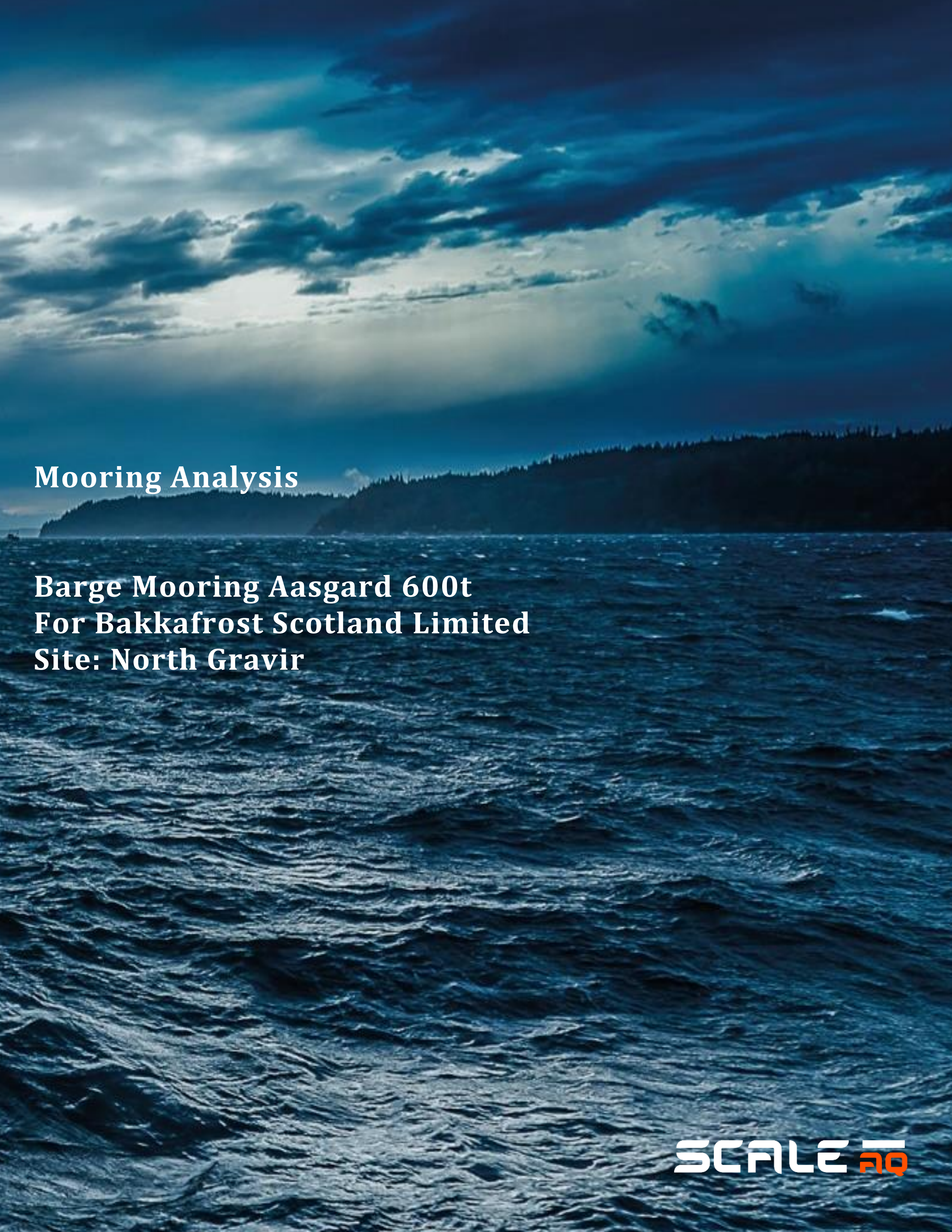


Mooring Analysis

Barge Mooring Aasgard 600t
For Bakkafrost Scotland Limited
Site: North Gravir

Date calculation:	Project:
05.06.2024	20029
Approved by: Kasper Wåsjø	Company: Scale Aquaculture AS, Trondheim
Client: Bakkafrost Scotland Limited	Client Ref: 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 in Isle of Lewis, Scotland. 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 barge mooring connection points is checked and found sufficient.

Requirements to the mooring components are described in chapter 5 and Appendix A.

Reliability class:	Index:
2	NS9415:2009
Title: Mooring analysis - Barge Bakkafrost Scotland Limited – North Gravir	Mooring analysis Global analysis North Gravir
Performed by: Tonje Spangelo	☒No distribution without Client approval

Date this revision:	Rev. No.:	Pages:
18.09.2024	3.0	27

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

3.0	Location of the barge 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 to perform an analysis of the mooring system at the fish farming site North Gravir, on the Isle of Lewis, Scotland. The analysis is performed according to the partial coefficient method, and the load- and material factors in the Norwegian Standard (NS9415:2009) are applied. The center coordinate of the barge is 58°03.260 N 6°21.411W.

Site location is shown in Figure 1.

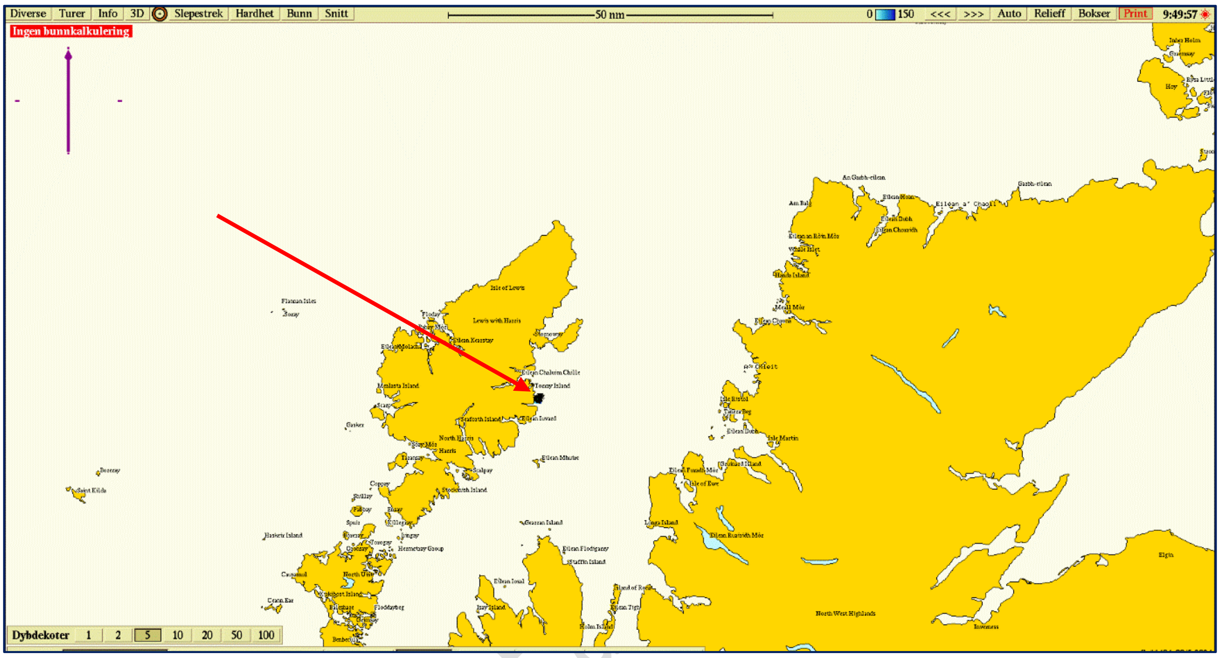


Figure 1: Location North Gravir, Isle of Lewis

Background and choices made for the analyses performed by Scale Aquaculture AS are described in procedure «ID- 2142-Fortøyningsanalyse Fôrflåte – Bakgrunn og valg».

1.1. As-built

This report is not an as-built revision.

2. SYSTEM DESCRIPTION

2.1. Barge used in the analyses

Name	Aasgard 600t
Type	Steel barge
Orientation	Transverse - 172° clockwise from North
Size [m]	33.0x13.5x6.9
Height of superstructure longitudinal [m]*	5.4
Height of superstructure transversal [m]*	4.1
Draught fully loaded [m]	4.90
Draught empty [m]	1.65
VCG fully loaded [m]	4.3
VCG empty [m]	3.9
Capacity of mooring points [t]	100 ton per line

Table 1: Details of barge used for the analysis. *Projected area of superstructure related to length/ width of barge.

Analyses has been performed with both fully loaded and light ship condition. The light ship condition is governing for the mooring component dimensions and has been chosen for further analyses.

Details of each component is further described.

2.2. Elastic modulus materials

Elastic modulus rope = 1870 MPa

Elastic modulus anchor chain = 110000 MPa

Elastic modulus long-linked chain = 210000 MPa

2.3. Details mooring lines

The barge is moored by 8 mooring lines. The distance from the barge to the nearest floating collar is ca. 160m.

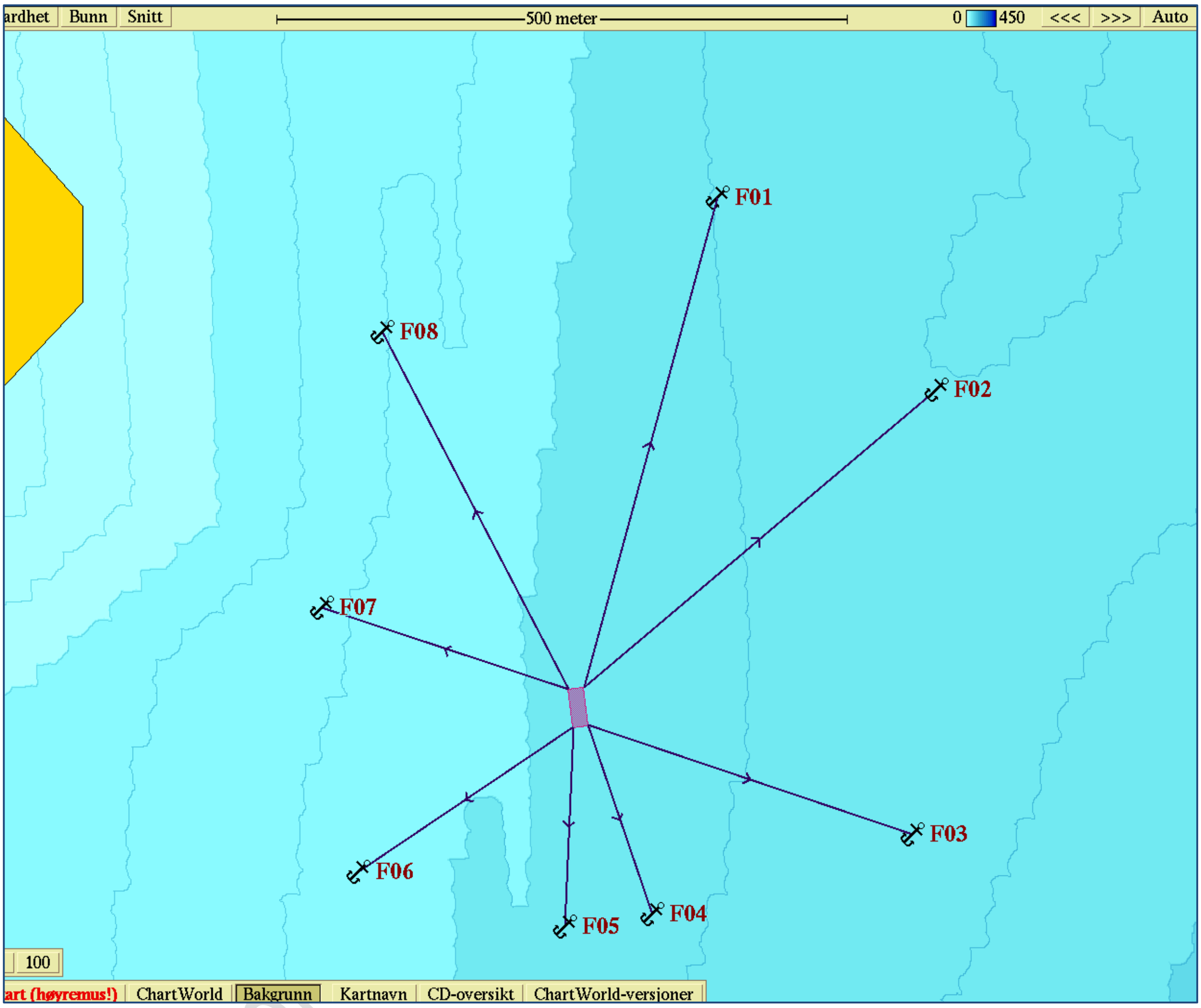


Figure 2: Mooring system

Line No.	Length 2D [m]	Depth [m]	2D/Depth	Direction [°]	Anchoring	Position (N)	Position (W)
F01	445	70	6.8	15	Anchor	58°03.501	6°21.287
F02	405	70	6.2	50	Anchor	58°03.410	6°21.091
F03	300	75	4.3	109	Anchor	58°03.200	6°21.112
F04	175	68	2.8	161	Anchor	58°03.162	6°21.345
F05	176	62	3.1	182	Anchor	58°03.156	6°21.423
F06	228	54	4.7	236	Anchor	58°03.182	6°21.608
F07	228	48	5.3	288	Anchor	58°03.307	6°21.641
F08	352	49	7.9	333	Anchor	58°03.437	6°21.586

Table 2: Details of mooring lines used in the analyses

Line No.	Chain towards barge			Rope		Anchor chain		
	[m]	Dim. [mm]	Weight [kg/m]	Dim. [mm]	Weight [kg/m]	[m]	Dim. [mm]	Weight [kg/m]
F01	41.3	36mm studless	27.6	64mm 8-br. ST	2.04	55.0	40mm studless	34.0
F02	41.3	36mm studless	27.6	64mm 8-br. ST	2.04	55.0	40mm studless	34.0
F03	27.5	36mm studless	27.6	64mm 8-br. ST	2.04	55.0	40mm studless	34.0
F04	27.5	36mm studless	27.6	64mm 8-br. ST	2.04	55.0	40mm studless	34.0
F05	27.5	36mm studless	27.6	64mm 8-br. ST	2.04	55.0	40mm studless	34.0
F06	27.5	36mm studless	27.6	64mm 8-br. ST	2.04	55.0	40mm studless	34.0
F07	27.5	36mm studless	27.6	64mm 8-br. ST	2.04	55.0	40mm studless	34.0
F08	27.5	36mm studless	27.6	64mm 8-br. ST	2.04	55.0	40mm studless	34.0

Table 3: Details of components used in the analyses. All weights are dry weights.

Lengths, depths and directions for all mooring lines are given in Table 3 and Table 2. The numbering is according to Figure 2. All lines are modelled with anchor chain both towards the anchor and the barge, the rest of the line is fibre rope as specified.

2.4. Components used in the analyses

The dimensions and components used for rope and chain in the analyses are based on calculations with 50-year return periods for current and waves according to environmental conditions in chapter 3.

2.5. Site condition and anchor positions

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.

Detailed survey of the seabed has been performed by the Client and has been used by ScaleAQ.

Line profiles are provided 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 environmental data utilized in the analysis is presented in Table 4 for the ultimate limit state, Table 5 for the accidental limit state and Table 6 for the fatigue calculations.

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

3.1. Ultimate limit state

Cond.	Hs [m]	Tp [s]	Wave dir. [°]	vc [m/s]	Current dir. [°]	Wind [m/s]
1	4.3	12.0	44	0.79	180	23
2	5.1	12.5	48	0.79	225	23
3	4.8	10.0	52	0.30	270	23
4	2.6	6.0	81	0.45	315	28
5	2.8	6.0	117	0.50	0	30
6	2.8	6.5	144	0.50	45	31
7	0.4	2.8	270	0.24	90	31
8	0.8	3.8	315	0.71	135	28
9	5.0	13.9	44	0.70	180	23
10	6.0	13.5	49	0.70	225	23
11	5.6	11.7	52	0.27	270	23
12	3.1	6.7	81	0.41	315	28
13	3.3	6.8	117	0.45	0	30
14	3.3	7.8	144	0.45	45	31
15	0.5	3.0	270	0.21	90	31
16	0.9	4.0	315	0.63	135	28

Table 4: Environmental conditions, ultimate limit state.

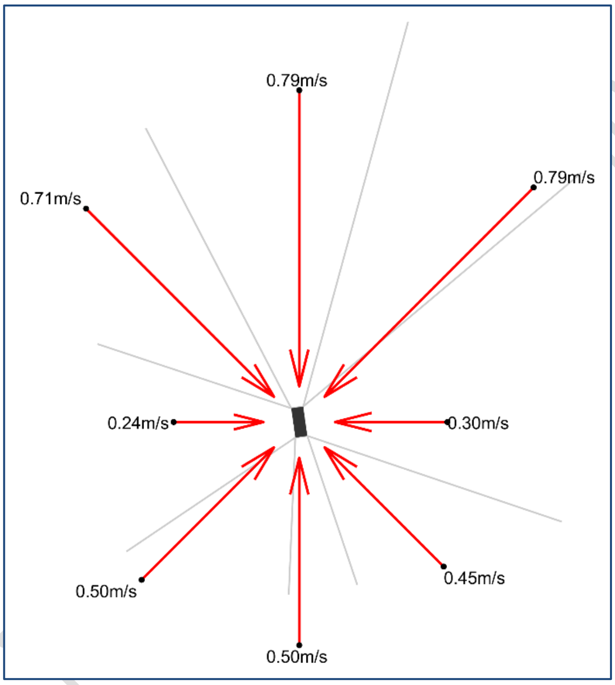


Figure 3: 50-year current at 5m depth

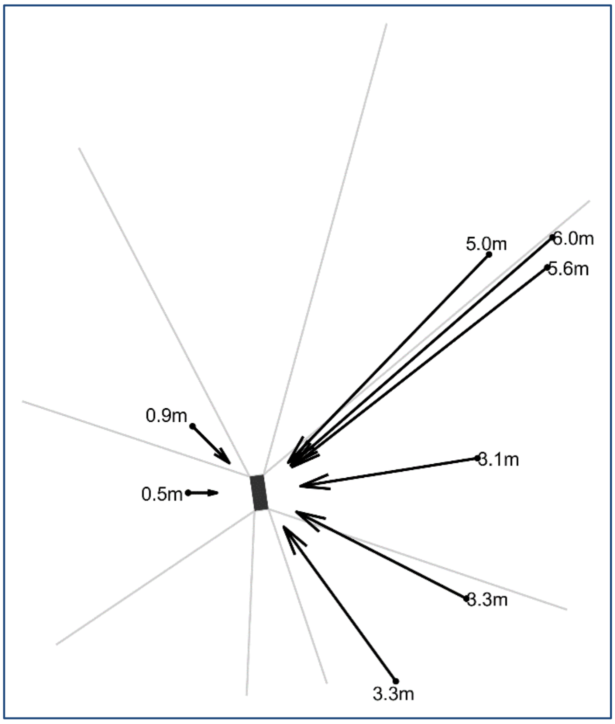


Figure 4: Significant wave heights, 50-year return period

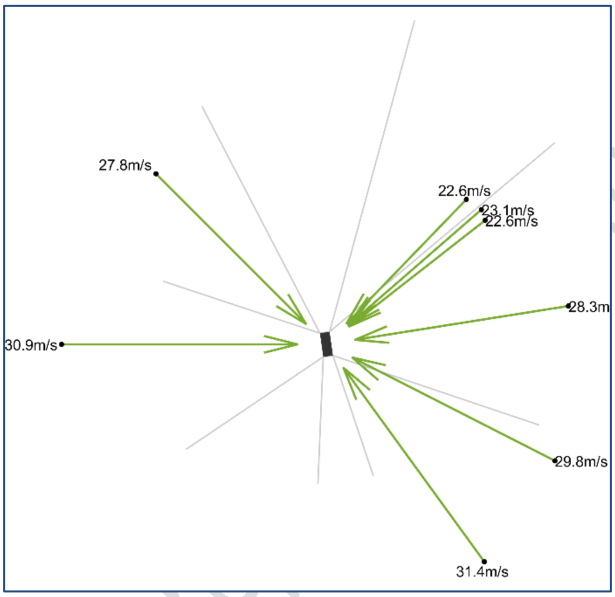


Figure 5: Wind with 50-year return period

3.2. Accidental limit state

Cond.	Hs [m]	Tp [s]	Wave dir. [°]	vc [m/s]	Current dir. [°]	Wind [m/s]
17	6.0	13.5	49	0.70	225	23
18	6.0	13.5	49	0.70	225	23

Table 5: Environmental conditions, accidental limit state.

Condition 17: Mooring line F02 broken, Light ship condition
Condition 18: Mooring line F03 broken, Light ship condition

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.

Cond.	Hs [m]	Tp [s]	Wave dir. [°]	v_c [m/s]	Current dir. [°]	Wind [m/s]
1	0.31	2.08	0	0.35	180	11.6
2	0.61	2.94	0	0.35	180	11.6
3	0.92	3.60	0	0.35	180	11.6
4	1.22	4.16	0	0.35	180	11.6
5	1.53	4.65	0	0.35	180	11.6
6	1.84	5.10	0	0.35	180	11.6
7	2.14	5.50	0	0.35	180	11.6
8	2.45	5.88	0	0.35	180	11.6
9	0.17	1.55	90	0.22	270	14.9
10	0.34	2.19	90	0.22	270	14.9
11	0.51	2.68	90	0.22	270	14.9
12	0.68	3.09	90	0.22	270	14.9
13	0.85	3.46	90	0.22	270	14.9
14	1.02	3.79	90	0.22	270	14.9
15	1.19	4.09	90	0.22	270	14.9
16	1.36	4.38	90	0.22	270	14.9
17	0.17	1.54	180	0.22	0	15.7
18	0.34	2.18	180	0.22	0	15.7
19	0.51	2.68	180	0.22	0	15.7
20	0.68	3.09	180	0.22	0	15.7
21	0.84	3.45	180	0.22	0	15.7
22	1.01	3.78	180	0.22	0	15.7
23	1.18	4.09	180	0.22	0	15.7
24	1.35	4.37	180	0.22	0	15.7
25	0.05	0.81	270	0.32	90	13.9
26	0.09	1.14	270	0.32	90	13.9
27	0.14	1.40	270	0.32	90	13.9
28	0.18	1.61	270	0.32	90	13.9
29	0.23	1.80	270	0.32	90	13.9
30	0.28	1.97	270	0.32	90	13.9
31	0.32	2.13	270	0.32	90	13.9
32	0.37	2.28	270	0.32	90	13.9

Table 6: Fatigue load conditions

4. RESULTS

4.1. Static Equilibrium

Component	Design load [metric ton]
F01	2.5
F02	2.2
F03	1.9
F04	1.9
F05	2.1
F06	2.1
F07	1.9
F08	1.6

Table 7: Design loads, pretension

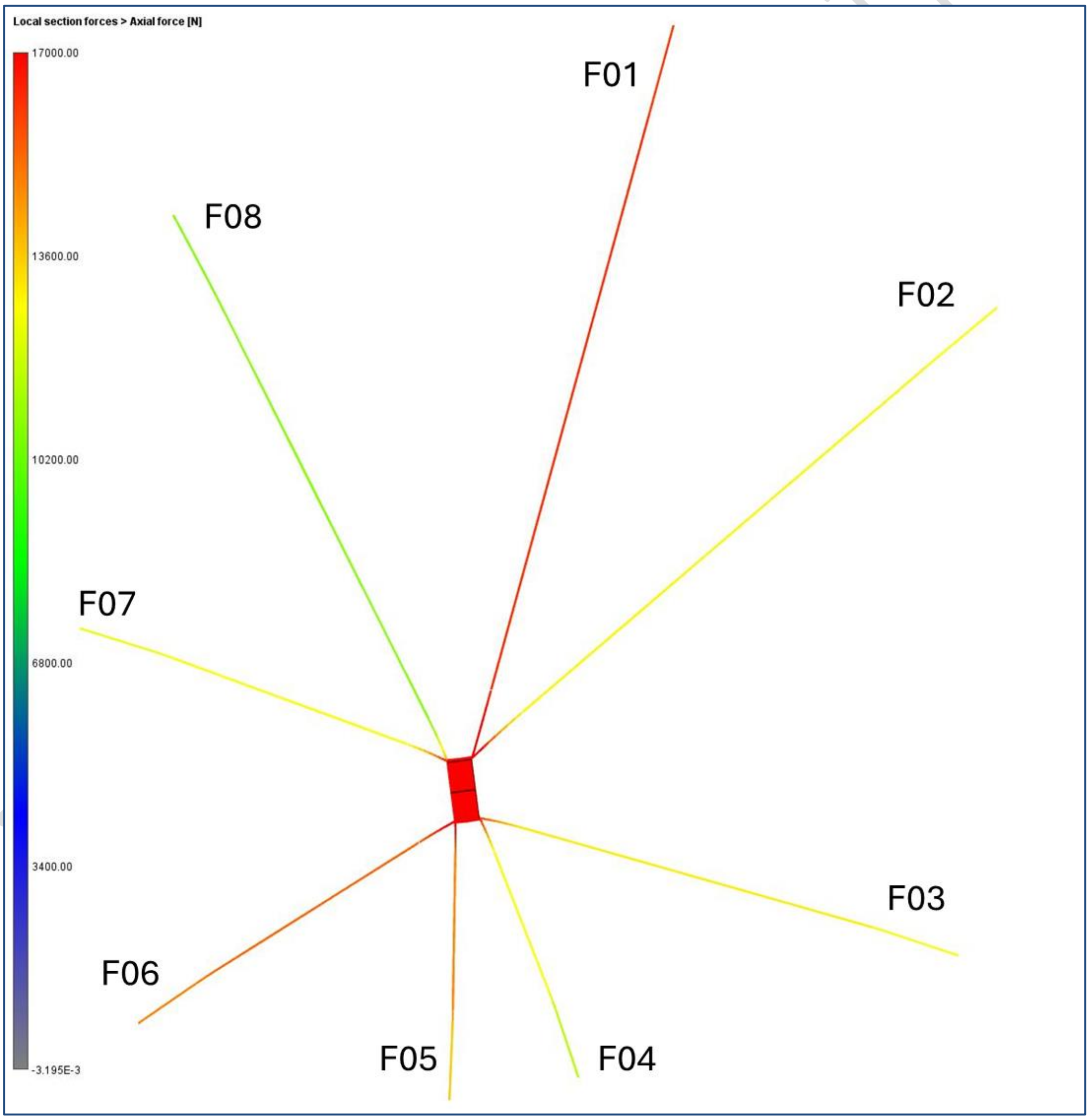


Figure 6: Static Equilibrium, pretension

4.2. Loads in ultimate limit state

Component	Design load [metric ton]
F01	16.1
F02	24.1
F03	24.5
F04	15.1
F05	10.7
F06	11.4
F07	10.6
F08	5.1

Table 8: Design loads, intact condition

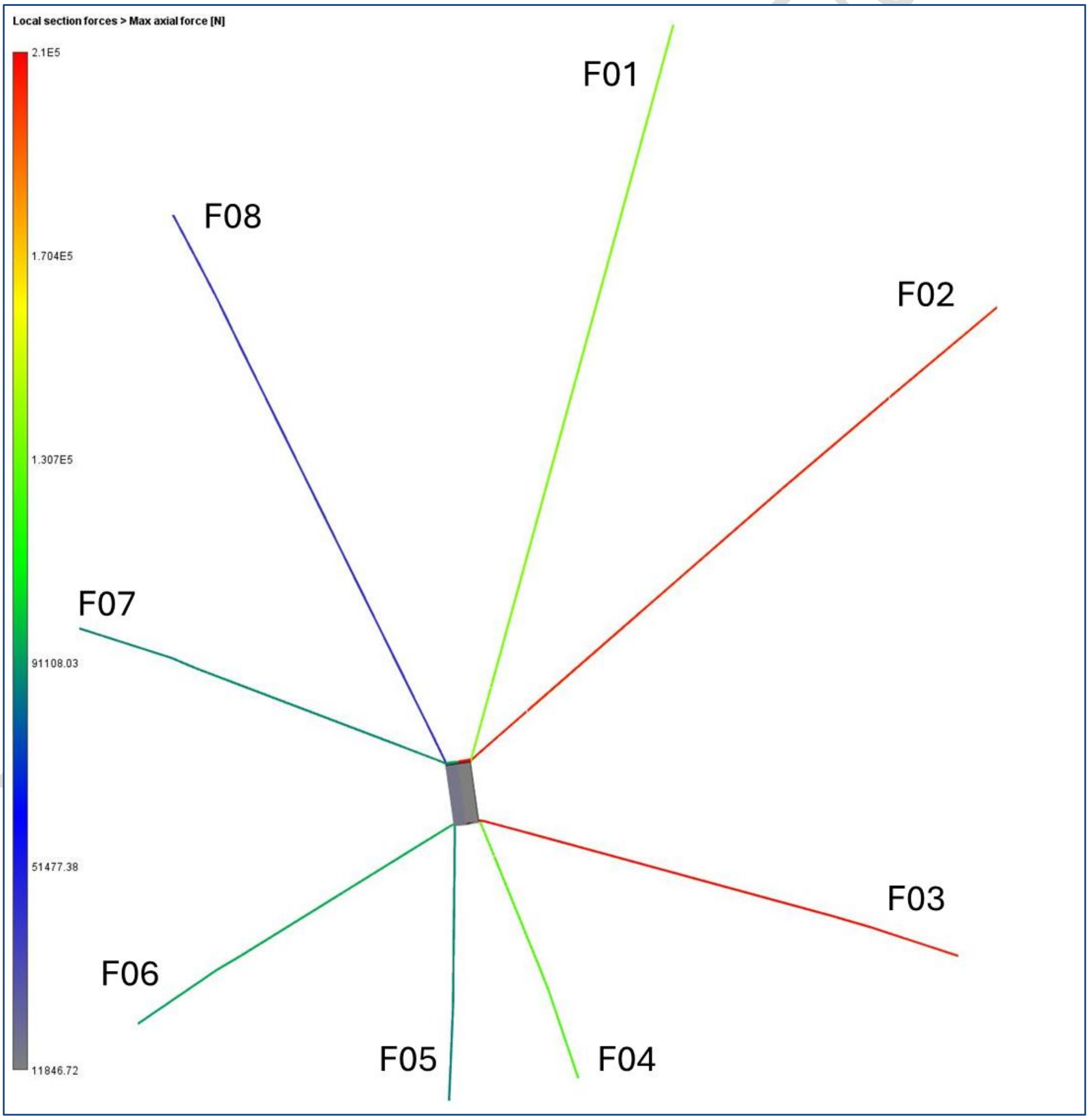


Figure 7: ULS dimensioning loads

Barge movement in ultimate limit state

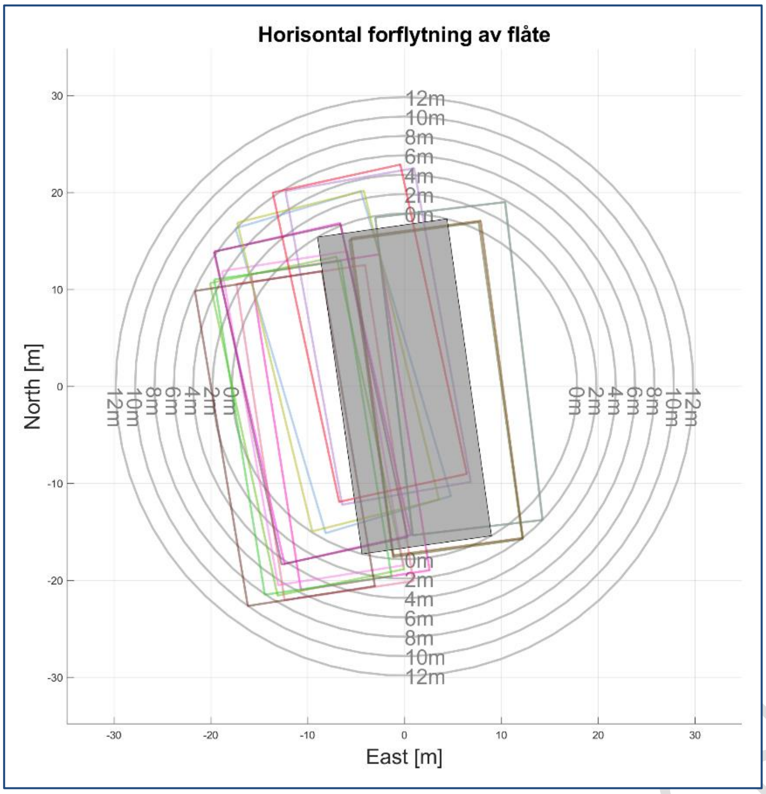


Figure 8: Barge movement in ultimate limit state

4.3. Accidental limit state

Based on the results of the intact system, the accident limit state conditions are defined. Mooring line F5 and F6 has the highest amount of load. Conditions where these lines are broken are hence analysed. In addition, mooring line F8 broken is also included in the analysis.

Component	Design load F02 broken [t]	Design load F03 broken [t]	Design load [t]
F01	27.1	12.6	27.1
F02	-	20.9	20.9
F03	28.7	-	28.7
F04	13.1	26.1	26.1
F05	7.7	13.0	13.0
F06	9.7	9.6	9.7
F07	8.7	9.2	9.2
F08	7.6	3.4	7.6

Table 9: Design loads ALS

Barge movement in accidental limit states

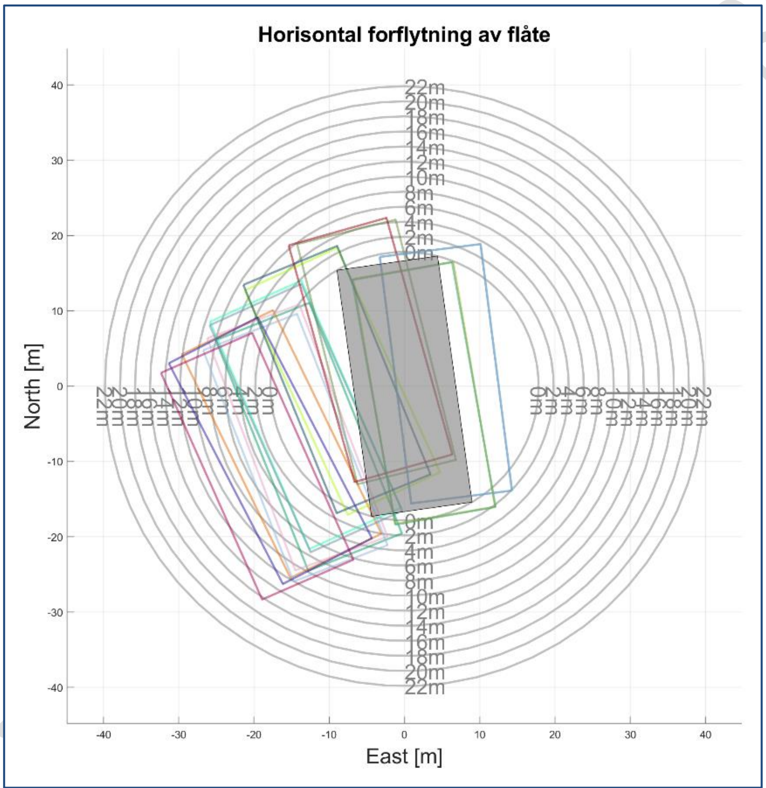


Figure 9: Barge movement in ALS 1 (mooring line F02 broken).

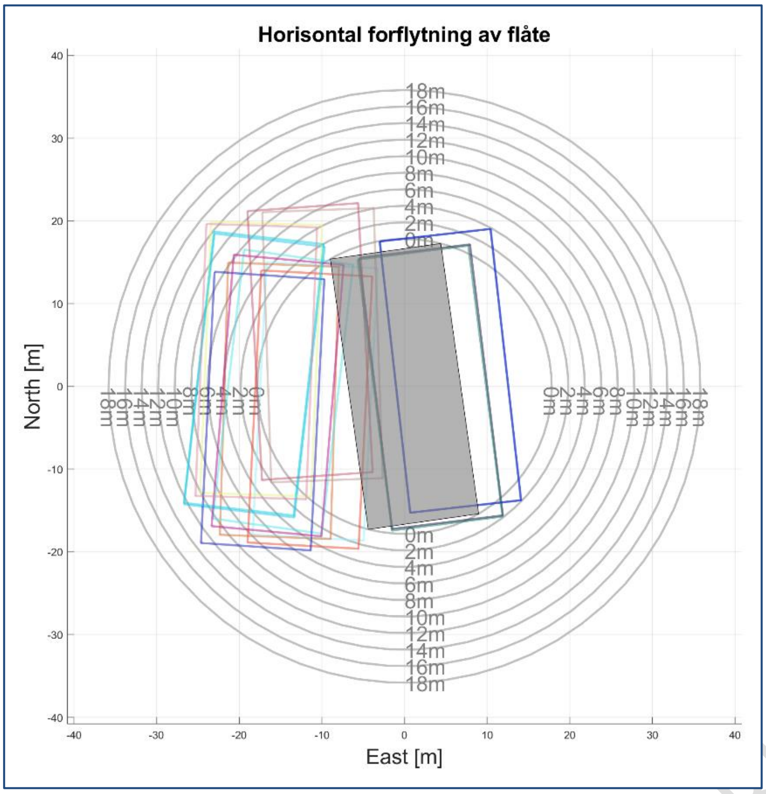


Figure 10: Barge movement in ALS 2 (mooring line F03 broken).

4.1. Fatigue

Fatigue calculation in chain with highest nominal stress range in ULS condition is performed. This is the chain towards the barge in Line F03 and the chain towards the anchor in Line F02.

Chain towards the barge

Block	North	East	South	West
1	0.09 MPa	0.07 MPa	0.01 MPa	0.00 MPa
2	0.58 MPa	0.31 MPa	0.36 MPa	0.01 MPa
3	1.12 MPa	1.26 MPa	0.53 MPa	0.01 MPa
4	0.64 MPa	2.46 MPa	1.19 MPa	0.02 MPa
5	3.07 MPa	4.60 MPa	1.48 MPa	0.03 MPa
6	5.55 MPa	7.53 MPa	0.56 MPa	0.07 MPa
7	7.35 MPa	10.93 MPa	0.57 MPa	0.09 MPa
8	7.87 MPa	14.42 MPa	1.65 MPa	0.12 MPa

Table 10: Fatigue anchor chain – stress range

Fatigue lifetime in the anchor chain is calculated to above 20 years.

Anchor Chain

Block	North	East	South	West
1	0.07 MPa	0.02 MPa	0.01 MPa	0.00 MPa
2	0.28 MPa	0.14 MPa	0.21 MPa	0.00 MPa
3	0.67 MPa	0.52 MPa	0.23 MPa	0.00 MPa
4	0.30 MPa	1.19 MPa	0.63 MPa	0.01 MPa
5	2.11 MPa	2.12 MPa	0.83 MPa	0.02 MPa
6	5.65 MPa	3.38 MPa	0.24 MPa	0.03 MPa
7	9.34 MPa	4.76 MPa	0.25 MPa	0.04 MPa
8	12.88 MPa	6.12 MPa	0.67 MPa	0.06 MPa

Table 11: Fatigue anchor chain – stress range

Fatigue lifetime in the anchor chain is calculated to above 20 years.

5. CONCLUSION– REQUIREMENTS TO CAPACITY

5.1. Mooring lines requirements

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

Line	ULS load [t]	ALS load [t]	Req. MBL rope [t]	Req. MBL steel components [t]	Req. holding power anchor [t]	Vertical force anchor [t]
F01	16.1	27.1*	54.3	36.2	27.1	0.2
F02	24.1*	20.9	72.2	48.1	24.1	1.4
F03	24.5*	28.7	73.5	49.0	24.5	3.3
F04	15.1	26.1*	52.2	34.8	26.1	2.3
F05	10.7*	13.0	32.0	21.3	10.7	0.8
F06	11.4*	9.7	34.1	22.8	11.4	0.6
F07	10.6*	9.2	31.9	21.3	10.6	0.3
F08	5.1*	7.6	15.4	10.2	5.1	0.0

Table 12: Mooring line requirement. Dimensioning load in the line is marked with *.

Resistance force of the anchors shall be tested during installation. It is the Client's responsibility that this is executed.

5.2. Lift in mooring point

Largest lift toward anchor is 3.3 metric tons in line F03.

5.3. Fatigue

Fatigue lifetime is above 50 years for anchor chain.

5.4. Barge mooring points

Largest force in the barge mooring point is 24.5 metric tons for ULS condition and 28.7 metric tons for ALS condition.

The capacity of the mooring connection points on barge Aasgard 600t is 100 ton per line. The capacity is sufficient.

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. If the data for wind, wave and current represents the most severe conditions at the site the recommended system is sufficiently dimensioned according to NS9415. This also includes information regarding the depths at the site.

Calculations are performed with the original breaking loads and specifications. Corrosion and wear will reduce the capacities for the components.

We also would like to point out that the soil conditions at the seabed are essential for the efficiency for anchors.

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

Aquastructures (2006) "Verification and benchmarking of AquaSim. a software tool for safety simulation of flexible offshore facilities exposed to environmental and operational loads". Aquastructures report 2003-002.

Aquastructures (2006) «AquaSim the Aquastructuresimulator. Theorethical Formulation of structure and load modeling». Report no. Report NO. 2006-FO06. 4.

Aquastructures (2010), Teknisk Rapport. Klasse notat utmatting Aquastructures notat prosjekt 1219, 10.08.2010. 5.

Aquastructures (2012) «Verification and Benchmarking of AquaSim, a Softwaretool for Simulation of Flexible Offshore Facilities Exposed to Environmental and Operational Loads» Report no. 2012-1755-1. 6.

Aquastructures (2013) «On the analysis of moored large mass floating objects and how to carry out such analysis with AquaSim» Report No. 2174-1, revision 02.

Norwegian Standard: "NS 9415 Marine fish farms - Requirements for design, dimensioning, production, installation and operation".

«ID- 2142-Fortøyningsanalyse Fôrflåte – Bakgrunn og valg», Scale Aquaculture AS.

APPENDIX A: COMPONENT UTILIZATIONS

The utilization for the installed components compared to the requirements is shown in Table 13.

Line No.	MBL fiber rope [t]	MBL Top and Anchor chain* [t]	MBL anchor [t]	Utilization fiber rope	Utilization Top and Anchor chain	Utilization Anchoring
F01	83.9	68.5	36/54	0.65	0.53	0.36
F02	83.9	68.5	36/54	0.86	0.70	0.48
F03	83.9	68.5	36/54	0.88	0.72	0.49
F04	83.9	68.5	36/54	0.62	0.51	0.35
F05	83.9	68.5	36/54	0.38	0.31	0.21
F06	83.9	68.5	36/54	0.41	0.33	0.32
F07	83.9	68.5	36/54	0.38	0.31	0.30
F08	83.9	68.5	36/54	0.18	0.15	0.10

Table 13: Utilization barge moorings. *MBL for chain towards barge and anchor chain is considered together and the component with the lowest MBL is shown here.

APPENDIX B: INTERACTION WITH GRID MOORING

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

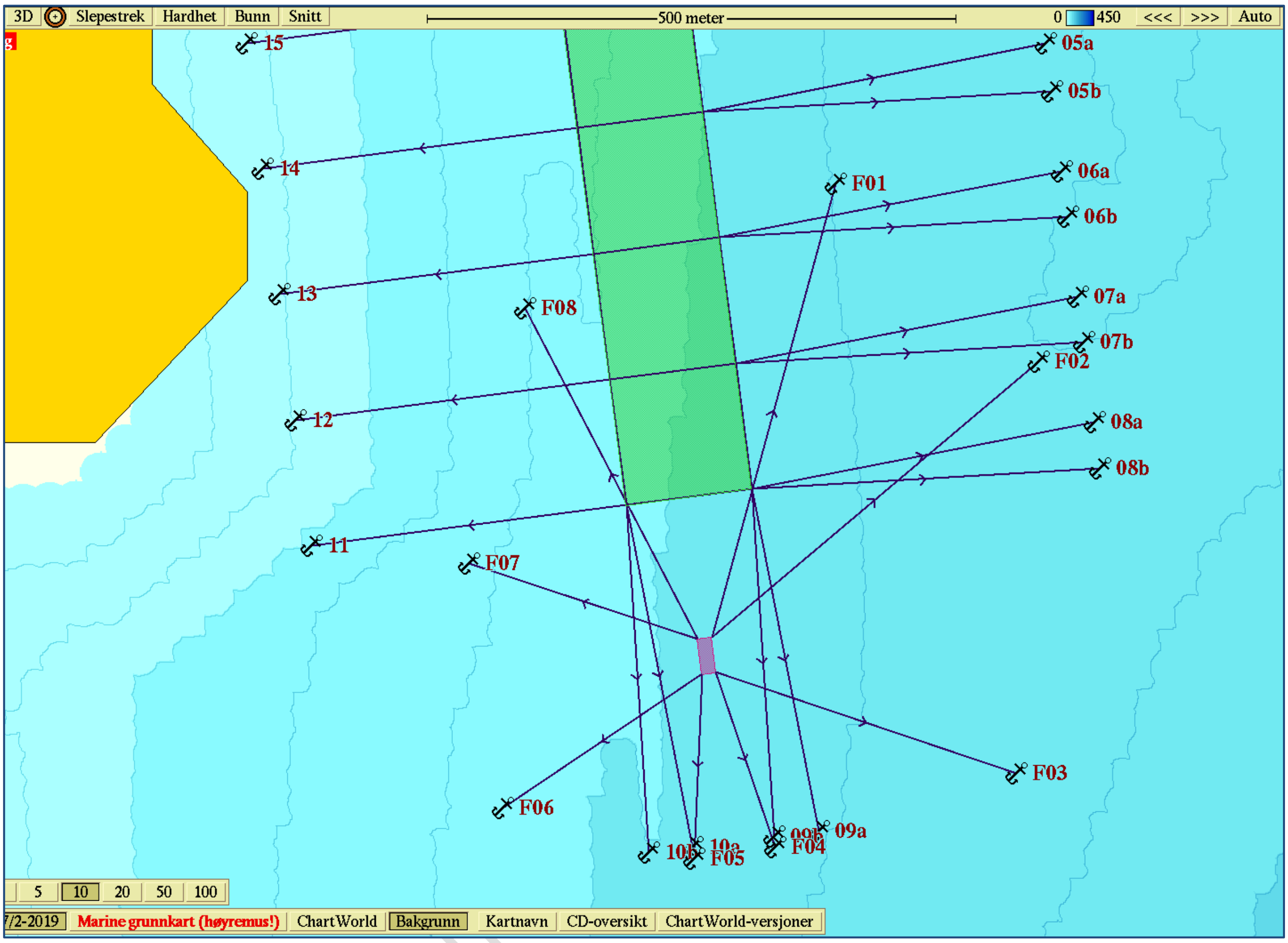


Figure 11: Grid- and barge mooring.

Contact between grid and barge mooring is not observed in static equilibrium. The vertical distance between the mooring lines is approximately 5m. As the barge location was changed after the grid mooring analysis finished, some adjustments to the mooring lines could be necessary to increase the distance between mooring lines in the grid- and barge mooring systems.

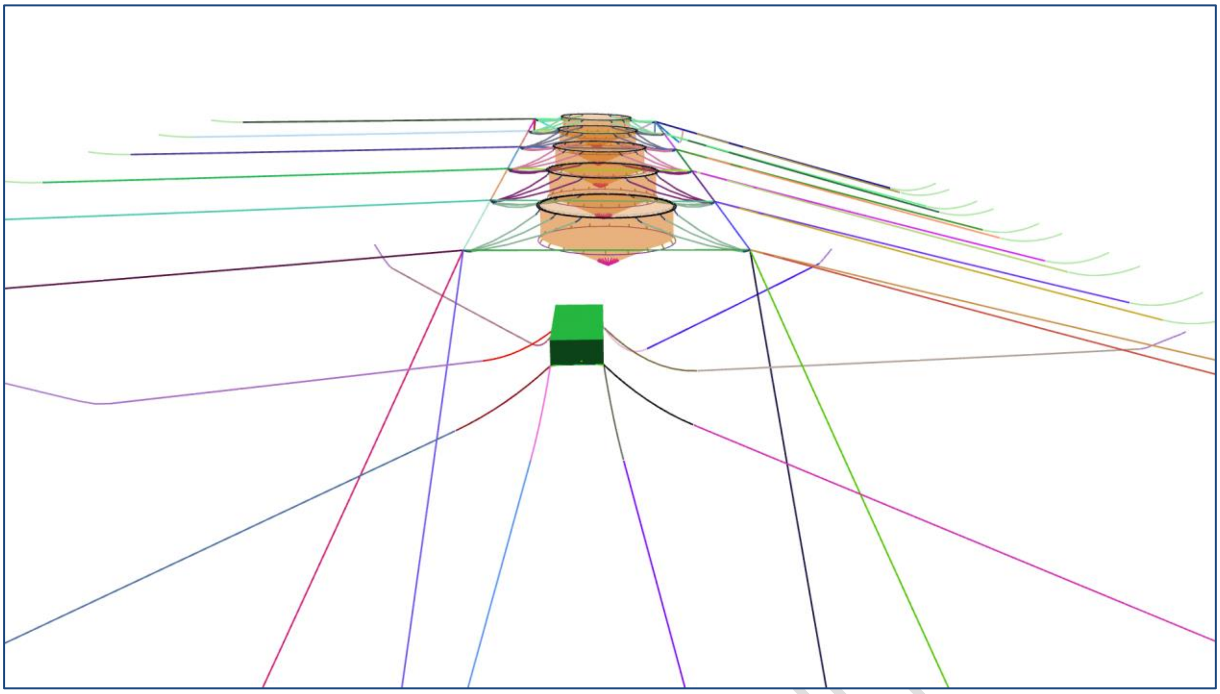
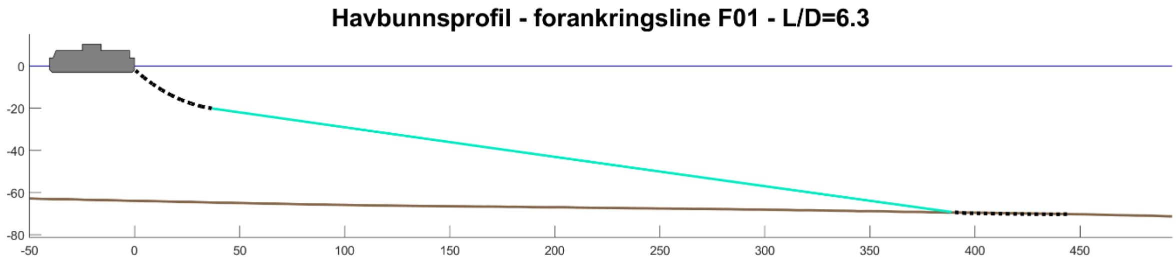
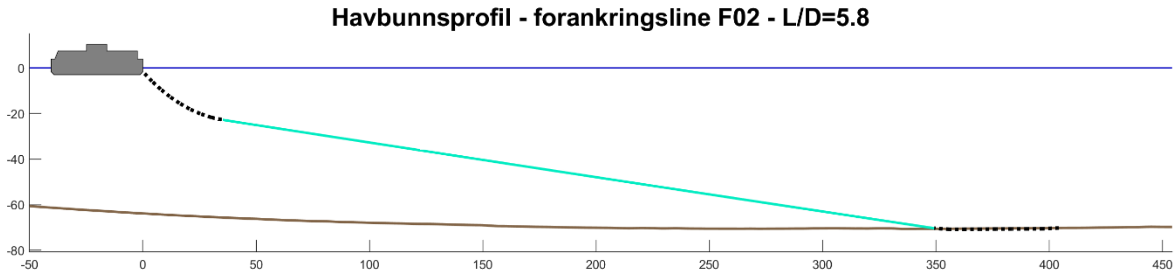


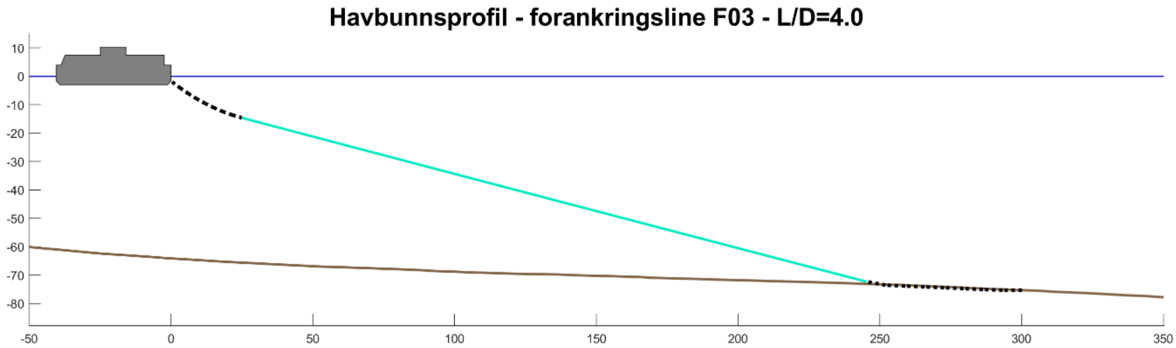
Figure 12: Grid- and barge mooring.

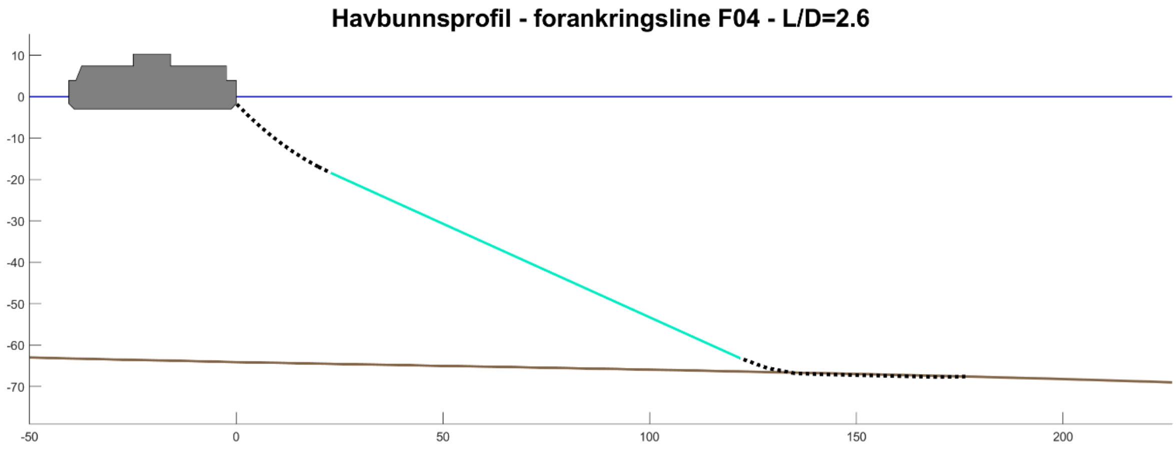
APPENDIX C: LINE PROFILES

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 barge mooring, from the seabed connection point towards the connection point on the barge. The anchor chain is marked with a black, stapled l ine. 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.

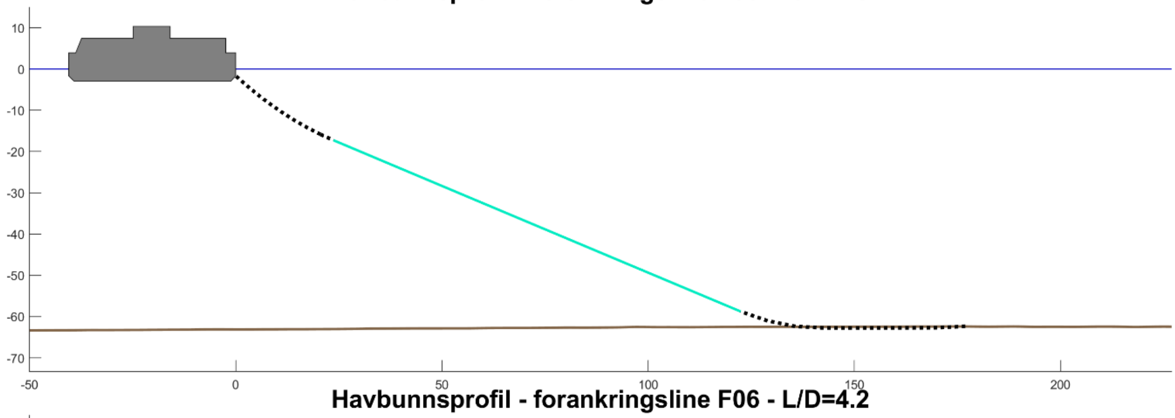








Havbunnsprofil - forankringsline F05 - L/D=2.8



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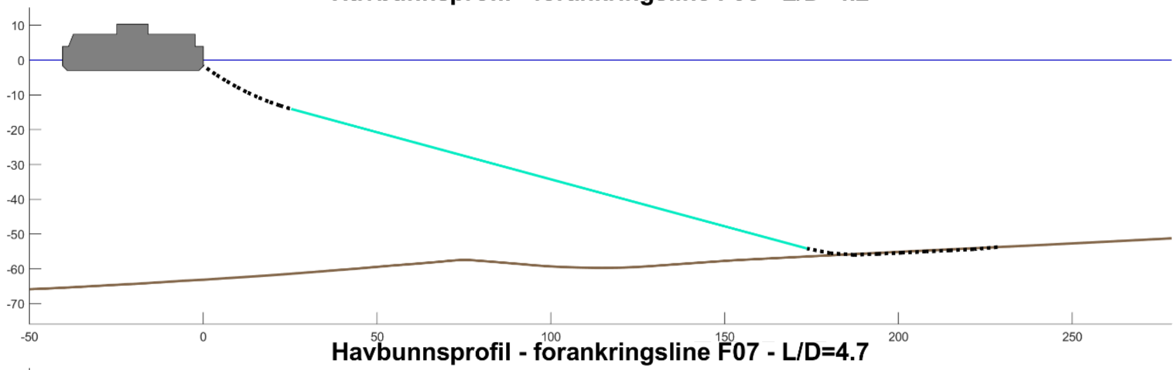
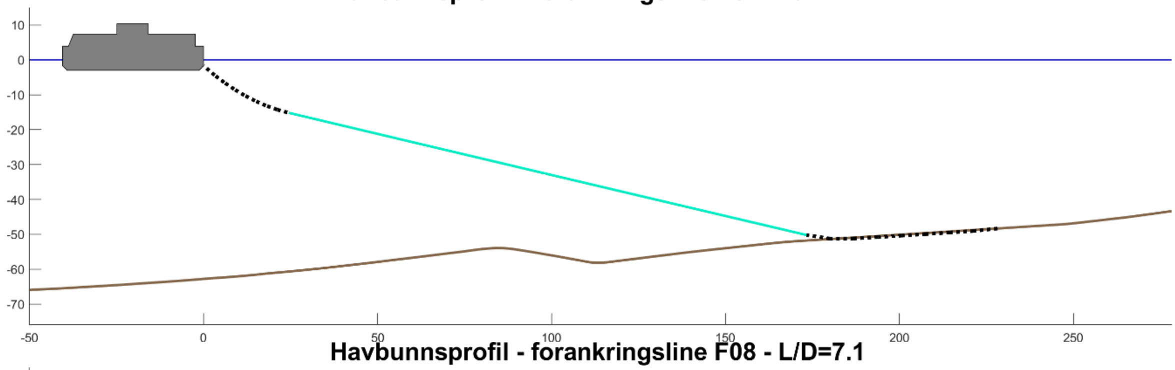


Havbunnsprofil - forankringsline F07 - L/D=4.7



Havbunnsprofil - forankringsline F08 - L/D=7.1