OMAE2018-78542

A CASE STUDY FOR AN OFFSHORE STRUCTURE FOR AQUACULTURE. COMPARISON OF ANALYSIS WITH MODEL TESTING.

Are Johan Berstad
Dr. Ing. Aquastructures, Trondheim Norway.
www.aquastructures.no,
Email: are@aquastructures.no

Jan Vidar Aarsnes
Dr. Ing. CeFront, Arendal Norway
www.CeFront.com
Email: jva@cefront.com

ABSTRACT

This paper presents a case study of a structure of a novel fish farm cage. The "AquaTraz" cage is more similar to structures known to the the oil and gas industry. The cage has the same shape as the normal cages used in the aquaculture industry and can be introduced to existing grid-moorings.

Model testing has been carried out and results from the model test are compared with results from numerical simulations using the tool AquaSim. The response deviating from classic fish farms is shown and what extra considerations that should be carried out for this type of systems compared to classic fish farms is discussed.

INTRODUCTION

The aquaculture industry in Norway has increased rapidly the last decades. In the early years the industry was regulated only under the laws for free enterprise until the first specific laws were put into place in 1973. Since then rules and regulations have evolved and in 2003 the design code NS 9415 was introduced, establishing design criteria. In 2009, the Norwegian standard, NS 9415 was revised and in 2011 corresponding regulations were enforced. Structural integrity to defined load criteria had to be documented. This largely increased the engineering effort within the industry and as more systems were assessed and documented to this regime, the number of escaped fish plummeted.

In 2015 development concessions (in Norwegian; "utviklingstillatelser") were introduced. This basically meant that to increase the production from fishfarming, some novel concept had to be introduced. This has lead to a large increase in novel concepts ranging from fully submerged flexible units to classic offshore structures used for fishfarming.

In addition, recent years have seen the introduction of other innovations such as "lice skirts" leading the structural response to be more mass dominated than drag dominated response of classic net based units, which was the dominating design when NS 9415 was introduced in 2003 and revised in 2009.

90% of the fish farms in Norway are based on polyethylene floating collars with a flexible net underneath as shown Figure 1.
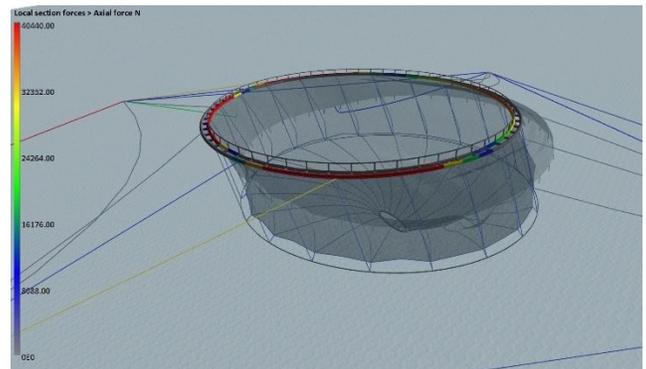

Figure 1 Net in floating collar

Figure 1 shows a net with an impermeable lice skirt in the upper part. The net cages are normally laid out in a grid like the one shown in Figure 2.
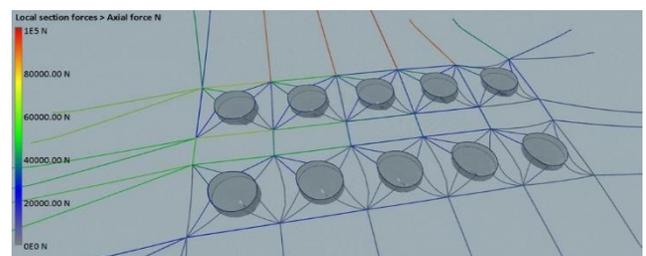

Figure 2 Grid system

The AquaTraz cage is installed in a grid system together with classic polyethylene based cages.

The first development concessions were granted to the "Ocean farm" operated by Salmar (see Figure 3). In this system a permeable net is spread out within a steel frame.

The Ocean farm was also the first applicant. In total it was applied for 104 concepts before the closure date. Most are being processed while only a few have been granted concessions.

Figure 3 The Salmar concept "Ocean farm" (Teknisk ukeblad 2017)

THE AQUATRAZ CASE STYDY

Midt-Norsk Havbruk AS (MNH) has been granted development licenses in connection with development of the AquaTraz concept. The development takes place in cooperation with Seafarming System AS (SFS), which owns the rights to the AquaTraz concept. The AquaTraz cage concept is a semi-closed steel cage developed to be located in relatively sheltered areas. The concept consists of an outer circular floating collar (steel) surrounding an inner semi-closed steel cylinder with a conical shaped net in the bottom, see Figure 4 for the cage in normal operating condition. The cut-outs in the steel cylinder are covered by net. 4 vertical beams are used for lifting the steel cylinder and net bottom out of water for cleaning of the net and for maintenance.

This paper outlines a comparison between analysis and model testing of the AquaTraz fish farm cage seen in Figure 4.

Figure 4 AquaTraz fish farm

The theoretical basis of the numerical analysis is presented, and the cage model and test set up used for the model test and numerical analysis are described.

THEORETICAL BASIS FOR THE ANALYSIS PROGRAM AQUASIM

The AquaSim program is based on the finite element method. It utilizes beam and shell elements with rotational degrees of freedom, (DOF's), as well as membrane elements and truss elements with no rotational stiffness. Geometric nonlinearities are accounted for in all element types, such that the program handles large structural deformations. The program is based on time domain simulation where it is iterated to equilibrium at each time instant. Both static and dynamic time domain simulation may be carried out. Features such as buoys, weights, hinges and springs are included in the program

The basic idea of the FE analysis program is to establish equilibrium between external loads acting on the structure at a given time instant and internal reaction forces.

$$\sum F = R_{ext} + R_{int} = 0 \qquad (1)$$

where R_{ext} is the total of the external static forces acting on the structure at a given time instant and R_{int} is the internal forces. The structure is discretized to a finite number of DOF's. Equation 1 is then discretized as

$$F^{idof} = R_{ext}^{idof} + R_{int}^{idof} = 0, \qquad idof = 1, N_{dof} \quad (2)$$

where N_{dof} is the discrete number of DOF's the structure has been discretized into. The current element program deals with strongly nonlinear behaviour both in loads and structural response. To establish equilibrium, the tangential stiffness method is used. External loads are incremented to find the state of equilibrium. Having established equilibrium in time step *i-1*, the condition for displacement *r*, step *i*, is predicted as

$$\Delta R^i(r_{i-1}) = R_{ext}^i(r_{i-1}) + R_{int}^{i-1}(r_{i-1}) = K_t^{i-1} \Delta r \quad (3)$$

where K_t^{i-1} is the tangential stiffness matrix at configuration *i-1*. The external load is calculated based on the configuration of the structure at *i-1*. This gives a prediction for a new set of displacements *(j=1)*. Based on Equation 3, a prediction for the total displacement $r_{(j=1)}$, is found as

$$\bar{r}_{j-1} = r_{i-1} + \Delta r \qquad (4)$$

Based on this estimate for new displacements, both external and internal forces are derived based on the new structural geometry and the residual force, *ΔR* is put into the equation of equilibrium as follows

$$\Delta R(\bar{r}_j) = R_{ext}^i(\bar{r}_j) + R_{int}^i(\bar{r}_j) = K_t^i \Delta r \qquad (5)$$

Note that both the external and internal forces will vary for each iteration due to the strongly hydroelastic nature of the fluid

structure interaction. Equation 5 is solved for the displacement Δr. Incrementing j with one, the total displacement is now updated as

$$\bar{r}_j = \bar{r}_{j-1} + \Delta r \qquad (6)$$

Now if Δr found from Equation 5 is larger than the tolerated error in the displacements, Equation 4 is updated $(j = j+1)$ and Equation 5 is solved based on the new prediction for displacements, this is repeated until, Δr is smaller than a tolerated error, then

$$r_i = \bar{r}_j \qquad (7)$$

i is increased with one, and Equation 4 is carried out for the new load increment.

At the default configuration, the program works as this: Static analysis is used to establish static equilibrium including buoyancy. Secondly, current loads are applied then wind and wave loads are added. (Still static analysis). Then dynamic analysis commences. Waves are introduced with the first wave used to build up the wave amplitude. Both regular waves and irregular waves may be simulated. Waves are assumed to be sufficiently described by linear wave theory. Inertia and damping are accounted for in the wave analysis, meaning that mass and damping are accounted for in the equations of equilibrium. The Newmark-Beta scheme is applied for the dynamic time domain simulation. Note that the above equations imply using the Euler angles for rotations. This is just a simplification for easy typing. For rotational DOF´s AquaSim uses a tensor formulation for the rotations as outlined in e.g. Eggen (2000) which should be applied to handle 3D rotations in an appropriate manner.

Wave loads may be derived using the Morison formulae (Morison et al 1950) or using diffraction theory.

AquaSim utilize different techniques for finding diffraction forces. To find forces on the impermeable tank in this case, numerical 3D source technique as described by Babarit and Delhommeau (2015) and verification assessment is described in Parisella and Gourlay (2016). When numerical analysis is applied for diffraction forces, also added mass and damping from wave generation is found by the same numerical technique with the option to scale the added mass effect in AquaSim. Added mass and damping are derived for the steady state position and kept unchanged. Diffraction forces are calculated at the actual position including the systems actual deformation. Linearized values for diffraction, added mass and damping are derived for the elements mean wetted position. For irregular waves, linearized added mass and damping for the characteristic period in the wave spectrum are used in the calculations. Wave interaction between separate components is not accounted for.

For elements where the Morison formulae is applicable, the cross flow principle is applied for beams and truss elements (see. e.g. Faltinsen 1990). The drag load term of this equation is quadratic with respect to the relative velocity between the undisturbed fluid and the structure. Both the mass of the structure as well as added mass in the cross sectional plane is accounted for. Due to the large deflections occurring, the added mass is nonlinear. For nets the method presented by Berstad et. al. (2012) is applied. A main difference in the drag load on nets compared with drag loads to lines is the increase of the drag due to the presence of the net. Berstad et al (2012) formulated this as an increased drag coefficient

$$Cd_{mem} = Cd_{cyl} \frac{1}{\left(1 - \frac{Sn}{2}\right)^3} \qquad (8)$$

Where Sn is the solidity of the net.

A further description of load and response for permeable nets in AquaSim see e.g. Aquastructures (2018) or Berstad et. al. (2012)

The drift forces to the main cylinder in the analysis are calculated by keeping the 2nd order terms giving a nonzero mean, integrating the pressure all the way to the water line;

$$p = -\rho g \int_0^{\zeta} z \, dz - \rho \frac{\partial \varnothing_1}{\partial t}|_{z=0} \zeta \qquad (9)$$

Where p is the pressure, ρ is the density of the fluid, g is gravitation acceleration coefficient, ζ is the water elevations, z is the vertical location, t is time, ∂ is the derivative operator and ϕ_1 is the velocity potential (see Faltinsen 1990).

Note that the wave elevation is accounted for also below the mean water line so that the total pressure is not allowed to be less than 0 after also the velocity term of the Bernoulli equation is included:

$$-\frac{\rho}{2} \int_{-\infty}^{0} \left\{ \left(\frac{\partial \phi_1}{\partial x}\right)^2 + \left(\frac{\partial \phi_1}{\partial y}\right)^2 + \left(\frac{\partial \phi_1}{\partial z}\right)^2 \right\} dz \qquad (10)$$

x, y and z are the directions in space respectively.

AquaSim has undertaken a versatile verification scheme: Analysis has been carried out on a wide range of computational cases where results have been compared to handbook formula or other programs, see Aquastructures (2012). Tank testing has been carried out and compared to analysis, see Berstad et al (2004). The program has been compared to accidents where the capsize origins were known (Aquastructures 2003 and 2005). In addition, experience have been obtained during several years where the program has been the most used program for calculation of the structural integrity of fish farm systems in Norway. These systems in general consist of moorings, structure and nets responding to wave and current in a strongly hydro elastic manner. The program is also used for a wide range of offshore applications such as towing for seismic operations (Berstad and Tronstad 2008), operations and installations offshore, mooring analysis of offshore units and structural and mooring analysis of equipment for renewable equipment offshore (see e.g. Berstad et. al. 2007)

MODEL TEST

Model basin testing have been carried out for the fish farming cage seen in Figure 5 with further details in Figure 7. The model test was carried out in the Ocean Basin at Sintef Ocean in Trondheim, Norway (Sintef 2017). Only the normal operating condition was used in the model tests.
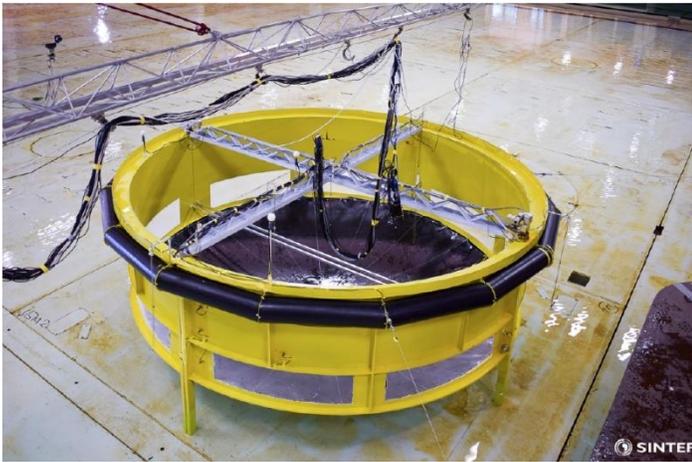

Figure 5 Test tank model.

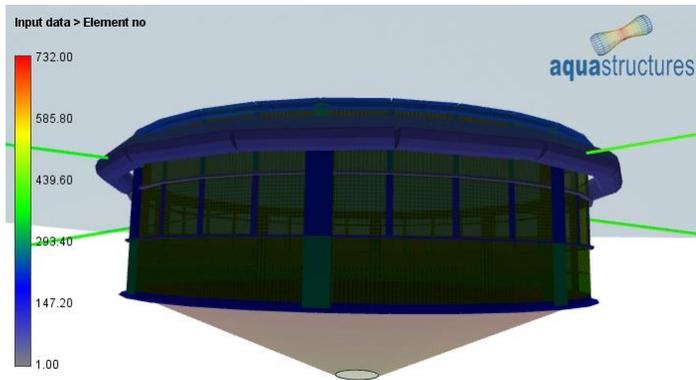The AquaSim analysis model is made in full scale coordinates and is shown in Figure 6.

Figure 6 Used Analysis model element discretization.

The cage including floater ring is a steel cage where the upper 9.6 meters of the cage is impermeable steel. The main particulars of the AquaTraz concept as used in the model tests are summarized in Table 1.

Two versions of the cage have been tested in the model tests:

- "Base": The cut-outs in the steel cylinder were covered by stiff, removable plexiglass plates (to obtained closed cylinder walls)
- "Alt. 1": The plates covering the cut-outs were replaced by permeable net.

Both these cases have been modeled and results have been compared.

Table 1 Main particulars floater.

| Main particulars Cage	Analysis model	Tank model (full scale values)
Freeboard in still water [m]	2.223	2.235
Scale factor	1	15
Type of scale		Froude
Diameter main cage [m]	51	51
Diameter floating collar at water line [m]	2.4	2.4
Horizontal distance from tank[m] center to floater at knuckle points	27.8	27.8
Total height vertical part [m]	14.6	14.6
Vertical centre of gravity [m] (from baseline)	9.72	9.75
Weight of system [Tonnes]	598	597
Vertical height conical part of net [m]	10.1	10.1
Net solidity [%]	23	23
Scale factor net mesh		1
Weight in water bottom cone [kg]	800	800
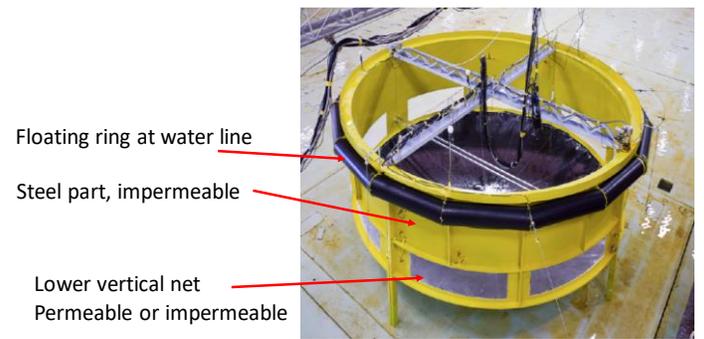
Figure 7 Two versions were tested; "Base" with impermeable vertical net and "Alt 1" with permeable net (solidity 23%)

The AquaTraz concept will be used in an existing standard frame mooring system for cages. For the model test set up a simplified mooring arrangement was used as shown in Figure 8. The 4 mooring line connections and the entire mooring line is above still water line to give horizontal force contributions only. The lines were equipped with linear springs. The specified spring stiffness for each line was k=30 kN/m. The working range of the springs was sufficient to cover the maximum horizontal motions of the cage within the linear area. The definition of wave and current directions used in the model tests is also shown in Figure 8. Heading 0 degrees represent wave/current in-between mooring lines.

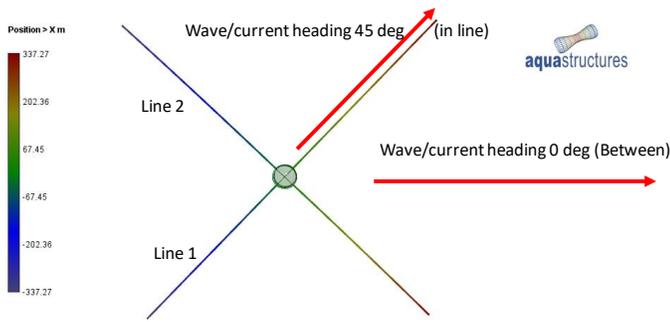The main particulars for the mooring system are summarized in Table 2.

Copyright © 2018 by ASME

Figure 8 Mooring system as used in model test.

Table 2 Main particulars for mooring system.

Main particulars mooring system	Analysis model	Tank model (full scale values)
Length of each mooring line	450	>280
Axial stiffness of each mooring line [kN/m]	30	30
Elastic module of each mooring line, EA [kN]	13524	
Pretension [kN]	500	500

The horizontal stiffness of the mooring system used in the analysis was set equal to the stiffness in the model tests at 60 kN/m. As shown in Figure 9 the pretension both in the test and in the analysis is 500 kN.
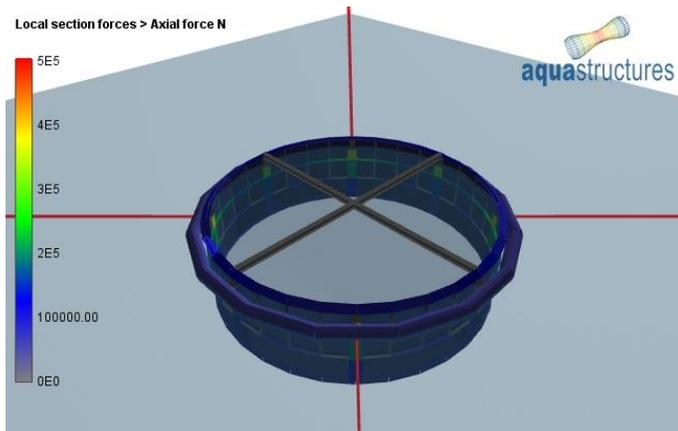

Figure 9 Pretension 500 kN

Figure 10 shows the horizontal stiffness of the mooring system as used in the analysis model. This compares well to the model test stiffness.
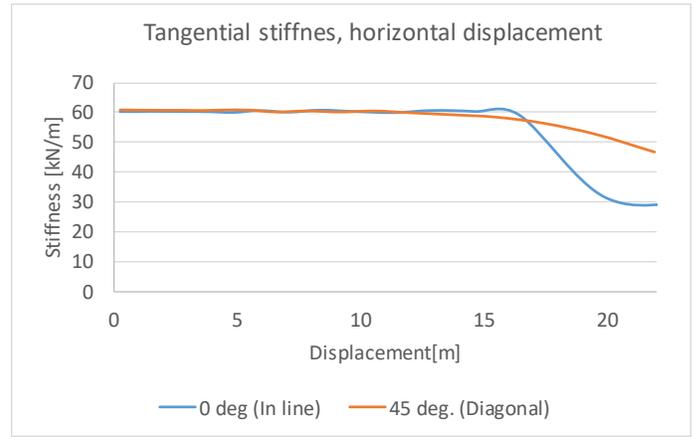

Figure 10 Horizontal stiffness of the system

Pressure due to current have been calculated by the default formulation in AquaSim (see e.g. Aquastructures 2018) where a drag coefficient is given for the large volume structure and pressures is applied such that the force in total corresponds to the drag coefficient multiplied with the projected area being diameter * height.

Response from current

The 3 cases shown in Table 3 have been tested in the tank with current and no waves.

Table 3 Test cases current

Test no	Cage condition	Heading	U_C [m/s]
1310	Base	0 deg	0.732
1320	Base	45 deg	0.697
1330	Alt. 1	0 deg	0.727

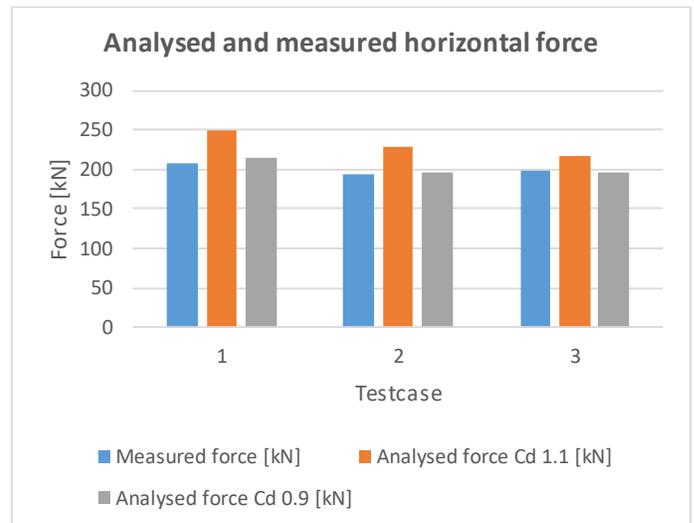Figure 11 shows comparison between analysis and measurements for current forces.

Figure 11 Analysis compared with measurements for current

As seen from Figure 11 calculated results with the base drag coefficient of 1.1 are slightly conservative. Reducing the drag

coefficient to 0.9, good correspondence is obtained. This is in line with what was observed during testing that the water flowed more underneath the cage than around the sides. This is natural since that diameter is much larger than the draught. The bottom ring of the cage is a sharp corner structure. Also the cage sides are equipped with vertical stiffeners as shown in Figure 5. This imply flow separation basically from sharp corners and hence the scale effect from viscous forces should be insignificant

Decay test and added mass

Decay testing was carried out and results are shown in Figure 12. Decay testing was carried out for the "Base" model only.

First the decay test was used to investigate the amount of surge added mass the system is subjected to both from fluid inside the tank and outside the tank. As seen from Figure 12 the period of the system is approximately 130 seconds. The internal and external added mass was chosen to fit this. This means that the surge added mass was set to be 19E6 kg which is slightly less than half (41%) of the internal mass and the added mass. This was used for the succeeding analysis. The reason not all inside mass contributes as added mass is probably that the diameter is approx. 5 times larger than the draft which means water is flowing underneath. This is probably also the case for the added mass. Note that this system is open in the bottom such that there is very little added mass vertically. The two versions "Base" and "Alt 1" will have different added mass. Further investigations to this is outside both test and paper scope. Also much of the water was pushed under the cage through a net making the analogy to a cylinder poor.

Two versions of the analysis are compared with the testing

- Analysis 1 is the analysis model with default drag coefficients and no extra damping.

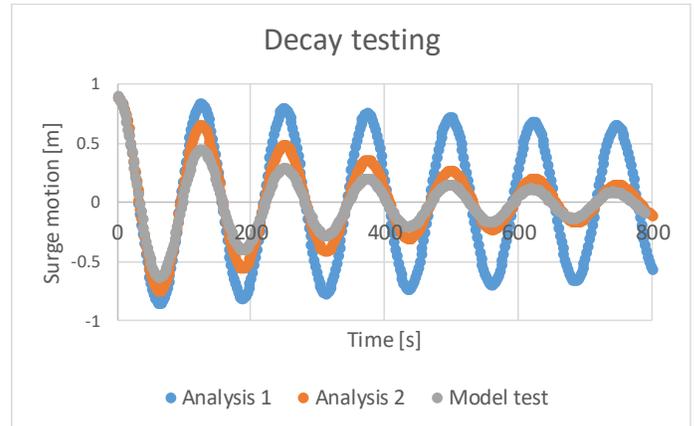- In Analysis 2 a linear damping coefficient = 0.3% of the systems mass matrix is added.

Figure 12 Decay test analysis compared to testing

As seen from Figure 12 the decay is a lot slower if only damping from drag loads based on the drag coefficients used in the analysis is applied. In real life it is probably other and local damping effects causing the increased decay such as vortices trough sharp corners, wave generation or damping in measurement cabling and system. For this system, and in particular for the "Alt 1" case, the damping due to Morison loads to the net mesh will dominate damping, and in a grid system there are even more Morison damping.

Regular wave

A regular wave with wave height H=0.97 meters and period T=6 seconds is compared in There is no current.
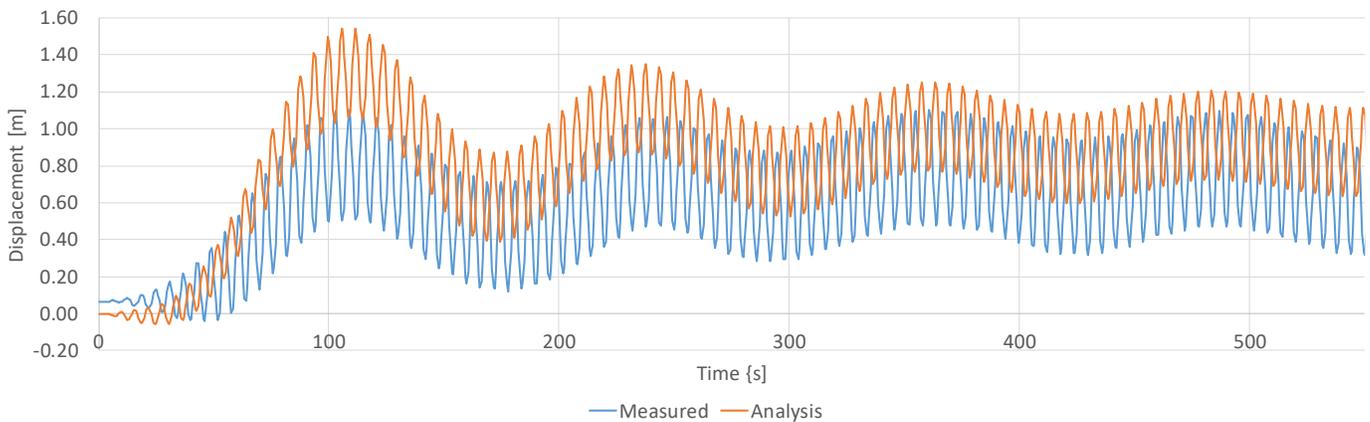

Figure 13 Regular wave amplitude 0.485 m , period 6 seconds. Displacement centre of ring.

The analysis results shown in Figure 13 have been carried out with default drag settings. The non-linear effect of the part of floating collar goes in and out of water and wave drift forces is accounted for in the analysis.

Irregular waves

Table 4 shows the 3 irregular wave conditions considered. Jonswap spectrum was used.

Table 4 irregular wave conditions. JONSWAP spectrum.

Test	Hs	Tp	U$_C$	γ	Direction
3221	1.7	5.2	0	3.2	0

3240	2.8	6.8	0	2.9	0
3260	2.8	6.8	0.72	2.92	0

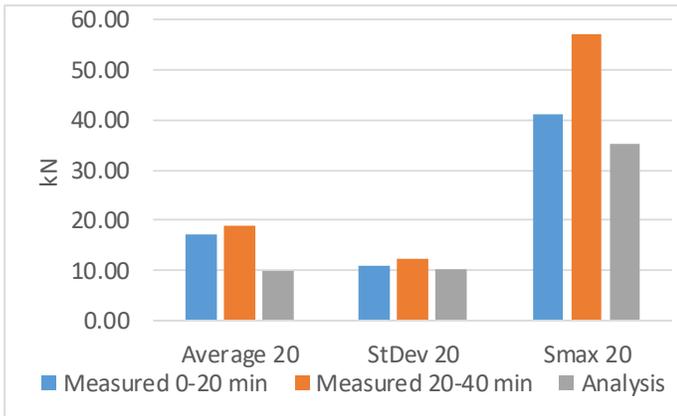Figure 14 shows statistical key parameters for test case 3221.

Figure 14 Comparison analysis and measurements testcase 3221. Axial force line 1

The labels in Figure 14 means:
- Average 20: The average value of the measurements during 20 minutes.
- StDev 20 The standard deviation for measurements during 20 minutes.
- Smax 20: Maximum value during the 20 minutes
- Analysis: Calculated by numerical analysis. 20 minutes calculation. The wave spectrum is subdivided to 100 individual waves and the mean period of each wave block is chosen randomly in the interval between the lowest and the highest wave in the block. The same random seeds have been used for all base analysis cases for the conditions in Table 4. For further information on this see e.g. Aquastructures (2018)

- Measured 0-20 min. Measured first 20 minutes
- Measured 20-40 min. Measured from 20 min to 40 minutes into the time series of the model test.

Figure 15 shows the same as Figure 14, but in this case the displacement at the cage centre is compared. The trend is the same, but the standard deviation of the analysis and the first 20 minutes of the test is even more similar.
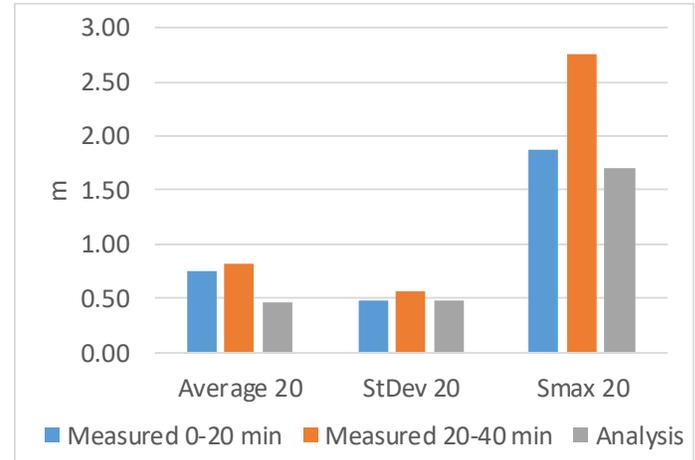

Figure 15 Comparison analysis and measurements testcase 3221. Surge displacement centre point of cage.

Figure 16 shows the time series from the analysis compared with the two first 20 minutes periods of the testing. As seen from the figure the horizontal displacement is govern by the low frequency response of the system around the eigen period for horizontal motion of the system. This document the importance of accounting for the low frequency response when changing from normal drag dominated systems (i.e. traditional floating collar systems with flexible net) to mass dominated system which will be the case for this cage.
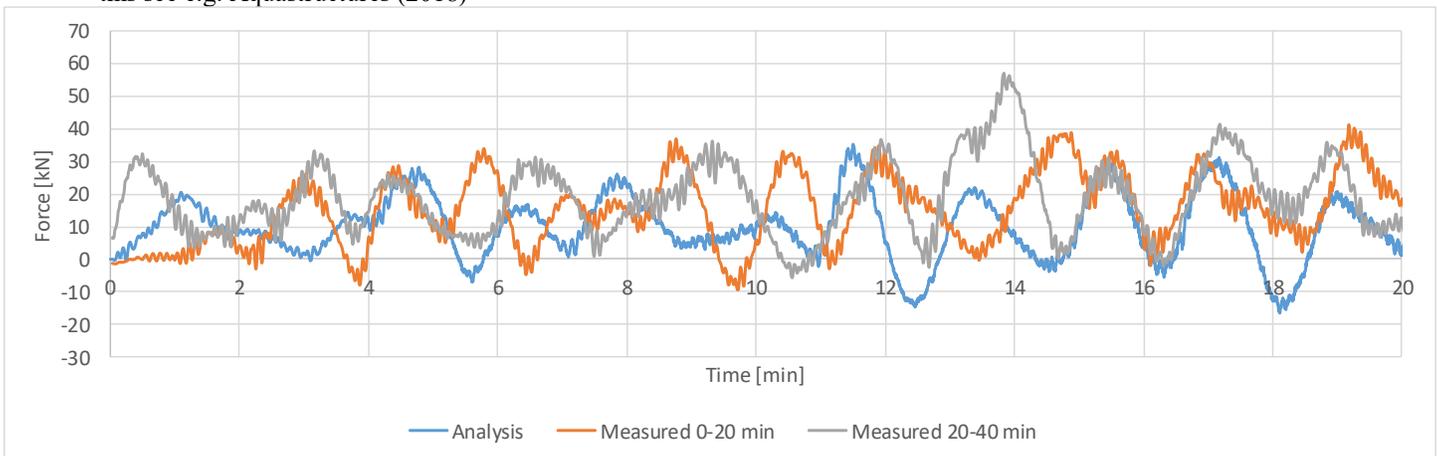

Figure 16 Comparison analysis and measurements testcase 3221. Axial force mooring line 1. Time series 20 minutes excerps

Note that the eigen period of the system for the case "Alt 1" is lower than the Base case due to permeable net. For the analysis, the eigen period is 93 seconds which seem to correspond well with the test which looks to be in the +- 100 range based on visual inspection of Figure 16. Note that simulated response is based on time series generated from the wave spectrum and not directly from the measured wave

elevation from model tests. (Note that only the "Base" case was exposed to decay test).

Figure 17 shows the same as Figure 14 but for test case 3240.

Figure 17 shows the same trend as Figure 14 meaning that the mean drift force is underpredicted by the analysis whereas the standard deviation corresponds well.

Figure 18 shows the time series of the analysis compared with the two first 20 minutes periods of the testing. Also, in this case the drift of the system related to the eigen period for horizontal motion of the system dominates the response.
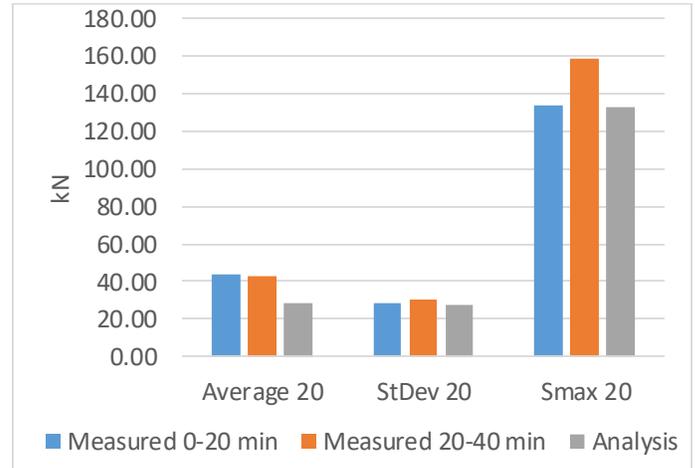

Figure 17 Comparison analysis and measurements testcase 3240. Axial force line 1
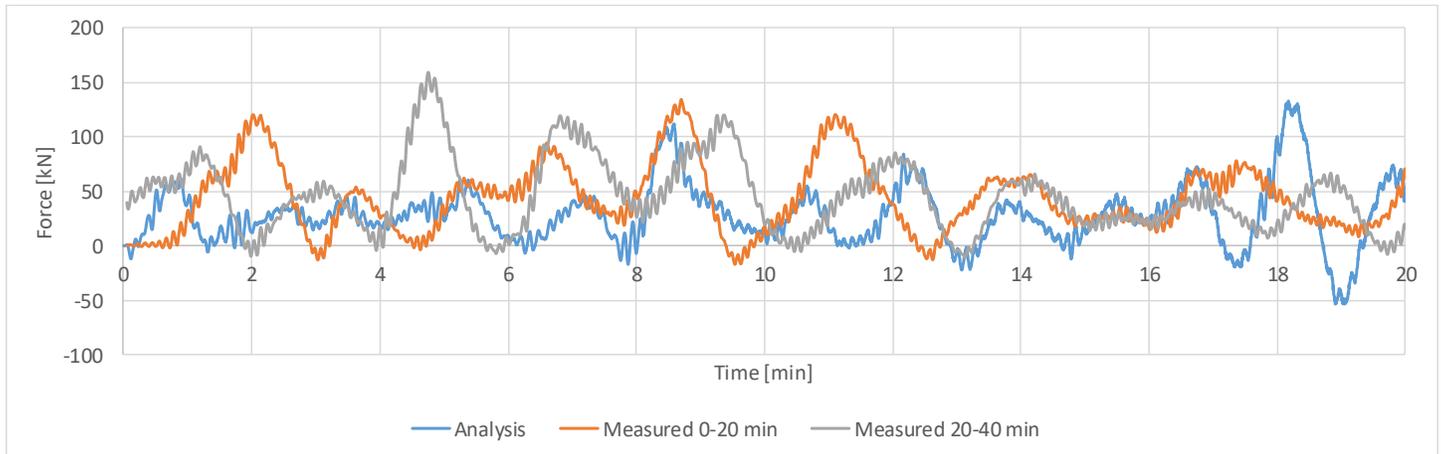

Figure 18 Comparison analysis and measurements testcase 3240. Axial force mooring line 1. Time series 20 minutes excerpts.

Figure 19 shows the same as Figure 14 and Figure 17 but for test case 3260. In this case 2 versions of the analysis has been carried out:

- Analysis 1: Wave periods representing each of the 100 sinusoidal waves making up the irregular waves are applied to the interval for wave period randomly
- Analysis 2: Wave periods are the average wave period within the range.

As seen from Figure 19 the analysis shows in general larger response than the measurements for this case. Note how dependent the response is to whether the period of the individual waves is randomized or not.

Time series are seen in Figure 20. This shows how the calculated response from slowly drifting systems needs long time series to obtain stable statistically significant response parameters. Due to the hydroelasticity and nonlinearity of moored fish farming systems such analysis will be very time consuming.
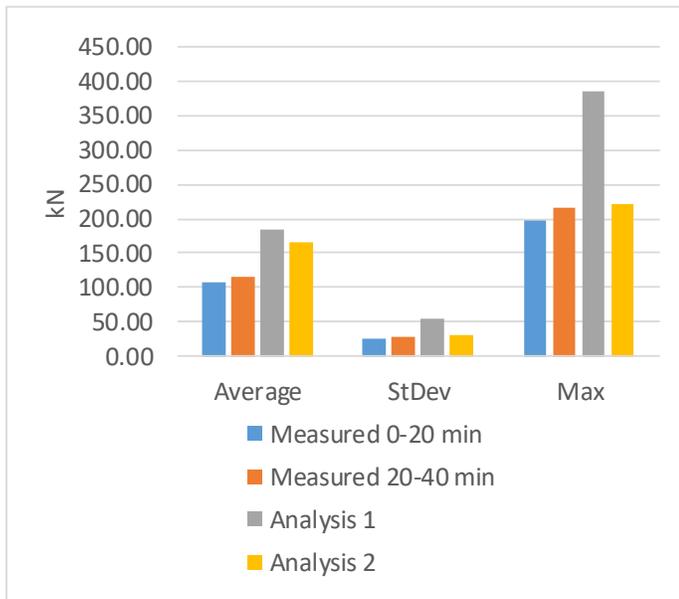
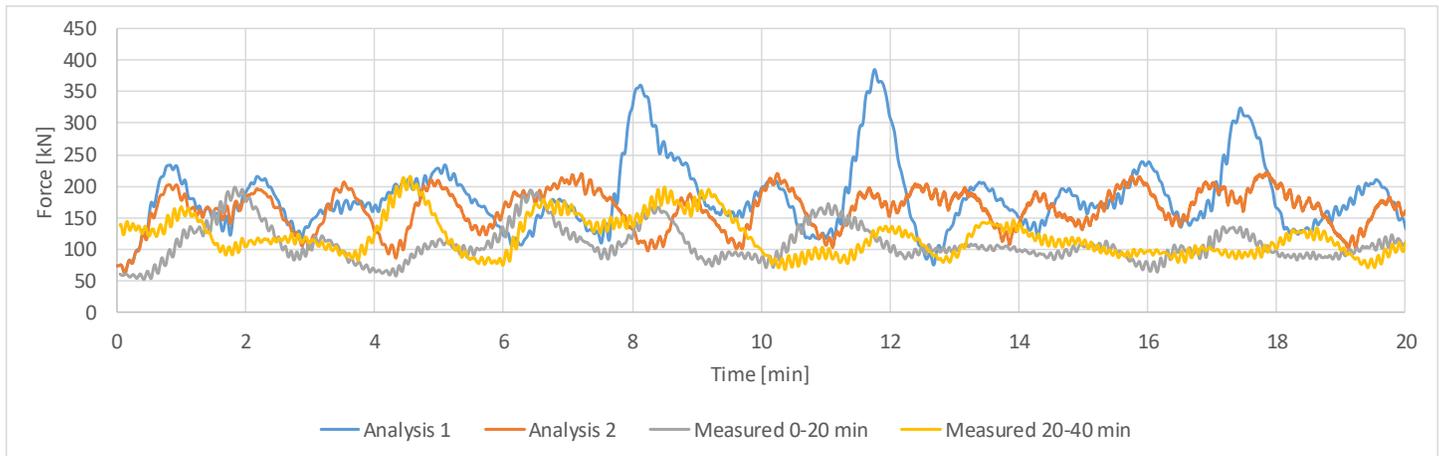**Figure 19 Comparison analysis and measurements testcase 3260. Axial force line 1**

Figure 20 Comparison analysis and measurements testcase 3260. Axial force mooring line 1. Time series 20 minutes excerpts

As seen from Figure 19 both the mean value, the standard deviation and the measured maximum are larger in the analysis

Both analysis and measurements have larger uncertainties for the case with combined waves and current. The measured results have larger uncertainty since they are based on one measurement of current velocity in the tank. The analysis also have a larger in this case due to more viscous forces combined with hydrodynamic response.

As seen from the time series the analysis with randomized wave periods (analysis 1) have some additional peaks compared with the nonrandomized (analysis 2). This means one should be careful when performing irregular analysis such that one manages to obtain the relevant measured maximum.

It is the condition with combined effect of waves and current that matter for design so further studies should emphasize on this.

DISCUSSION AND APPLICATION FOR ENGINEERING

For engineering for fishfarming structures one would like a fast but conservative base method. The approach used should in addition open up for more refined analysis. A combination of analysis and model testing will be required for validation and verification of the used approach.

For the model test case, the eigen period was approximately 100 seconds. Finding an appropriate eigen period is not as easy for a real case as for this model test case. For a real case, the surge eigen period will vary strongly dependent on the actual load condition due to the nonlinear behaviour of the mooring system. The way these systems are moored, there is very low tension in the bridles attaching each cage to the grid such that the stiffness is very low and hence eigen period is very high. In general, the more current the lower eigen period. The eigen period with current is the relevant eigen period to determine the length of the analysis.

The response of moored aquaculture grid systems (e.g hydroelastic and strongly nonlinear. Due to this the analysis culture is to analyse with design waves where a time domain simulation with 1-2 waves is applied. For normal drag response dominated grid systems this works fine, but when such a system is combined with components with large mass such as AquaTraz also wave drift will be of importance.

Moored barges also have nonlinear response due to the mooring but they are not hydroelastic. This means simpler analysis models and irregular analysis is carried out on a regular basis.

The results in this paper and the fact that the drift period is in the range 100 seconds for the testing and in the range of 200+ for grid systems means standard regular wave analysis are too short to introduce drift response. This means one must carry out analysis with longer time series and irregular waves.

The difference to normal offshore structures is that the grid system have so much drag both due to the net in AquaTraz and

9   Copyright © 2018 by ASME

also the other classic nets in the system that one must account for drag forces explicitly and not only in terms of damping coefficients being introduced in order to ensure a sufficient design for the mooring system.

For design, the dynamic peak load is by far the most important parameter. As seen from this paper the peak load is underpredicted in analysis compared with testing for cases where there is no average current. For cases with current, however, the peak load is estimated higher than model testing. There is an uncertainty in the measures current velocity, but the analysis results are on the conservative side. These systems are heavily damped due to the Morison load to nets in the grid system. This means current velocity is very important for peak load and the combined waves and current are the important load cases such that given uncertainties both in testing and analysis one should make sure that analysis parameters are set such that they are on the conservative side.

To find the full response statistics one will have to analyse enough realizations. This is outside the scope of both testing and analysis for this case study.

CONCLUSIONS

From the comparison between analysis and measurements the following can be concluded:

For the cases with no current velocity, the standard deviation of the results compare well to test data within the accuracy level limited by the scope of measurements. In order to fully understand the differences of the response statistics further work should be carried out.

For the cases with current velocity the difference in testing and analysis is larger. In this case there is larger uncertainty both in the analysis and the actual current velocity in the tank.

Both analysis and testing confirm that mass dominated fish farms leads to some extra assessment needed for response calculation. One must make sure to include 2nd order wave effects leading to wave drift forces and responses.

For design it is load conditions with wave and current combined that is most relevant. For these conditions, the analysis is shown to be conservative as long as the wave train realization is built up with randomized periods. Variations are larger for this case indicating that further studies should be carried out.

This paper has not presented enough time domain response to fully investigate the statistical variations of response. This would require a broader scope and should be a subject for further studies.

For the irregular wave cases, this paper has only compared testing with analysis with the same wave statistics. Comparison with the exact same wave realization would be of interest but is outside the scope of this work.

ACKNOWLEDGMENTS

REFERENCES

Aquastructures(2003)"Havari Laksefjord" (in norwegian). Report no. 2003-132. Aquastructures, Kjøpmannsgata 21 7013 Trondheim. www.aquastructures.no.

Aquastructures(2005) "Teknisk vurdering av anlegg, Tustna kommune" (in norwegian). Report no. HR-300083-103, Aquastructures, Kjøpmannsgata 21 7013 Trondheim. www.aquastructures.no..

Aquastructures (2012) "Verification and Benchmarking of AquaSim,a Softwaretool for Simulation of Flexible Offshore Facilities Exposed to Environmental and Operational Loads. Aquastructures report no. 2012-1755-1. Aquastructures, Kjøpmannsgata 21 7013 Trondheim. www.aquastructures.no.

Aquastructures (2018) "THE AQUASIM PACKAGE THEORY USER MANUAL" TR-30000-2049-2018 02.01.2018. Aquastructures, Kjøpmannsgata 21 7013 Trondheim. www.aquastructures.no.

Babarit, A., & Delhommeau, G. (2015, September): "Theoretical and numerical aspects of the open source BEM solver NEMOH". In 11th European Wave and Tidal Energy Conference (EWTEC2015).

Berstad, A. J., Tronstad, H., Ytterland, A. (2004)" Design Rules for Marine Fish Farms in Norway. Calculation of the Structural Response of such Flexible Structures to Verify Structural Integrity." Proceedings of OMAE2004 23rd International Conference on Offshore Mechanics and Arctic Engineering June 2004, Vancouver, Canada. OMAE2004-51577

Berstad, A. J. and H. Tronstad (2007) "Development and design verification of a floating tidal power unit" OMAE 2007, The 26th International Conference on Offshore Mechanics and Arctic Engineering San Diego, California, 10-15 June, 2007. Paper 29052.

Berstad, A.J. and H. Tronstad (OMAE 2008) "Use of Hydroelastic Analysis for Verification of Towed equipment for Aquisition of Seismic Data" Proceedings of OMAE2008 27th International Conference on Offshore Mechanics and Arctic Engineering June 15-20 2008 Estoril, Portugal OMAE2008-57850

Berstad A. J., L F. Heimstad and J. Walaunet (2014) "Model Testing of Fish Farms for Validation of Analysis Programs" Proceedings of the ASME 2014 33th International Conference on Ocean, Offshore and Arctic Engineering OMAE2014 June 8-13, 2014, San Francisco, California OMAE2014-24647.

Berstad, A.J., J. Walaunet and L. F. Heimstad (2012) "Loads From Currents and Waves on Net Structures" Proceedings of the ASME 2012 31st International Conference on Ocean, Offshore and Arctic Engineering OMAE2012 July 1-6, 2012, Rio de Janeiro, Brazil OMAE2012-83757

Eggen, T.E. (2000) "Buckling and geometrical nonlinear beam-type analyses of timber structures" PhD Thesis Institute of civil engineering NTNU.

Faltinsen, Odd M. (1990) "Sea loads on ships and offshore structures." Cambridge university press ISBN 0 521 37285 2

Sintef (2017) "AquaTraz. Model tests" Report no. OC2017 F-190. Auth. Ivar Nygaard. Sintef Ocean Postboks 4762 Torgården 7465 Trondheim.

Morison, J. R., M.P. O'Brien, J.W. Johnson and S.A. Schaaf (1950), "The Force Exerted by Surface Waves on Piles," *Petroleum Transactions,* AIME. Vol. bold 189, 1950, 149-154

NS 9415(2009) Marine fish farms, Requirements for design, dimensioning, production, installations and operation. Pronorm. Postboks 252, 1326 Lysaker.

Parisella, G. & Gourlay, T.P. (2016): "Comparison of open-source code Nemoh with Wamit for cargo ship motions in shallow water" (2016-23). Faculty of Marine Technology (NTNU), Curtin University.

Teknisk ukeblad (2017) https://www.tu.no/artikler/verdens-storste-flytende-oppdrettsanlegg-pa-plass-i-norge/405213. Grensen 3, 0159 Oslo, Norway.