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DESIGN RULES FOR MARINE FISH FARMS IN NORWAY. CALCULATION OF THE STRUCTURAL RESPONSE OF SUCH FLEXIBLE STRUCTURES TO VERIFY STRUCTURAL INTEGRITY

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ABSTRACT

As of April 1st 2004 all new marine fish farms in Norway need to be certified to comply with technical criteria in a new Norwegian Standard, NS 9415 (NAS, 2003). This paper gives an overview of the design rules.

Marine fish farms have a strongly flexible hydroelastic behavior. The design rules have revealed the need for calculations to verify the structural capacity of such facilities. This paper describes how loads and response are derived on the fish farm structures. In order to account for the large geometrical deflections occurring in fish farm components such as the net and anchor cables which interacts with stiffer structural components, time domain simulations analysis of such facilities is required to assess the structural integrity. This paper report a proposed practical calculation method and results from model tests have been carried out to validate calculations. Good correspondence was shown. Additionally some applications are described.

INTRODUCTION

Historically there have been limited design guidelines and no design rules for sea based aquaculture facilities in Norway. This has resulted in large variations in the structural integrity of such facilities along the Norwegian coast and hence many incidents where fish have escaped, polluting nearby coastal areas. April 1st 2004 design rules for such facilities were introduced in Norway.

The rule development revealed the need for hydroelastic calculations of such facilities in order to derive the structural capacity from loads introduced by wind, waves and current. The marine fish farms consist of highly flexible structural components such as the fish net and anchor cables as well as stiffer components such as steel or polyethylene floaters and possibly integrated barges. The largest challenge is hence to carry out calculations for the full integrated system, which need to be carried out to fulfill the requirements specified in NS 9415. As the (presently single) certification body for marine fish farms, Aquastructures initiated a research project to establish an algorithm and tool for calculating the response of fish farm structures and to validate calculated results against model tests. Within the scope of the project, calculations were also carried out for a ship wrecked fish farm as well as other existing fish farms.

BASIC FEATURES OF NS 9415

The standard, NS 9415 enforced in Norway specify that all new equipment for marine fish farms need to be certified according to environmental classes depending on wave and current. Both waves and current subdivided to 5 different categories A-E for waves and a-e for current.

The governmental regulations (NMF, 2003), referring to the standard, specify that marine fish farm components, such as the net, need to be certified as components, and integrated systems need to be certified as such by a certification body. Although products are certified for environmental classes, the total combined system must be considered at a specific location since the combined structural response of the facility depends on the actual geometry of the anchored facility.

The standard specifies methods to classify a specific location according to wave and current climate. Then section by section design rules are given for floater, food barges, net, anchoring, and the total integrated system. Depending on what is relevant for each part of the structure, environmental loads, accidental loads, operational loads, fatigue and maintenance need to be assessed.

Floater

The floater must be assessed with strength calculations documenting structural integrity when exposed to the 50 year design storm or design wave specified in NS 9415. Forces introduced to the floater from other components such as the net and anchor lines need to be accounted for, hence a model including surrounding components is necessary. This means that time domain simulations are carried for a set of wave, current (and if applicable wind) combinations. Material and load factors are applied depending on parameters such as material, load type and calculation method.

Food barges
Food barges are assessed with respect to strength, stability and damage stability, much like what is assessed in common ship classification rules such as DNV or ABS. Both steel barges and concrete barges are considered. Food barges may be anchored by it self, or integrated to the floaters. In the latter case the food barges and floaters need to be calculated at an integrated system.

Net
Net structures can be assessed by an experience based net table. This table is valid for nets ordinary net shapes used in currently marine fish farm designs. Alternatively nets may be designed by applying load cases defined in the standard. Innovative designs as well ordinary nets to be applied in high seas need to be assessed by the specified load cases.

Anchor lines
The anchor line configurations are designed case by case, tailor made for each location.

The total integrated system
Total integrated systems can be type approved as entities. In that case a standard net and anchor geometry is used. In case the anchor line geometry differs, which it usually does, the integrated system must be considered at a specific location. In case there is no total system that is applied at location, a total system is modeled for the case and the anchor lines at well as floater is assessed to see that forces both in anchor lines and floater is below accepted criteria.

Validation of design rules
In order to validate the design rules (NAS 2003) numerical analysis were carried out using the numerical tool described in this paper. Analysis were carried out for floaters, nets, anchor lines and integrated systems (Aquastructures, 2003b). Two of the four considered facilities are shown in Figure 1 and Figure 2.

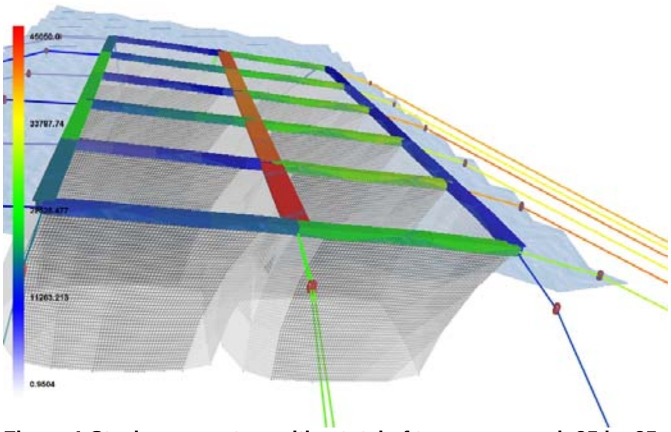

Figure 1 Steel cage system with a total of ten cages, each 25 by 25 meters. The facility consists of several small components approximately 12 meters long hinged together.

In general the results showed that the considered cases would meet the new design rules, both the steel structures and the polyethylene structures. In general both floaters, and anchor lines showed to use almost 100 % of their capacities while the nets used only 20-30 % of their capacities when numerical calculations were introduced, showing that the net table in NS 9415 is conservative. This conservativeness may be originated by common handling of marine fish farm nets is generally rougher than present described algorithms.

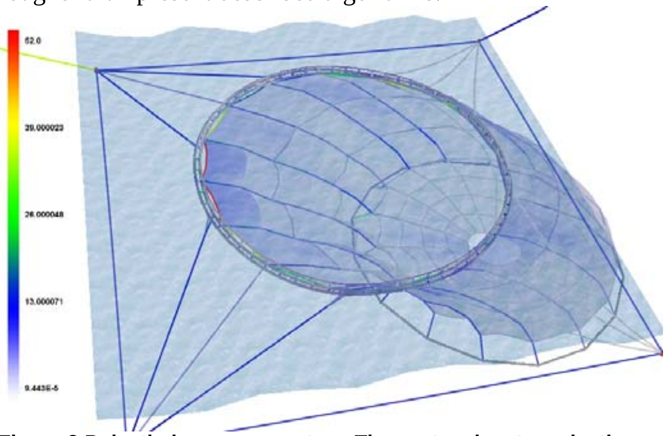

Figure 2 Polyethylene cage system. The system has two plastic rings contributing to the buoyancy. The shown cage is located in a system of several similar polyethylene cages.

CALCULATION ALGORITHM AND TOOL TO ASSESS COMPONENTS AND INTEGRATED SYSTEMS

In order to make the calculations required by the standard, a FEM program, AquaSim was established. This program is based on the finite element method. It utilize beam elements (Halse, 1997), membrane elements (Tronstad 2000) and bar elements. Geometric nonlinearities are accounted for in all element types, such that the program handles large structural deformations. That is a necessity for this kind of structures being very flexible. 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 at 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.

$$\sum F = \mathbf{R}_{ext} + \mathbf{R}_{int} = 0 \qquad (1)$$

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 degrees of freedom (DOF's).Equation 1 is then discretized as

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

where N_{dof} is the discrete number of DOF's the structure has been discretized into. The current element program deals with strongly nonlinear behavior both in loads and structural response. In order 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 step i, is predicted as

$$\Delta\mathbf{R}^{i}(\mathbf{r}_{i-1}) = \mathbf{R}_{ext}{}^{i}(\mathbf{r}_{i-1}) + \mathbf{R}_{int}{}^{i-1}(\mathbf{r}_{i-1}) = \mathbf{K}_{t}^{i-1}\Delta\mathbf{r} \quad (3)$$

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

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

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

$$\Delta\mathbf{R}(\bar{\mathbf{r}}_{j}) = \mathbf{R}_{ext}{}^{i}(\bar{\mathbf{r}}_{j}) + \mathbf{R}_{int}{}^{i}(\bar{\mathbf{r}}_{j}) = \mathbf{K}_{t}{}^{i}\Delta\mathbf{r} \quad (5)$$

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

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

Now if Δr found from Equation 6 is larger then 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

$$\mathbf{r}_{i} = \bar{\mathbf{r}}_{j} \quad (7)$$

i is increased with one, and Equation 4 is carried out for the new load increment. Static analysis is used to establish static equilibrium including buoyancy. Secondly, current loads are applied then wind and wave loads are added. Both regular waves and irregular waves may be simulated. In the present study only regular waves have been calculated and compared to model test results. 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 (e.g. Langen and Sigbjørnson 1979).

Wave loads may be derived using the Morison formulae (Morison et al 1950) or using diffraction theory. The diffraction theory used in AquaSim is a form of “strip theory” (e.g. . Salvesen et al 1970), but in this case hull forces are derived by direct pressure integration over the mean hull surface. Load application to membrane elements are described in Tronstad (2000). The load application to membranes is analogue to the Morrison approach used for cables, but for membranes a lift component is accounted for (See Løland 1991). For beams and bars the cross flow principle is used (see. e.g. Faltinsen 1990) when using the Morison formulae. This load term is quadratic with respect to the relative velocity between the undisturbed fluid and the structure. When Morison loads are applied 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. Diffraction loads may be applied to beams or bars. In this case linearized values for diffraction, added mass and damping are derived for the elements mean wetted position. Linearized added mass and damping for the peak period in the wave spectrum are used in the calculations. The Froude Kriloff part of the hydrodynamic pressure is applied at the actual location of the component. Wave interaction between separate components is not accounted for. In the model testing carried out, only all structural elements were so slender that the Morison equation was applied for all beams.

Generally speaking for ordinary marine fish farms, Morison type loading is applied to net and anchor cabled while the floater elements are assessed by hydrodynamic loading.

The above presented algorithm represents a practical approach to simulate this type of integrated structures, given the size of the structures and current computer capabilities. The research on fluid structure interaction has been steadily progressing recent years. Fredheim and Faltinsen (2003) have proposed a model to calculate the response of net structures. In this model the wake behind meshes is derived and hence fluid velocities making it possible to account for velocity reduction behind the mesh analytically. So far this has generally been based on empirical values. Lader et. al. (2003) use a drag load approach similar to the present for waves and current, but have an alternative formulation for the net structure elements.

Benchmarking and verification

Numerical calculations have been applied on simple geometries in order to investigate the accuracy of the program for cases where results can be found analytically or from hand book formulas. Figure 3 shows the quasi-static displacement of a beam for a case study where the small body approximation is applicable for the diffraction type loading (see e.g. Faltinsen 1990). As seen from the figure, results correspond well. Further cases can be seen in Berstad (2003).

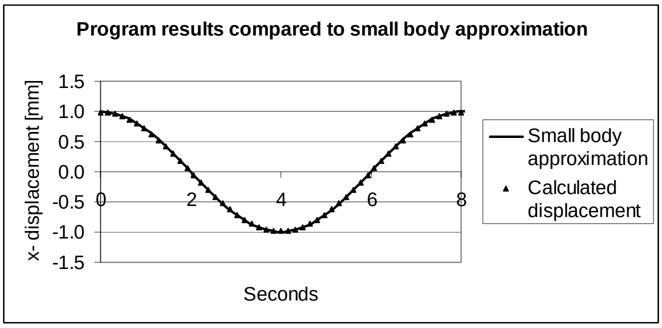

Figure 3 Numerical and analytical results for a cantilever beam exposed to wave loads

ASSESSMENT OF A CAPSIZED FACILITY

Calculation has been to investigate the structural capacity of a facility that capsized outside the coast of Norway (Aquastructures, 2003a). The system is an integrated system where a food carrying barge is hinged to the fish net cages. The facility consists of 3 different parts hinged together. As pointed out in Figure 4 there are side bridges and a mid bridge connected to pontoons. A “stiff” E shaped part consisting of one pontoon, two side bridges and a centre bridge is connected to the next E part by hinges, where the next E is hinged to an integrated food barge. The facility was located in a fjord where the main direction of large waves is from left to right as seen in Figure 4 and Figure 5. The length of the pontoons is 54 meters.

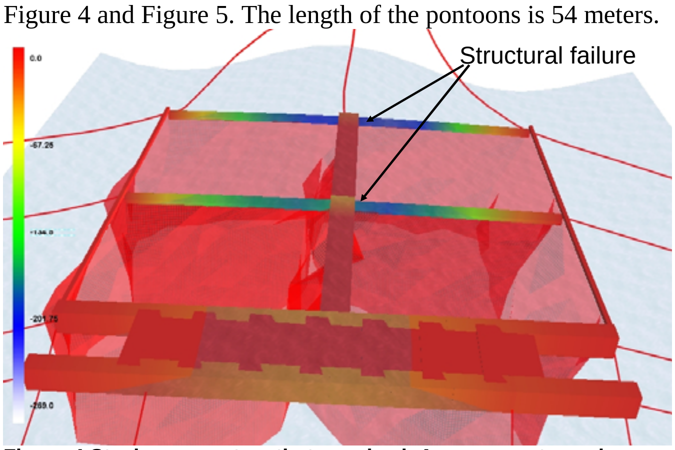

Figure 4 Steel cage system that capsized. A wave crest passing trough the facility from left to right.

The facility capsized from structural overloading in the area pinpointed in Figure 4. Preceding the capsize buckles had been observed on the top flange of the pontoons in this area. The storm condition present when the facility capsized had 3 meters significant waves and wave lengths of 50-60 meters. The calculations showed that these loads introduced stress levels in the flanges approximately twice of the structural capacity explaining why the structure broke down.

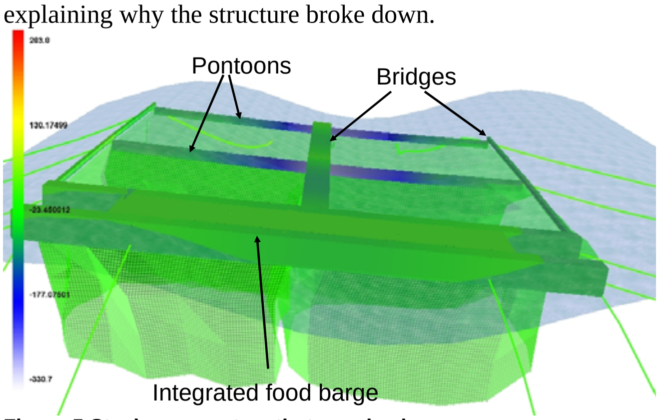

Figure 5 Steel cage system that capsized.

Model test case study

The model test case was set up to compare calculations with measurements. The case study is a globe shaped marine fish farm shown in Figure 6. The "Globe" is shown in Figure 7 and Figure 8. A further description is given in Ytterland (2003). A nylon cable is connecting the globe to the test rig as seen in Figure 6 and Figure 7. The test setup is dragged through the water both with and without waves, and forces and motions as well as current velocity inside the globe are measured. The overall model parameters are given in Table I and further structural data is given in Table II.

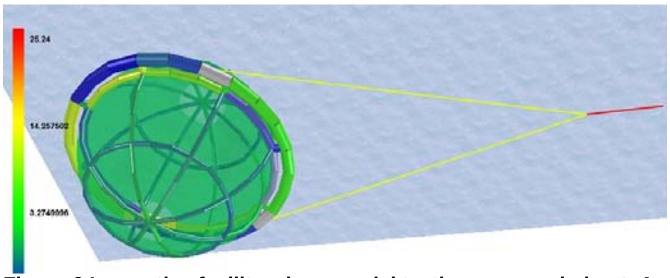

Figure 6 Innovative facility where model testing was carried out. A net (mesh) is spawn by vertical and horizontal tubes.

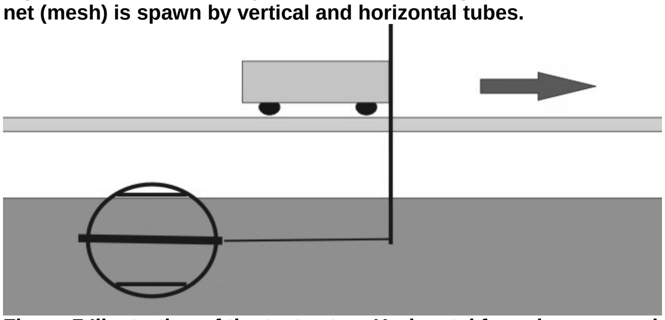

Figure 7 Illustration of the test setup. Horizontal force is measured where the nylon cable is split in two as seen in Figure 6.

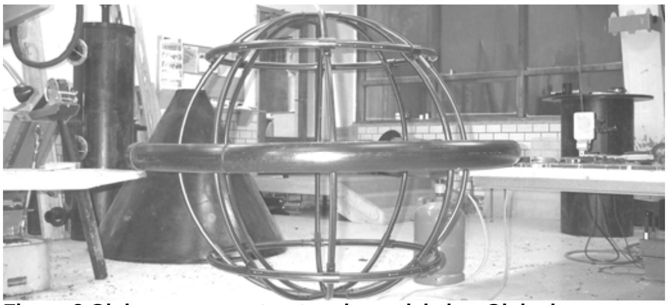

Figure 8 Globe sea cage structure in model size. Globe is seen before mesh (net) is installed.

Morison loads have been applied to all submerged details. The vertical location of each structural element is compared to the wave elevation at each time instant and only if the element is submerged at the specific time instant fluid forces are introduced. Accounting for nonlinear forces due to the structure intermittent submergence is an option in AquaSim.

Table I Overall data for the globe

Diameter (*D*) of globe	1.2 m	*D*, Upper and lower hor. Rings	32 mm
D, vertical rings	25 mm	Solidity of mesh	0.24
D, inner horizontal centre ring	63 mm	Drag coefficient, mesh	1.2
D, Outer horizontal centre ring	90 mm	Drag coefficient, rings	1.0

Total weight of globe excluding net membrane in air is 53,7 kg. The polyethylene material of the ring has a mass density of 0.96 giving a total weight of 19 kg. Sand is evenly distributed totally 7.4 kg. in the vertical rings, 2.8 kg. in the lower horizontal ring and 13.9 kg. in the centre ring. Lead weights are distributed along the outer centre ring, in total 10.7 kg. Structural and material properties of the globe are given in Table II. The added mass coefficient is 1.0 for all rings and cable. For the membrane a drag coefficient of 1.2 is used. The added mass coefficient is set to 1.0. The relative mass density of the mesh and the cable is 1.14.

Table II Structural and material properties of globe structure

Structural properties of globe	Value
Material thickness, vertical rings	2.3 mm
Material thickness, inner horizontal centre ring	5.8 mm
Material thickness, outer horizontal centre ring	5.1 mm
Material thickness upper and lower centre ring	3.0 mm
Material thickness nylon cable	2 mm
Young's module, rings	0.8 GPa
Young's module, membrane	1.0 GPA
Young's module, nylon cable	1.0 GPa
Shear module rings	0.28 GPa
Distance from centre of globe to end of nylon cable	11 m

The upper horizontal ring is located at tangential to the water line. In the AquaSim model the water plane area of this ring is not taken into account. Buoyancy of the vertical rings has been accounted for by introducing a buoy at the top of the model, with the buoy having a water plane area of 50 cm^2. This buoyancy is assumed constant irrespective of the vertical location of the globe. This represents an approximation as this buoyancy for the globe is nonlinear with respect to vertical locations relative to the wave surface. The buoyancy used in the present case represents an average value. This is further discussed in Ytterland (2003).

In the AquaSim model, the relative weight of all the rings are set to 0, apart from the upper and lower horizontal beam which have an evenly distributed vertical force of 14 N upwards and downwards, respectively. The centre horizontal ring is modeled 424.4 mm below the mean surface and the free surface is located 175.6 mm above the mean surface.

Test conditions

Table III shows the considered test conditions. Totally 9 conditions have been considered, 3 considering forward motion of the test rig on calm water and 6 considering forward motion in combination with waves. The model sea states reflect rough offshore sea conditions in the full scale.

Table III Test conditions

Test condition	Wave height	Wave period	Test rig velocity
1	0 m	NA	0.05 m/s
2	0 m	NA	0.11 m/s
3	0 m	NA	0.22 m/s
4	0.07 m	1.3 s	0.11 m/s
5	0.07 m	1.3 s	0.22 m/s
6	0.13 m	1.6 s	0.11 m/s
7	0.13 m	1.6 s	0.22 m/s
8	0.2 m	2.9 s	0.11 m/s
9	0.2 m	2.9 s	0.22 m/s

Results

Figure 9 shows a comparison between calculated and measured axial force in the cable connected to the test bridge as shown in Figure 7. As seen from, calculated results correspond very well with measurements. Results are within a difference of 10 % to the measured results.

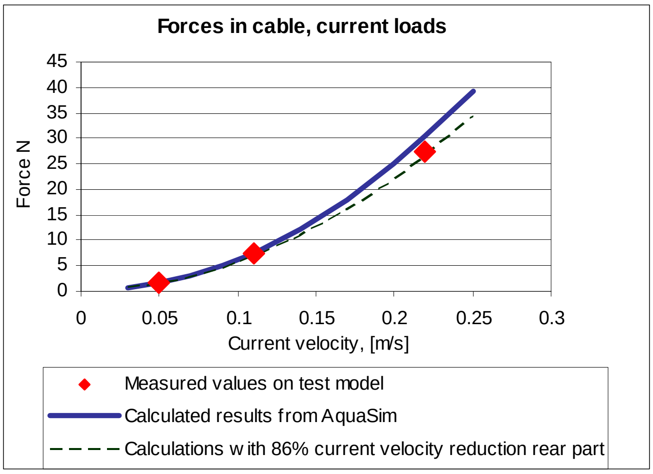

Figure 9 Results comparing measurements with calculated results, test condition 1, 2 and 3.

The calculations seen in the solid line in Figure 9 have not accounted for velocity reduction in the rear part of the globe caused by water flowing through the forepart of the globe. Løland (1991) has proposed a simplified formulae for velocity reduction behind meshes. This formulae gives 14 % current velocity reduction in the rear part. Results when velocity reduction has been introduced are shown in the dashed line in Figure 9. As seen from this figure the results applying this formulae is slightly on the lower side compared to test results. The Løland(1991) reduction formulae has not been used in the further results presented in this paper.

In load condition 4-9 the test rig is moved forward opposite the direction of waves. The wave and test rig velocities considered are given in Table III. Figure 10 shows an excerpt of a response time series for load case 7. As seen from this time series force amplitude as well as the mean value of each cycle varies. The pattern of variation is different for the different load conditions considered. This can be seen further in Ytterland (2003).

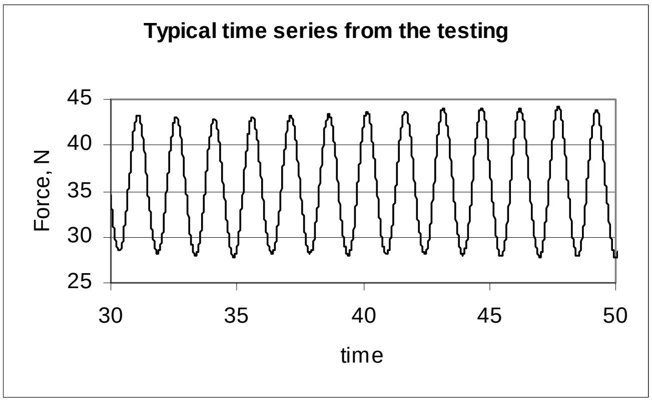

Figure 10 Excerpt of time series load condition 7.

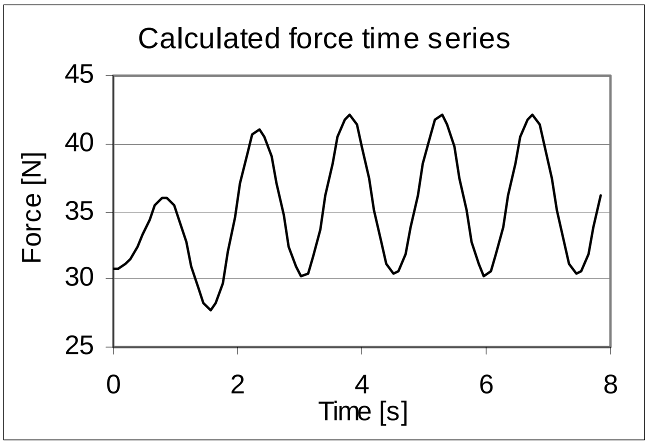

Figure 11 Force in cable as a function of time calculated in AquaSim. Load condition 7.

Figure 11 shows a calculated time series of load condition 7. Comparing Figure 10 and Figure 11 it is seen that the maximum calculated force in the cable corresponds well with measurements. For this load case the lowest force during a load cycle is higher in AquaSim than in the results derived from the tank testing. Probable origins for deviations between measured and calculated results are discussed later in the paper.

Figure 12 shows maximum amplitudes in the time series calculated using AquaSim compared to corresponding measured values. For measured values it is not accounted for the part of the time series where the test rig is increasing or decreasing velocity.

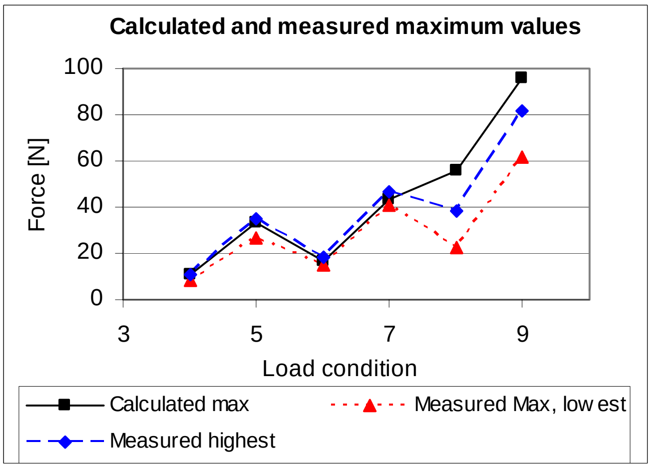

Figure 12 Maximum values in the time series calculated by AquaSim compared to measured values from tank testing

As seen from Figure 12 calculated maximum values compares very well with measurements, and they are generally in the high end.

Figure 13 shows calculated and measured minimum values. As seen from Figure 13 calculated values are in general within or close to the range of measured values. Calculated forces depend strongly on the Young's modulo of the nylon cable. Figure 14 shows calculations carried out varying the Young's modulus for the nylon cable. As seen from the figure, cable forces depended strongly on this. For the nylon cable used in the testing, some variation in the Young's module was seen as reported in Ytterland (2003). The linearized value used in the calculations represents an approximation and hence some deviation between measured and calculated results should be expected. As seen from Figure 12, Figure 13 and Figure 15 the deviation is small suggesting the value used in the calculation is a representative value.

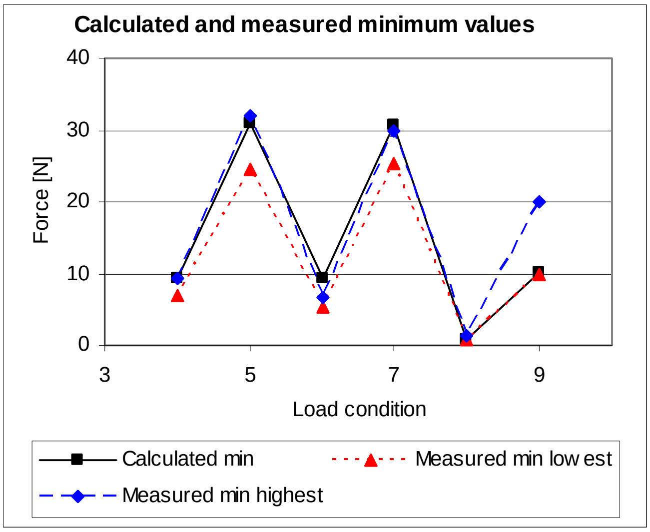

Figure 13 Minimum values in the time series calculated by AquaSim compared to measured values from tank testing

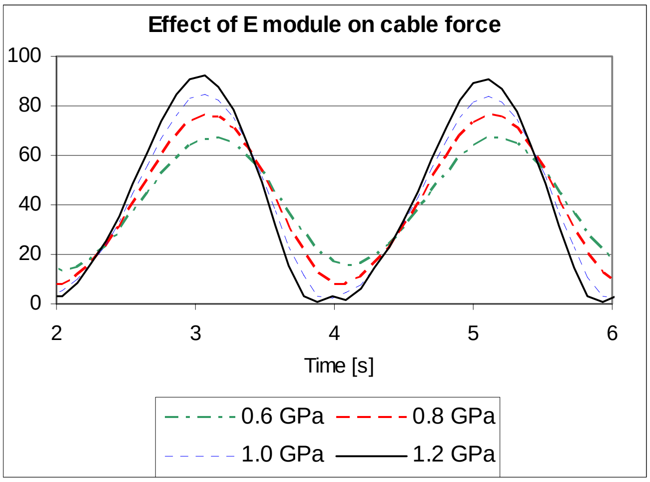

Figure 14 Force in nylon analysed nylon cable as a function of time depending on Young's module used in the calculations

Figure 15 shows mean values and amplitudes both measured and calculated. The lines shows mean values. It is seen that calculated mean values in general are to the conservative side relative to measurements. In load case 9 the maximum values in the load measurements were truncated (see Ytterland 2003). Mean values as well as maximum values for this load case have been estimated based on extrapolation.

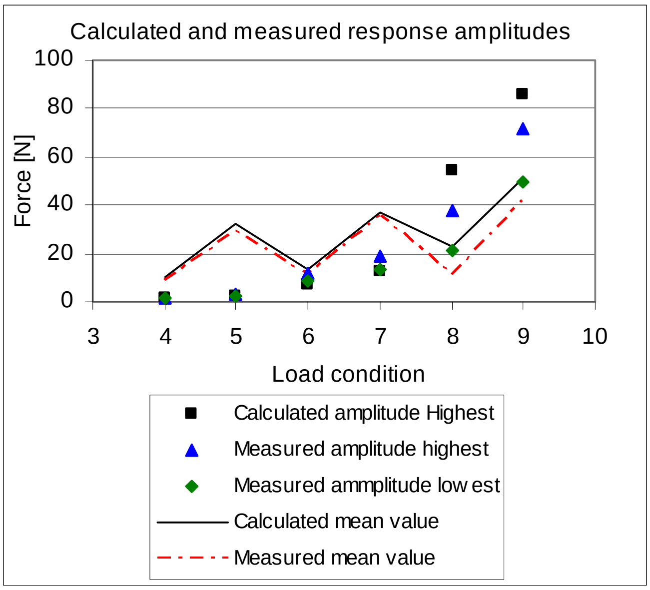

Figure 15 Calculated and measured mean values and amplitudes load case 4-9. Dots shows response amplitudes and the lines shows mean values.

Figure 16 shows measured and calculated amplitudes of heave motions for load condition 9. Figure 17 shows the same as Figure 16 but for load condition 7.

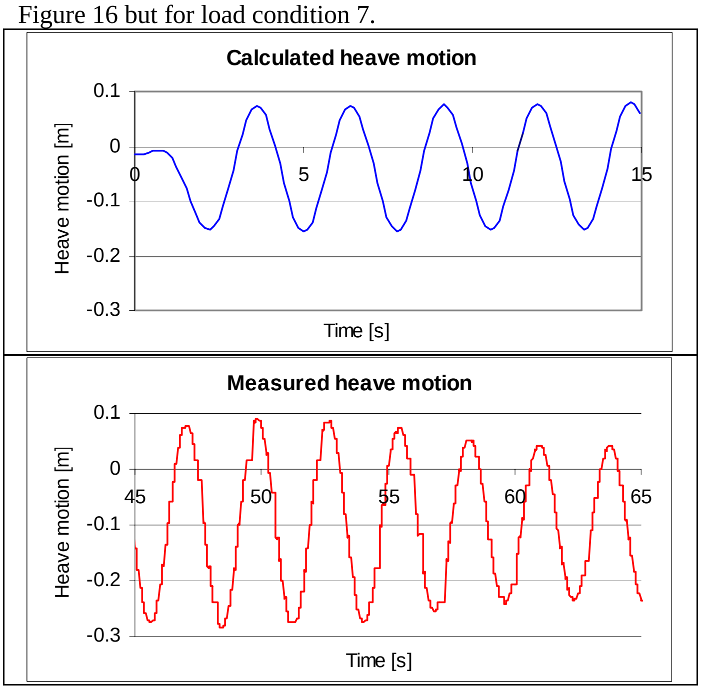

Figure 16 Heave motions. Load condition 9. On the upper figure, calculated values are shown. In the lower tank test measurements are shown.

As seen from Figure 16 and Figure 17, the heave motions are lower in the calculations than in the measurements. This is because the complex nonlinear buoyancy has been simplified in the AquaSim model. This effect is considered in Figure 18. In this figure results have been compared for two numerical models. The original model as well as one model where the buoyancy of the upper horizontal ring is added to the buoyancy caused by the vertical rings. As seen from this figure this change in numerical model has a strong influence of the amplitude of the heave motion. It is seen that the measurements falls within these two models. This shows that both effects most probably are present in the laboratory test results. A more detailed simulation of this effect in the numerical model requires a more detailed modeling than what has been carried out in the present study

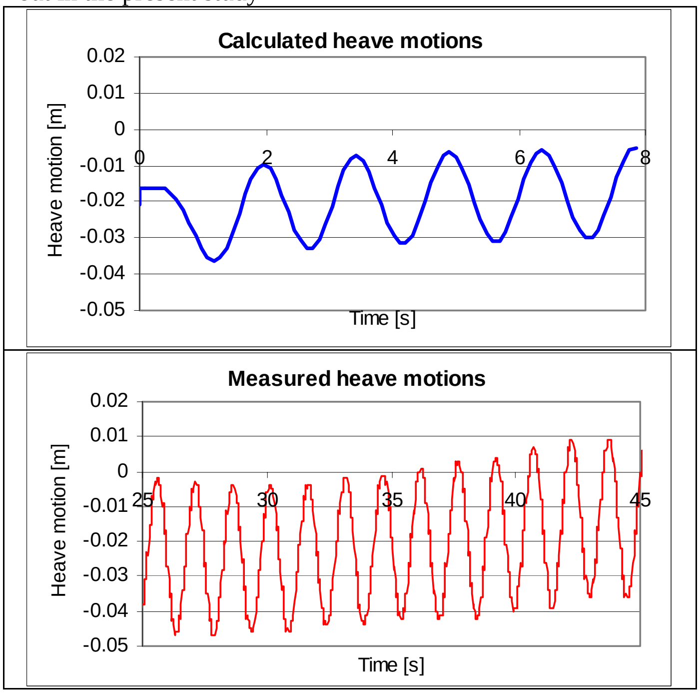

Figure 17 Heave motions. Load condition 7. On the upper figure, calculated values are shown. In the lower tank test measurements are shown.

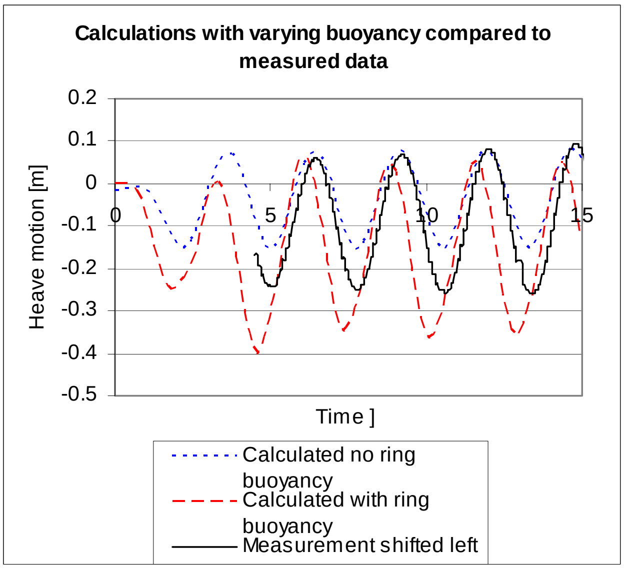

Figure 18 Results for two different models with varying buoyancy of the globe compared to measured data. The measured data are and excerpt from the full time series and have been shifted left.

Figure 19 shows surge motions for load condition 9. As seen from the figure, results correspond very well with measured amplitudes in general slightly higher than calculated. In the measured data a slight envelope can be observed. A similar effect can be observed in other measured data. This may be originated by startup effects of second order wave effects, or wave reflection in the testing tank. Such effects are not accounted for in the numerical calculations.

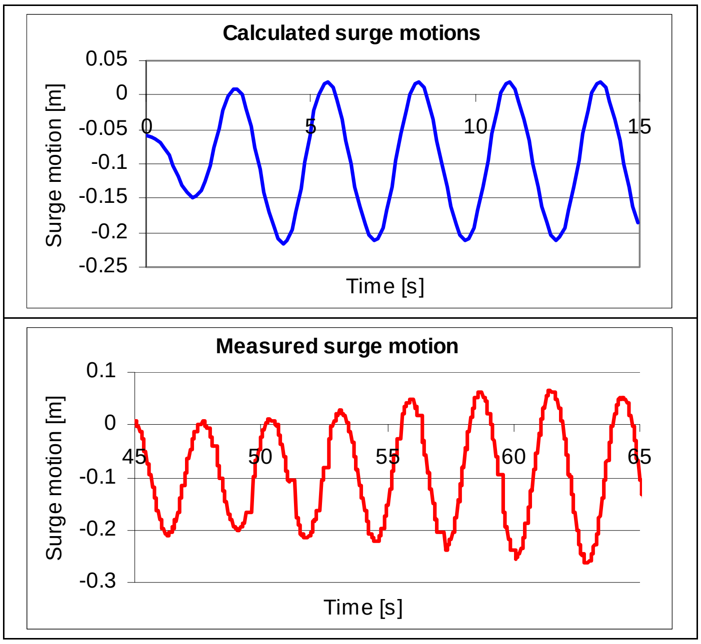

Figure 19 Surge motions. Load condition 9. The upper figure shows calculated values and the lower figure shows measured data.

Conclusions

An algorithm and software tool for calculation of marine fish farms has been established. The capability of this tool to investigate response of a wide range of fish farm facilities has been demonstrated.

Model testing has been carried out for a novel design and response from waves and current have been compared to results calculated by the computer simulation program, AquaSim. The results show good agreement. It is shown that forces depend strongly on the stiffness of the cable attaching the globe to the test rig. Transferred to full scale conditions this means that the length of anchor line cables is of large influence for the forces in the structure. It has been shown how variation in parameters such as line stiffness or buoyancy can be investigated by AquaSim.

Numerical calculations have been carried out for a capsized marine fish farm. The results showed that the present fish farm at this location did not have capacity to cope with the wave environment at its location.

In order for reduce structural failures for new fish farms, design rules for such facilities have been introduced in Norway. The calculations carried out in this paper demonstrate the necessity for such rules.

ACKNOWLEDGMENTS

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REFERENCES

Aquastructures (2003a) Norwegian: “Havari av oppdrettsanlegg i Finnmark” (Trans: Capsizing of a marine fish farm in Finnmark, Norway). Aquastructures report 2003.

Aquastructures (2003b): Norwegian: Regelsjekk av oppdrettsanlegg i henhold til prNS 9415. English: ”Rule cheque of marine fish farm according to prNS 9415” 4 reports Aquastructures 2003.

Berstad, A. J. (2003): “Verification and benchmarking of AquaSim, a softwaretool for safety simulation of flexible offshore facilities exposed to environmental and operational loads”. Aquastructures report 2003-002.

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

Fredheim and Faltinsen (2003) “Hydroelastic analysis of a fishing net in steady inflow conditions”, Hydroelasticity in Marine Technology, Oxford, UK.

Lader, P. F., B. Enerhaug, A. Fredheim and J. Krokstad (2003) “Modelling of 3D Net Structures Exposed to Waves and Current”, Hydroelasticity in Marine Technology, Oxford, UK.

Halse, K. H. (1997) “On Vortex Shedding and Prediction of Vortex-Induced Vibrations of Circular Cylinders.” Phd. Thesis. Department of Marine Structures, Faculty of Marine Technology, Norwegian University of Science and Technology (NTNU).

Langen, I. and R. Sigbjørnsson (1979) "Dynamisk analyse av marine konstruksjoner",
TAPIR forlag, Trondheim Norway.

Løland, G. (1991) Current forces on and flow through fish farms. Phd Thesis. Department of Marine Hydrodynamics, , Faculty of Marine Technology, Norwegian University of Science and Technology (NTNU).

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.

NAS(2003): “NS 9415 Marine fish farms – requirements for design, dimensjoning, production, installation and operation”. Publisher: Standards Norway, Pronorm AS Postboks 252, 1322 Lysaker, Norway. http://www.standard.no.

NMF (2003) “FOR 2003-08-12 nr 1052: Forskrift om krav til teknisk standard for anlegg som nyttes i oppdrettsvirksomhet” (English: Regulation concerning requirements for the technical standard for installations which are used in fish farming activities) Norwegian Ministry of Fisheries. Postboks 8118 Dep, 0032 Oslo.

Salvesen, N., Tuck, E.O. and Faltinsen, O. (1970) "Ship motions and sea loads", Transactions, Society of Naval Architects and Marine Engineers, New York, 78, 250-287.

Tronstad, H. (2000) “Nonlinear Hydroelastic Analysis and Design of Cable Net Structures Like Fishing Gear Based on the Finite Element Method” PHd thesis. Institute of Marine Technology NTNU, Trondheim.

Ytterland, Anders (2003), "Hydrodynamisk analyse av *Utaskjærs kulemerd* – et anlegg for fiskeoppdrett i åpne havområder", Msc thesis. Institutt for marin teknikk – faggruppe marin prosjektering, NTNU, Trondheim.