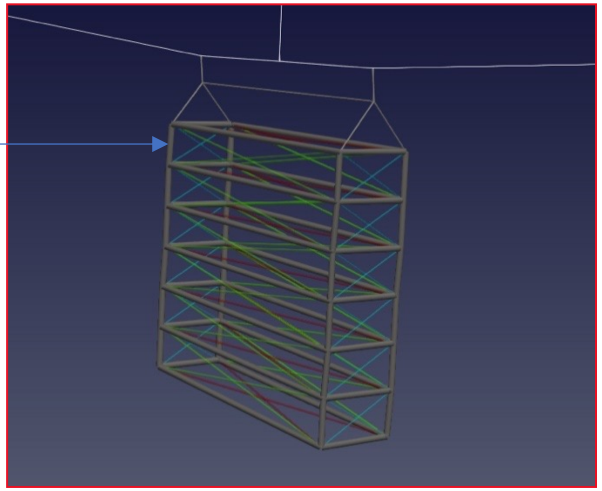
2. Methodology

2.3 Numerical modelling – BE pilot

2.3.1 Ladder frame -> SEAPA baskets [1]

2.3.2 Dropper lines

2.3.3 Trays



[1] SEAPA, "SEAPA Oyster & aquaculture basket," [Online]. Available: http://seapa.co.jp/wp-content/uploads/2014/07/SEAPA-OysterBasket-brochure_5-14.pdf. [Accessed 18 February 2021].

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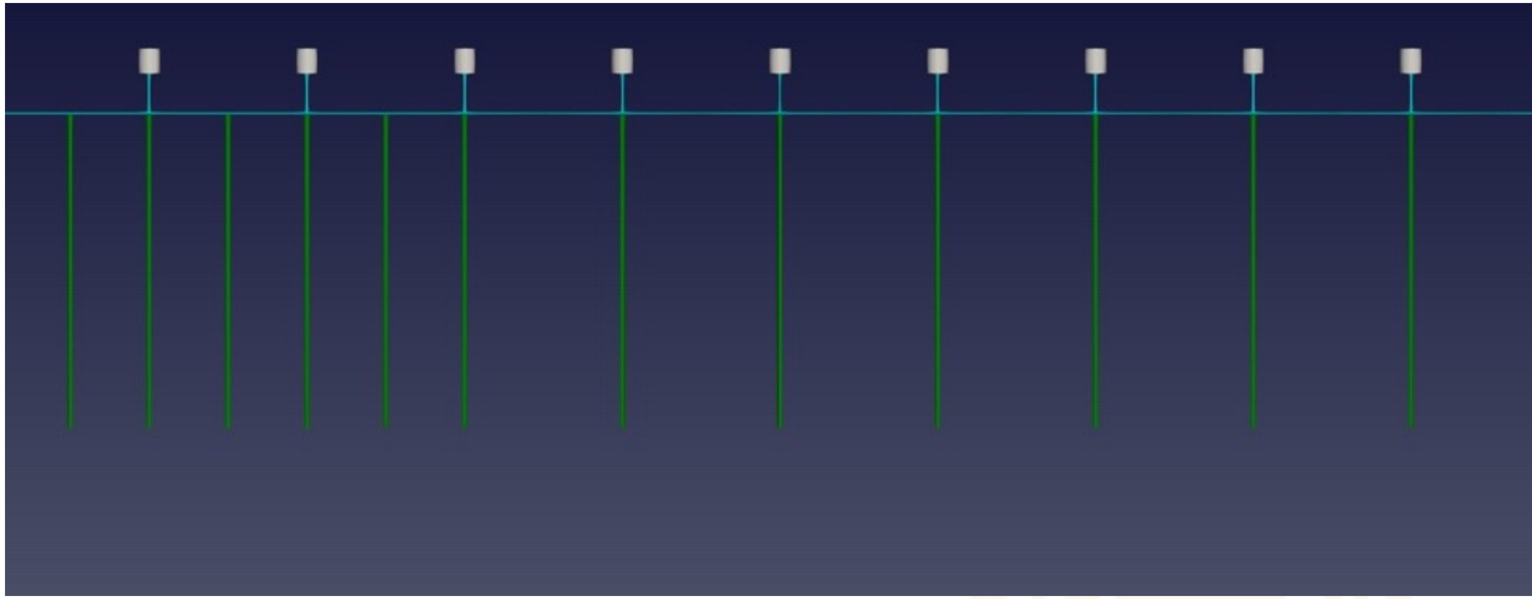

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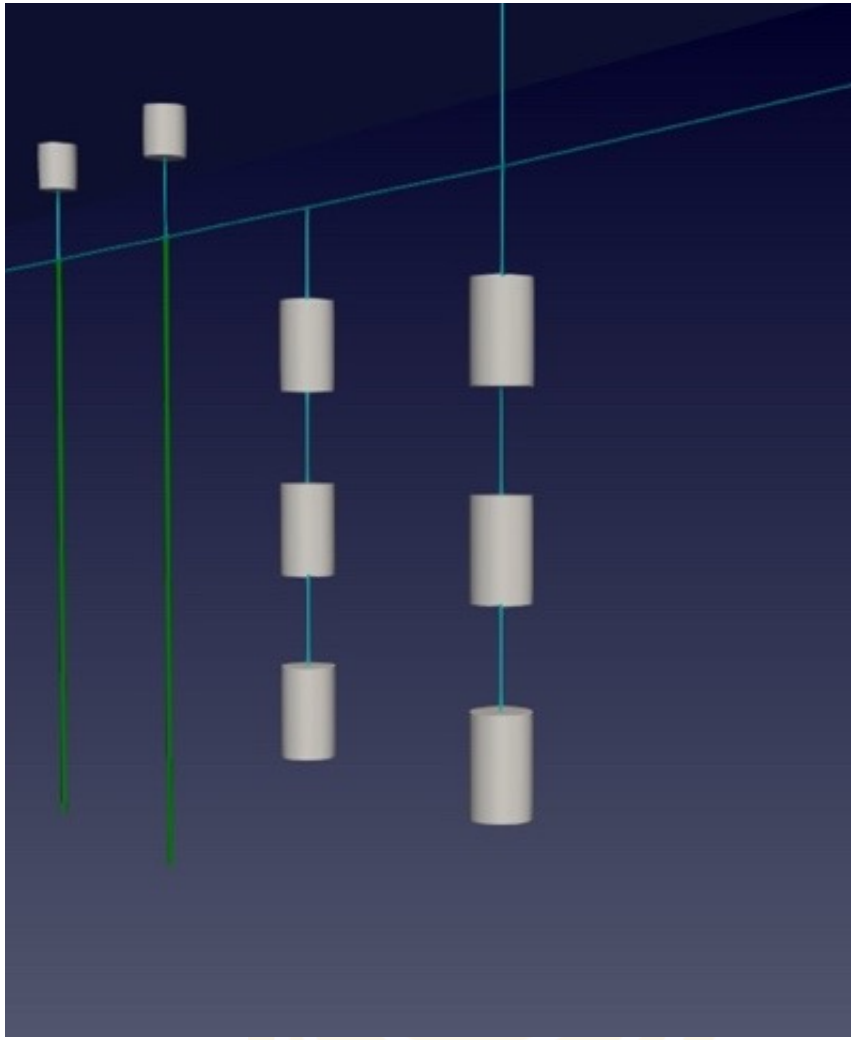
[1] Acqua&co , "Ostriga," [Online]. Available: https://www.acquaeco.com/prodotti.php?idx=23. [Accessed 18 February 2021].



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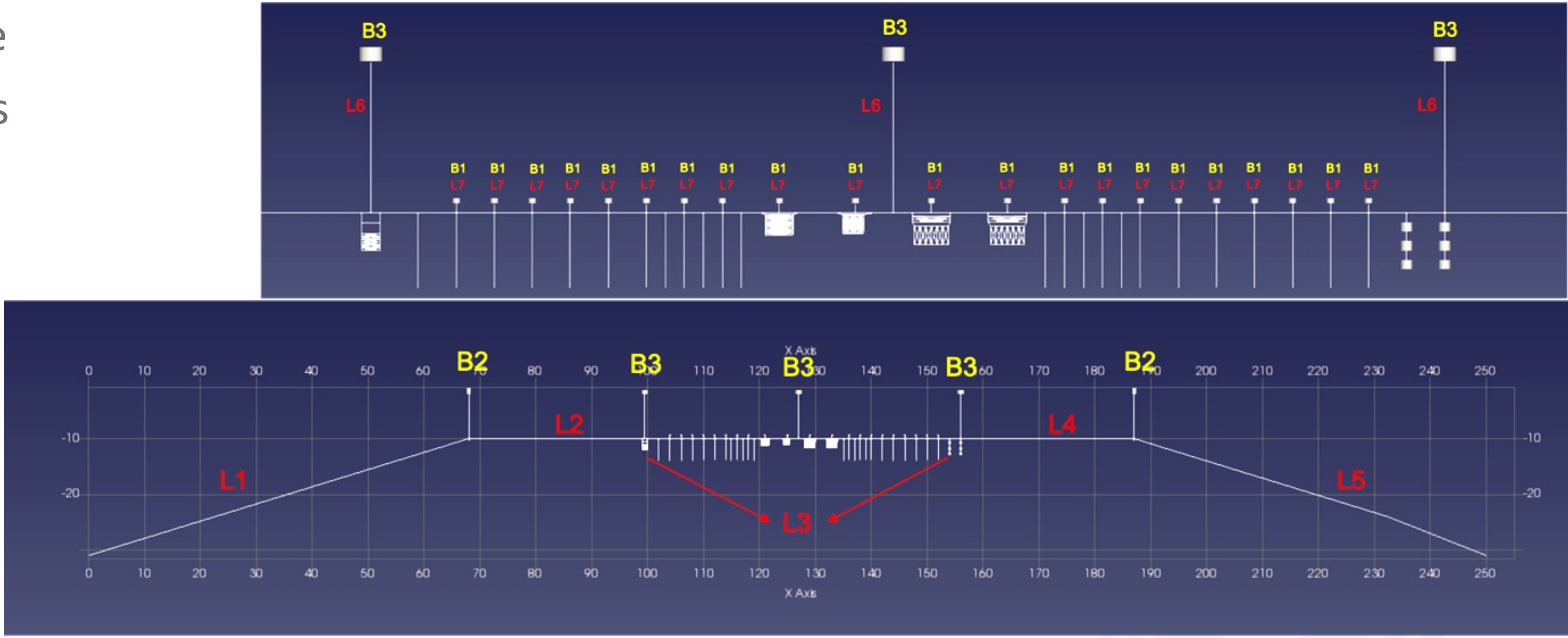

[1] Strothotte, Eva, Strothotte Jaeger, Julian Pforth, Annelies Declercq, Brecht Stechele, Nancy Nevejan, Jessica Knoop, et al. *Delivrable 7.2 - Blueprint for the offshore site operation*. H2020UNITED, 2021. https://www.h2020united.eu/images/PDF_Reports/D72_blueprint_for_the_offshore_site_operation_v30220224.pdf.

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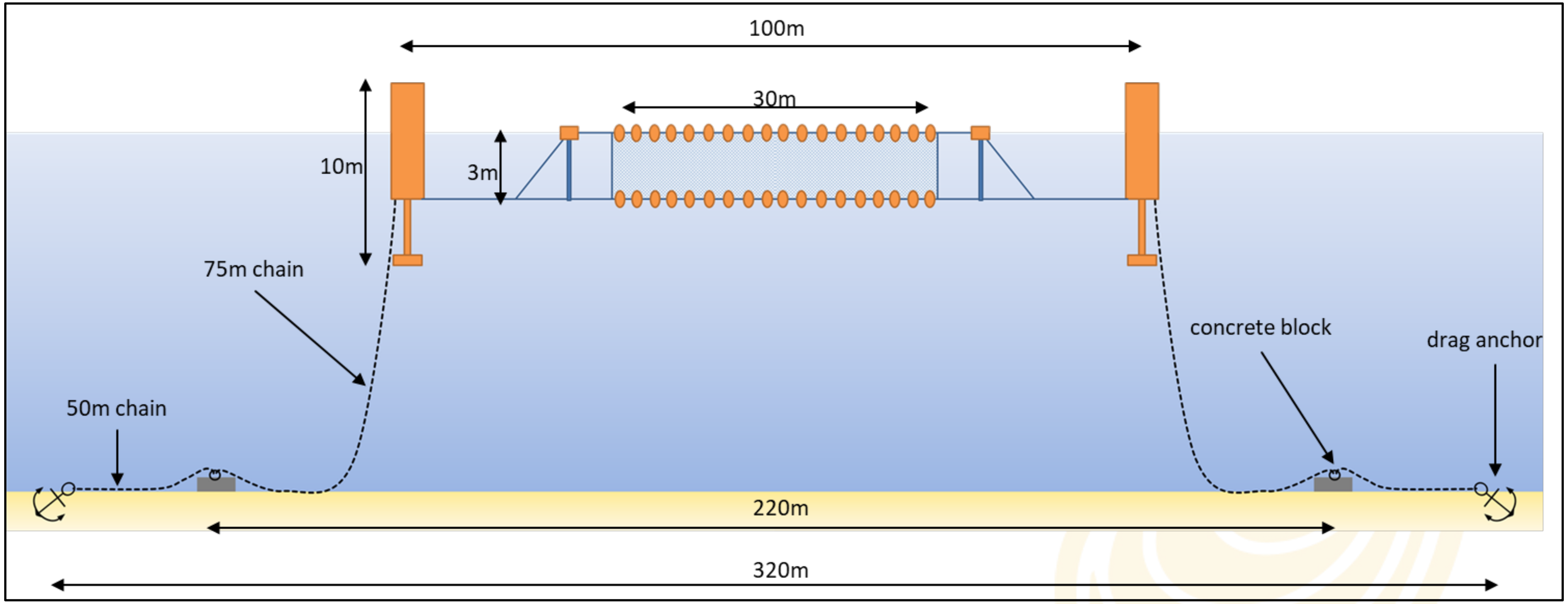
2. Methodology

2.4 Numerical modelling – DE pilot

2.4.1 Seaweed cultivator system [1]

2.4.2 Mooring elements

- 2.4.2.1 Chains
- 2.4.2.2 Ropes
- 2.4.2.3 Buoys
- 2.4.2.4 Clump weights
- **2.4.2.5 Seaweed nets**



[1] Strothotte, Eva, Strothotte Jaeger, Julian Pforth, Annelies Declercq, Brecht Stechele, Nancy Nevejan, Jessica Knoop, et al. *Delivrable 7.2 - Blueprint for the offshore site operation*. H2020UNITED, 2021. https://www.h2020united.eu/images/PDF_Reports/D72_blueprint_for_the_offshore_site_operation_v30220224.pdf.

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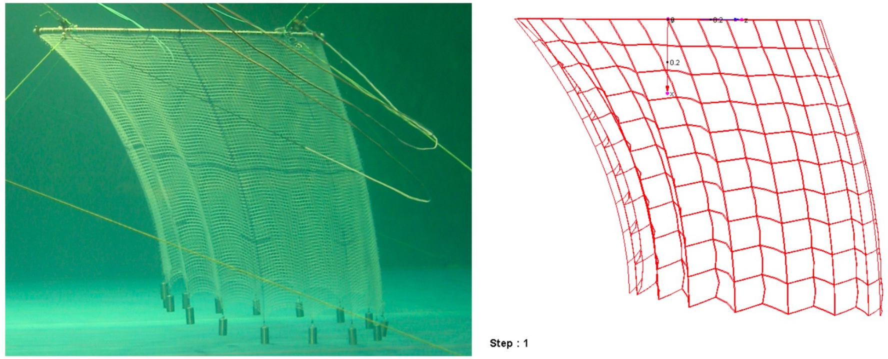
2. Methodology

2.4 Numerical modelling – DE pilot

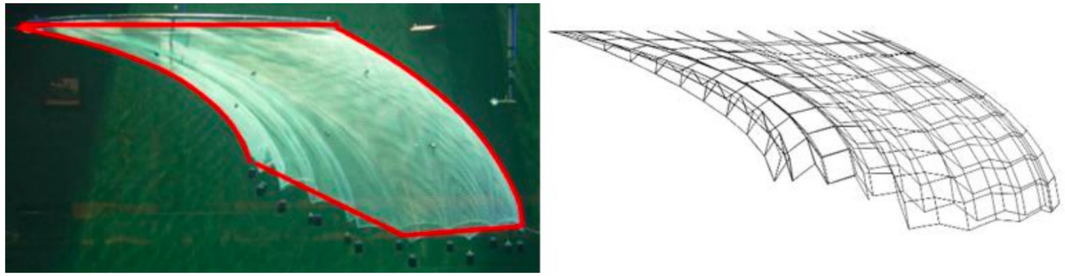
2.4.3 Fish net modelling

2.4.3.1 Cylindrical elements

2.4.3.2 Morison coefficients from experiment



[1] B. Enerhaug, "Model tests of net structures, SINTEF Report STF80 A034007, "SINTEF Fisheries and Aquaculture, 2004.



[2] C. Cifuentes and M. H. Kim, "Numerical simulation of fish nets in currents using a Morison force model," Systems Engineering, vol. 7, no. 2, pp. 143-155, 2017.

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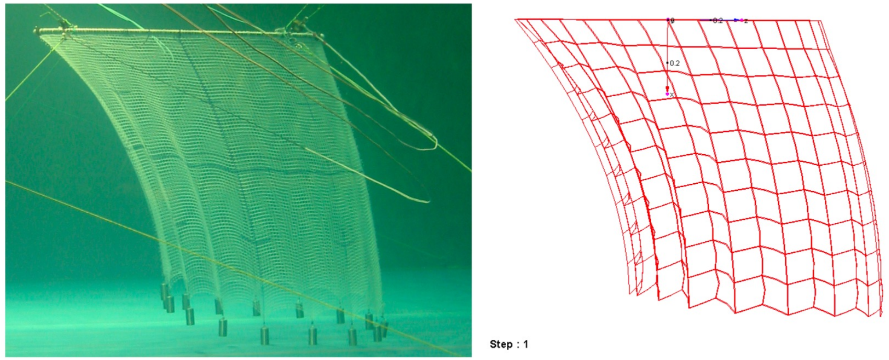


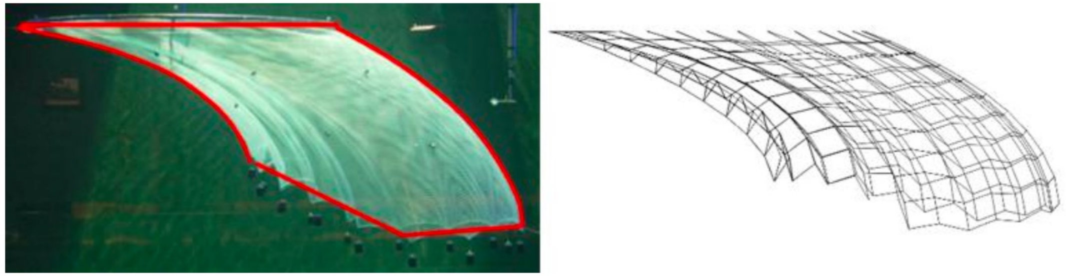
[1] B. Enerhaug, "Model tests of net structures, SINTEF Report STF80 A034007, "SINTEF Fisheries and Aquaculture, 2004.

2.4.4 Empirical formulae proposed by DeCew et al. [3]

2.4.4.1 Reynolds Number dependent

2.4.4.2 Effect of seaweeds not included

$$C_{dn} = \begin{cases} \frac{8\pi}{Re\,s}(1 - 0.87s^{-2}), & 0 < Re < 1 \\ 1.45 + 8.55\,Re^{-0.90}, & 1 < Re \le 30 \\ 1.1 + 4\,Re^{-0.5}, & 30 < Re \le 2.33 \times 10^5 \\ -3.41 \times 10^{-6}(Re - 5.78 \times 10^5), & 2.33 \times 10^5 < Re \le 4.92 \times 10^5 \\ 0.401\left(1 - e^{-\frac{Re}{5.99}\times 10^5}\right), & 4.92 \times 10^5 < Re \le 10^7 \end{cases}$$



[2] C. Cifuentes and M. H. Kim, "Numerical simulation of fish nets in currents using a Morison force model," Systems Engineering, vol. 7, no. 2, pp. 143-155, 2017.

Where:

$$s = -0.077215655 + \ln\left(\frac{8}{Re}\right)$$

[3] J. DeCew, I. Tsukrov, A. Risso, M. R. Swift and B. Celikkol, "Modeling of dynamic behavior of a single-point moored submersible fish cage under currents," *Aquaculture Engineering*, vol. 43, pp. 38-45, 2010.

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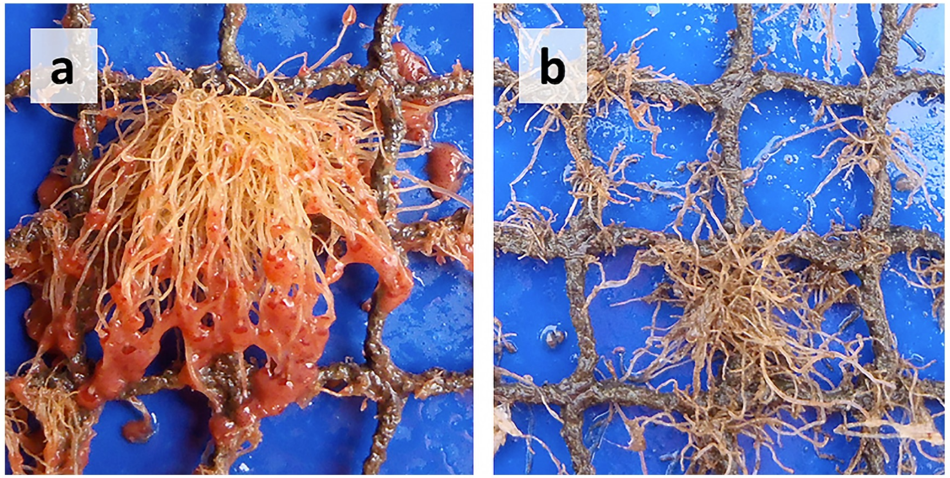
2. Methodology

2.4 Numerical modelling – DE pilot

2.4.5 Seaweed as fouling on nets

2.4.6 DNV guideline suggests to adjust the drag area and volume based on:

- 2.4.6.1 Mass of biofouling (seaweed)
- 2.4.6.2 Line diameter (net twine)
- 2.4.6.3 Initial drag coefficient (net)



[1] L. C. Gansel, D. R. Plew, P. C. Endressen, A. I. Olsen, E. Misimi, J. Guenther and Ø. Jensen, "Drag of Clean and Fouled Net Panels – Measurements and Parameterization of Fouling," PLoS ONE, vol. 10, no. 7, 2015.

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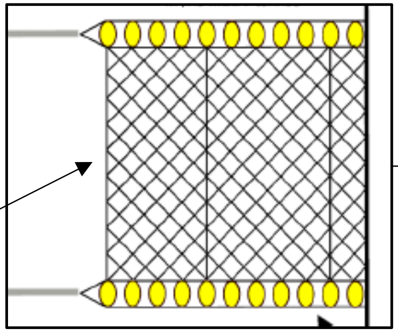
2. Methodology

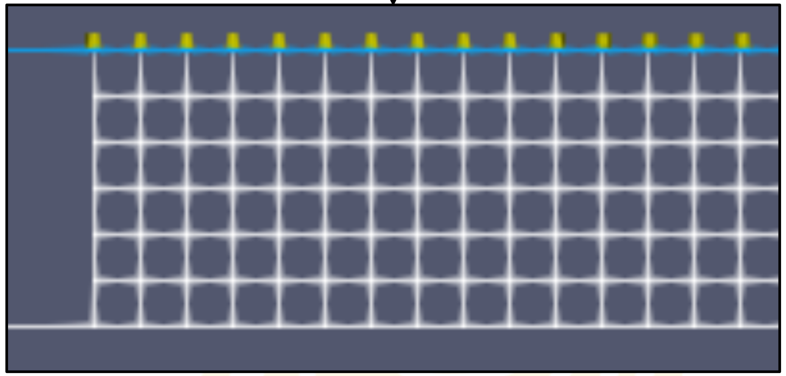
2.4 Numerical modelling – DE pilot

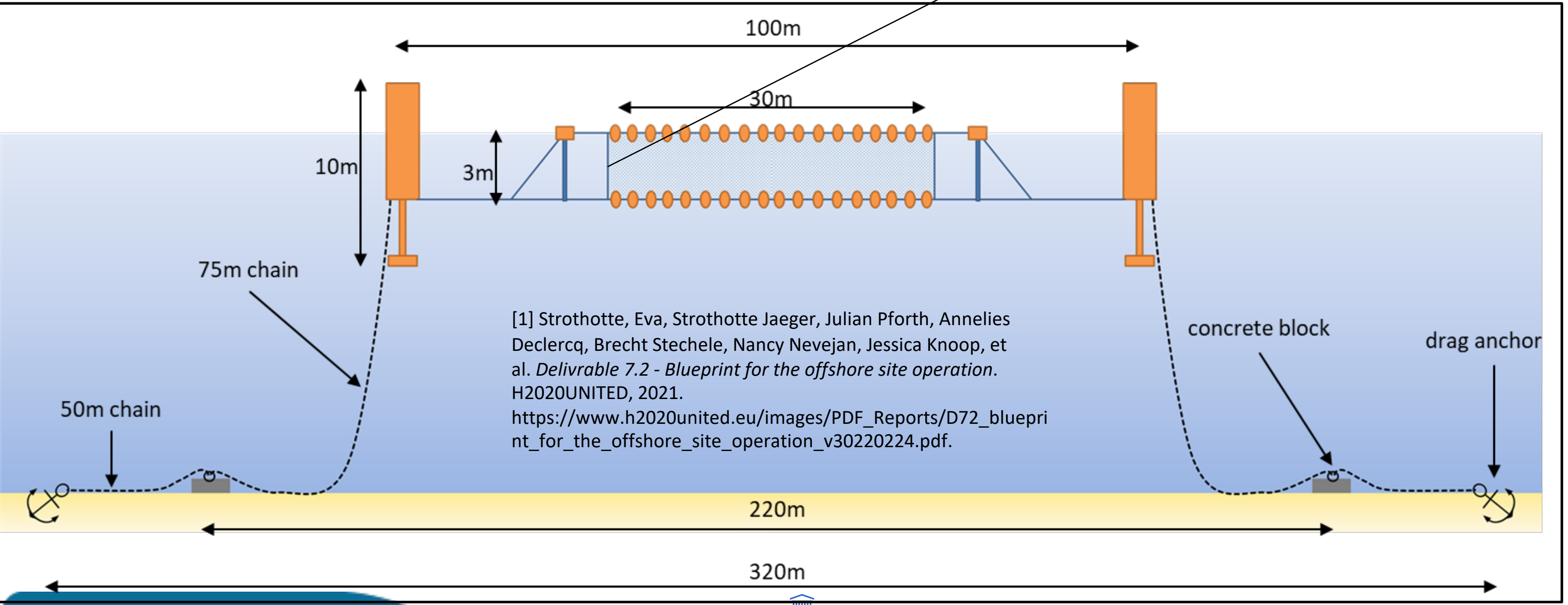
2.4.7 Numerical approach for fish nets

2.4.8 Drag coefficient adjusted based on DNV guideline



Numerical net





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Retaining the same hydrostatic and hydrodynamic properties

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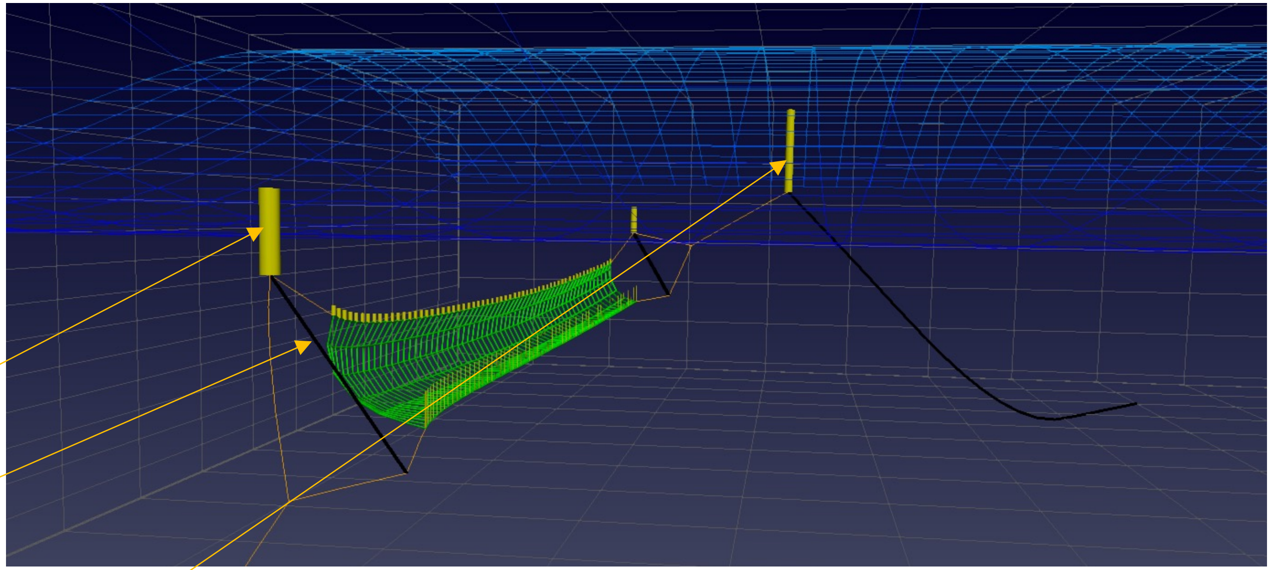
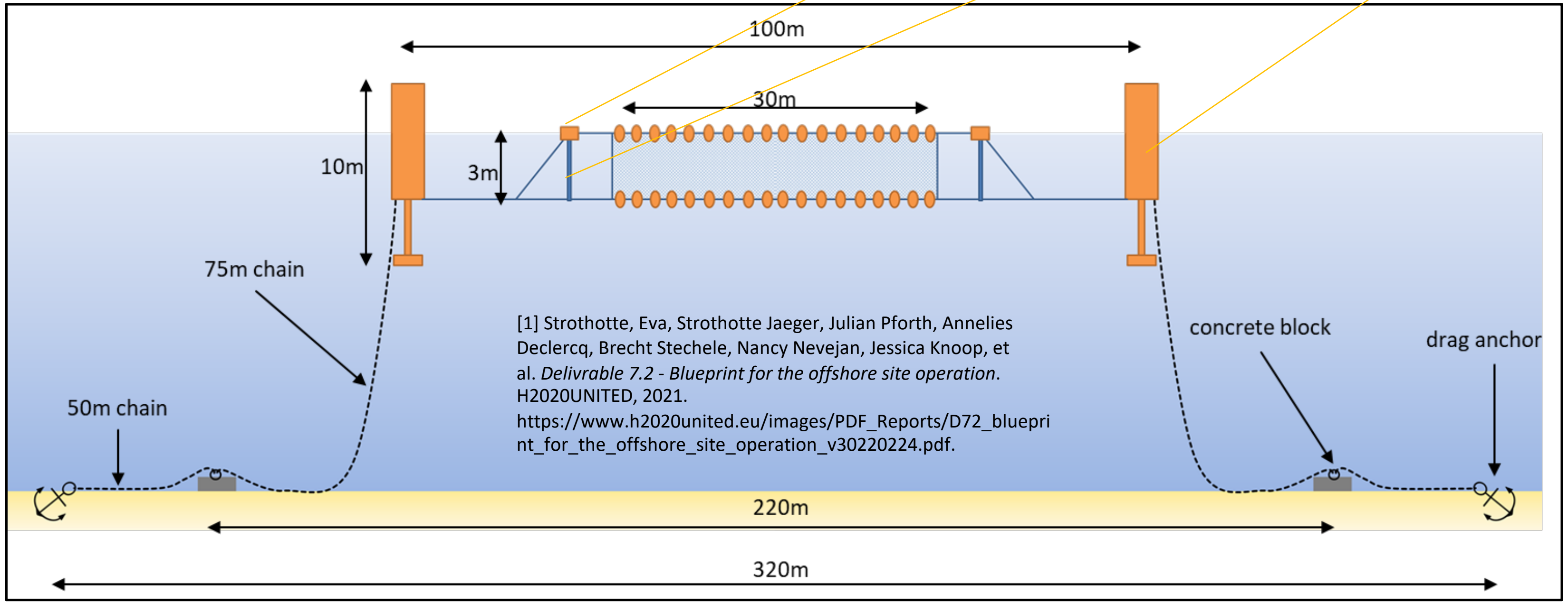
2. Methodology

2.4 Numerical modelling – DE pilot

2.4.9 Mooring elements

2.4.9.1 Chains, ropes, buoys





[1] Strothotte, Eva, Strothotte Jaeger, Julian Pforth, Annelies Declercq, Brecht Stechele, Nancy Nevejan, Jessica Knoop, et al. *Delivrable 7.2 - Blueprint for the offshore site operation*. H2020UNITED, 2021. https://www.h2020united.eu/images/PDF_Reports/D72_blueprint_for_the_offshore_site_operation_v30220224.pdf.

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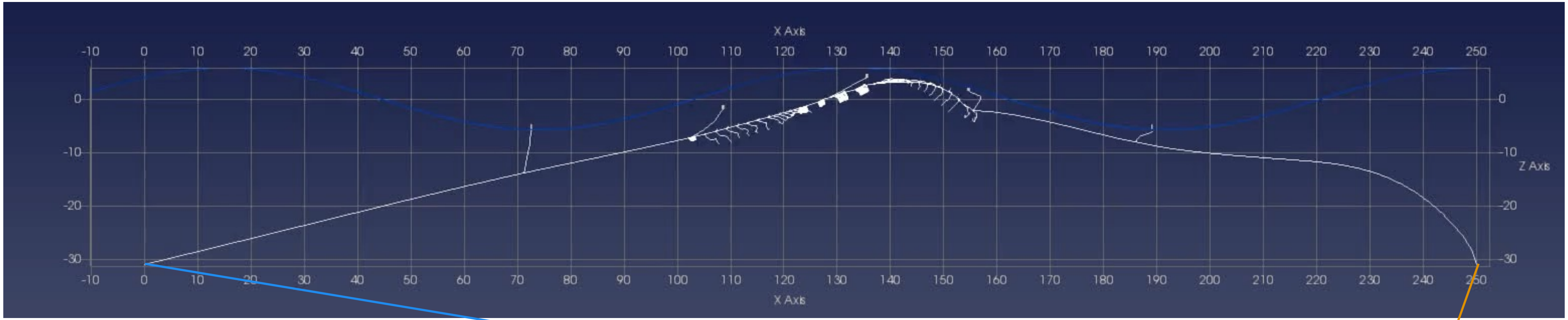
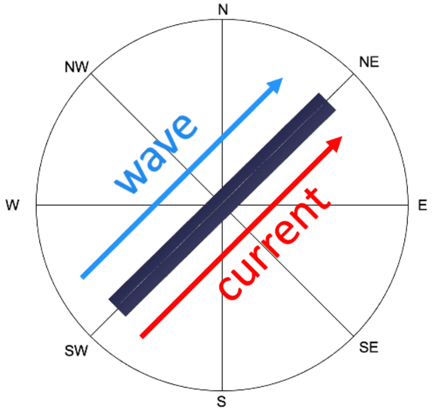
3. Results

3.1 BE pilot – Ultimate limit state (ULS) simulation





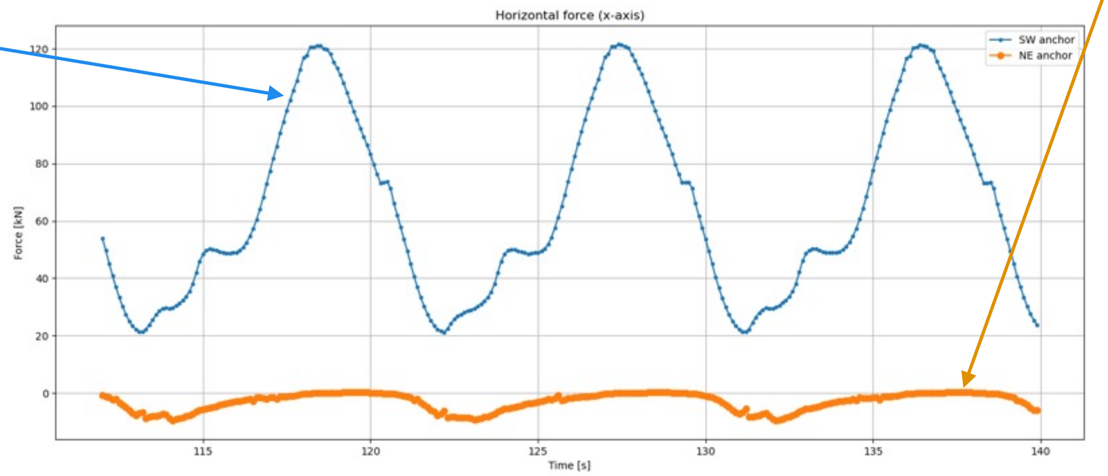
3.1.1 Regular waves train

3.1.1.1 Wave height: 11.6 m

3.1.1.1 Wave period: 9.0 s

3.1.2 Current

3.1.2.1 Depth-averaged speed: 1.4



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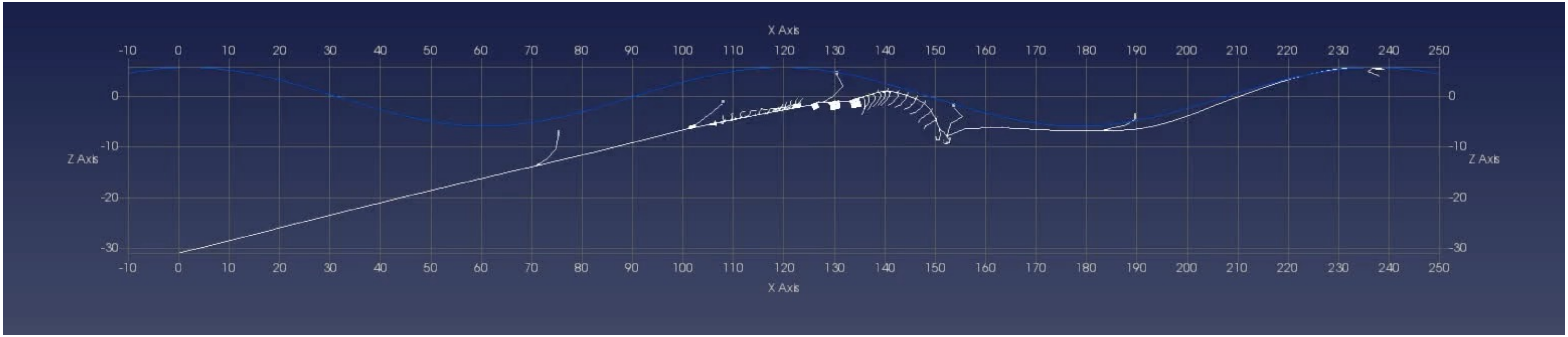
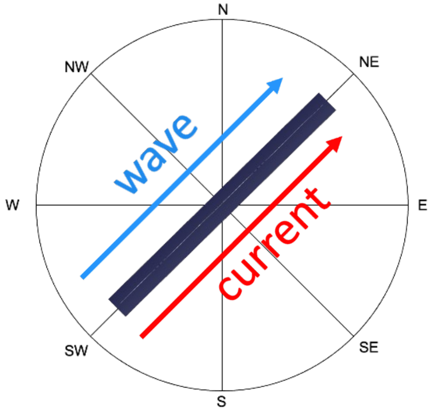
3. Results

3.1 BE pilot – Accidental limit state (ALS) simulation





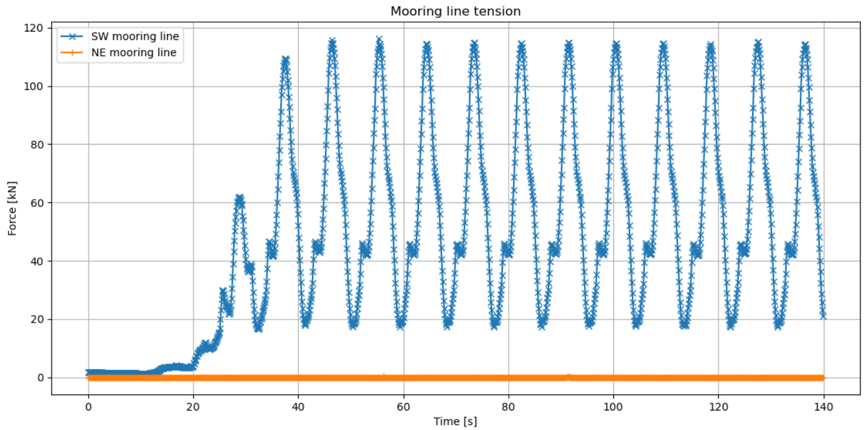
3.1.1 Regular waves train

3.1.1.1 Wave height: 11.6 m

3.1.1.1 Wave period: 9.0 s

3.1.2 Current

3.1.2.1 Depth-averaged speed: 1.4 m/s



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3. Results

3.2 DE pilot – 5-year return period

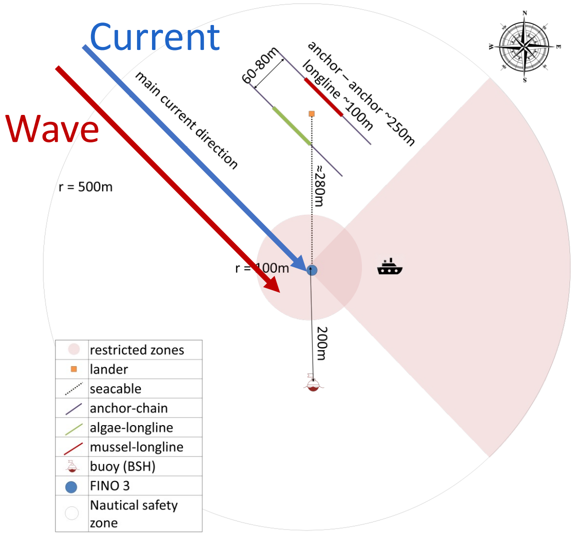
3.2.1 Regular waves train

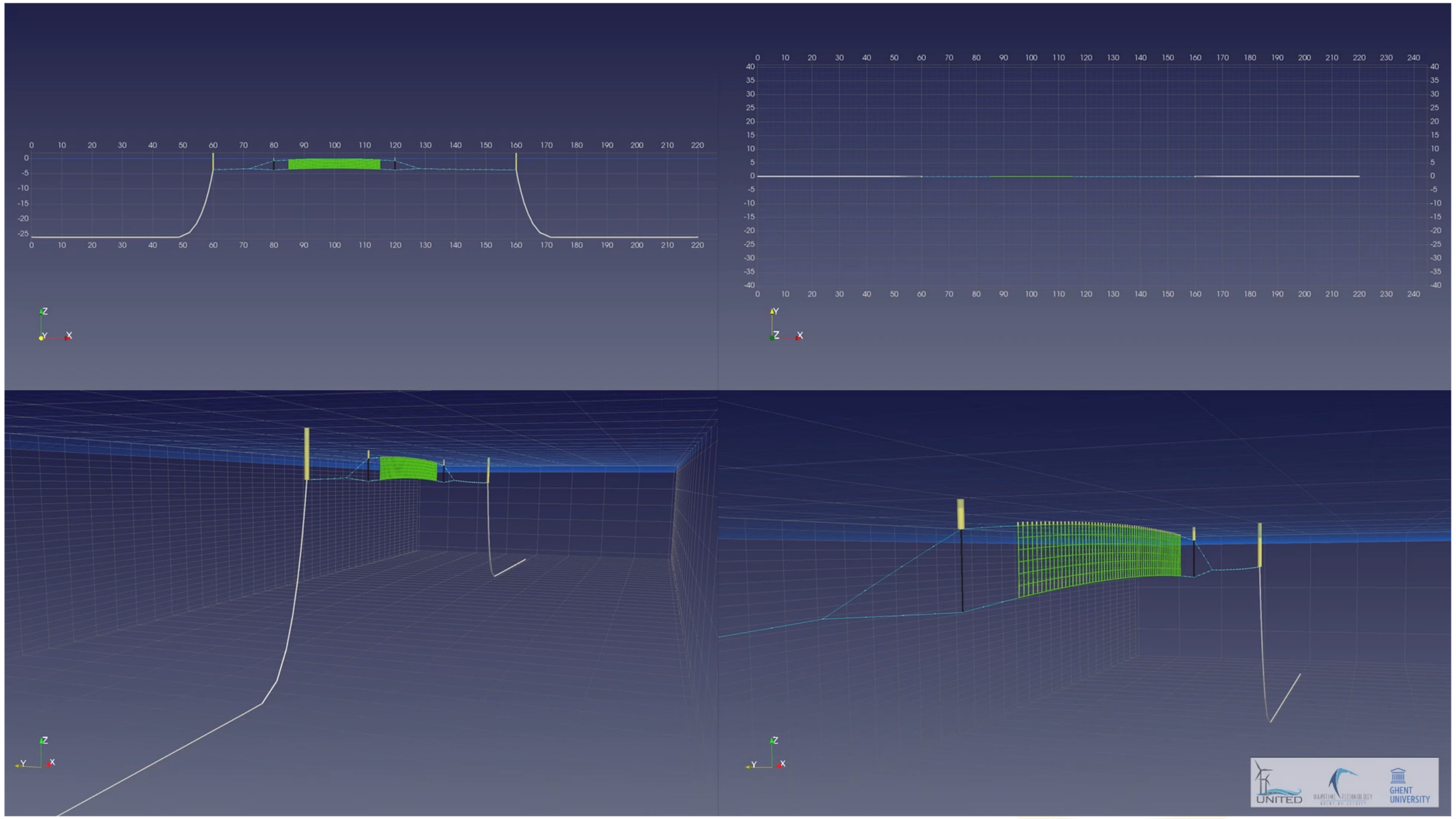
3.2.1.1 Wave height: 14.5 m

3.2.1.2 Wave period: 12.1 s

3.2.2 Current

3.2.2.1 Depth-averaged speed: 1.2 m/s





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3. Results

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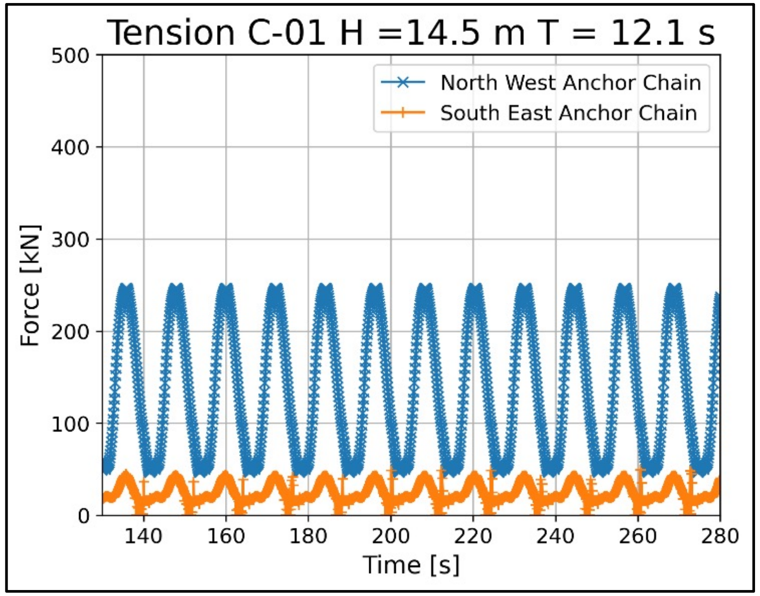
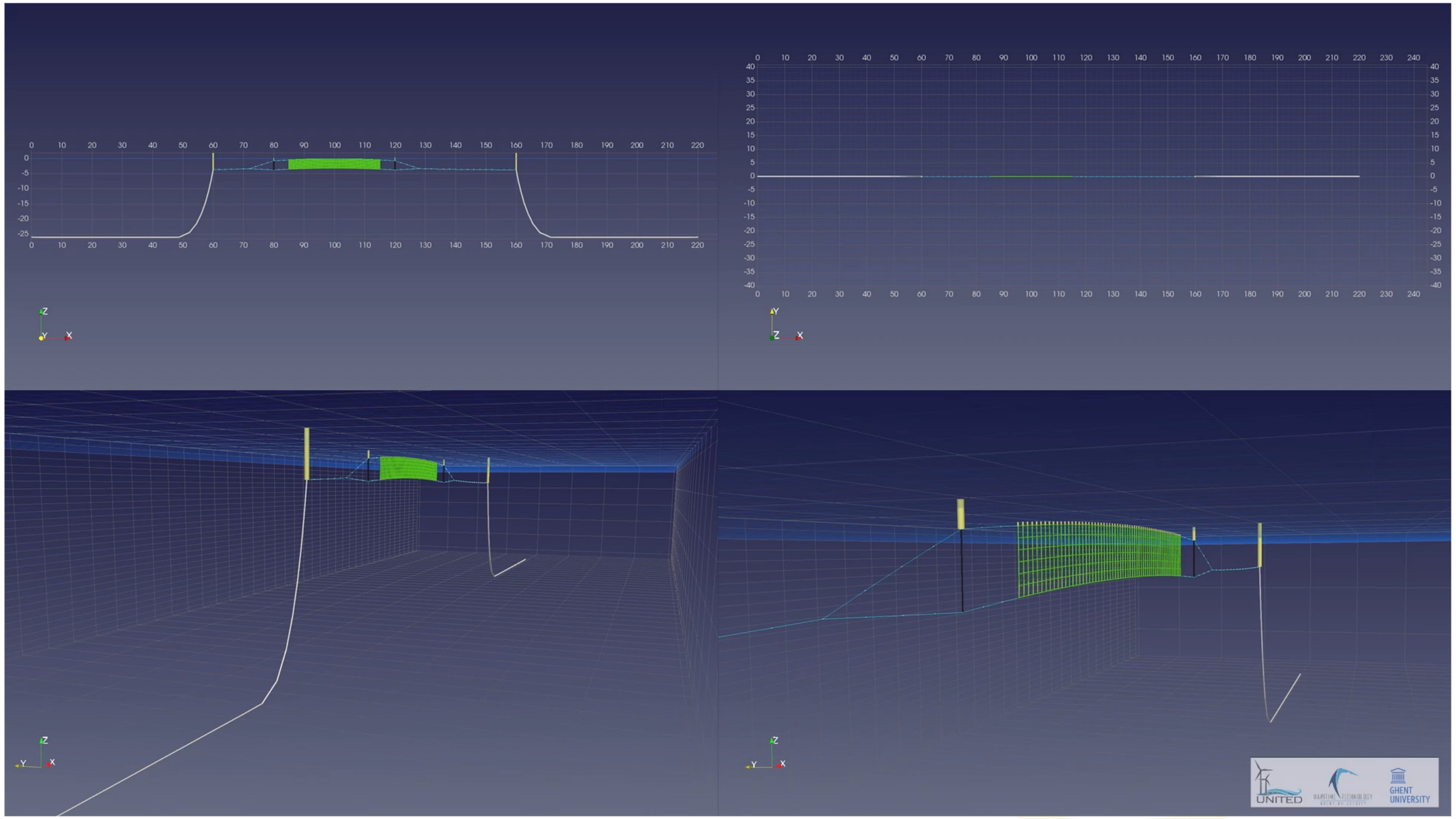
3.2.1.2 Wave period: 12.1 s

3.2.2 Current

3.2.2.1 Depth-averaged speed: 1.2 m/s





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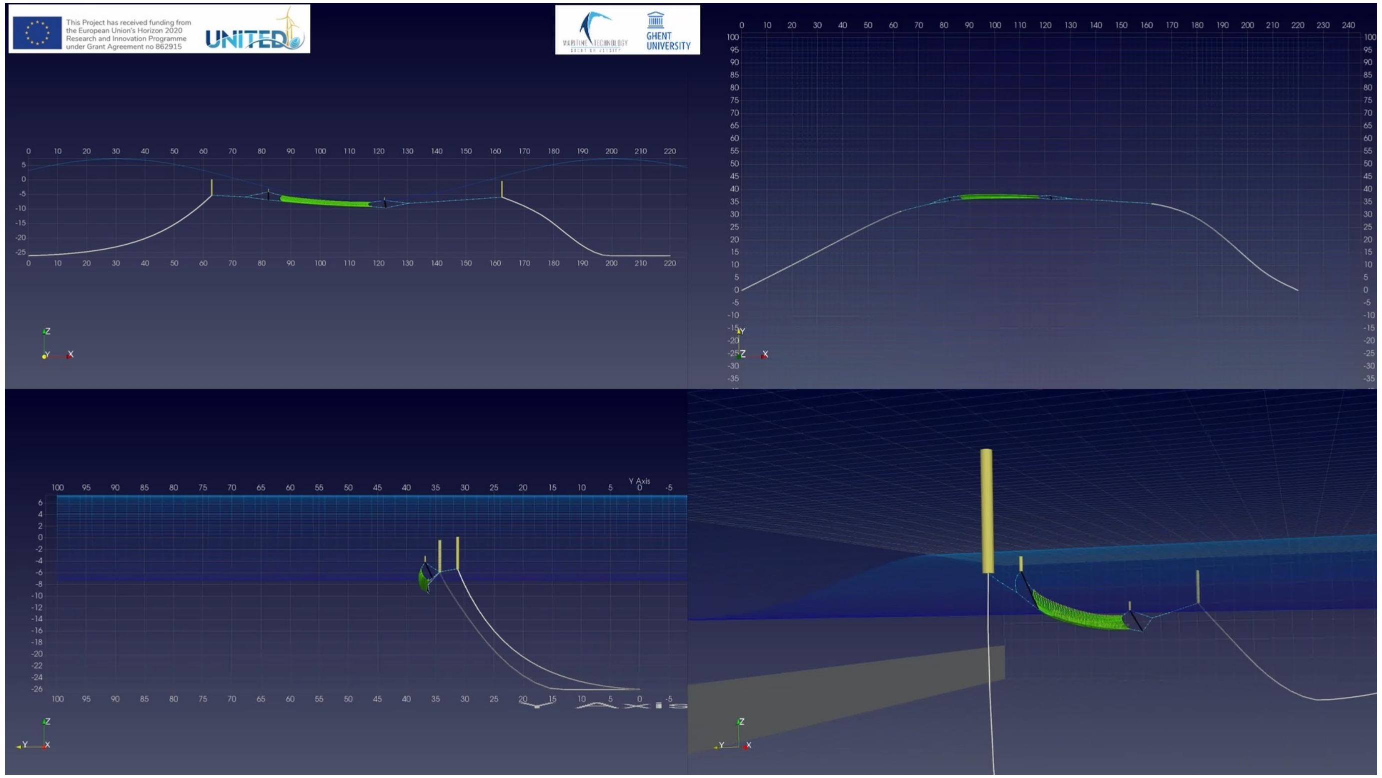
3. Results

3.2 DE pilot – Summary results

Structural Element	Maximum Tension at mooring chain (kN)	
Load case	No-Fouling	Fouling
1	171	174
2	246	249
3	408	373
4	153	160
5	244	265
6	121	101



	Wave					Current	
Case	input	return period	height	period	direction	speed	direction
[-]	[-]	year	[m]	[s]	[going-to]	[m/s]	[going-to]
1	Regular wave	1	11.2	11.1	South-East	1.20	South-East
2	Regular wave	5	14.5	12.1	South-East	1.20	South-East
3	Regular wave	50	17.9	13.9	South-East	1.40	South-East
4	Regular wave	5	14.5	12.1	South-East	1.20	North-East
5	Regular wave	5	14.5	12.1	North-East	1.20	North-East
6	Regular wave	5	14.5	12.1	North-East	1.20	South-East

[1] Strothotte, Eva, Strothotte Jaeger, Julian Pforth, Annelies Declercq, Brecht Stechele, Nancy Nevejan, Jessica Knoop, et al. *Delivrable 7.2 - Blueprint for the offshore site operation*. H2020UNITED, 2021. https://www.h2020united.eu/images/PDF_Reports/D72_blueprint_for_the_offshore_site_operation_v30220224.pdf.

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2. *Methodology*
3. *Results*
4. ***Conclusions***

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4. Conclusions

4. 1 Offshore aquaculture systems have been **numerically modelled**

4.1.1 Seaweed and **oyster longline** in the Belgian pilot

4.1.2 Seaweed cultivation system in the German pilot

4.2 At FINO3 location

4.2.1 System in-line with currents and waves provides the best solution

4.2.2 Waves are the main driving load

4.3 At Belwind location

4.3 System operates within given safety zone

4.4 Future work -> ULTFARMS

4.4.1 Morison coefficients determination from model tests

4.4.2 Experimental validation study

[1] Strothotte, Eva, Strothotte Jaeger, Julian Pforth, Annelies Declercq, Brecht Stechele, Nancy Nevejan, Jessica Knoop, et al. *Delivrable 7.2 - Blueprint for the offshore site operation*. H2020UNITED, 2021. https://www.h2020united.eu/images/PDF_Reports/D72_blueprint_for_the_offshore_site_operation_v30220224.pdf.

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