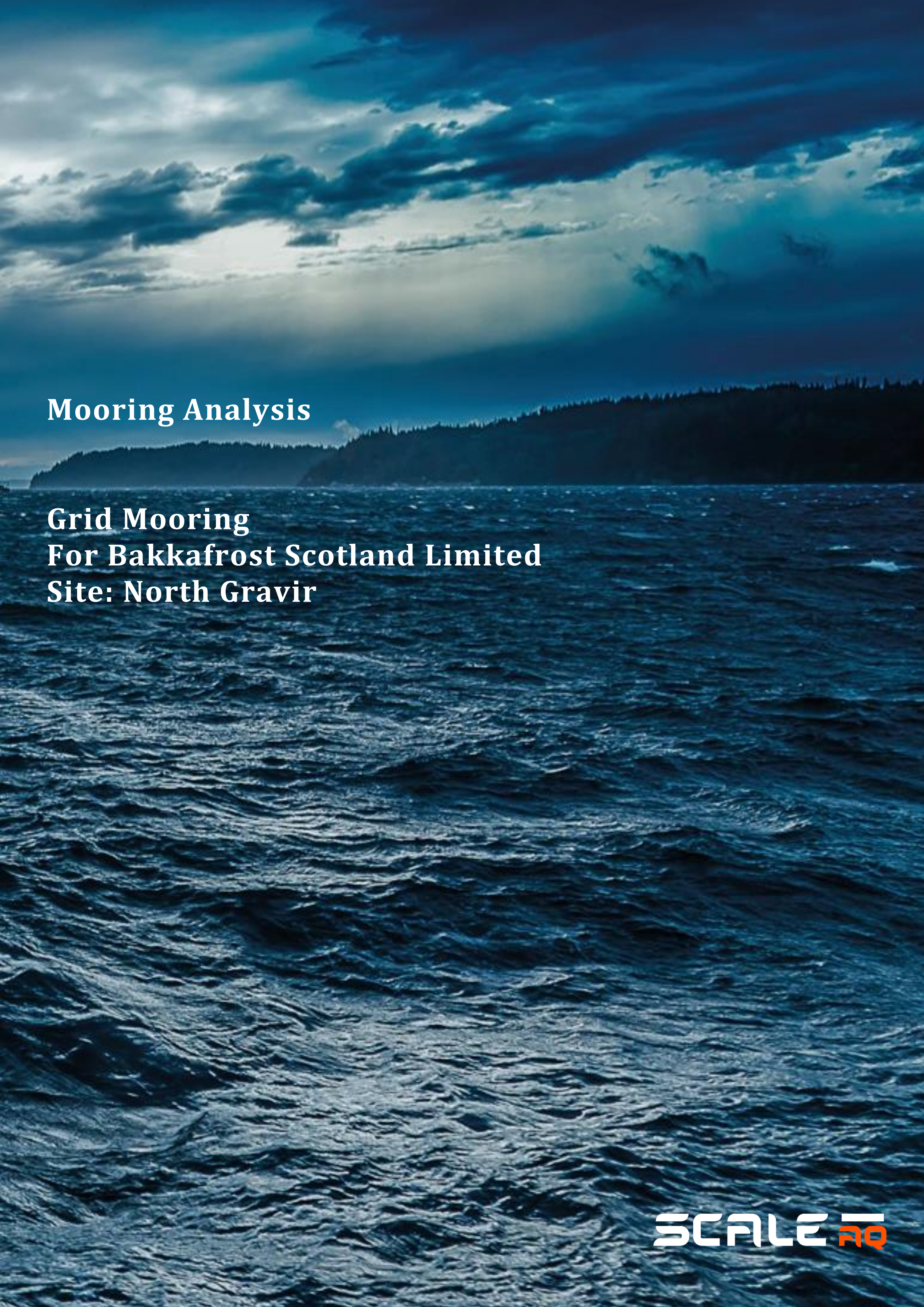

Mooring Analysis

Grid Mooring
For Bakkafrost Scotland Limited
Site: North Gravir

Date Calculation:	Project No.:
03.06.2024	20028
Approved by: Kasper Wåsjø	Inspection body: Scale Aquaculture AS, Trondheim.
Client: Bakkafrost Scotland Limited	Client reference: Jamie Bilsland

Summary:

Scale Aquaculture AS is hired to perform an analysis for the mooring system to be placed at the fish farming site North Gravir. Load and material factors used for designing the system are given in the Norwegian Standard NS9415:2009. Current measurements are received from the Client, and Scottish standards for weakly tidal current was used when obtaining 50/10 year return period applied in the analysis. Wave climate is based on a Technical Note received from the Client with wave climate assessment of the site. In addition, fetch lengths and wind data from nearby weather station at Stornoway Airport is applied for wave sectors not covered by the wave assessment technical note. It is Client's responsibility to verify the applied data in the analyses.

The capacity of the floating collar is checked and found sufficient for both ULS and ALS situations. The fatigue lifetime is calculated to be more than 20 years for the bridle chains. Contact between the net and mooring is not observed in the analysis.

Requirements for the mooring components are described in Section 5 and in the appendices.

Reliability Class:	Index:
2	NS9415:2009 Mooring analysis Global analysis
Title: Grid Mooring Analysis Report Bakkafrost Scotland Limited – North Gravir	
Performed by: Tonje Spangelo	☒No distribution without Client approval

Date this revision:	Rev. No.:	Pages:
04.09.2024	2.0	45

Revision:	Last approved revision prevails previous revisions.	AS BUILT
1.0	Mooring analysis of grid mooring.	NO
2.0	Location and orientation of the grid mooring system is changed based on new information provided by the Client. New analysis is performed, and the results are updated.	NO

1 BACKGROUND

Scale Aquaculture AS is hired to perform the analysis of the mooring system at the fish farming site North Gravir at the Isle of Lewis. The center position of the grid system is 58°03.502 N, 6°21.466 W.

Site location is shown in Figure 1.

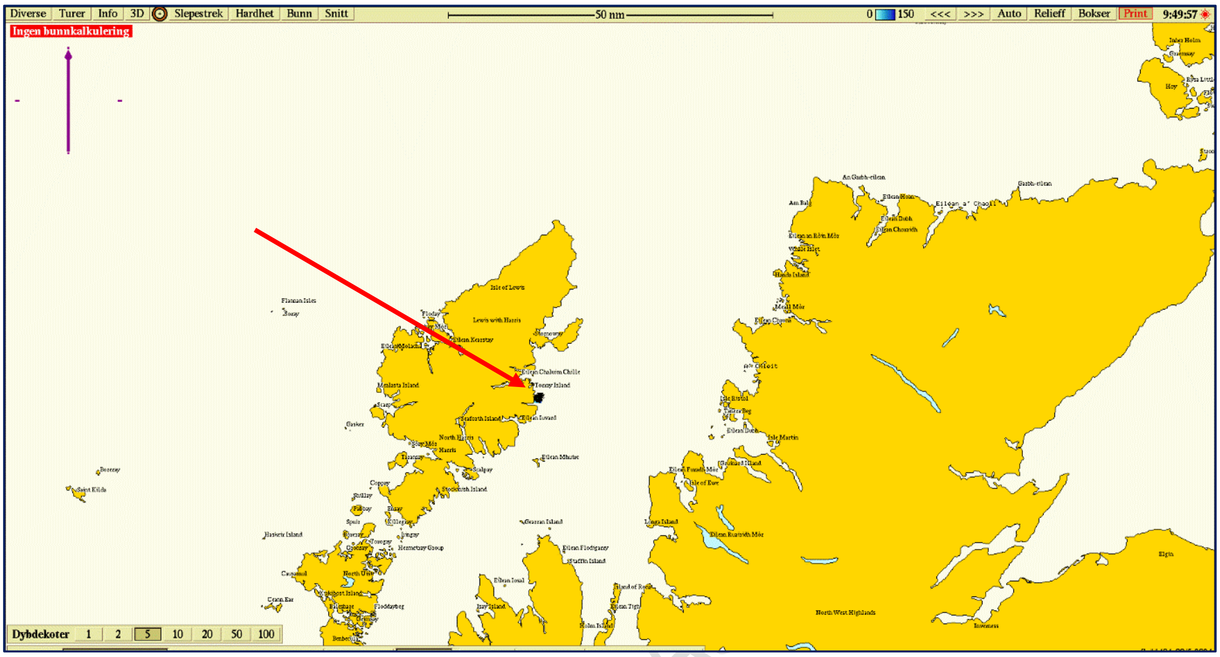

Figure 1: Location North Gravir, at the Isle of Lewis.

1.1 Background documentation for the mooring analysis

The following documentation is applied as the basis for the mooring analysis:

Background and choices made for analyses of mooring systems for floating fish farms executed by Scale Aquaculture AS is described by the procedure «ID- 2143-Fortøyningsanalyse Flytende oppdrettsanlegg – Bakgrunn og valg».

Technical Note is received from the Client: "PC2241-RHD-ZZ-XX-NT-Z-0013-Wave Climate Assessment", Royal HaskoningDHV. The note contains site specific wave data from N, NE, E, SE and S direction, waves for the other directions have been estimated by "fetch length" and wind data for the location. Current data is provided by the Client, and it is assumed that the site is weakly tidal. In addition, an adjustment for time of year is applied to the provided data. In accordance with Scottish standards a factor of 1.7 and 1.1 is applied to obtain the 50-year current. The site report/technical note is not accredited, and hence, the present mooring analysis report is not accredited.

Position of facility received from the Client:
Planned positions for the mooring system have been received from the Client.

1.1.1 As-built

This report is not an as-built revision.

1.1.2 Reliability class

This analysis report is in reliability class 2.

2 SYSTEM DESCRIPTION

The system consists of a 5x1 grid mooring for cages. Further description of the mooring system is given in the following sections.

2.1 Grid Corner Coordinates

Corner	Connection plate number (Figure 2)	Latitude (N)	Longitude (W)
NW	B1	58°03.658	6°21.567
SW	B6	58°03.337	6°21.489
NE	B7	58°03.666	6°21.446
SE	B12	58°03.345	6°21.367

Table 1: Grid corner coordinates.

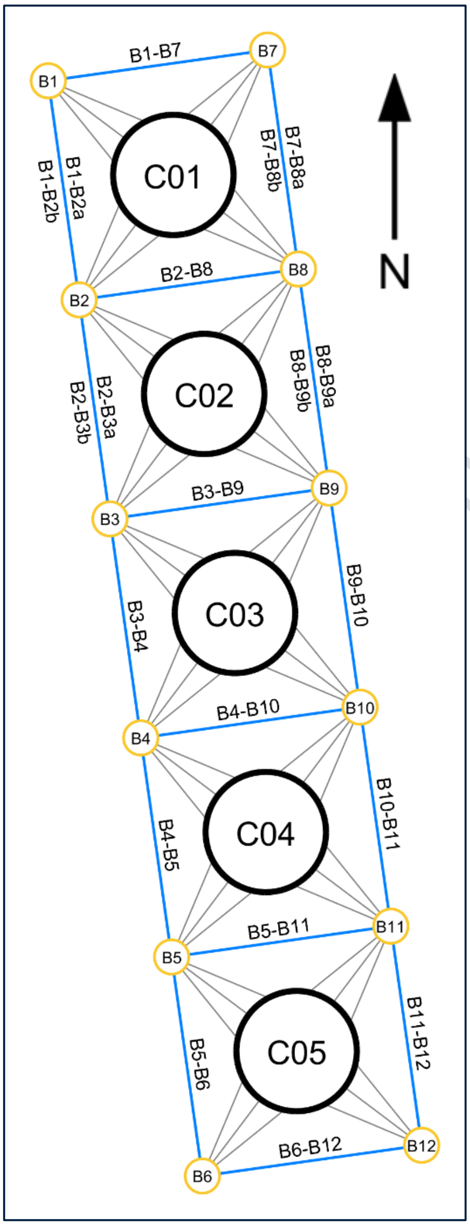

Figure 2: Numbering of bridles and connection plates/buoys.

2.2 Grid Mooring

The grid mooring is configured in an 5x1 configuration with grid size 120mx120m.

Grid depth is 8m.

Material	Weight [kg/m]	Grid lines
72mm 8-br. SuperTec	2.58	All longitudinal grid lines. **Note that cage C01 and C02 has double longitudinal grid lines.**
64mm 8-br.	2.04	All Transversal grid lines

Table 2: Grid lines.

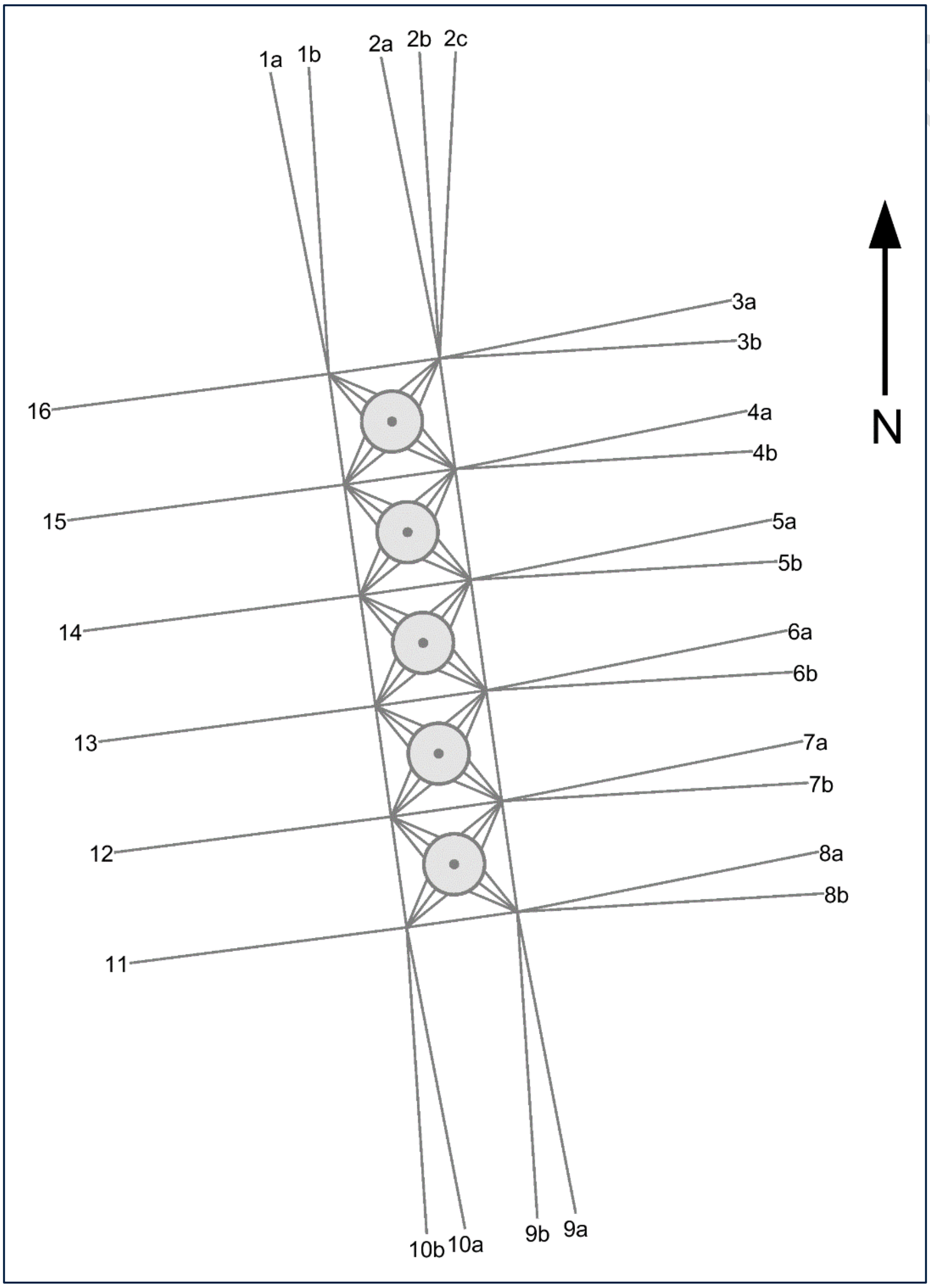

Figure 3: Grid mooring system overview.

2.3 Bridles

Conf.	Layout	Material	Weight in air [kg/m]	Parameters fatigue
3-part	No forerunner	Rope 64mm 3-st. sinking rope	2.61	
		25mm chain	11.0	m=3.0 a=8.6E10

Table 3: Bridle configuration.

The configuration from the mooring plate to the floating collar is:

4m chain - Fibre rope – 4m chain.

2.4 Buoys

The buoy size is adjusted to ensure a flexible mooring system.

Type and size [liter]	Placement
AQUA APB 6600liter	B12
AQUA APB 4400liter	B6, B7
AQUA APB 2200liter	B1, B10, B11, B8, B9
AQUA APB 1000liter	B2, B3, B4, B5

Table 4: Buoys in the grid mooring system.

2.5 Details Mooring Lines

The mooring lines are connected to the frame. Numbering of the lines is shown in Figure 4.

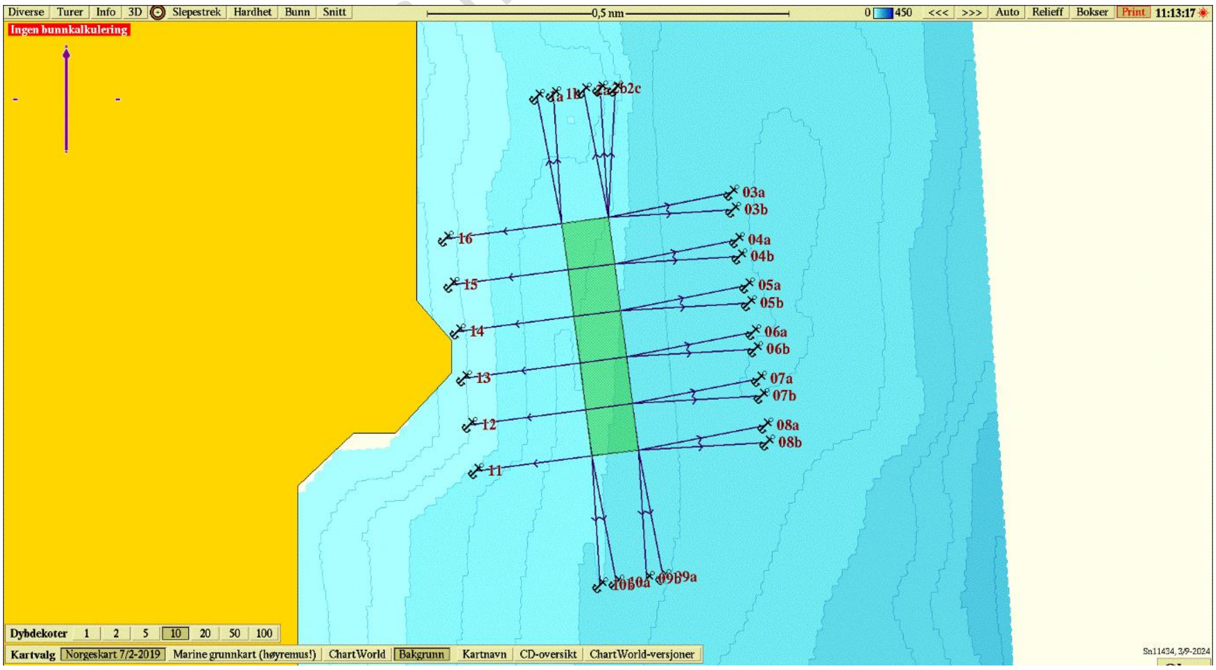

Figure 4: Mooring line numbering.

2.5.1 Positions for the Mooring Line Connection Points

Line no.	Position lower connection point		Position upper connection point		Length and direction in the horizontal plane		Depth	
	North	West	North	West	Length [m]	Direction [°]	Depth [m]	Length /depth
1a	58°03.833	6°21.631	58°03.658	6°21.567	330	349	38	>10
1b	58°03.836	6°21.589	58°03.658	6°21.567	330	356	38	>10
2a	58°03.841	6°21.510	58°03.666	6°21.446	330	349	38	>10
2b	58°03.844	6°21.468	58°03.666	6°21.446	330	356	38	>10
2c	58°03.844	6°21.427	58°03.666	6°21.446	330	3	48	8.3
03a	58°03.700	6°21.126	58°03.666	6°21.446	320	79	72	5.0
03b	58°03.677	6°21.120	58°03.666	6°21.446	320	87	72	5.0
04a	58°03.636	6°21.110	58°03.602	6°21.430	320	79	71	5.1
04b	58°03.612	6°21.104	58°03.602	6°21.430	320	87	71	5.1
05a	58°03.573	6°21.084	58°03.538	6°21.414	330	79	71	5.3
05b	58°03.548	6°21.078	58°03.538	6°21.414	330	87	70	5.3
06a	58°03.508	6°21.069	58°03.474	6°21.399	330	79	70	5.3
06b	58°03.484	6°21.063	58°03.474	6°21.399	330	87	70	5.3
07a	58°03.444	6°21.053	58°03.409	6°21.383	330	79	70	5.4
07b	58°03.420	6°21.047	58°03.409	6°21.383	330	87	70	5.3
08a	58°03.380	6°21.037	58°03.345	6°21.367	330	79	72	5.2
08b	58°03.356	6°21.031	58°03.345	6°21.367	330	87	73	5.1
09a	58°03.170	6°21.303	58°03.345	6°21.367	330	169	69	5.4
09b	58°03.168	6°21.345	58°03.345	6°21.367	330	176	67	5.5
10a	58°03.162	6°21.425	58°03.337	6°21.489	330	169	62	6.1
10b	58°03.159	6°21.467	58°03.337	6°21.489	330	176	61	6.3
11	58°03.316	6°21.792	58°03.337	6°21.489	300	263	32	>10
12	58°03.380	6°21.808	58°03.401	6°21.504	300	263	21	>10
13	58°03.445	6°21.823	58°03.465	6°21.520	300	263	19	>10
14	58°03.509	6°21.839	58°03.530	6°21.536	300	263	17	>10
15	58°03.573	6°21.855	58°03.594	6°21.551	300	263	17	>10
16	58°03.637	6°21.870	58°03.658	6°21.567	300	263	16	>10

Table 5: Positions mooring connection points.

2.5.2 Mooring Line Composition

Line no.	Rope			Anchor chain			Lower connection type
	Dim. [mm]	Length [m]	Weight [Kg/m]	Dim. [mm]	Length [m]	Weight [Kg/m]	
1a	72mm 8-fl. SuperTec	280	2.58	40mm stolpeløs	55	34.0	Plow anchor 1500kg
1b	72mm 8-fl. SuperTec	280	2.58	40mm stolpeløs	55	34.0	Plow anchor 1500kg
2a	72mm 8-fl. SuperTec	280	2.58	40mm stolpeløs	55	34.0	Plow anchor 1500kg
2b	72mm 8-fl. SuperTec	280	2.58	40mm stolpeløs	55	34.0	Plow anchor 1500kg
2c	72mm 8-fl. SuperTec	280	2.58	40mm stolpeløs	55	34.0	Plow anchor 1500kg
03a	64mm 8-fl. SuperTec	275	2.04	36mm stolpeløs	55	27.6	Plow anchor 1500kg
03b	64mm 8-fl. SuperTec	275	2.04	36mm stolpeløs	55	27.6	Plow anchor 1500kg
04a	64mm 8-fl. SuperTec	275	2.04	36mm stolpeløs	55	27.6	Plow anchor 1500kg
04b	64mm 8-fl. SuperTec	275	2.04	36mm stolpeløs	55	27.6	Plow anchor 1500kg
05a	64mm 8-fl. SuperTec	285	2.04	36mm stolpeløs	55	27.6	Plow anchor 1500kg
05b	64mm 8-fl. SuperTec	285	2.04	36mm stolpeløs	55	27.6	Plow anchor 1500kg
06a	64mm 8-fl. SuperTec	285	2.04	36mm stolpeløs	55	27.6	Plow anchor 1500kg
06b	64mm 8-fl. SuperTec	285	2.04	36mm stolpeløs	55	27.6	Plow anchor 1500kg
07a	64mm 8-fl. SuperTec	285	2.04	36mm stolpeløs	55	27.6	Plow anchor 1500kg
07b	64mm 8-fl. SuperTec	285	2.04	36mm stolpeløs	55	27.6	Plow anchor 1500kg
08a	64mm 8-fl. SuperTec	285	2.04	36mm stolpeløs	55	27.6	Plow anchor 1500kg
08b	64mm 8-fl. SuperTec	285	2.04	36mm stolpeløs	55	27.6	Plow anchor 1500kg
09a	64mm 8-fl. SuperTec	285	2.04	36mm stolpeløs	55	27.6	Plow anchor 1500kg
09b	64mm 8-fl. SuperTec	285	2.04	36mm stolpeløs	55	27.6	Plow anchor 1500kg
10a	64mm 8-fl. SuperTec	280	2.04	36mm stolpeløs	55	27.6	Plow anchor 1500kg
10b	64mm 8-fl. SuperTec	280	2.04	36mm stolpeløs	55	27.6	Plow anchor 1500kg
11	64mm 8-fl. SuperTec	250	2.04	36mm stolpeløs	55	27.6	Plow anchor 1500kg
12	64mm 8-fl. SuperTec	250	2.04	36mm stolpeløs	55	27.6	Plow anchor 1500kg
13	64mm 8-fl. SuperTec	250	2.04	36mm stolpeløs	55	27.6	Plow anchor 1500kg

14	64mm 8-fl. SuperTec	250	2.04	36mm stolpeløs	55	27.6	Plow anchor 1500kg
15	64mm 8-fl. SuperTec	250	2.04	36mm stolpeløs	55	27.6	Plow anchor 1500kg
16	64mm 8-fl. SuperTec	250	2.04	36mm stolpeløs	55	27.6	Plow anchor 1500kg

Table 6: Mooring line composition. All weights are weight in air.

Lengths, depths, and directions for all mooring lines are given in Table 5 . The numbering is according to Figure 4. All lines are modelled with anchor chain towards the anchor and the rest of the line is fiber rope as specified.

This configuration is chosen to accommodate for highest astronomical tide (HAT).

2.6 Modulus of Elasticity for Materials

Young's modulus rope = 1870 MPa

Young's modulus anchor chain = 110000 MPa

Young's modulus long-linked chain = 210000 MPa

2.7 Floating Collar and Sinker Tube

Amount	Type	Pipe-diameter [mm]	SDR	Material specification	Circumference	Capacity bridle connection ULS/ALS
5	ScaleAQ	560	13.6	PE 100	200meter	35t ULS / 40t ALS

Table 7: Floating collar and cage

Amount	Material -specification	Pipe diameter [mm]	SDR	Suspension weight [kg/m]
5	PE 100	450	11.0	70

Table 8: Sinker tube

2.8 Net Details

Amount	General net design	Half mesh size [mm]	Twine size [mm]	Side wall depth [m]	Cone Depth [m]	Solidity incl. 50% marine growth	Total weight used in the cone [kg]
5	ScaleAQ HDPE Midgard	18	2.07	15	30	34.5%	1200

Table 9: Net details.

2.9 Cage, Nets and Suspensions Configuration

All cages are modelled with floating collars and ScaleAQ Midgard net type as described in the previous chapters.

2.10 Site Condition and Seabed Connections

It is assumed that the seabed conditions are suitable for the proposed seabed connection type. It is Client's responsibility to verify that the proposed seabed connection type is suitable for the site.

All anchor lines are evaluated with respect to possible contact between the seabed and the rope section of the anchor line.

The distance between the depth of net for the dimensioning cone tip and the seabed is 18 m.

Line profiles are shown in Appendix C.

3 ENVIRONMENTAL CONDITIONS

The current, wind and waves used in the calculations is described below. Note that it is the Client's responsibility to verify the environmental conditions used in the analyses.

Current

The current velocity data is received from the Client as max current speed in eight evenly distributed sectors. The received data is assumed to be weakly tidal and according to Scottish standards for weakly tidal current, a factor of 1.7 is applied to the current measurements to find the extreme current velocity with 50-year return period. In addition, an adjustment for the time of year of the measurements is applied to current speeds, with a factor of 1.1. The extreme current velocity with 10-year return period is found by scaling with a factor of 0.89, which is based on the factors in the Norwegian standard (1.65/1.85)

Waves

Data for wave climate at the site is found in the Technical Note "PC2241-RHD-ZZ-XX-NT-Z-0013" where the worst wave direction is found. This wave direction (30°N) was adopted for extreme wave and wind conditions in the wave transformation model runs for the full set of return period events. For offshore direction 330°, 0°, 60°, 90°, 120° and 150°, the results from the sensitivity tests are applied in the analysis as waves with 50-year return period. For other sectors, fetch calculations based on wind data at the nearby weather station at Stornoway Airport was applied. Wave heights for 10-year return period was assumed based on the ratio between wave heights with 10- and 50-year return period for the worst wave direction (30°N).

The analyzed load cases in accidental limit state are seen in regard to the ultimate limit state and the combinations identified as the most unfavorable for the system is applied in the further analysis.

It is Client's responsibility to verify the applied data in the analyses.

3.1 Ultimate Limit State

Load Case	Hs [m]	Tp [s]	Wave direction [°]	v_c 0m and 5m [m/s]	v_c 15m [m/s]	Current direction 5m / 15m [°]
1	4.3	12.0	44	0.79	0.82	180 / 180
2	5.1	12.5	48	0.79	0.65	225 / 225
3	4.8	10.0	52	0.30	0.35	270 / 270
4	2.6	6.0	81	0.45	0.52	315 / 315
5	2.8	6.0	117	0.50	0.51	0 / 0
6	2.8	6.5	144	0.50	0.46	45 / 45
7	0.4	2.8	270	0.24	0.23	90 / 90
8	0.8	3.8	315	0.71	0.83	135 / 135
9	5.0	13.9	44	0.70	0.73	180 / 180
10	6.0	13.5	49	0.70	0.58	225 / 225
11	5.6	11.7	52	0.27	0.32	270 / 270
12	3.1	6.7	81	0.41	0.46	315 / 315
13	3.3	6.8	117	0.45	0.46	0 / 0
14	3.3	7.8	144	0.45	0.41	45 / 45
15	0.5	3.0	270	0.21	0.21	90 / 90
16	0.9	4.0	315	0.63	0.74	135 / 135

Table 10: Ultimate limit state.

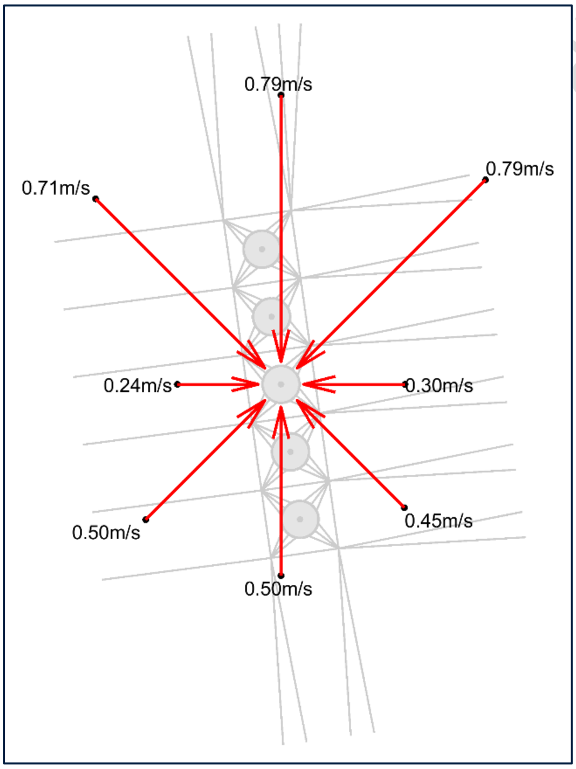

Figure 5: Current speed with 50-year return period at 5m water depth.

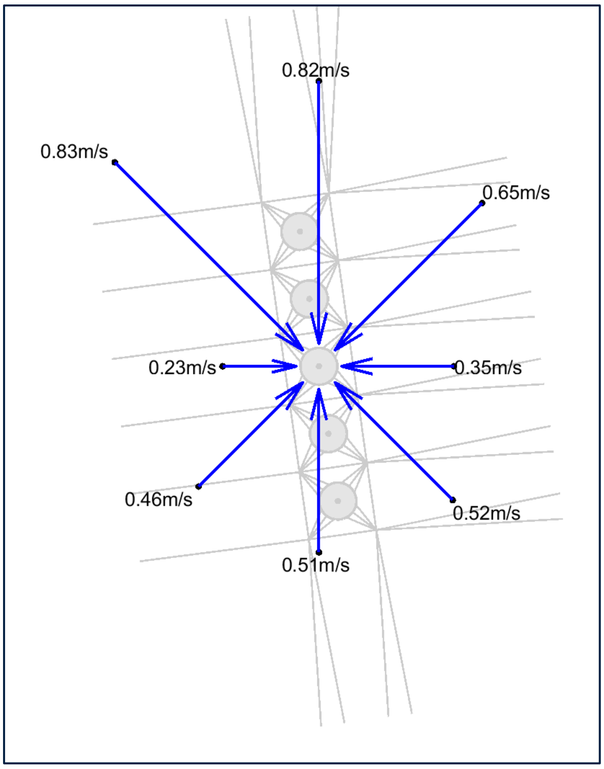

Figure 6: Current speed with 50-year return period at 15m water depth.

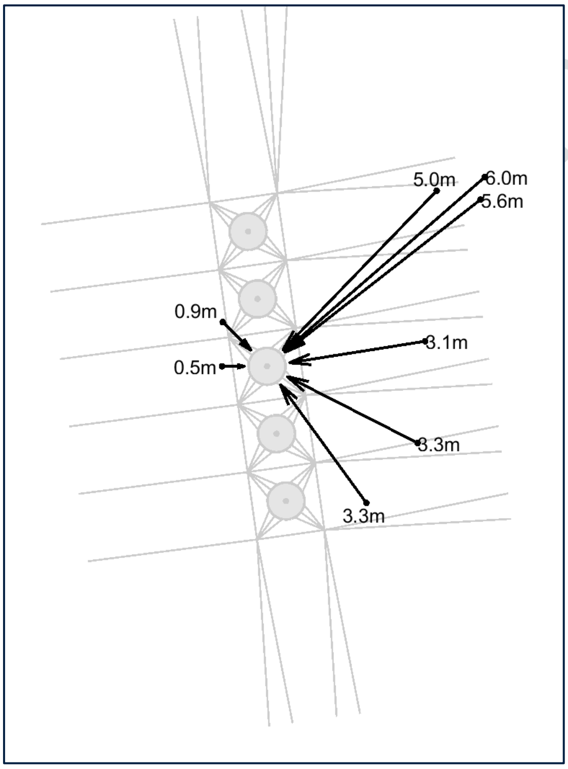

Figure 7: Significant wave height with 50-year return period.

3.2 Accidental Limit State

Load Case	Hs [m]	Tp [s]	Wave direction [°]	v_c 0m and 5m [m/s]	v_c 15m [m/s]	Current direction 5m / 15m [°]
17	0.8	3.8	315	0.71	0.83	135 / 135
18	0.8	3.8	315	0.71	0.83	135 / 135
19	6.0	13.5	49	0.70	0.58	225 / 225
20	0.8	3.8	315	0.71	0.83	135 / 135
21	4.3	12.0	44	0.79	0.82	180 / 180
22	2.8	6.0	117	0.50	0.51	0 / 0
23	4.3	12.0	44	0.79	0.82	180 / 180
24	5.1	12.5	48	0.79	0.65	225 / 225
25	6.0	13.5	49	0.70	0.58	225 / 225

Table 11: Accidental limit state

Load Case 17: Broken mooring line with highest load, 1a
Load Case 18: Broken mooring line, control of progressive line break, 1b
Load Case 19: Broken mooring line, control of progressive line break, 6a
Load Case 20: Broken mooring line, control of cage deformations, 15
Load Case 21: Broken grid line with highest load, B7-B8a
Load Case 22: Broken grid line, control of floating collar integrity, B5-B6
Load Case 23: Broken grid line, control of floating collar integrity, B9-B10
Load Case 24: Broken bridle with highest load, C01
Load Case 25: Broken, control of floating collar integrity, C05

See Figure 10.

3.3 Fatigue

By using historical wind data of wind directions from Stornoway Airport, we get weighting values for four wave directions to be used in the fatigue calculation.

North	0.1973
East	0.1587
South	0.3418
West	0.2797

Based on the defined wave conditions we find the following waves to estimate fatigue in the mooring line anchor chain.

Load Case	Hs [m]	Tp [s]	Wave direction [°]	v_c [m/s]	Current direction [°]
1	0.31	2.08	0	0.35	180
2	0.61	2.94	0	0.35	180
3	0.92	3.60	0	0.35	180
4	1.22	4.16	0	0.35	180
5	1.53	4.65	0	0.35	180
6	1.84	5.10	0	0.35	180
7	2.14	5.50	0	0.35	180
8	2.45	5.88	0	0.35	180
9	0.17	1.55	90	0.22	270
10	0.34	2.19	90	0.22	270
11	0.51	2.68	90	0.22	270
12	0.68	3.09	90	0.22	270
13	0.85	3.46	90	0.22	270
14	1.02	3.79	90	0.22	270
15	1.19	4.09	90	0.22	270
16	1.36	4.38	90	0.22	270
17	0.17	1.54	180	0.22	0
18	0.34	2.18	180	0.22	0
19	0.51	2.68	180	0.22	0
20	0.68	3.09	180	0.22	0
21	0.84	3.45	180	0.22	0
22	1.01	3.78	180	0.22	0
23	1.18	4.09	180	0.22	0
24	1.35	4.37	180	0.22	0
25	0.05	0.81	270	0.32	90
26	0.09	1.14	270	0.32	90
27	0.14	1.40	270	0.32	90
28	0.18	1.61	270	0.32	90
29	0.23	1.80	270	0.32	90
30	0.28	1.97	270	0.32	90
31	0.32	2.13	270	0.32	90
32	0.37	2.28	270	0.32	90

Table 12: Fatigue

4 RESULTS

Dynamic analyses are performed in both ultimate-, accidental- and fatigue limit state. The results from the analysis are presented below.

Interaction between the net and grid mooring components is evaluated. Environmental conditions found in Table 10 are applied for this evaluation. This is considered a control in the serviceability limit state of characteristic loads (50-year condition). Operational conditions are not considered for the mooring system.

4.1 Static

Pretension in the mooring system is calculated based on the static configuration and is based on the mooring components physical properties in addition to the line profiles.

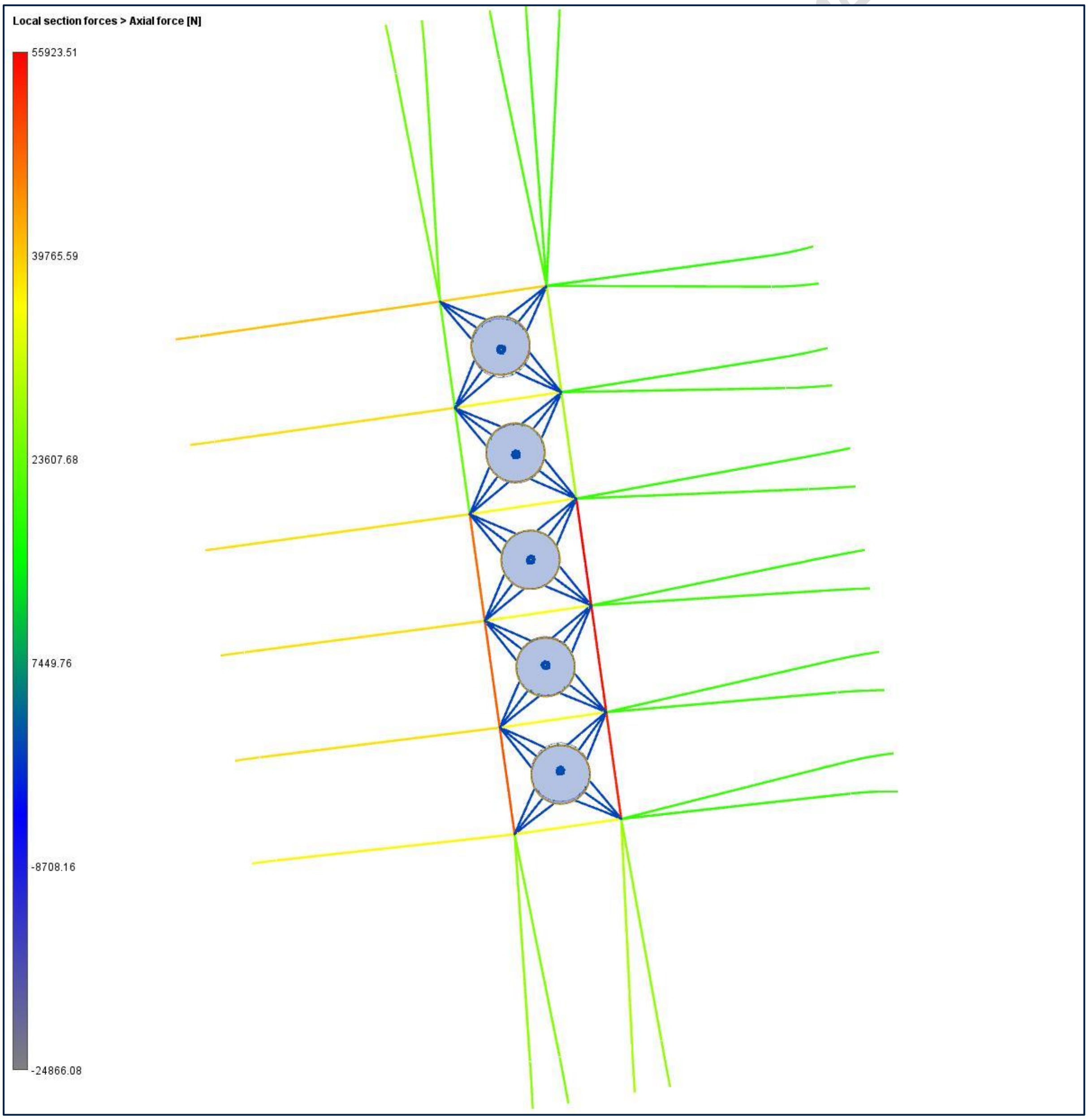

Figure 8: Static equilibrium.

4.1.1 Pretension in Grid Ropes and Bridles

Placement	Minimum pretension [t]	Maximum pretension [t]
Longitudinal grid ropes	2.7	6.6
Transversal grid ropes	4.2	4.6
Bridles	0.1	0.1

Table 13: Pretension in grid ropes and bridles

4.1.2 Pretension in Mooring Lines

Line no.	Pretension [t]
1a	2.8
1b	2.7
2a	2.5
2b	2.4
2c	2.4
03a	2.2
03b	2.3
04a	2.3
04b	2.4
05a	2.3
05b	2.4
06a	2.3
06b	2.3
07a	2.3
07b	2.3
08a	2.3
08b	2.3
09a	3.2
09b	3.4
10a	3.0
10b	3.1
11	4.3
12	4.5
13	4.5
14	4.5
15	4.5
16	4.7

Table 14: Mooring line pretension in static equilibrium

4.2 Ultimate Limit State

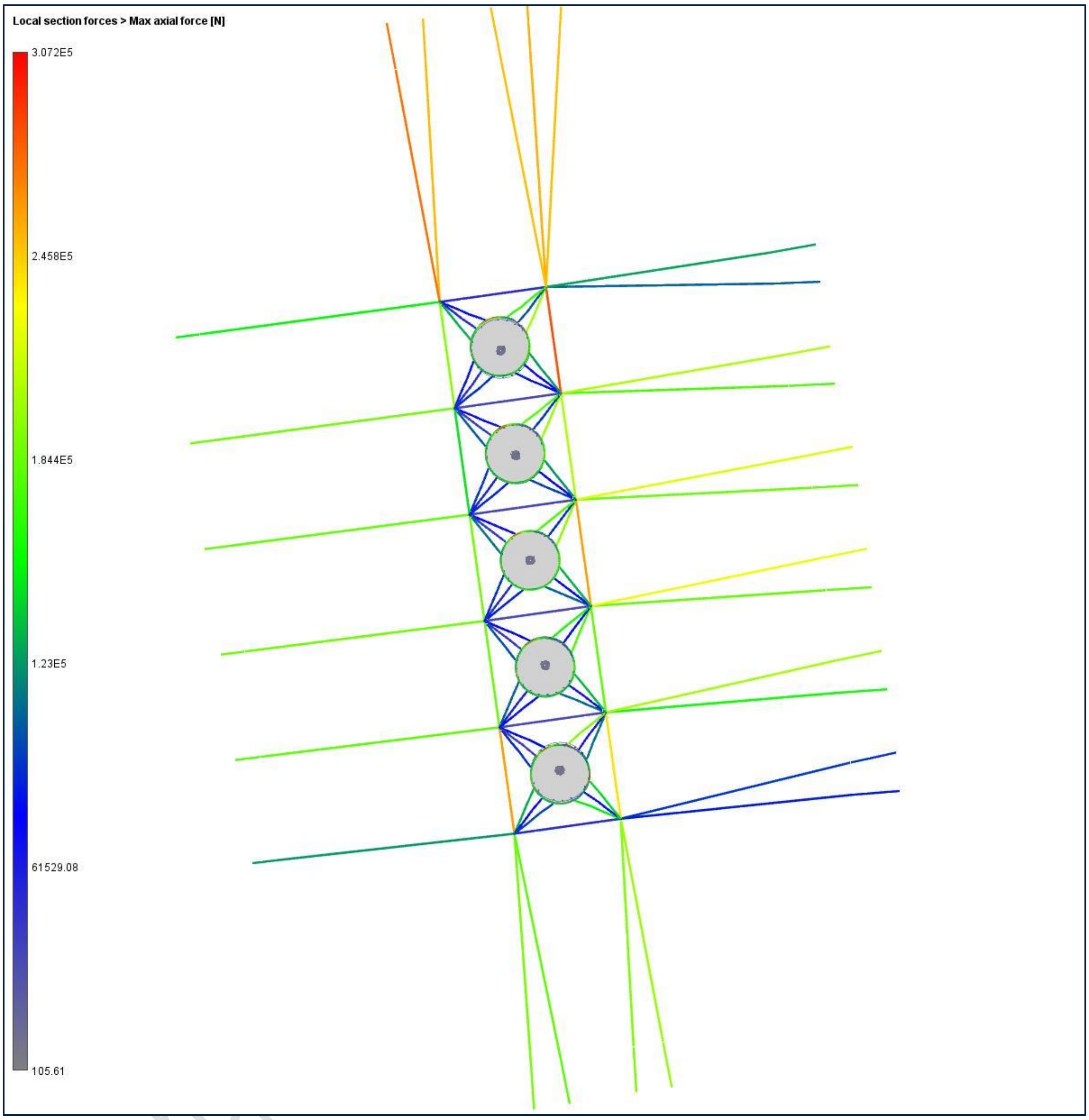

Figure 9: Loads in ultimate limit state.

4.2.1 Design Loads in Ultimate Limit State

Line no.	Design loads [t]
Longitudinal grid ropes	33.3
Transversal grid ropes	6.2
Bridles	23.7
1a	32.0
1b	29.4
2a	29.2
2b	29.8
2c	29.2
03a	14.9
03b	12.5
04a	24.2
04b	20.7
05a	26.0
05b	21.7
06a	26.5
06b	21.5
07a	23.9
07b	18.5
08a	10.8
08b	9.9
09a	23.4
09b	22.4
10a	21.3
10b	22.1
11	14.4
12	21.2
13	21.9
14	21.4
15	22.0
16	17.9

Table 15: Design loads in ultimate limit state

4.3 Accidental- and Fatigue Limit State

Based on the results of the intact system, the accidental limit state conditions are defined. Figure 10 shows the lines with the highest loads, and the lines with highest stress amplitude for fatigue analyses. The environmental conditions for accidental limit state are described in Table 11. The environmental conditions for fatigue analyses are described in Table 12.

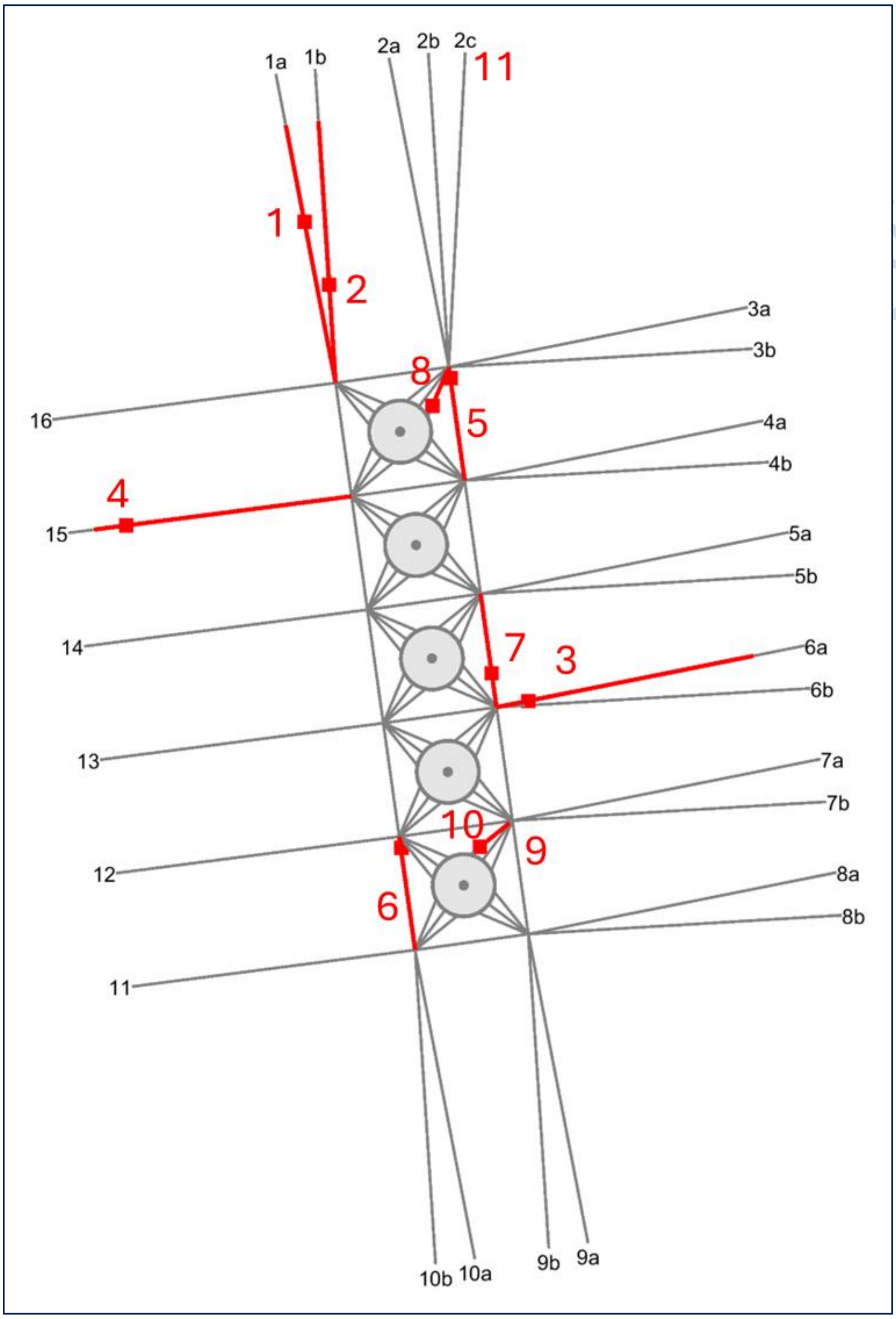

Figure 10: Load cases for accidental limit state and components evaluated for fatigue damage.

1. Mooring line with highest load
2. Mooring line, control of progressive line break
3. Mooring line, control of progressive line break
4. Mooring line, control of cage deformations
5. Grid rope with the highest load
6. Grid rope, control of floating collar integrity
7. Grid rope, control of floating collar integrity
8. Bridle with the highest load
9. Bridle, control of floating collar integrity
10. Fatigue analysis of bridle chain with highest stress amplitude
11. Fatigue analysis of anchor chain in line with highest stress amplitude

4.3.1 Design Loads in Accidental Limit State

Design loads in accidental limit state are given in Table 16.

Line no.	Design loads [t]
Longitudinal grid ropes	51.2
Transversal grid ropes	5.8
Bridles	24.7
1a	43.7
1b	42.6
2a	23.6
2b	24.2
2c	23.8
03a	13.3
03b	11.2
04a	21.2
04b	18.1
05a	23.3
05b	19.5
06a	23.1
06b	29.8
07a	21.5
07b	17.0
08a	9.5
08b	9.2
09a	21.3
09b	20.4
10a	15.3
10b	15.5
11	12.0
12	19.3
13	20.2
14	26.1
15	20.5
16	21.4

Table 16: Design loads in accidental limit state.

4.4 Fatigue

Analyses in 4 directions divided by 8 blocks are performed. The mooring- and bridle chain with highest stress range in the ultimate limit state shown in Figure 10 is chosen for fatigue life assessment.

4.4.1 Mooring Chain

The calculated stress ranges are presented below:

Block	North	East	South	West
1	1.65 MPa	0.51 MPa	0.75 MPa	0.13 MPa
2	4.36 MPa	1.09 MPa	1.35 MPa	0.46 MPa
3	7.43 MPa	0.86 MPa	0.64 MPa	0.62 MPa
4	6.84 MPa	2.64 MPa	0.89 MPa	0.47 MPa
5	8.98 MPa	2.16 MPa	0.89 MPa	0.56 MPa
6	18.05 MPa	1.14 MPa	0.92 MPa	0.90 MPa
7	16.82 MPa	1.72 MPa	1.38 MPa	0.73 MPa
8	19.33 MPa	2.51 MPa	2.26 MPa	1.36 MPa

Table 17: Stress ranges for mooring chain.

The fatigue damage is calculated to 0.02, resulting in a fatigue life for the anchor chain of more than 50 years.

4.4.2 Bridle Chain

The calculated stress ranges are presented below:

Block	North	East	South	West
1	7.02 MPa	2.57 MPa	0.63 MPa	0.62 MPa
2	19.87 MPa	4.80 MPa	0.69 MPa	0.61 MPa
3	29.34 MPa	5.78 MPa	1.95 MPa	0.54 MPa
4	23.14 MPa	17.52 MPa	0.51 MPa	0.63 MPa
5	27.29 MPa	30.74 MPa	1.50 MPa	1.19 MPa
6	33.73 MPa	20.38 MPa	1.47 MPa	0.49 MPa
7	36.76 MPa	31.05 MPa	1.86 MPa	1.23 MPa
8	42.94 MPa	28.07 MPa	1.18 MPa	1.13 MPa

Table 18: Stress ranges for bridle chain.

The fatigue damage is calculated to 0.86, resulting in a fatigue life for the bridle chain of 23 years.

4.4.3 Fatigue Assessment of Fiber Rope

Fatigue assessment for fiber rope is not relevant as the stress range is below 170 MPa (Ref. NS9515:2009).

5 CONCLUSION – REQUIRED CAPACITIES

5.1 Grid Lines and Bridles

Component	Requirement rope[1)] [t]	Requirement steel components[1)] [t]
Longitudinal grid ropes	102.4	68.2
Transversal grid ropes	18.5	12.3
Bridles	71.1	47.4

Table 19: Requirements to MBL in grid ropes and bridles.

Comment:

1) The partial coefficient method is applied including load factor and material factor according to the Norwegian Standard (NS9415-2009).

5.1.1 Forces in Grid Ropes and Bridles

Grid forces are specified as strength requirements, including load- and material factor according to the Norwegian Standard (NS9415-2009). Bridle forces are given for the highest force (dimensioning load effect) towards the floating collar. Forces in accidental limit state are marked in red for bridles.

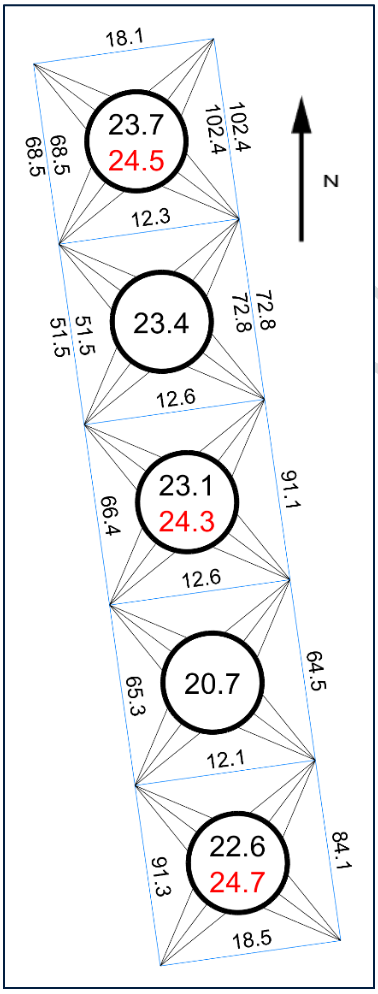

Figure 11: Forces in grid rope and bridles.

5.2 Mooring Plate

Component	Requirement MBL[1)] [t]
Mooring plate	68.2

Table 20: Requirements to mooring plate. 1) The partial coefficient method is applied including load factor and material factor of 2 according to the Norwegian Standard (NS9415:2021).

5.3 Bridles

Fatigue lifetime is calculated to be 23 years for the bridle chains.

Maximum force from the bridles to the floating collar is 23.7 metric tons in ULS and 24.7 metric tons in ALS.

The capacity of the mooring points on the specified floating collar is 35t and 40t (ULS and ALS). The capacity of the floating collar is sufficient.

Maximum dimensioning vertical force in the floating collar is calculated to be 5.6 metric tons.

A submergence control of the floating collar has been made with the loading condition that exhibits the most force into the floating collar. This check shows that the floating collar has leftover buoyancy and that it is not fully submerged in 50-year currents.

5.4 Mooring Lines

Fatigue lifetime is calculated to be more than 50 years for the anchor chains.

The highest vertical force in the lower connection points found in the analysis is 1.5 metric tons and is found in mooring line 9a.

5.5 Mooring Line Requirements

Note: The partial coefficient method is applied including load factor and material factor according to the Norwegian Standard (NS9415:2009).

Line no.	ULS load [t]	ALS load [t]	Req. rope and anchor MBL [t]	Req. steel comp. MBL [t]	Req. anchoring capacity Holding power anchor [t]	Vertical force lower connection point [t]
1a	32.0	43.7	95.9	64.0	32.0	0.8
1b	29.4	42.6	88.2	58.8	29.4	0.6
2a	29.2	23.6	87.7	58.4	29.2	0.2
2b	29.8	24.2	89.4	59.6	29.8	0.2
2c	29.2	23.8	87.7	58.5	29.2	0.7
03a	14.9	13.3	44.6	29.7	14.9	0.0
03b	12.5	11.2	37.5	25.0	12.5	-
04a	24.2	21.2	72.7	48.5	24.2	0.9
04b	20.7	18.1	62.0	41.3	20.7	0.4
05a	26.0	23.3	77.9	51.9	26.0	0.9
05b	21.7	19.5	65.1	43.4	21.7	0.4
06a	26.5	23.1	79.4	53.0	26.5	1.0
06b	21.5	29.8	64.6	43.0	21.5	0.4
07a	23.9	21.5	71.6	47.7	23.9	1.0
07b	18.5	17.0	55.4	36.9	18.5	0.3
08a	10.8	9.5	32.4	21.6	10.8	-
08b	9.9	9.2	29.7	19.8	9.9	-
09a	23.4	21.3	70.2	46.8	23.4	1.5
09b	22.4	20.4	67.2	44.8	22.4	1.4
10a	21.3	15.3	63.8	42.6	21.3	1.0
10b	22.1	15.5	66.3	44.2	22.1	1.1
11	14.4	12.0	43.1	28.7	14.4	0.1
12	21.2	19.3	63.7	42.5	21.2	0.1
13	21.9	20.2	65.7	43.8	21.9	0.1
14	21.4	26.1	64.3	42.9	21.4	-
15	22.0	20.5	66.0	44.0	22.0	-
16	17.9	21.4	53.8	35.8	17.9	-

Table 21: Requirements to rope, chain/shackles and anchoring in the mooring lines.

5.6 Forces in Buoy Lines

Forces in the chains between the mooring plates and the buoys are shown in the table below for load cases analyzed with 50-year return period current and no waves.

Reference is made to Figure 2 for numbering of buoys.

It is recommended to use buoys to make easy access to the connection plates.

Component	Design loads [t]	Equivalent buoyancy [liter]	Submergence [m]
B1 - APB 2200 Aqua	2.3	1 950	-
B2 - APB 1000 Aqua	1.0	450	-
B3 - APB 1000 Aqua	1.0	400	-
B4 - APB 1000 Aqua	1.0	450	-
B5 - APB 1000 Aqua	1.0	450	-
B6 - APB 4400 Aqua	4.5	3 500	-
B7 - APB 4400 Aqua	4.5	4 400	-
B8 - APB 2200 Aqua	2.3	1 300	-
B9 - APB 2200 Aqua	2.3	1 250	-
B10 - APB 2200 Aqua	2.3	1 200	-
B11 - APB 2200 Aqua	2.3	1 200	-
B12 - APB 6600 Aqua	6.6	5 300	-

Table 22: Loads in buoy chains

6 COMMENTS

It is important to take into consideration that the validity of the results in the mooring analysis is dependent on the received environmental data. It is assumed that the data for wind, wave and current represents the most severe conditions at the site. This also includes information regarding the depths at the site.

Note that the soil and rock conditions at the seabed are essential for the efficiency of the anchors and rock pins.

7 RESPONSIBILITY CLAUSE

Scale Aquaculture AS is only responsible for correcting mistakes and flaws in the analysis reported within 1 year after delivery. Scale Aquaculture AS is not responsible for any errors in the actual calculations or in the calculation software used.

Scale Aquaculture AS has no responsibility for further mistakes neither towards the client nor third parties. This includes damage to material, property, stock (incl. fish etc.), personal injury, loss in profit or other economic loss of consequence.

In case of any demands from third parties the client shall hold Scale Aquaculture AS blameless. The client has the insurance responsibilities for accidental situations falling into these limitations of responsibility.

8 REFERENCES

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Aquastructures (2014), «Numerisk og analytisk analyse på ei flat plate i strøm», Rapport nr. 2454-01.

Norsk Standard: “NS 9415:2009 Flytende oppdrettsanlegg – Krav til lokalitetsundersøkelse, risikoanalyse, utforming, dimensjonering, utførelse, montering og drift”.

«ID- 2143-Fortøyningsanalyse Flytende oppdrettsanlegg – Bakgrunn og valg», Scale Aquaculture AS.

APPENDIX A COMPONENT UTILISATIONS

The required MBL for mooring line components, grid ropes and bridles found in this mooring analysis is controlled against the MBL for the planned components. Note that the partial coefficient method is applied including load factor and material factor according to the Norwegian Standard (NS9415-2009). See Table 23 for mooring lines and Table 24 for grid ropes and bridles.

Line	MBL Rope [t]	MBL anchor chain [t]	MBL anchor [t]	Utilization Rope [-]	Utilization anchor chain [-]	Utilization seabed connection [-]
1a	105.5	84.5	108.0	0.91	0.76	0.89
1b	105.5	84.5	108.0	0.84	0.70	0.82
2a	105.5	84.5	108.0	0.83	0.69	0.81
2b	105.5	84.5	108.0	0.85	0.71	0.83
2c	105.5	84.5	108.0	0.83	0.69	0.81
03a	83.9	68.5	108.0	0.53	0.43	0.41
03b	83.9	68.5	108.0	0.45	0.36	0.35
04a	83.9	68.5	108.0	0.87	0.71	0.67
04b	83.9	68.5	108.0	0.74	0.60	0.57
05a	83.9	68.5	108.0	0.93	0.76	0.72
05b	83.9	68.5	108.0	0.78	0.63	0.60
06a	83.9	68.5	108.0	0.95	0.77	0.74
06b	83.9	68.5	108.0	0.77	0.63	0.60
07a	83.9	68.5	108.0	0.85	0.70	0.66
07b	83.9	68.5	108.0	0.66	0.54	0.51
08a	83.9	68.5	108.0	0.39	0.31	0.30
08b	83.9	68.5	108.0	0.35	0.29	0.28
09a	83.9	68.5	108.0	0.84	0.68	0.65
09b	83.9	68.5	108.0	0.80	0.65	0.62
10a	83.9	68.5	108.0	0.76	0.62	0.59
10b	83.9	68.5	108.0	0.79	0.65	0.61
11	83.9	68.5	108.0	0.51	0.42	0.40
12	83.9	68.5	108.0	0.76	0.62	0.59
13	83.9	68.5	108.0	0.78	0.64	0.61
14	83.9	68.5	108.0	0.77	0.63	0.60
15	83.9	68.5	108.0	0.79	0.64	0.61
16	83.9	68.5	108.0	0.64	0.52	0.50

Table 23: Utilization in mooring lines.

Line	MBL rope [t]	MBL shackle [t]	MBL chain [t]	Utilization rope [-]	Utilization shackle [-]	Utilization Chain [-]
B1-B2a	105.5	90	-	0.65	0.51	-
B1-B2a	105.5	90	-	0.65	0.51	-
B2-B3a	105.5	90		0.49	0.38	-
B2-B3a	105.5	90		0.49	0.38	-
B3-B4	105.5	90		0.63	0.49	-
B4-B5	105.5	90	-	0.62	0.48	-
B5-B6	105.5	90	-	0.87	0.68	-
B7-B8a	105.5	90	-	0.95	0.74	-
B7-B8a	105.5	90	-	0.95	0.74	-
B8-B9a	105.5	90	-	0.69	0.54	-
B8-B9a	105.5	90	-	0.69	0.54	-
B9-B10	105.5	90	-	0.86	0.67	-
B10-B11	105.5	90	-	0.61	0.48	-
B11-B12	105.5	90	-	0.80	0.62	-
B1-B7	68.2	90	-	0.27	0.13	-
B2-B8	68.2	90	-	0.18	0.09	-
B3-B9	68.2	90	-	0.18	0.09	-
B4-B10	68.2	90	-	0.19	0.09	-
B5-B11	68.2	90	-	0.18	0.09	-
B6-B12	68.2	90	-	0.27	0.14	-
Bridles C01	92.7	60	64.0	0.77	0.79	0.74
Bridles C02	92.7	60	64.0	0.76	0.78	0.73
Bridles C03	92.7	60	64.0	0.75	0.77	0.72
Bridles C04	92.7	60	64.0	0.67	0.69	0.65
Bridles C05	92.7	60	64.0	0.73	0.75	0.71

Table 24 Utilization in grid ropes and bridles

APPENDIX B DEFORMATION OF SYSTEM IN ULTIMATE LIMIT STATE

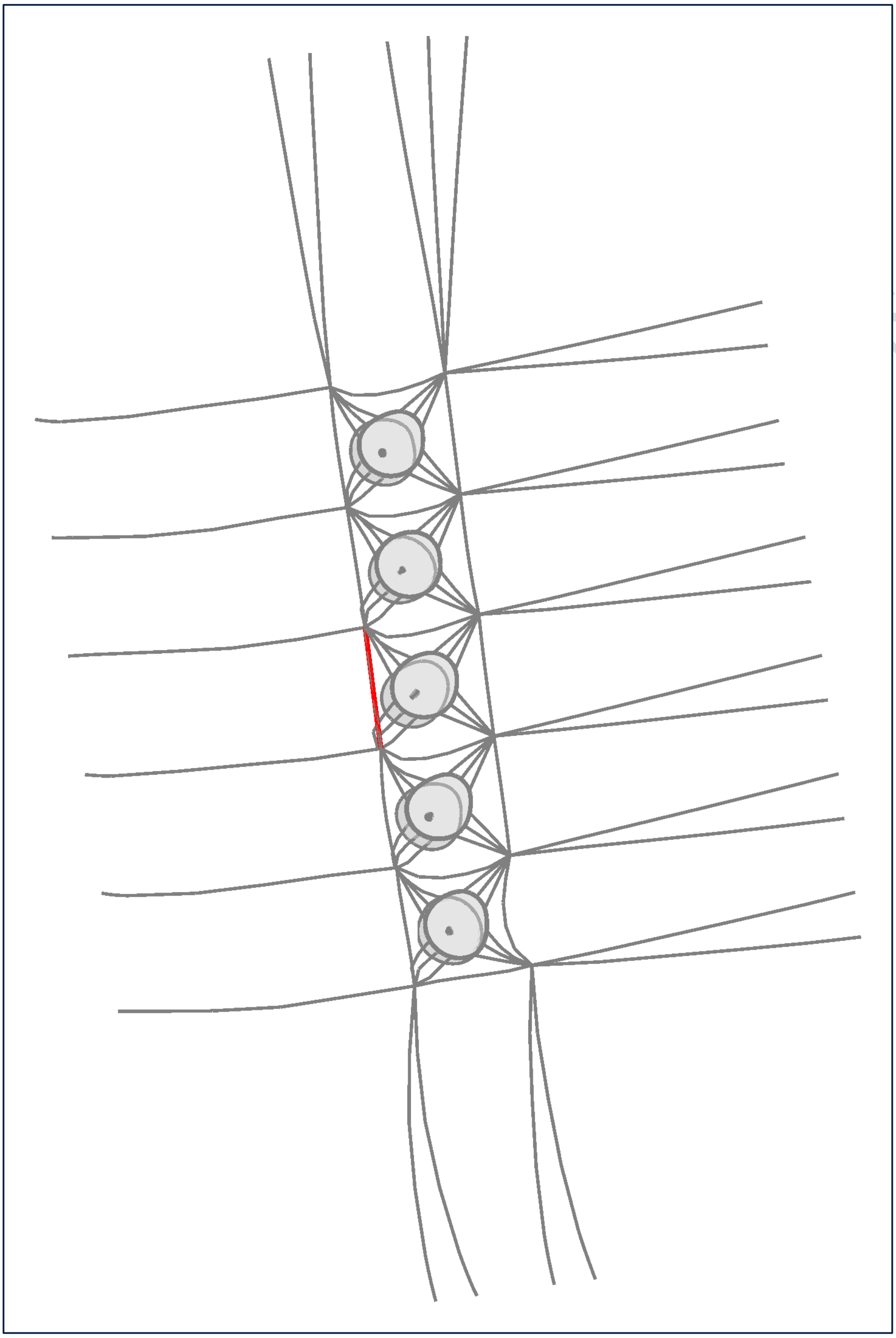
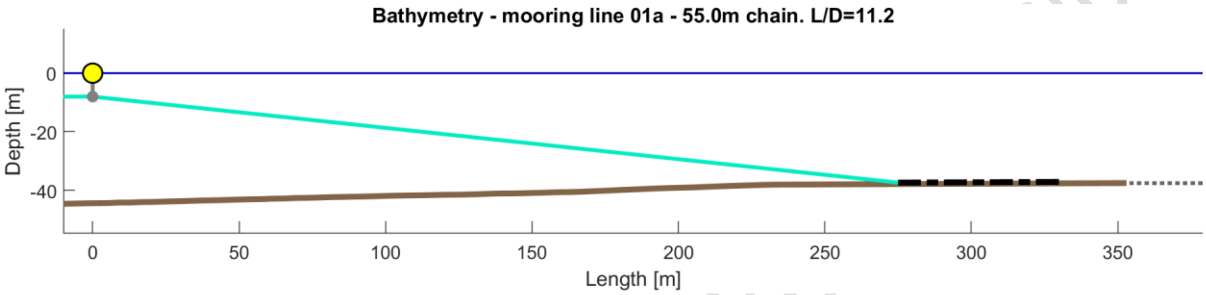


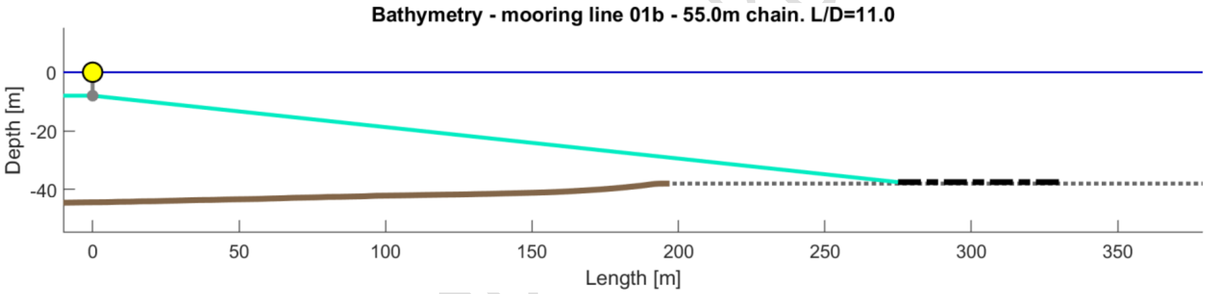
Figure 12: Shortest distance between net and grid rope in ultimate limit state.

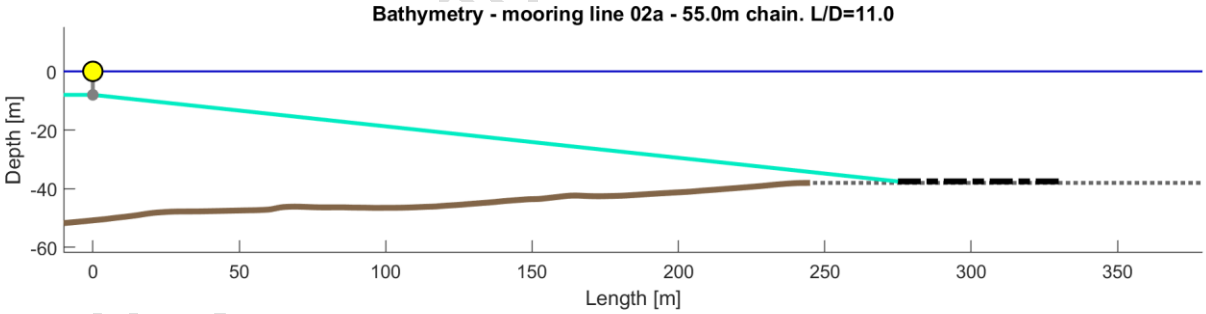
The shortest distance observed between net and grid rope is 9 m, between net C03 and grid rope B3-B4.

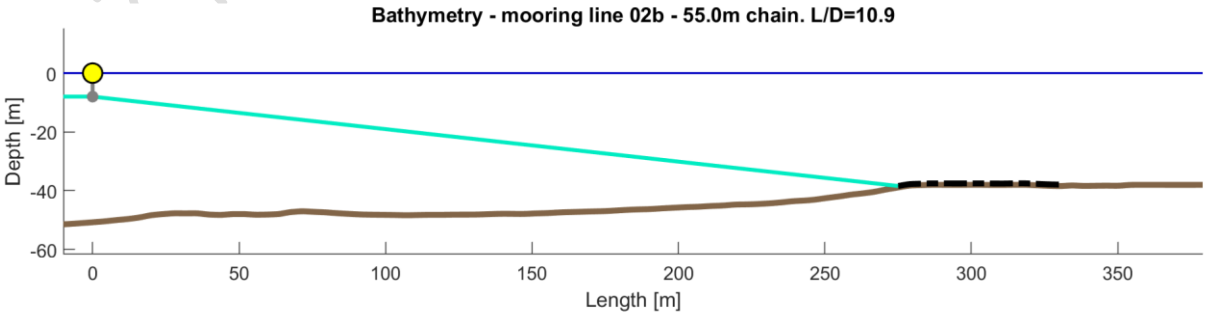
APPENDIX C LINE PROFILES

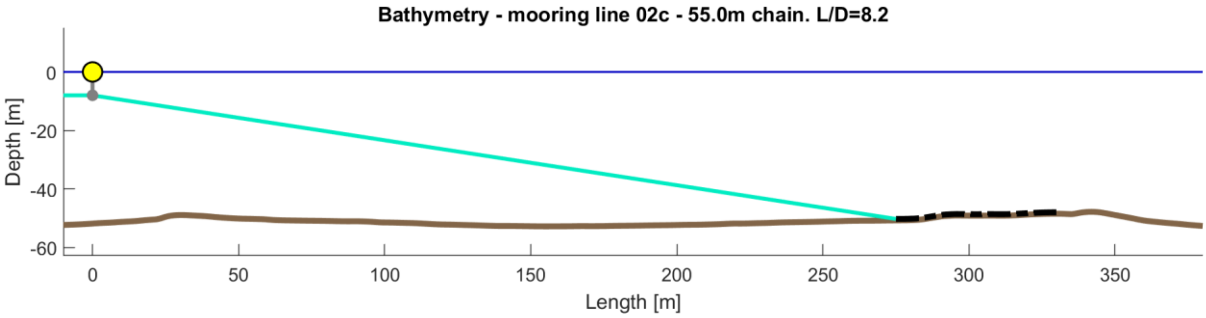
The bathymetry plots in this appendix are based on the received olex-plot and depth-data for the site. The figures illustrate the seabed profiles under each mooring line in the grid mooring, from the seabed connection point towards the connection point in the grid. The anchor chain is marked with a black, stapled line and is drawn completely in contact with the seabed, corresponding to a line without any tension. The rope is drawn as a blue line from the anchor chain to the connection point. The accuracy of the line profile plots depends on the olex-plot and depth data. Some deviations in lengths/depths in the line profiles may occur.

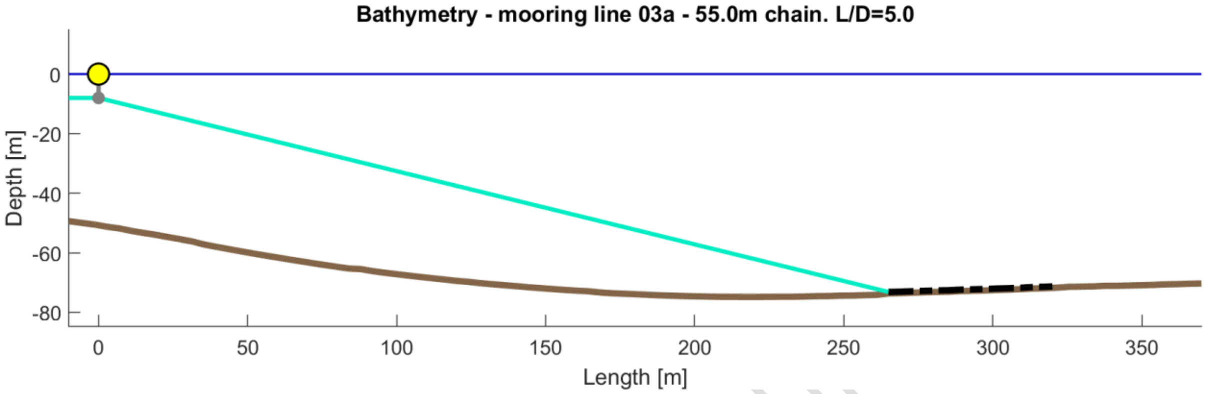









Bathymetry - mooring line 02c - 55.0m chain. L/D=8.2
Depth [m]
Length [m]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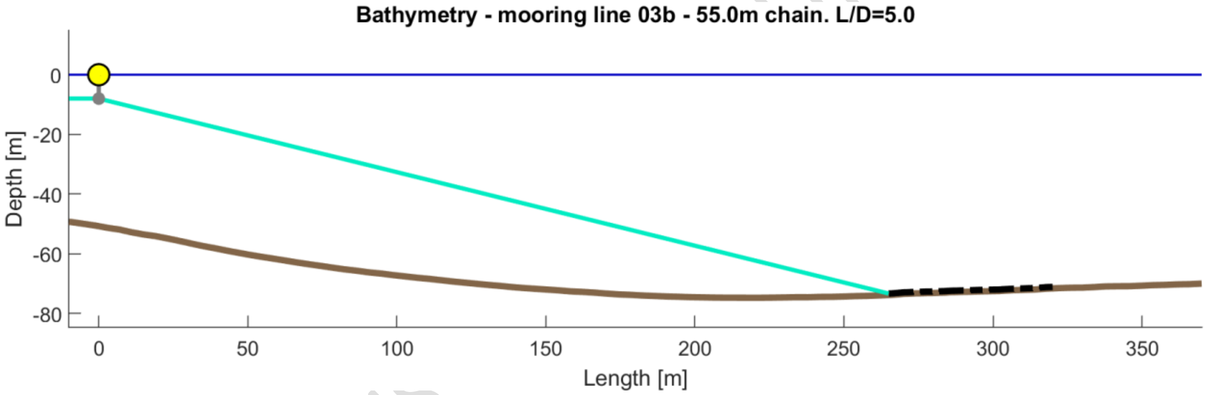
Depth [m]
Length [m]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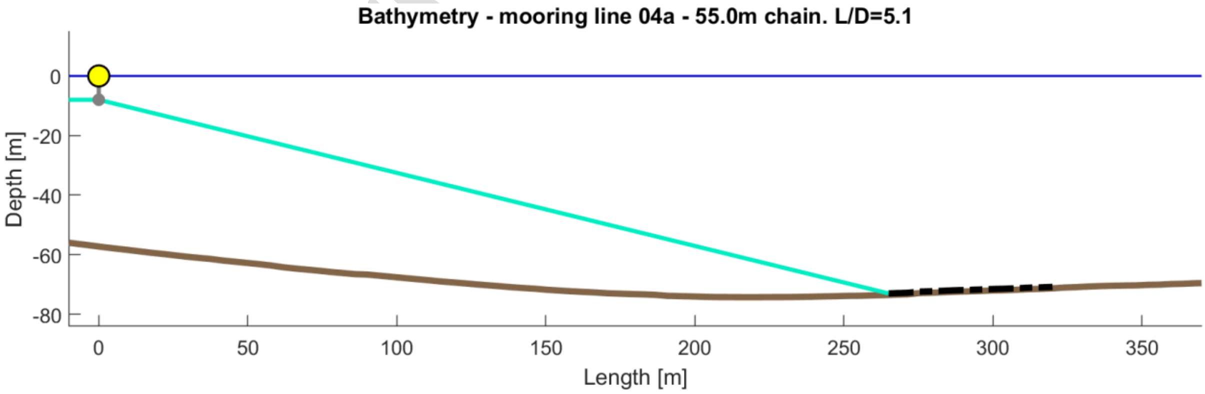
Length [m]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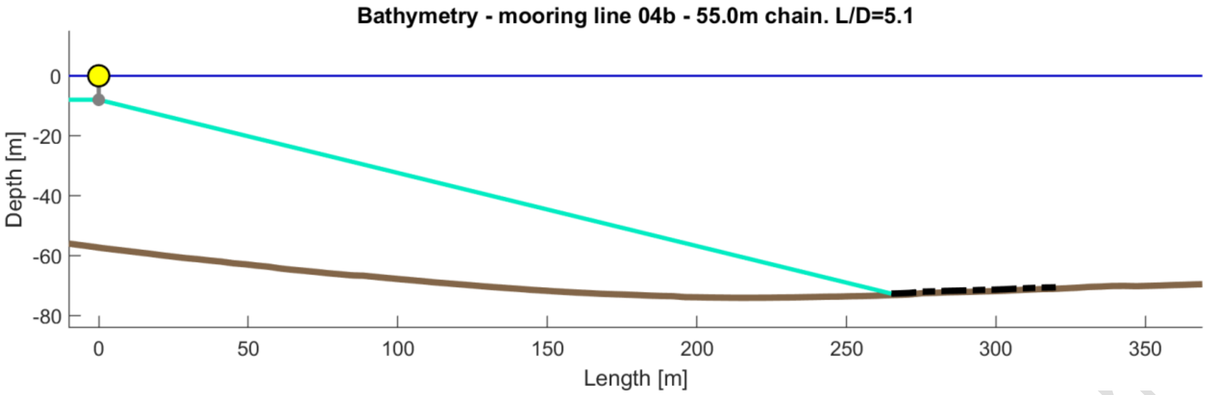
Depth [m]
Length [m]


Bathymetry - mooring line 04b - 55.0m chain. L/D=5.1
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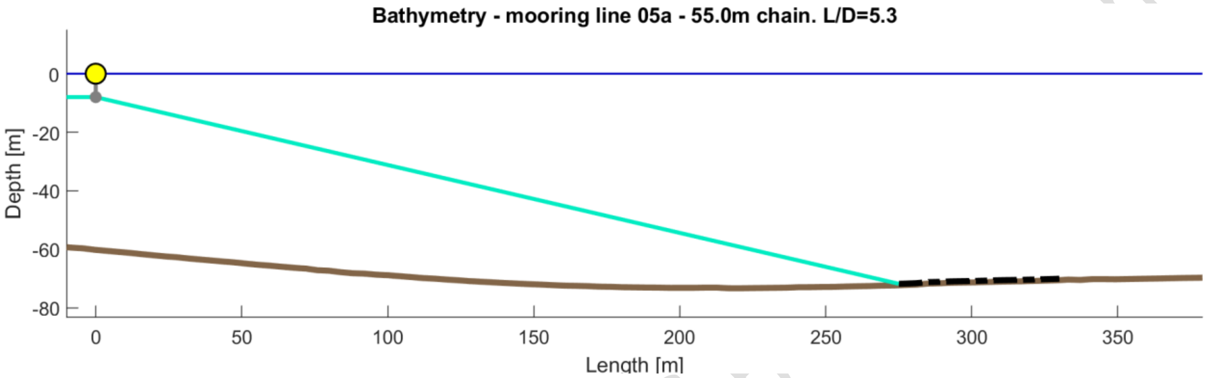
-40
-60
-80
0
50
100
150
200
250
300
350
Length [m]


Bathymetry - mooring line 05a - 55.0m chain. L/D=5.3
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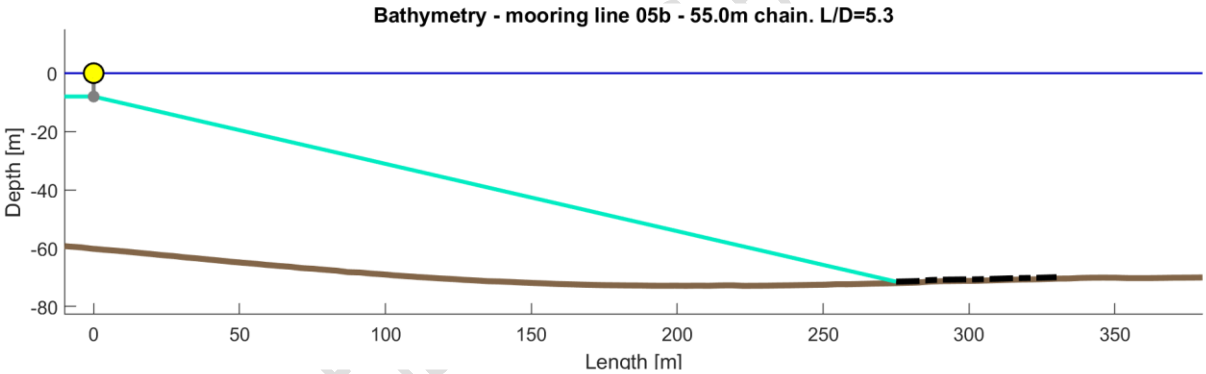
-60
-80
0
50
100
150
200
250
300
350
Length [m]


Bathymetry - mooring line 05b - 55.0m chain. L/D=5.3
Depth [m]
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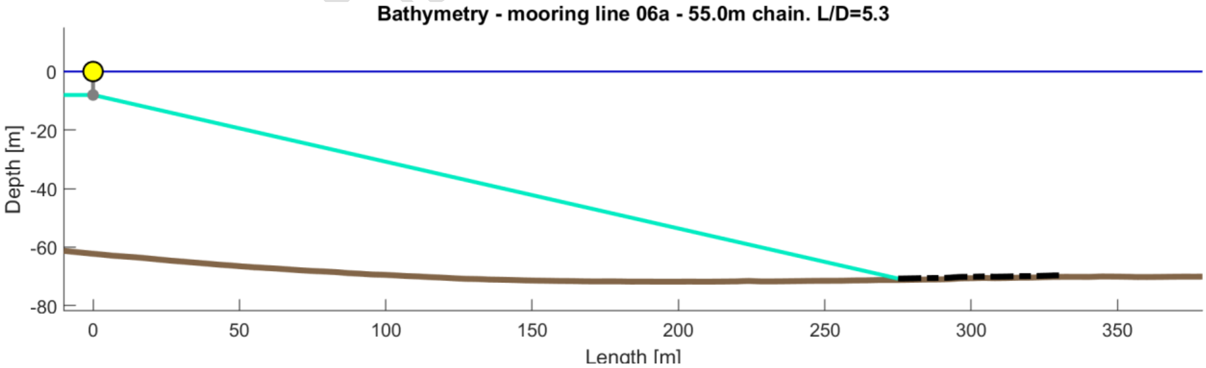
-20
-40
-60
-80
0
50
100
150
200
250
300
350
Length [m]


Bathymetry - mooring line 06a - 55.0m chain. L/D=5.3
Depth [m]
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-20
-40
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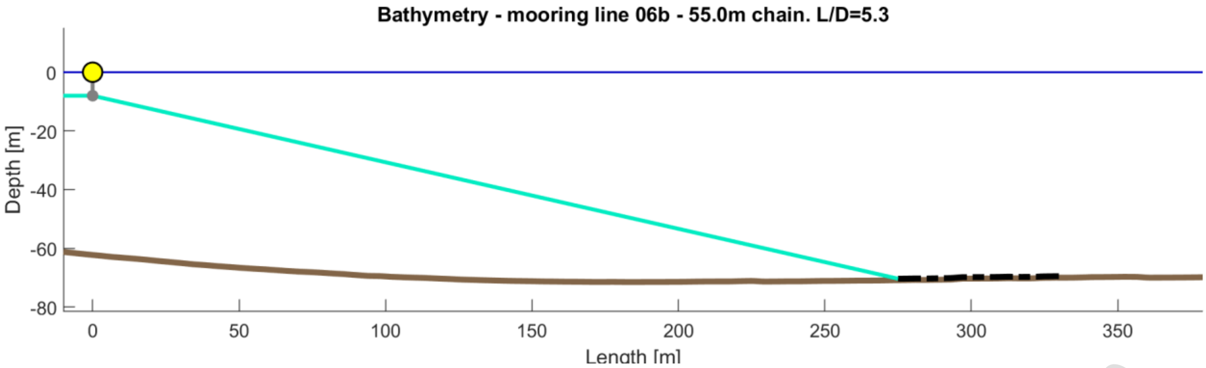
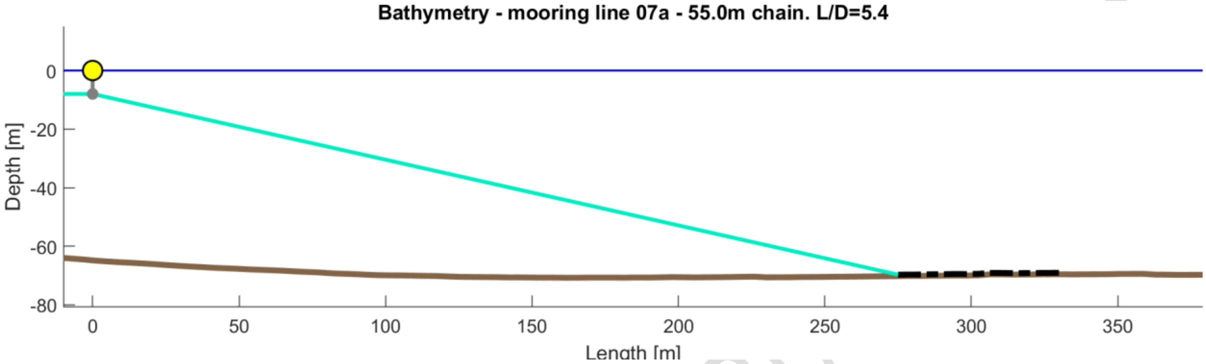
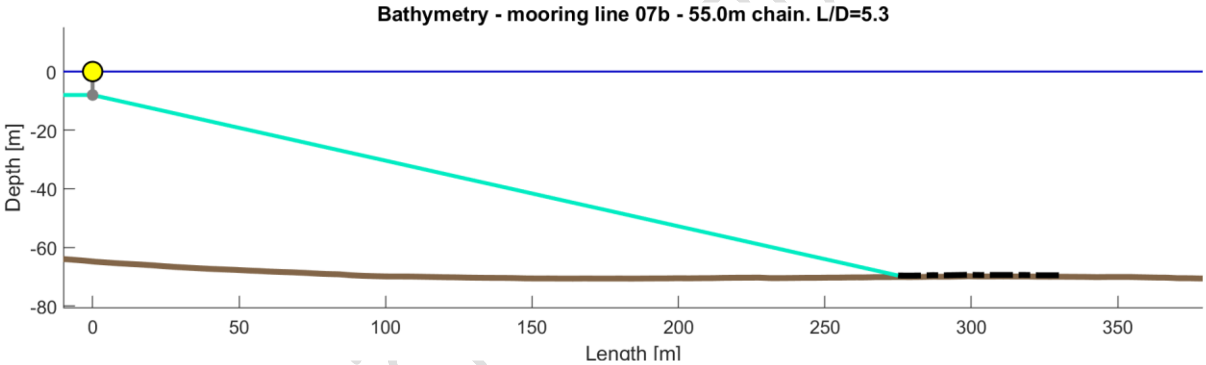
-80
0
50
100
150
200
250
300
350
Length [m]


Bathymetry - mooring line 06b - 55.0m chain. L/D=5.3
Depth [m]
Length [m]


Bathymetry - mooring line 07a - 55.0m chain. L/D=5.4
Depth [m]
Length [m]


Bathymetry - mooring line 07b - 55.0m chain. L/D=5.3
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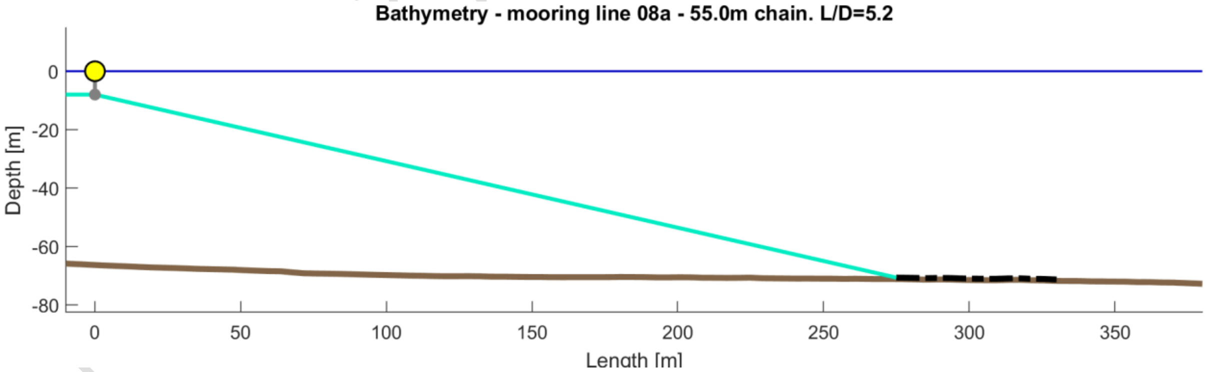
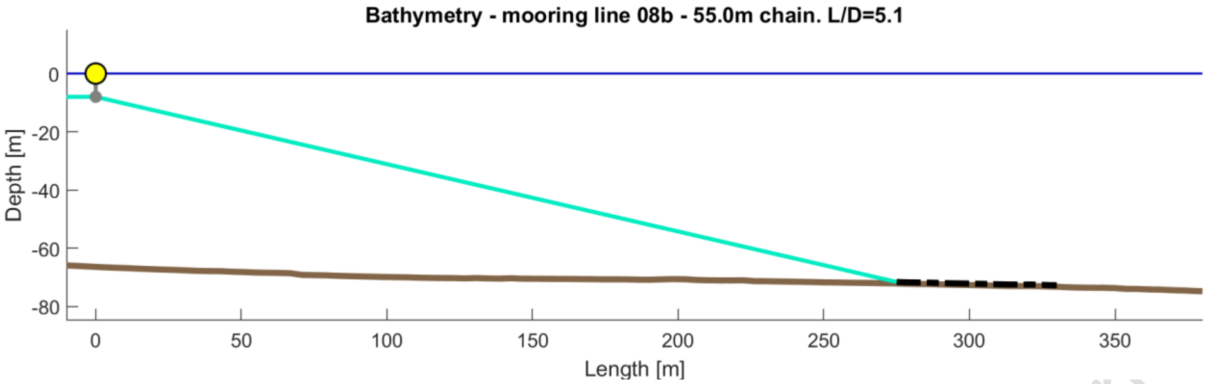
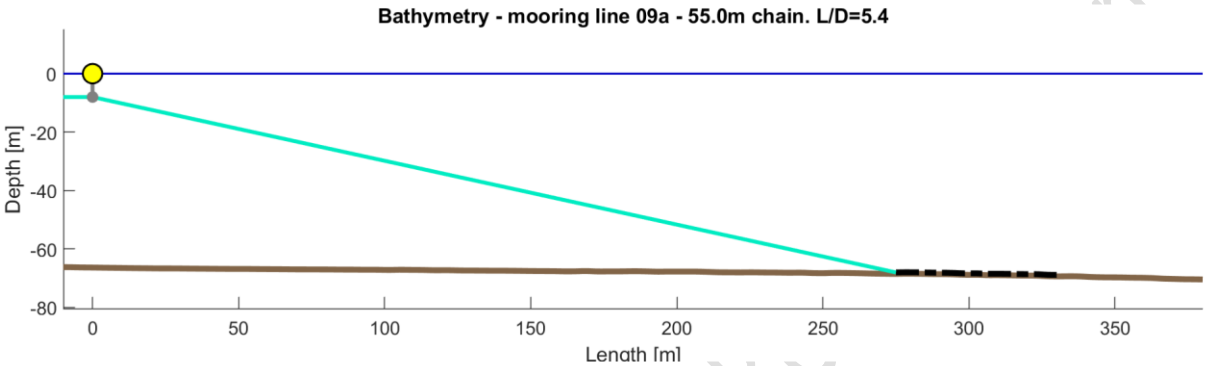
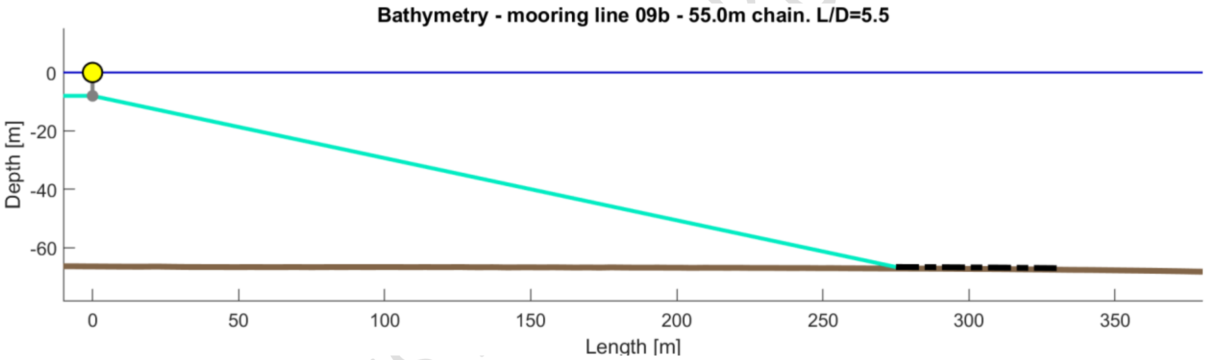
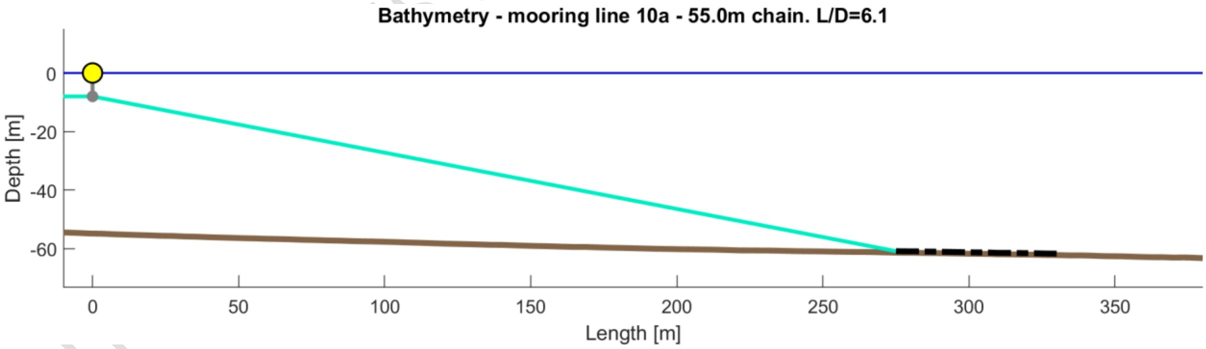
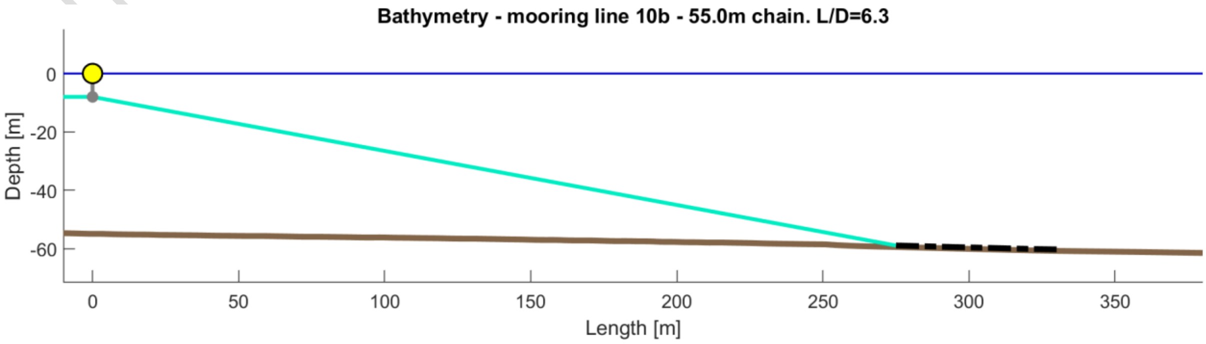

Bathymetry - mooring line 08a - 55.0m chain. L/D=5.2
Depth [m]
Length [m]

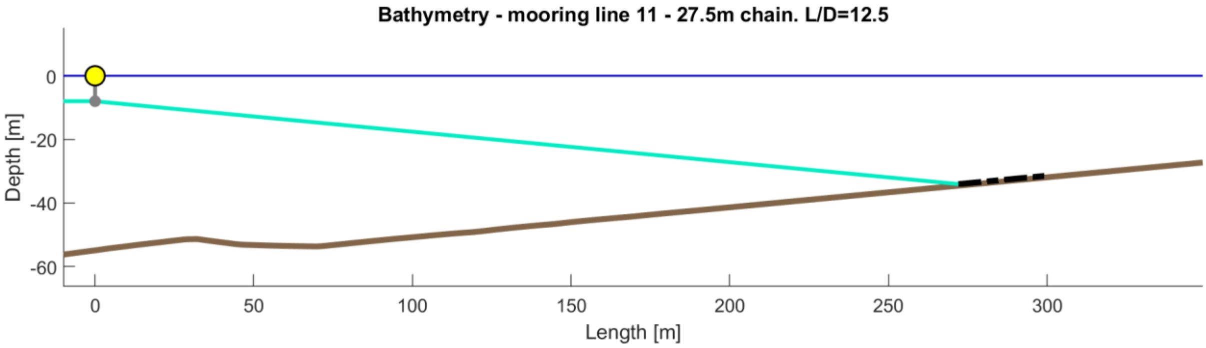

Bathymetry - mooring line 08b - 55.0m chain. L/D=5.1
Depth [m]
Length [m]

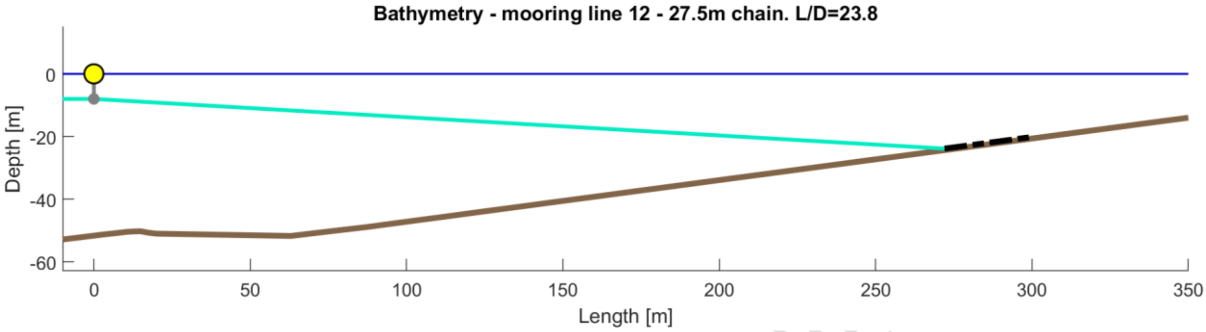

Bathymetry - mooring line 09a - 55.0m chain. L/D=5.4
Depth [m]
Length [m]

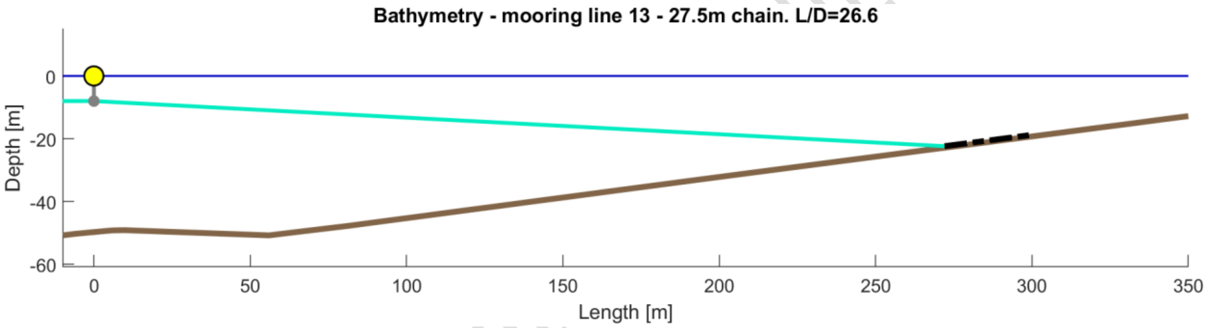

Bathymetry - mooring line 09b - 55.0m chain. L/D=5.5
Depth [m]
Length [m]

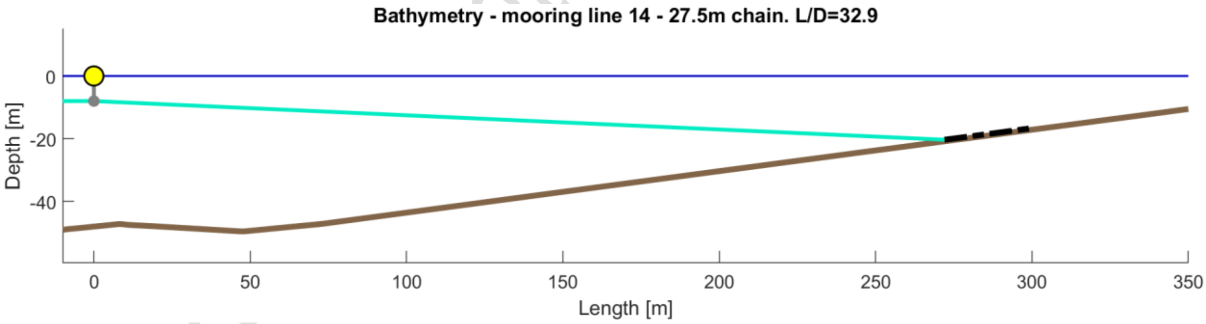

Bathymetry - mooring line 10a - 55.0m chain. L/D=6.1
Depth [m]
Length [m]

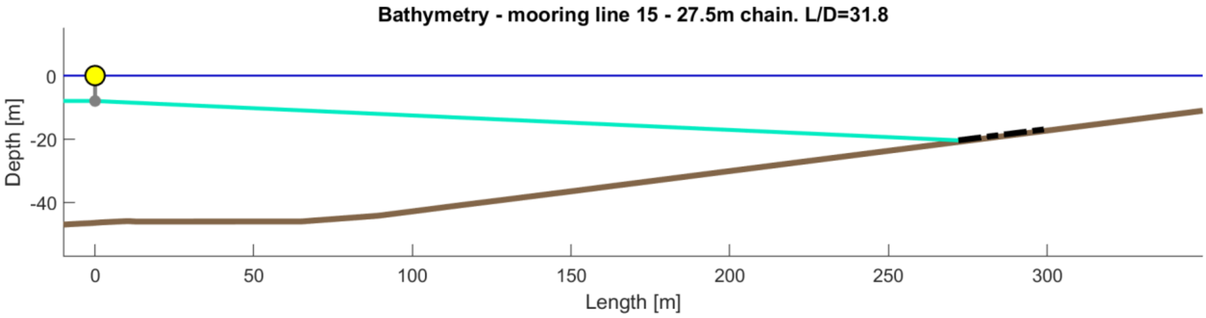

Bathymetry - mooring line 10b - 55.0m chain. L/D=6.3
Depth [m]
Length [m]

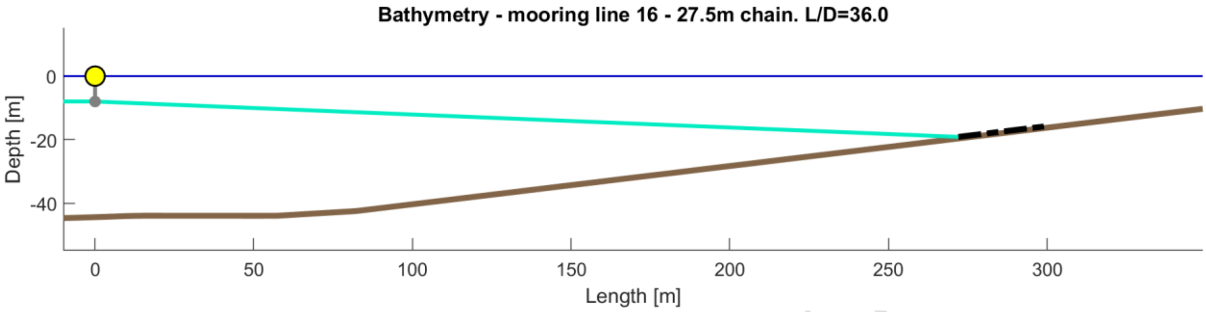

Bathymetry - mooring line 11 - 27.5m chain. L/D=12.5
Depth [m]
Length [m]


Bathymetry - mooring line 12 - 27.5m chain. L/D=23.8
Depth [m]
Length [m]

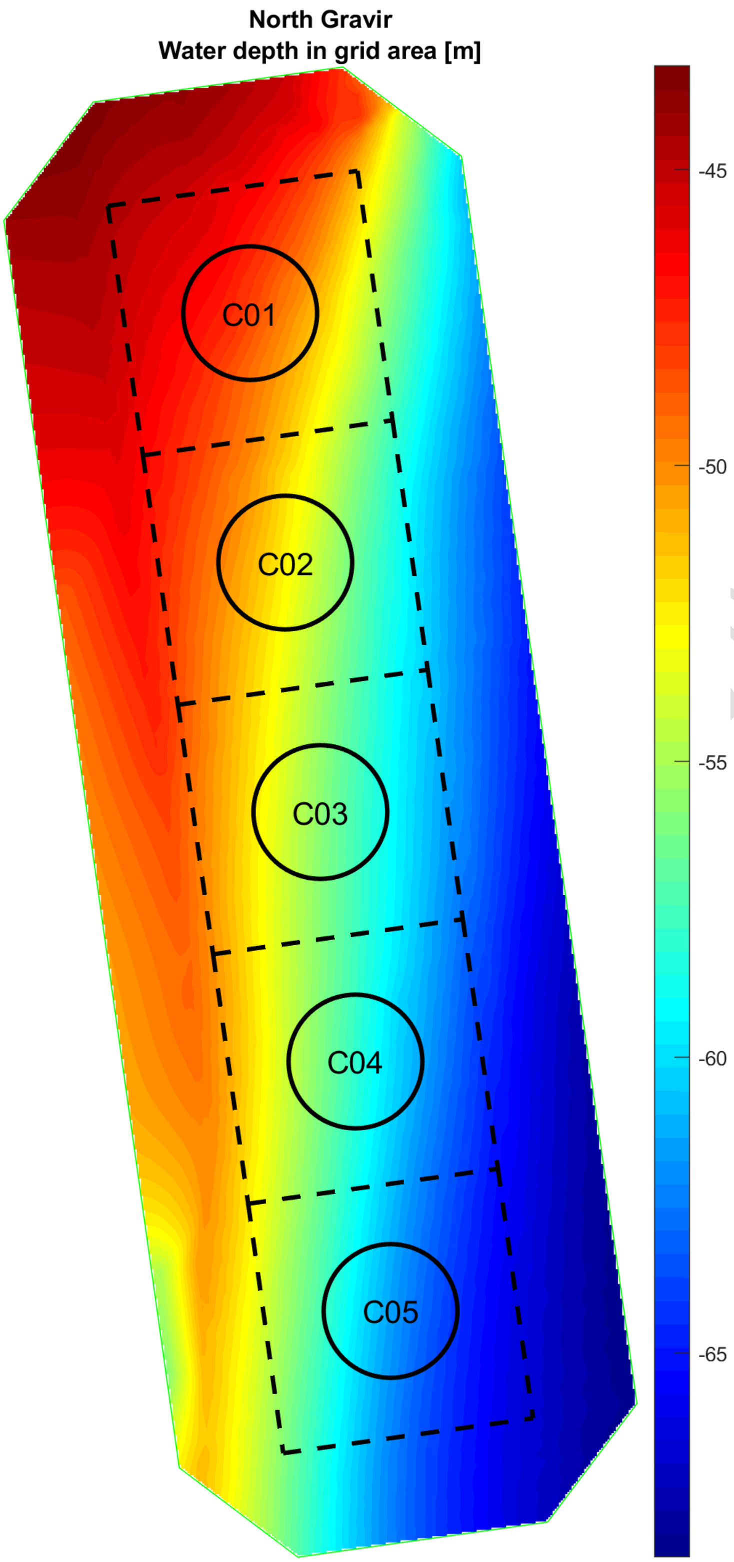

Bathymetry - mooring line 13 - 27.5m chain. L/D=26.6
Depth [m]
Length [m]


Bathymetry - mooring line 14 - 27.5m chain. L/D=32.9
Depth [m]
Length [m]

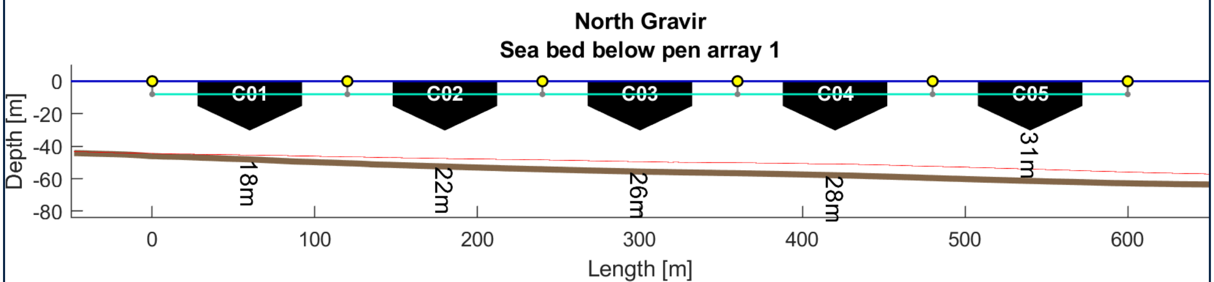

Bathymetry - mooring line 15 - 27.5m chain. L/D=31.8
Depth [m]
0
-20
-40
0
50
100
150
200
250
300
Length [m]


Bathymetry - mooring line 16 - 27.5m chain. L/D=36.0
Depth [m]
0
-20
-40
0
50
100
150
200
250
300
Length [m]

APPENDIX D WATER DEPTH IN GRID AREA



APPENDIX E SEABED PROFILE UNDER CAGES



Nominal depth for design pen is 30m.
Brown line indicates depth direcly beneath cone tips (Value beneath pen gives distance direcly under cone bottom)
The red line indicates shallowest depth within grid area.

APPENDIX F INTERACTION WITH BARGE MOORING

The barge and grid mooring are modelled together to control potential interaction between the two separate mooring systems.

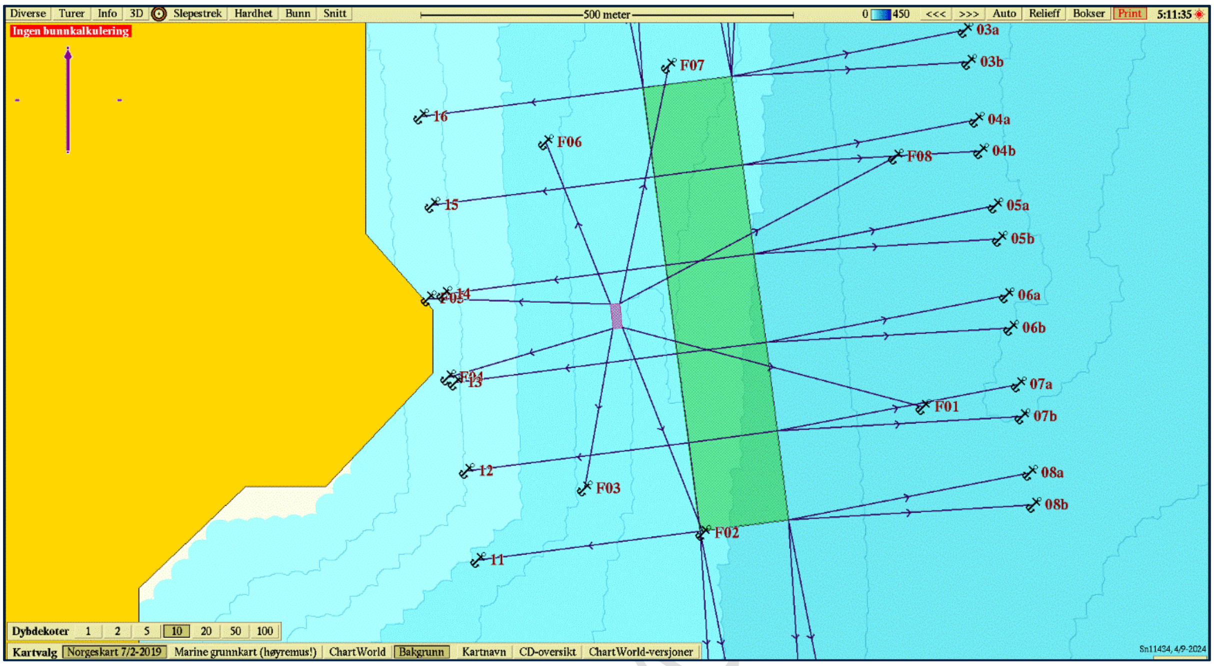


Figure 13: Grid- and barge mooring.

Contact between grid and barge mooring is not observed in static equilibrium. The vertical distance between the mooring lines is approximately 5-10m. In scenarios with current associated with 50-year return period, it is not observed any contact between the mooring lines, however the distance is close to 1m. Mooring lines that may touch are on the leeward side and hence they are slack.

All barge mooring lines cross under the grid mooring lines.

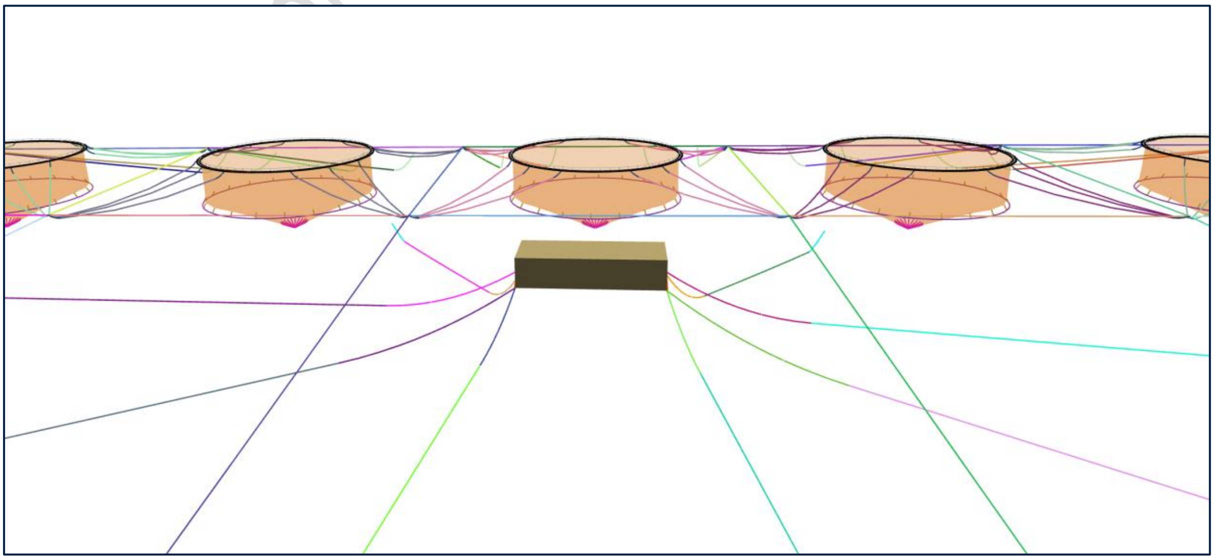


Figure 14: Bird view of the grid and barge mooring layout.