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The Structural Response Investigation of Modular Pontoon Collar Floating Cage due to Current Load to Support Fish Farming Activities

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Abstract. The size of net cages increases rapidly, reaching volumes above current experience. More exposed locations are used for fish production, introducing higher loads on the net cage and fish farm from strong water currents and large waves. Strength analysis can be a useful tool for development of net-cage designs to avoid escape of fish and ensure sufficient volume for good fish welfare and water quality. The main objectives of this research are to investigate the structural response of modular pontoon collar floating cage due to the current load to support the fish farming activities. Strength analysis was performed using commercial explicit finite element software to calculate the distribution of loads in the net cage due to current, weights and gravity. The net cage was modeled using truss elements that represented several parallel twines. Sub-elements allowed the trusses to buckle in compression, and only negligible compressive forces were seen in the numerical results. Resulting drag loads and cage volume were shown to be dependent on the net cage size and collar shape.

1 Introduction

Good practical cage designs should resolve engineering and cost considerations with the requirements of the species being farmed and those of the farmer who must operate the system. Cage structures must withstand the forces of winds and waves while holding stock securely. The design is important to the fish in that it both circumscribes living space and, within the site chosen, influences environmental quality inside the cage. From the farmer's point of view, the cage must be safe, secure and easy to manage. All of this must be achieved cost-effectively.

Net cages for aquaculture have traditionally been dimensioned and produced based on empirical data, [1]. However, the requirements for documentation of net-cage strength and volume increase, and the need for the development of methods for structural analysis arises. In addition, fish farming is developing outside the borders of experience. The size of net cages increases rapidly, reaching volumes above current experience. More exposed

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locations are used for fish production, introducing higher loads on the net cage and fish farm from strong water currents and large waves. Strength analysis can also be a useful tool for development of net-cage designs, [2], to avoid escape of fish and ensure sufficient volume for good fish welfare and water quality.

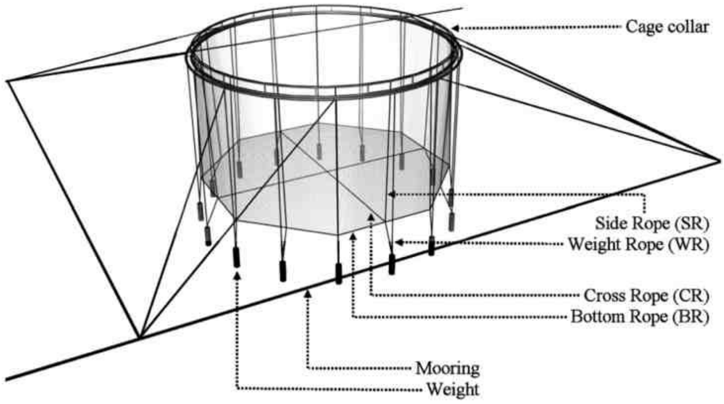


Fig. 1. Illustration of circular collar floating cage.

It is not straightforward to analyze a fish farm or a single net cage (**Fig. 1**). The loads acting on the structure will be the result of a fluid-structure interaction between moving sea-water and the deformed net. Analyses of net cages involve a high degree of non-linearity, both in loads, deformation and sometimes also material properties. In addition, loads from waves and current, damping and inertia loads are complex to model for netting materials in a general Finite Element Analysis (FEA) program, while programs with appropriate load modules often have shortcomings in the structural model. There is ongoing work to verify and develop CFD methods for flow around net structures. This work reveals the complexity of such flows and the need of new knowledge and methods, thus, the only current option is to use methods to calculate loads from moving fluids on netting structures, such as Morison's equation or equations based on tank test results, [3]. However, both these methods currently have limitations concerning amongst other the solidity of the net panel (ratio between the area of the net and total area), deformations and current velocity.

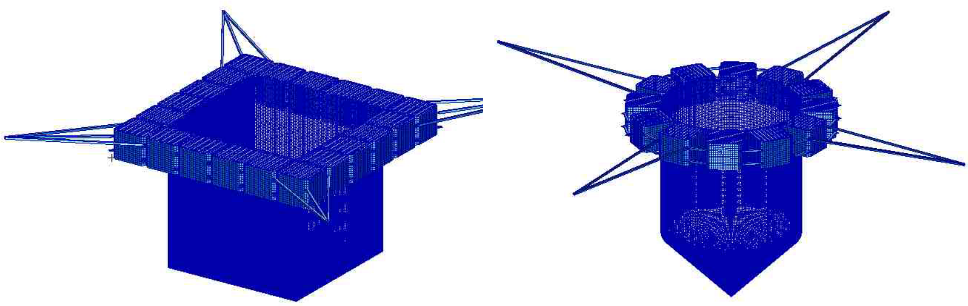
Based on the condition the structural response investigation of Modular Pontoon collar floating cage was proposed to estimate the structural behavior of the floating cage due to the current load. Our approach to structural analyses was to apply commercial FEA software, which could include various material models and ensure effective modelling, processing and post-processing. In this work, truss elements were applied to model the net cage. The fact that netting and ropes do not take compression was modelled by introducing sub-elements, which combined with an explicit finite element code allowed the elements to buckle in compression.

2 Research Method

In the study of the development of modern cage technology, the articles reviewed were related to the mechanics of floating cages. Tiao-Jian Xu, [4] studied the hydrodynamic characteristics of submerged cages (submersible net cage) and the mooring system on currents and wave. Taeho Kim, [5] conduct engineering studies on the system of cages embedded in the cultivation of abalone shells. The flow characteristics of submerged cage structure were analyzed using the approach of computational fluid analysis (CFD analysis). Hydrodynamic response on the net binding structure investigated using Morison equation and the finite element model (FE model) is used for analysis of fluid-structure interaction (FSI analysis). Trygve Kristiansen, [6] performed experiments and numerical studies on the cage buoyed by considering the influence of waves and currents. Formerly, Trygve also did modeling studies of the current load on the cage, [6]. Li Li, [7] conducted a study hydroelastic nonlinear analysis of the floating cages on a wave of irregular (irregular waves). Heidi Moe, [8] conducted a study on the structural analysis of the influence of the current net cages. Previously, Heidi Moe has conducted studies of the tensile strength of the material used nets to cages, [9].

2.1 Structure Modeling of Floating Cage

Two different models, described in **Fig. 2**, were analyzed.The circular shaped collar model was assembled from modular pontoon unit using a rod hook in forming a circular pattern. For all models, the netting dimensions were equal to typical nets for Nila fish (Oreochromis niloticus). The floating cage net was modeled with truss element. This model was also analyzed using a detailed mesh with one bar for each twine to verify the model simplification. Two full-scale models represented the floating cage using rectangular and circular collar had 131992 and 77563 elements around the circumference, which should be sufficient to capture the global deformations in the net cage.



(a) (b)

Fig. 2. FE Models of the floating cages using modular pontoon collar: (a) Rectangular shaped collar; (b) the circular collar.

2.2 Boundary conditions and loads

The numerical models were subjected to loads representing a uniformly distributed current with constant velocity, *U*, acting in the *x*-direction. The cross-flow principle was applied assuming that the current could be separated into flow tangential and normal to the element axis. The first step in the current load calculation for an element was to decompose *U* into tangential and normal velocity components, U_T and U_N, as shown for an element in the *XZ*-plane. However, most elements were oriented in the *XYZ*-space and subjected to three-dimensional velocity vectors. Each truss element was considered as individual, friction-free cylinders, and tangential force was ignored. The resulting load acting on each truss element was the normal load, F_N, calculated using the drag term of Morison's equation:

$$F_N = 0.5 \rho C_D A_p U_N^{2} \tag{1}$$

where $\rho = 1025\ kg/m^3$ (density of seawater) and C_D is the drag coefficient. A_p is the projected area of the truss element, which is the sum of the projected area for all twines represented by the truss element. $A_p = ndL$, where *n* is a number of twines represented by the truss, d the twine diameter and L the truss length. F_N was decomposed in the X-, Y- and Z-directions and applied as concentrated loads in adjacent nodes. Drag load (F_D) and lift load (F_L) were found as the x and z components of F_N, respectively.

Rectangular collar shaped was analyzed using four different bottom weight configurations: *4* weights of *400*, *600* and *800 gram*s (*3*, *4.5* and *6N* submerged weight) and the circular shaped using *1* weights of *6N*. The weights were attached directly to the netting and equally distributed along the circumference. The floating cage net was subjected to a concentrated load of $1.2\times106\ N$ at the end of each truss element.

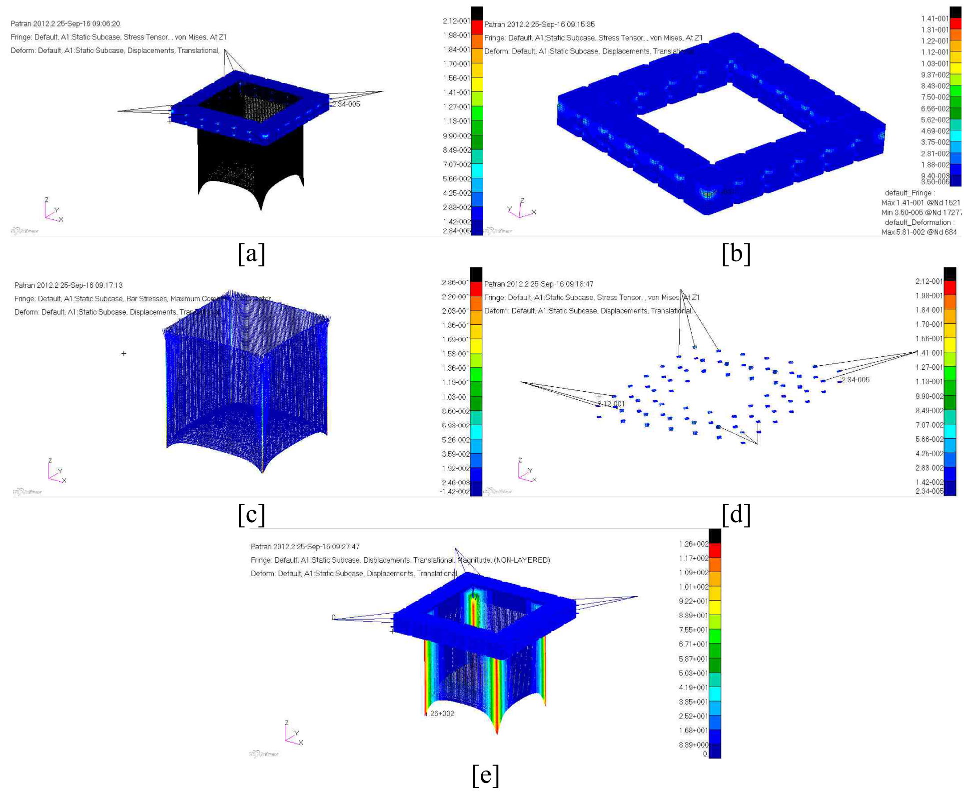


Fig. 3. Numerical results of rectangular collar floating cage: [a] Full model; [b] Rectangular collar; [c] Cage net; [d] Collar connector; [e] Displacement of full model

3 Results and Discussion

3.1 Strength analysis of full-scale net cages

The FE model that has been defined with the loading and boundary condition was analyzed using finite element method. The linear static analysis was chosen to solve the problem case. The structure of the rectangular shaped floating cage was modeled using *310,021* shell elements and *100,971* bar elements. The shell elements were mixed using quadrilateral and triangular elements. The illustration of the results of numerical analysis of rectangular shaped floating cage can be seen in **Fig. 3**. Additionally, the structure of the circular shaped floating cage was modeled using *18,612* shell elements and *58,951* bar elements. The illustration of the results of numerical analysis of circular shaped floating cage can be seen in **Fig. 4**.

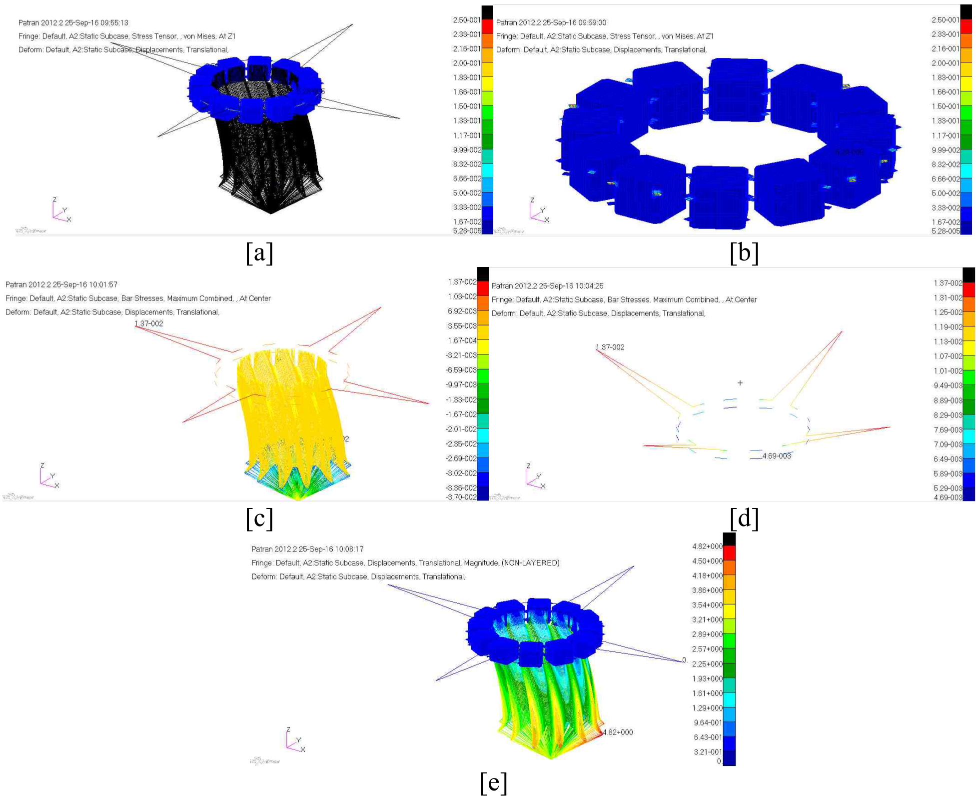


Fig. 4. Numerical results of circular collar floating cage: [a] Full model; [b] Circular collar; [c] Cage net; [d] Collar connector; [e] Displacement of full model

In **Fig. 3** the structural response of the rectangular floating was shown. The maximum stress appeared on the connection between the mooring cable and the floating collar. It can be explained that the stress was induced by the current loads has been responded by the mooring system. These stresses are about 0.212 MPa, significantly smaller than the permissible stress (68.9 MPa). The maximum stress of modular pontoon collar in **Fig. 3[b]** is about 0.141 MPa which was occurred in the same region of the connector of the pontoons (bolted clevis). The maximum stress of the cage net can be seen in **Fig. 3[c]**. The results show that the net has 0.236 MPa that was induced by the anchoring weight of the cage. The exact location of the maximum stress which is located at the connector can be seen in the **Fig. 3[d]**. Finally, the displacement of the floating cage, **Fig. 3[e]** shows that the maximum displacement appeared at the cage net which the anchoring weight is applied.

In **Fig. 4** the structural response of the circular floating was shown. The maximum stress appeared on the connection between the mooring cable and the floating collar. It can be explained that the stress was induced by the current loads has been responded by the mooring system. These stresses are about 0.250 MPa, significantly smaller than the permissible stress (68.9 MPa). The maximum stress of modular pontoon collar in **Fig. 4[b]** is about 0.250 MPa which was occurred in the same region of the connector of the pontoons (bolted clevis). The maximum stress of the cage net can be seen in **Fig. 4[c].** The results show that the net has 0.0137 MPa that was induced by the anchoring weight of the cage.

The exact location of the maximum stress can be seen in the **Fig. 4[d]**. Finally, the displacement of the floating cage, **Fig. 4[e]** shows that the maximum displacement appeared at the cage net which the anchoring weight is applied.
As expected, the results of the strength analysis show that both structure of modular pontoon collar floating cage is reliable to support the current load and anchoring load. The maximum stress occurred at the connector of the pontoons, the stresses are about 0.212-0.250 MPa essentially smaller than the permissible stress 68.9 MPa. It is indicated that the structure of the modular pontoon collar floating cage is reliable for supporting the current load in the aquaculture activities.

4 Conclusion

The evaluation of the floating cage strength was calculated using finite element method comprising, to build FE model (meshing), to define the load and boundary conditions, to define the material properties and structure scantlings. Full load condition was selected for the strength analysis since the condition was the most severe condition for the pontoon structure.

In the case of rectangular shaped collar floating cage, the maximum stress was 0.212 MPa which was occurred at the connector of the pontoons, significantly smaller than the permissible stress (68.9 MPa). The maximum stress of the cage net was 0.236 MPa which is induced by the anchoring weight. Additionally, the maximum displacement of the floating cage was 126 mm

In the case of the circular shaped collar floating cage, the maximum stress was 0.250 MPa which is occurred in the similar region as the rectangular shaped. The maximum stress of the cage net was 0.0137 MPa which is smaller than the stress of the rectangular shaped floating cage net. Finally, the maximum displacement of the floating cage was 4.82 mm. Accordingly, it can be concluded that the structure of rectangular and circular shaped collar of the floating cage is reliable for fish farming activities.

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