Mooring analysis of barge

TR-31256-6526-1

Revision 1

Site: North Killbrannan

Client: Mowi Scotland

aquastructures	Mooring analysis of barge

Report no.:	TR-31256-6531-1	Number of pages:	22
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Summary:

This report presents results from an analysis of the mooring lines belonging to feed barge and is in accordance with the Technical Standard for Scottish Finfish Aquaculture. The analysis is valid for barge of type Fluctus F500XL. Both lightship and fully loaded condition is accounted for.

1	18.12.2020	LFH	OKF	Mooring analysis
Revision	Date	Done by:	Controlled by:	Description

Contents

1 Conclusion

1.1 Required MBL for the mooring components

Table 1 gives the required MBL of the mooring components. The required MBL is calculated based on the mooring line configuration given in Table 2. It is considered material factors for unknotted line and unused chain.

Table 1 Required MBL for the mooring components.

Anchor line no.	MBL/Holdingpower anchor [ton]	Vertical force at end point [ton]	Required MBL rope [ton]	Required MBL chain [ton]	Required MBL shackles [ton]	Required MBL rope ring [ton]
F1	26.8	17.8	26.8/8.9	1.4	17.8	13.4
F2	111.2	74.1	111.2/37.1	0.0	74.1	55.6
F3	109.1	72.7	109.1/36.4	0.0	72.7	54.5
F4	92.9	61.9	92.9/31	1.8	61.9	46.4
F5	70.7	47.1	70.7/23.6	0.5	47.1	35.3
F6	123.0	82.0	123/41	0.8	82.0	61.5
F7	117.3	78.2	117.3/39.1	0.1	78.2	58.6
F8	32.5	21.7	32.5/10.8	0.8	21.7	16.3

1.2 Analyzed mooring line configuration

The analyzed mooring line configuration is given in Table 2. A sketch of the system is shown in Figure 1. Anchor line F4 and F5 have two 2000 kg mooring block connected to the chain, 7 m and 14 m from the anchor.

Table 2 Configuration of the analyzed mooring lines.

Anchor line [no]	Pre tension [ton]	Top chain			Rope			Bottom chain				Depth anchor[m]	Direction [°]
		Length [m]	Dim. [mm]	MBL [ton]	Length [m]	Dim. [mm]	MBL [ton]	Length [m]	Dim. [mm]	MBL [ton]	Weight [kg/m]		
F1	1.2	0.0	40.0	85.0	37.0	80.0	126.0	27.5	50.0	132.0	44.2	23.3	284
F2	2.1	0.0	40.0	85.0	246.8	80.0	126.0	55.0	50.0	132.0	44.2	20.3	357
F3	3.4	0.0	40.0	85.0	246.6	80.0	126.0	55.0	50.0	132.0	44.2	28.7	19
F4	1.4	0.0	40.0	85.0	47.3	80.0	126.0	27.5	50.0	132.0	44.2	32.1	93
F5	1.1	0.0	40.0	85.0	247.4	80.0	126.0	55.0	50.0	132.0	44.2	35.3	184
F6	3.0	0.0	40.0	85.0	247.3	80.0	126.0	55.0	50.0	132.0	44.2	34.6	190
F7	2.3	0.0	40.0	85.0	246.4	80.0	126.0	55.0	50.0	132.0	44.2	27.0	194
F8	1.2	0.0	40.0	85.0	246.2	80.0	126.0	55.0	50.0	132.0	44.2	25.0	198

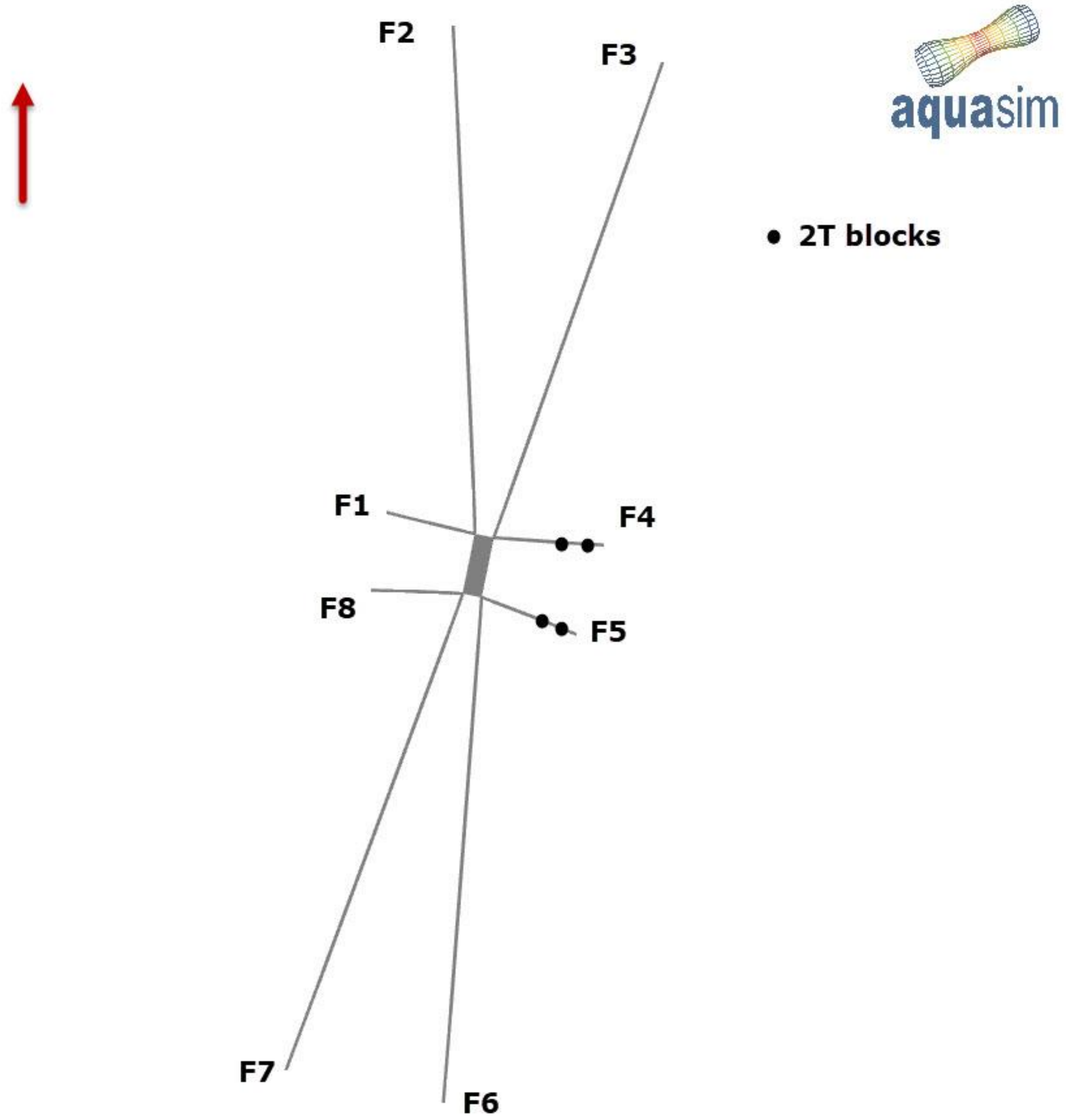

Figure 1 Line numbering

2 Description of the feed barge

The barges are of type Fluctus F500XL [8-10]. The barges are analyzed in lightship and fully loaded condition.

Table 3 Input data of the barge.

<table>
<tr><th>Barge</th><th>Condition</th><th>Length [m]</th><th>Width [m]</th><th>Freeboard [m]</th><th>Draft [m]</th><th>Weight [ton]</th><th>KG [m]</th><th>Height wheelhouse [m]</th><th>Capacity mooring single/double [ton]</th></tr>
<tr><td rowspan="2">Fluctus</td><td>Lightship</td><td rowspan="2">22.0</td><td rowspan="2">12.0</td><td>2.8</td><td>0.9</td><td>354.0</td><td>3.7</td><td rowspan="2">7.3*</td><td rowspan="2">56.0 / 112.0</td></tr>
<tr><td>Fully loaded</td><td>1.3</td><td>2.4</td><td>950.0</td><td>4.1</td></tr>
</table>

**Mean height of the barge*

2.1 Evaluation of eigenperiods

Table 4 lists the relevant eigenperiods of the barge.

The eigenperiod of sway is outside the range of the peak periods in the site report. Such wave periods are not likely to occur at the site.

The eigenperiods of surge, heave, roll, pitch and yaw are within the range of the peak periods in the site report. Such wave periods are likely to occur at the site. Load condition 1-9 are included in Table 5 to capture these resonant motions.

Table 4 Eigenperiods of the barge.

DOF's	Fluctus	
	Light [s]	Full [s]
Surge	16.5	27.2
Sway	42.0	66.8
Heave	5.3	6.2
Roll	3.6	6.1
Pitch	5.3	6.5
Yaw	17.9	29.6

3 Scope of work and analysis program

Aquastructures AS is engaged to perform a mooring analysis. The mooring analysis has been performed using safety factors from the Norwegian Standard NS 9415[1].

AquaSim analysis and simulation software tool is a finite element tool developed by Aquastructures AS for the real-time simulation of structural response of slender, light-weight constructions, flexible configurations and coupled systems of various elements exposed to environmental loads. [3-7].

4 Site and environmental loads

The site North Killbrannan is in southwestern Scotland in the council area of Argyll and Bute. The analysis is based on the mooring lines shown in Figure 2.

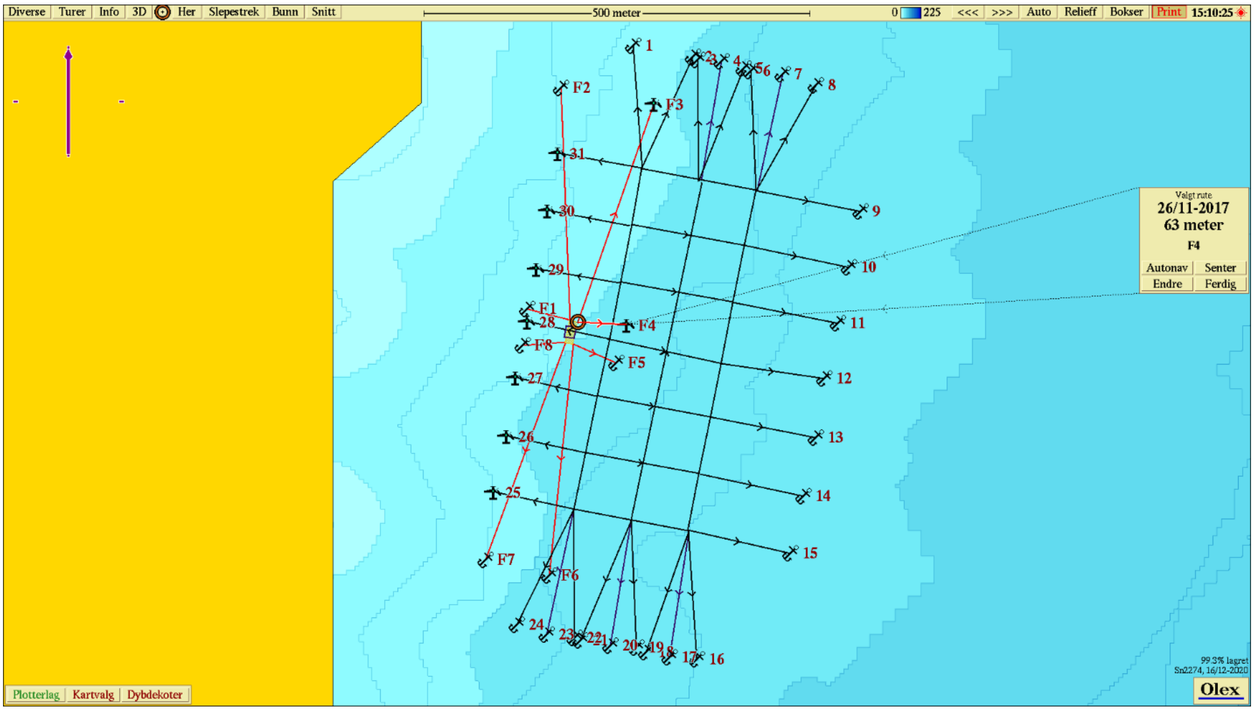

Figure 2 OLEX-plot of the site North Killbrannan.

The load conditions are shown in Table 5 [7]. It is analyzed with 8 load conditions that covers 8 directions. The combined swell and wind wave are also accounted for.

It is analysed with irregular waves of the type JONSWAP, which consist of 100 waves with a duration of 100 wave periods.

Table 5 Load conditions [7]

Load condition	Sector	Hs [m]	Tp [s]	Wave direction from [°]	Current [m/s]	Current dir. towards [°]	Wind velocity [m/s]	Comments
1	N	1.90	4.10	20	0.70	200	31.6	50 year wind/waves 50 year current
2	NE	2.40	5.40	48	0.80	210	23.1	
3	E	1.60	4.00	85	0.20	270	23.4	
4	SE	1.50	3.80	140	0.30	315	25.3	
5	S	3.70	14.50	183	0.70	20	28.4	
6	SW	1.00	2.60	225	0.80	35	31.6	
7	W	0.60	1.90	270	0.30	90	31.3	
8	NW	0.90	2.50	335	0.40	135	28.4	
9	S	3.80	14.50	183	0.70	20	28.4	Combined 50 year wave
10	S	3.80	14.50	183	0.7	20	28.4	Failure of F7
33	S	3.80	14.50	183	0.7	20	28.4	Failure of F6
34	S	3.80	14.50	183	0.7	20	28.4	Failure of F8

5 AquaSim-model

5.1 Barge

The model of the barge is divided in three component groups:

1. Main beam: modelled as a hydrodynamic beam element with length equal to the length of the barge.
2. Cross beam: modelled as a hydrodynamic beam element with length equal to the width of the barge.
3. Dummies for mooring attachment: modelled as Morrison beam element. Dummies are used to correctly position the mooring attachment on the barge.

For further information on modelling of barges, see AquaSim user manual, TR-2263-1[5].

5.2 Mooring lines

The mooring components are modelled as given in Table 2. E-modulus used in the analysis is 2.1 GPa and 110 GPa for the rope and chain, respectively.

6 Capacity control

Calculations have been performed to document that the barge is dimensioned to withstand the environmental forces at the site.

The following factors have been accounted for:

- All loads from weight of systems and buoyancy are included.
  - The forces from the pretension of lines are also included as well as environmental forces made by waves, wind and current.
- Effect from loads
  - The system and the moorings are analyzed in such a way that consequential damages caused by failure of a mooring line cause as little harm as possible.
- Control of limit states
  - Accidental limit states are controlled from the following events:
    - Failure of mooring line with highest axial load.
    - Failure of mooring line that is critical for the strength of the fish farm
    - Failure of connection point
    - Failure of line critical for position
    - Fatigue

The results are given as:

- Maximum forces in mooring lines.
- Requirement of holding capacity and lift force for anchor/block.
- Max forces into the barge.

6.1 Load- and material factors

Utilization is calculated by the following expression:

$$\frac{F_{max} \times \gamma_f}{\frac{F_{break}}{\gamma_m}}$$

Table 6 Explanation of expressions, load and material factors..

<table>
<tr><th>Parameter</th><th>Explanation</th><th colspan="4">Values</th></tr>
<tr><td>F_{maks}</td><td colspan="5">Max force in mooring line</td></tr>
<tr><td>F_{brudd}</td><td colspan="5">Breaking capacity of mooring line</td></tr>
<tr><td>γ_f</td><td>Load factor</td><td colspan="4">1.15 Dynamic analysis</td></tr>
<tr><td>$\gamma_{f\ Accident}$</td><td>Load factor</td><td colspan="4">1.00 Dynamic analysis</td></tr>
<tr><td rowspan="2">γ_m</td><td rowspan="2">Material factor</td><td>Rope</td><td>Rope with knot</td><td>Chain</td><td>Used chain</td></tr>
<tr><td>3.0</td><td>5.0</td><td>2.0</td><td>5.0</td></tr>
<tr><td rowspan="2">$\gamma_{m\ Accident}$</td><td rowspan="2">Material factor</td><td>Rope</td><td>Rope with knot</td><td>Chain</td><td>Used chain</td></tr>
<tr><td>2.0</td><td>3.33</td><td>1.33</td><td>3.33</td></tr>
<tr><td rowspan="2">γ_m</td><td rowspan="2">Material factor</td><td>Anchor</td><td>Shackles</td><td colspan="2">Coupling plate</td></tr>
<tr><td>3.0</td><td>2.0</td><td colspan="2">1.5</td></tr>
<tr><td rowspan="2">$\gamma_{m\ Accident}$</td><td rowspan="2">Material factor</td><td>Anchor</td><td>Shackles</td><td colspan="2">Coupling plate</td></tr>
<tr><td>1.5</td><td>1.33</td><td colspan="2">1.0</td></tr>
<tr><td rowspan="2">γ_m</td><td rowspan="2">Material factor</td><td colspan="2">Plastic</td><td colspan="2">Steel</td></tr>
<tr><td colspan="2">1.25</td><td colspan="2">1.1</td></tr>
<tr><td rowspan="2">$\gamma_{m\ Accident}$</td><td rowspan="2">Material factor</td><td colspan="2">Plastic</td><td colspan="2">Steel</td></tr>
<tr><td colspan="2">1.0</td><td colspan="2">1.0</td></tr>
<tr><td rowspan="2">γ_m</td><td rowspan="2">Material factor</td><td colspan="4">Screws, bolt friction and welded connections</td></tr>
<tr><td colspan="4">1.25</td></tr>
</table>

If the factor of utilization exceeds 1.0, the maximum force, including safety factors, in the mooring line exceeds the capacity.

6.2 Accidental limit states

The accidental limit states are based on the criteria given in Chapter 6. The simulated failures of lines are shown in Figure 3.

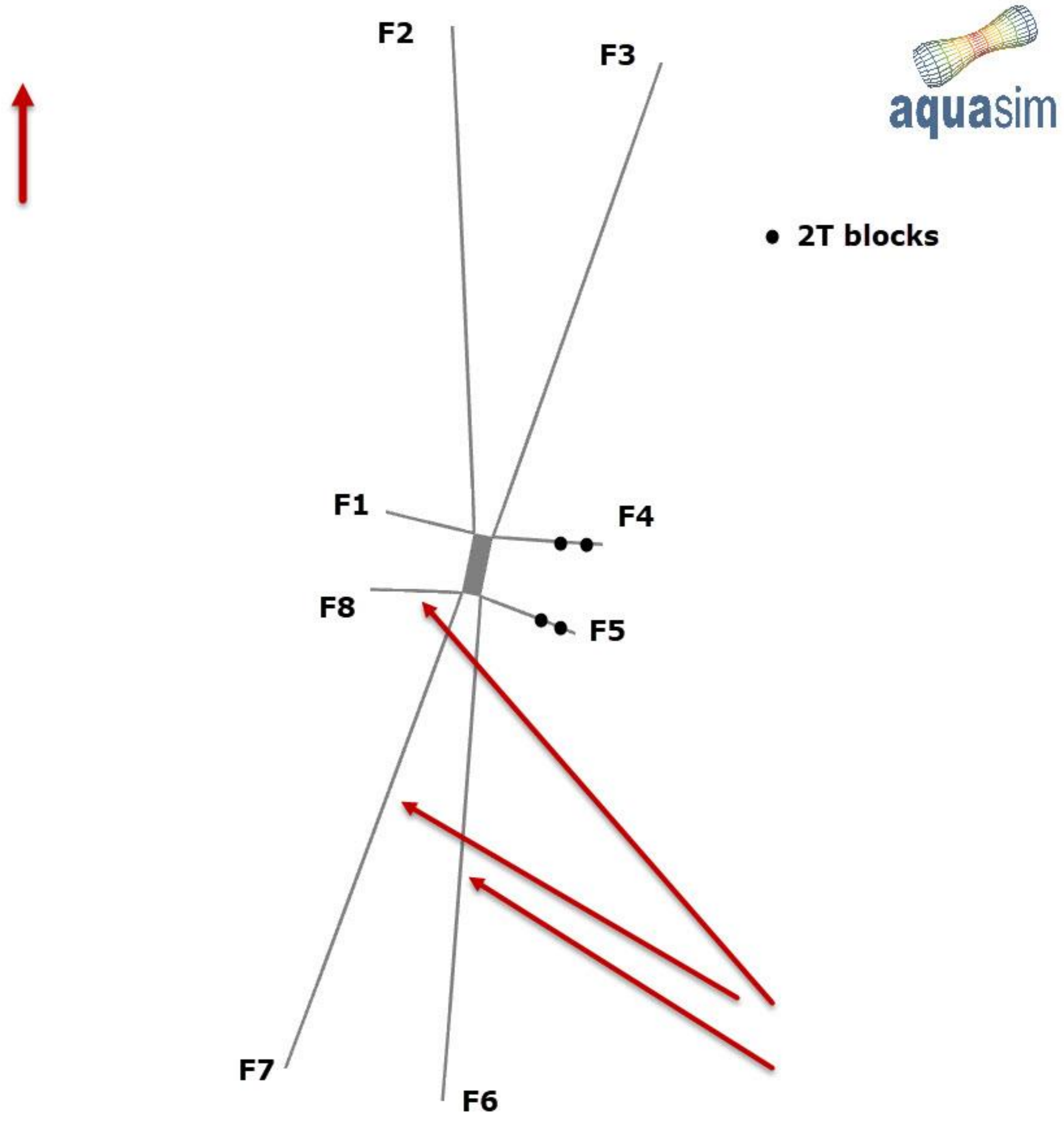

Figure 3 Simulated accidents.

7 Results

7.1 Intact mooring

Table 7 Utilization of mooring lines in intact condition.

Mooring line [no.]	Max load [N]	Required MBL rope [ton]	Required MBL chain [tonn]	Utilization (top chain)	Utilization (rope)	Utilization (bottom chain)
F1	76110	26.8	17.8	0.2	0.2	0.1
F2	316200	111.2	74.1	0.9	0.9	0.6
F3	310200	109.1	72.7	0.9	0.9	0.6
F4	264100	92.9	61.9	0.7	0.7	0.5
F5	201000	70.7	47.1	0.6	0.6	0.4
F6	349700	123.0	82.0	1.0	1.0	0.6
F7	333500	117.3	78.2	0.9	0.9	0.6
F8	92440	32.5	21.7	0.3	0.3	0.2

7.2 Mooring in accidental conditions

Table 8 Utilization of mooring lines in accidental condition.

Mooring line [no.]	Max load [N]	Required MBL rope [ton]	Required MBL chain [tonn]	Utilization (top chain)	Utilization (rope)	Utilization (bottom chain)
F1	120500	24.6	16.3	0.2	0.2	0.1
F2	315900	64.4	42.8	0.5	0.5	0.3
F3	307100	62.6	41.6	0.5	0.5	0.3
F4	157100	32.0	21.3	0.3	0.3	0.2
F5	130200	26.5	17.7	0.2	0.2	0.1
F6	372200	75.9	50.5	0.6	0.6	0.4
F7	404300	82.4	54.8	0.6	0.7	0.4
F8	110100	22.4	14.9	0.2	0.2	0.1

7.3 End points of mooring

Table 9 Max vertical lift and holding capacity at end point.

Anchor line [no.]	Max. load [N]	Holding power (anchor) [ton]	MBL anchor [ton]	Vertical force at end point [ton]
F1	76110	8.9	26.8	1.4
F2	316200	37.1	111.2	0.0
F3	310200	36.4	109.1	0.0
F4	264100	31.0	92.9	1.8
F5	201000	23.6	70.7	0.5
F6	349700	41.0	123.0	0.8
F7	333500	39.1	117.3	0.1
F8	92440	10.8	32.5	0.8

7.4 Mooring attachments

Max axial and vertical force into barge is given in Table 10. The values given in the table are included a load factor of 1.30 for ULS and 1.00 for ALS.

From [10] it is given that the allowable line pull, for single line, is 56 ton. The allowable line pull, for twin line, is 112 ton. The axial force occurring in the mooring connections belonging to Fluctus barge are hence within the capacity.

Table 10 Utilization of mooring attachments. The capacity of mooring attachments includes load factor.

Barge	Load condition	Axial force single [ton]	Axial force double [ton]	Vertical load single [ton]	Vertical load double [ton]	Utilization single	Utilization double
Fluctus	ULS	46.3	62.9	9.4	17.2	0.83	0.56
	ALS	38.3	44.8	6.9	10.9	0.68	0.40

7.5 Fatigue

Fatigue calculation of rope is not performed as the stress ranges in the rope are lower than 170 MPa.

The fatigue analysis of the chain is based on the load condition that gives the largest stress range in intact state, see Figure 4 and Table 11. The significant wave height from this load condition is used to establish 10 load conditions that represent both small and large sea states. The new load conditions are given in Table 12. Current - and wind velocity are half of the velocities in intact condition.

Table 11 Load conditions used as reference in the fatigue analysis.

Load condition	Sector	Hs [m]	T [s]	Wave direction from [°]	Current [m/s]	Current direction towards [°]	Wind velocity [m/s]
9	S	3.40	12.90	183	0.70	20	25.7

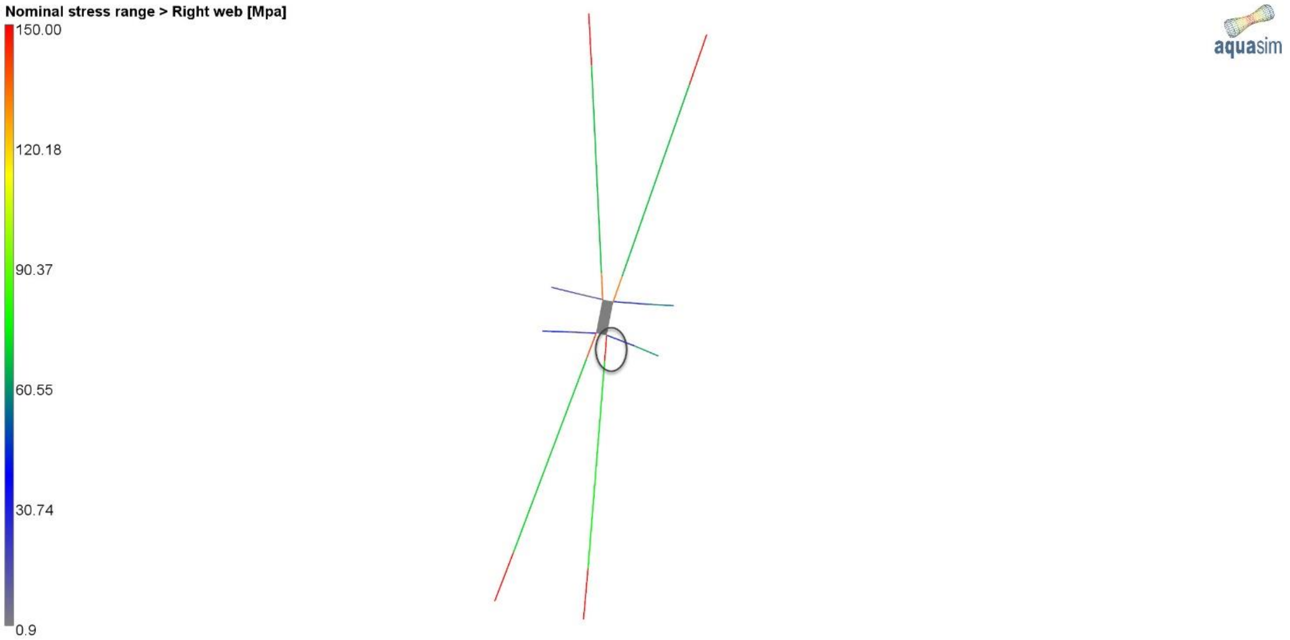

Figure 4 Components controlled in the fatigue calculations.

7.5.1 40 mm top chain

Amplitudes, periods, and stress range for the component that is controlled are given in Table 12.

Table 12 Stress range of component for each block.

A [m]	T [s]	Stress range [MPa]
0.13	1.40	0.24
0.26	1.97	1.48
0.40	2.42	2.51
0.53	2.79	2.95
0.66	3.12	3.02
0.79	3.42	3.51
0.93	3.69	2.11
1.06	3.95	2.63
1.19	4.19	4.39
1.32	4.41	6.60

The fatigue lifetime is calculated based on the stress ranges. The fatigue lifetime is shown in Table 13.

Table 13 Fatigue lifetime of component.

Diameter of chain [mm]	Calculated lifetime [year]
40	over 20

7.6 Result plots

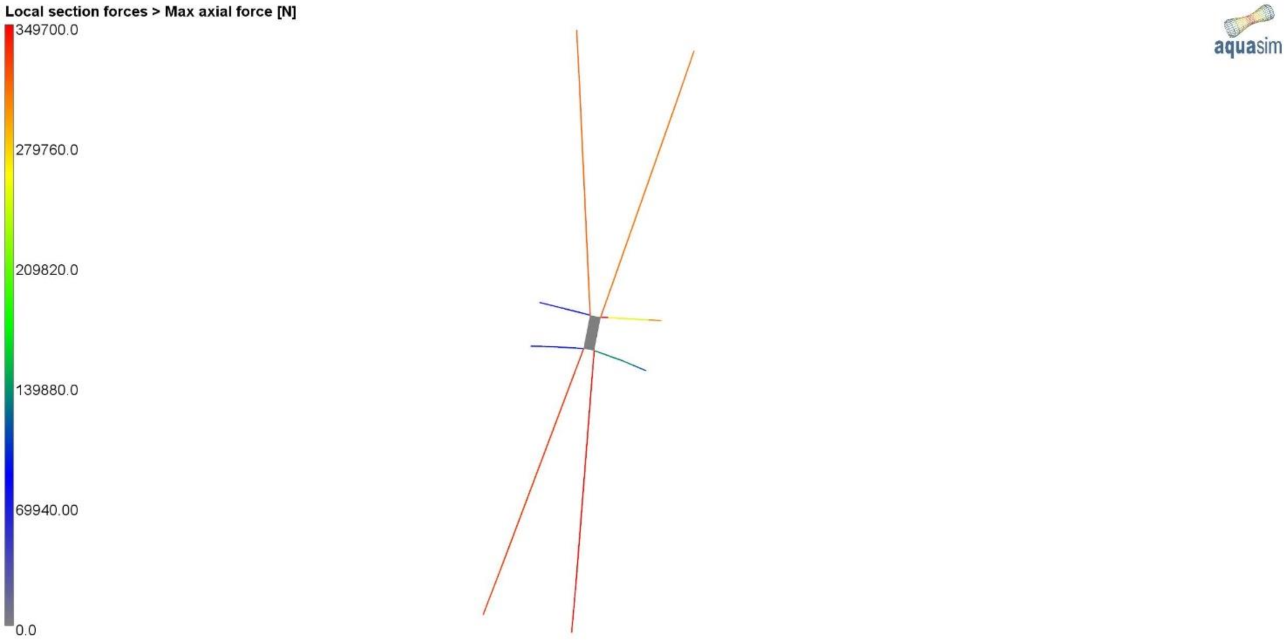

Figure 5 Fluctus light. Maximum axial loads in the mooring system, intact condition.

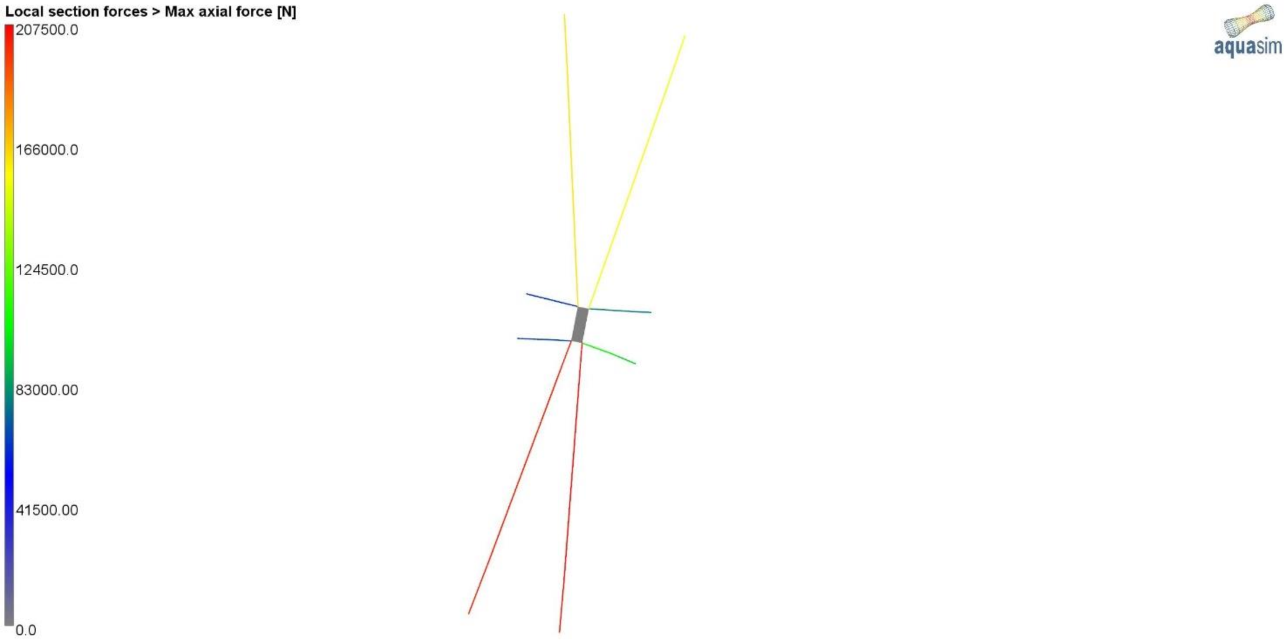

Figure 6 Fluctus full. Maximum axial loads in the mooring system, intact condition.

8 Discussion

8.1 Intact barge

The maximum axial loads in mooring lines are given in Table 7.

8.2 Accidental limit state

The max axial loads for accidental limit state are given in Table 8. An accidental limit state is said to be dimensional for a component if the required MBL of one (or several) accidental limit states is higher than the required MBL for intact mooring system.
The following accidental limit states are accounted for:

- Failure of mooring line exposed to the highest axial force.
- Failure of mooring line that is critical with thoughts of the strength of the structure.
- Failure of connection point.
- Failure of mooring line critical with thoughts of positioning.
- Progressive failure.
- Tidal rise.

If one or several of the mentioned accidental limit states is dimensional for the component belonging to the mooring system, this would be the value given in Chapter 1.1.

8.3 Required holding capacity of anchor and vertical lift at end point

The required holding capacity of anchor and vertical lift at end point is given in Chapter 0.

All bottom attachments should be tested based on the required holding capacity and the vertical force. If the vertical holding capacity of the anchor is not be verified, the vertical force can be reduced by replacing anchor rope with anchor chain, and/or by connecting extra weight (e.g. concrete blocks) in front of the anchor.

If the line is short, it is not recommended to reduce the rope length with use of extra chain to compensate for the vertical lift at the end point. This due to higher stiffness of the mooring line.

8.4 Mooring attachment

The capacity control of mooring attachment is given in Table 10.

8.5 Fatigue

The results from the fatigue analysis are in accordance with The Technical Standard for Scottish Finfish Aquaculture.

9 References

9.1 Theory

1. Norwegian Standard NS 9415:2009 Marine fish farms. Requirements for site survey, risk analyses, design, dimensioning, production, installation and operation
2. Aquastructures (2006) «AquaSim the Aquastructuresimulator.Theorethical Formulation of structure and load modeling». Report no. Report NO. 2006-FO06.
3. Aquastructures (2010), Teknisk Rapport. Klasse notat utmatting Aquastructures notat prosjekt 1219, 10.08.2010.
4. 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.
5. TR-2263-1, User manual AquaSim mooring analysis of feed barges. Aquastructures AS
6. Marine Scotland. A Technical Standard for Scottish Finfish Aquaculture.

9.2 Information on barge and site

7. Site Survey North Killbrannan. SS-30079-6503-1. Aquastructures AS. Dated: 20.11.2020.
8. Stability Calculations. Fluctus AS. F5010 feedbarge. F079/18-067. Sawicon AS.
9. Fluctus User Manual. Revision 00. Approved: 07.07.2017.
10. F500XL Pilothouse. Towing and Mooring. Drawing No. F5010.101.000.

Appendiks A Definitions

Axial load	Load that act along the long axis of a component. For example, the load that acts along a rope.
Vertical load	The decomposed load that act vertical in an element.
Horizontal load	The decomposed load that act horizontal in an element.
Environmental load	The loads that are applied to the barge from wind, waves and current.
Hs	Significant wave height.
Vc	Current velocity.
Tp	Wave period.
Load factor	Partial factor for load which expresses possible deviation for the loads in relation to characteristic capacities, reduced probability for different loads to act at the same time with their characteristic capacities, and uncertainties in modelling and analysis in the determination of load effects.
Material factor	Factor expressing possible deviation in strength of materials in relation to characteristic values, possible strength reduction of materials in the construction in relation to characteristic values derived from tests and uncertainties with modelling and the determination of construction's capacity, including specified tolerances.
Utilization	The proportion of a component that is utilized.
MBL	Minimum breaking load.
Fatigue limit state	Limit state quantifying the danger of fracture during the useful life of the barge because of repeated loads.

Appendiks B Dynamic analysis parameters

The dynamic analysis in AquaSim is performed with the parameters listed in Table 14. The analysis in AquaSim is performed by first establishing static equilibrium of the construction without current and waves. Then the current is applied increasing linearly towards the desired current velocity. Finally, waves are applied.

The analysis is performed with irregular sea of the type JONSWAP. Were max wave height is:

$$H_{max} = 1.9 \times H_s$$

Parameters used in the dynamic analysis are given in Table 14. The seastate for load condition no. 9 (see Table 5) is shown in Figure 7-

Table 14 Parameters in the dynamic analysis.

Number of steps where current is increased	Total number of analyzed waves	Number of steps for each wave
5	100	20

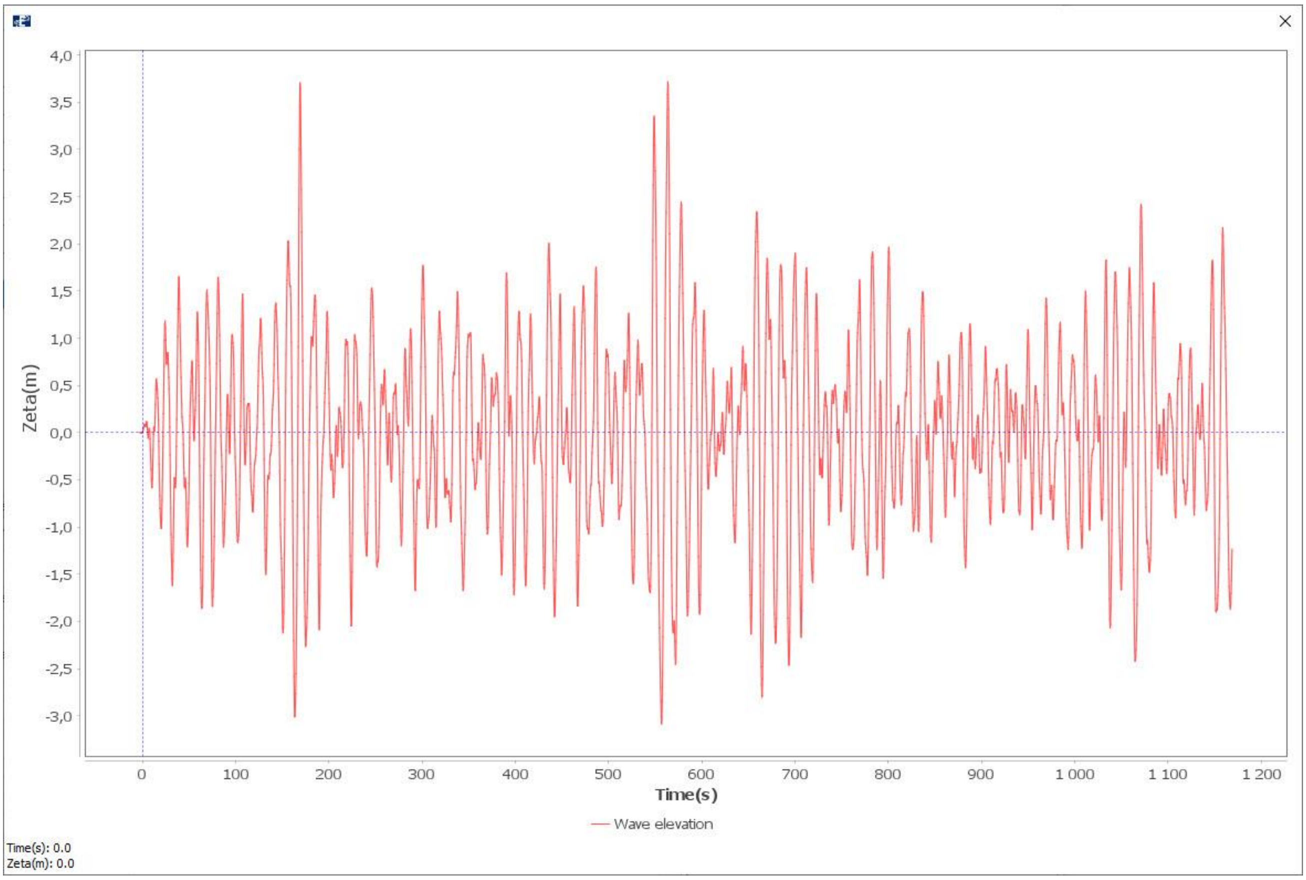

Figure 7 Seastate for load condition no. 9.