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Research Article

A Numerical Simulation of Full 3D Model of Net-Cage Structure - Mooring Line Tension

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Abstract

As the mariculture is expanding more to the offshore location because of the limitations of the space in near shore locations it becomes necessary to predict the behavior of the fishing cage structure when it is exposed to the more harsh environmental conditions of offshore region. The proposed model is a fully 3D dynamic model of fishing net with floaters and sinkers. The model is based on a super-element formulation where the net structure is divided into four-sided super-elements interconnected in each corner node. The model is simulated and analyzed by OrcaFlex software which is a 3D non-linear time domain finite element program capable of dealing with arbitrarily large deflections of the flexible from the initial configuration. In the present study the results analyzed are the behavior of mooring line in various waves and current conditions. Also the effect of different sinker systems is investigated.

Keywords: *3 D Flexible net, Mooring tension force, Numerical model, Oblique waves, Offshore Fishing Cage, OrcaFlex, sinker system, Waves and Current*

1. Introduction

Mariculture is continuously progressing towards the offshore region due to unavailability of near shore space and freshwater to install the cage and to continually increase the productivity. It is also important to recognize that mariculture is affected by environmental degradation of coastal and open ocean waters, for example by toxic pollution, which can harm aquatic animals and lead to concerns about food safety so the expansion of aquaculture into deeper and farther offshore waters is a high priority.

As the cages are being installed at offshore locations they are more exposed to waves, wind and current and placed different demands than nearshore location. In this context, it is necessary to understand the behavior of the structures as they are exposed to large sea-loads from waves and current. These can cause serious deformation of the fishing net and the effective volume of the net cage reduced sharply which is disadvantageous to fish comfort. Numerous studies have shown that, the force on cage net is proportional to the square of the flow velocity. Even if small velocity differences exist, this may lead to great force differences. So in the investigation on the forces acting on the net cage, the flow velocity distribution around the cage net usually cannot be ignored.

Offshore cages are complex flexible structures with infinite number degrees of freedom. This makes it necessary to develop new numerical tools for simulating the behavior of such structure.

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To investigate the performance and reliability of the net cage structure, there were several research efforts on net cage structure proposed to predict the dynamic behavior of 3D net structures which is based on a super-element formulation where the net structure is divided into four-sided super-elements interconnected in each corner node, the hydrodynamic and structural forces are calculated on each super-element (Lader, 2001). Structural forces were calculated by assuming that each element consists of six nonlinear springs, interconnecting each node to the other three (Lader and Enerhaug, 2003). To analyses the net deformation for different steady current velocities a flexible circular net with different weights attached to the bottom is modeled (Lader and Enerhaug, 2005). The structural and hydrodynamic forces were calculated of a flexible net sheet when exposed to waves and current by dividing it into super elements for each element (Lader and Fredheim, 2006). The numerical model may underestimate the environmental forces on a net-cage system if the Reynolds number is lower than the suggested range of 1400–1800 (Chai-Cheng Huang *et al,* 2006). By developing a specially designed tube-sinker to replace the bottom weights, volume reduction coefficient can be estimated (Chai-Cheng Huang *et al.,* 2007). Wave behavior predicted when it moved through net with several different regular wave cases with different solidity and wave geometry (Lader and Olsen *et al.,* 2007). Mooring tension calculated by considering the approach of velocity reduction and load characteristics that occur through the net pen system for both clean and fouled net conditions by developing a numerical model of fish farm (David W. Fredriksson and Judson *et al.,* 2007). Dynamic behaviors

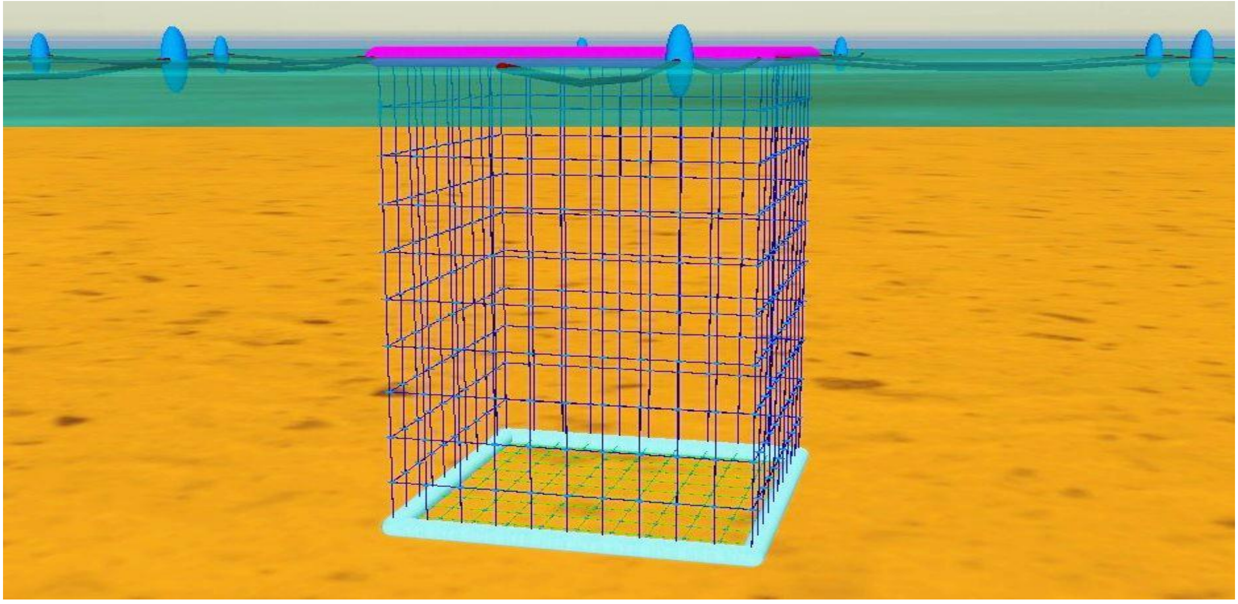


Fig.1 Numerical model of Net cage structure

of the net-cage system analyzed when impinged upon by surface waves from various angles over a uniform current and maximum tension of the mooring lines and the minimum volume reduction coefficients of the rearing system were analyzed (Chai-Cheng Huang and Hung-Jie Tang *et al.*, 2008. Experiments on drag forces on net panels, model-scale cages, the biological effects of fish, fish movements and fouling as the major topics (Pascal Klebert and Pål Lader *et al.*, 2013). A prototype of fish cage was designed and simulated in a towing tank under different waves and current load conditions to calculate the tension on the mooring chain and drag coefficient for the cage net twine was estimated (V. A. Sadhan and V. Nagarajan *et al.*, 2014).

Our analysis is based on the concepts of the lumped-mass method, which decomposes the whole net-cage system into several nodes and elements, with each element subjected to environmental forces that are evenly distributed onto the corresponding nodes. The study considers various conditions of waves over a uniform current that impinge on the cage from various directions. The objective of this paper is to consider the combined effects of waves and currents on the behavior of a mooring system of offshore net cage structure.

2. Model Description

2.1 Assumptions

Model is composed of many meshes, and each mesh can be regarded as a construction of four mesh bars connected each other at their two ends as shown in Fig. 1. In order to build up the numerical model, the following assumptions are used:

(1) There is only tension in the axis direction of a mesh bar and the tension is constant across the cross-section of the mesh bar.

(2) The relative displacements of all points on the cross-section of the mesh bar are equal.

(3) The cross-sectional area of the mesh bar remains constant during deformation.

(4) The netting twine is completely flexible and easily bent without resistance.

2.2 Building the Model

The important result for this model is the behavior of the net as a complete entity. This allows the net model to be simplified in two ways: the net mesh needs to be modeled in sufficient refinement to show the distribution of loading. This means an equivalent mesh can be generated that has the same resultant loads but does not need to show each individual knot and line. This is basically the same as defining the mesh refinement on a surface for an FE model. Detailed motions at each knot and the length of rope between are not required. Therefore the lines can be single segment and the knots can be 3DOF buoys. Pinned connections between the two can be used because bend stiffness is negligible so moment transfer would be too. These nets are suspended below floating rings. Again single segment lines are used. However the plastic ring does have bend stiffness so the bending moments need to be transferred. Therefore 6DOF buoys and built in connections (end connection stiffness of Infinity) are used. The whole structure is then moored using mooring lines.

2.3 Features of Offshore Fishing Cage Structure

The modeled fishing cage consists of nets, floating collars, weights, buoys and mooring lines as shown in Fig. 1

3D netting system is a closed space in which the fish can grow formed by a floating collar with a fish net underneath. The floating collar consists of a concentric double tube with a set of stanchions and a handrail on the top. Thus, the floating collar can be used as a working platform when fish farm workers want to inspect the growing conditions inside a net cage. The floating collar also supports the flexible net and is fastened to the mooring lines at each corner. The main purpose of the mooring system is to fasten net cages at a specific location and to prevent cages from drifting away as environmental loadings act on them. Therefore, the strength and durability of the material used for mooring lines are important factors. A mooring system failure can occur if the cage system encounters severe environmental forces. To reduce the impact forces that affect mooring lines, distance buoys (outermost buoys) are installed in front of cages to absorb these undesired forces so that forces will not directly hit the mooring lines.

3. Simulation

Numerical model of fishing cage system is modeled and simulated in OrcaFlex with different conditions of waves and current to analyze the influence of the environment on the mooring line system of fishing cage at water depth of 30m and, Table 1 shows the model specification which is used in simulation.

Table 1 Specification of a typical net cage system

Parameters	Size and Properties	Material
Fishing Net		**Nylon 210D/96**
Net depth (m)	5	
Twine diameter (m)	0.0085	
Mess size (m)	0 .5	
Elastic coefficient (N/m^2)	350900	
Floating collar		**HDPE**
Pipe diameter (m)	0.2	
Pipe thickness (m)	0.05	
Inner-collar circumference (m)	12	
Outer-collar circumference (m)	18	
Total mass (kg)	432	
Tube-sinker		**HDPE**
Tube diameter (m)	0 .1	
Tube thickness (m)	0.05	
Circumference (m)	12	
Total mass (kg)	427	
Mooring lines		**Nylon rope**
Diameter (m)	0.05	
Breaking strength (kN)	413	
Unit mass (kg/m)	304/200	
Main rope (m)	3	
Distance rope (m)	2	

3.1 Results and Discussion

3.1.1 Effects of Waves and Currents

Four cases analyzed to illustrate the effects of waves and current on the cage structure. Table 2 shows the environmental parameter used in analyses.

At a constant wave period, the higher waves created higher tension on the mooring line (i.e., higher waves had a stronger impact on the fishing cage).

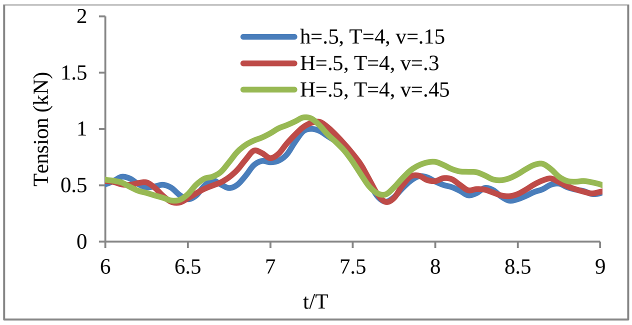
The fact that waves with higher wave steepness creates a more powerful impact force on the mooring system because the shortest wave period has the fastest fluid particle speed near the water surface.

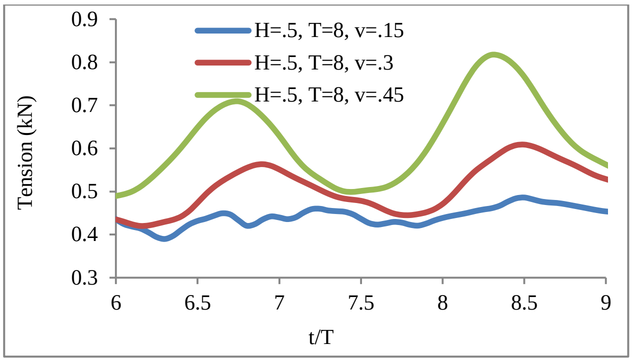
Table 2 Environmental parameters

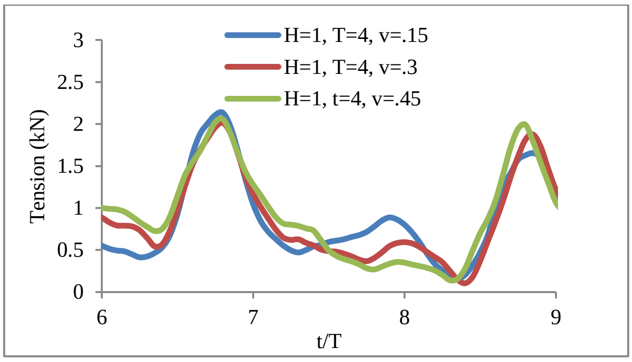
Cases	Uniform Parameters		Variable Parameters
	Wave height (m)	Wave period (s)	Current speed (m/s)
Case: 1	0.5	4	0.15, 0.3, 0.45
Case: 2	0.5	8	0.15, 0.3, 0.45
Case: 3	1	4	0.15, 0.3, 0.45
Case: 4	1	8	0.15, 0.3, 0.45

According to Morison Equation, the drag force acting on the cage is proportional to fluid velocity, and that is why the wave with shorter period had a larger impact force on the cage system and in turn transmitted the resultant forces to the mooring lines thus higher mooring tension.

In addition to the impact of sea waves, the influence of current is an important factor that affects mooring line tension, the maximum difference in mooring line tension caused by current speed 0.45 m/s (with H=1, T=8) is approximately 1.28kN, which is quite significant when compared to the maximum difference of 0.45kN at 0.15 current speed as shown in Fig. 2.







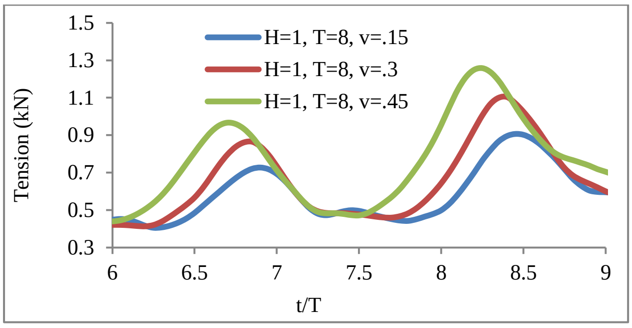


Fig.2 Maximum mooring line tension for a fishing cage system induced by various wave–current conditions

3.1.2 Effects of weight system

To maintain the fishing cage floating fishing cage is equipped with a floatation system on the top and to maintain the balance of buoyancy and weight of the structure a weight system is applied on the bottom. These systems also ensure that the cage maintains its volume during the fluid structure interaction which causes the death of the fishes inside the cage due to lack of oxygen which causes because of the large fishing net deformation.

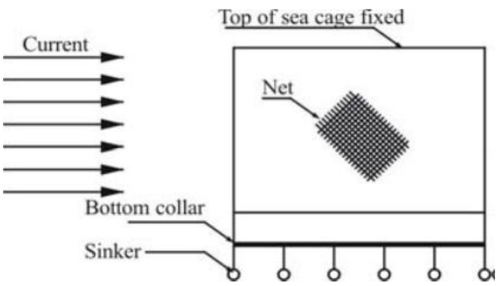


Fig.3 Schematic diagram of a sinker system and bottom collar system

To reduce the deformation an extra weight can be adding in the bottom but increase in weight can cause more tension the fishing net as shown in Fig. 4 then there will be chances of the breakage of the net means complete system failure

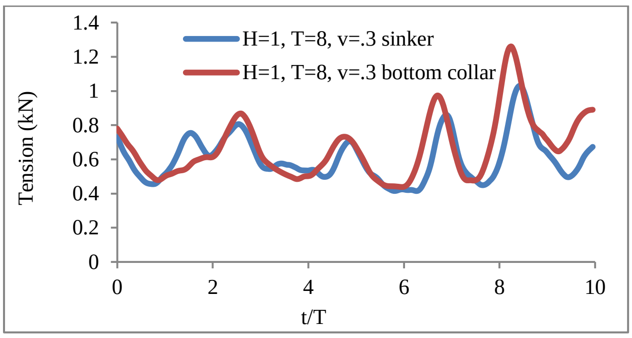


Fig.4 Effect of sinker system and bottom collar system on mooring line

Fig.3 shows the two common ways to increase the bottom weight (1) bottom collar (2) sinker system. Bottom collar is the circumferential tube around the bottom of net and sinker system is the suspension of some weights from the bottom of the net at specific positions. It is also investigated by Chun-Woo LEE, Jihoon Lee, Inhyun LEE, Bo-Hyong LEE and Hee-Jung KIM that bottom collar maintains the shape of the cage more effectively than sinker system but it causes higher tension in the net.

3.1.3 The effects of oblique waves on fishing cage

Modeling a well-designed cage system requires detailed examination of all possible wave–current effects on the system. In the open ocean, waves propagated along various directions in the open sea, and it will affect the behavior of grid cage structure. Therefore, two different wave directions are considered in this section.

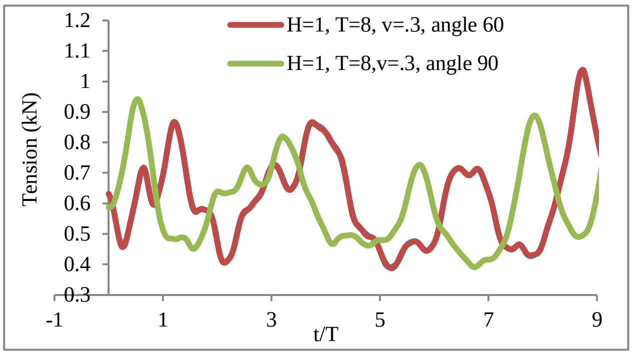


Fig.5 Maximum mooring tension on fishing cage systems exposed to oblique waves and currents

Concerning the symmetrical characteristics of mooring cage structures, wave directions of 60° and 90° are chosen. We assumed that uniform currents flow only in the positive x-axis direction but that incident waves propagate at various apparent angles.

When the cage is oriented at $\theta = 0^o$ and 90^o the movement of the net is confined to the xz and yz- plane respectively all forces on the elements lies in this plane and structure faces forces from either x or y direction. From the Fig. 5 we can see that when the wave direction is 60o structure faces the highest load because of the forces have component in both x- direction and y- direction directions.

3. Conclusions

The model is relevant for use in the design of marine fish farms, as new design rules require assessment of dynamic wave induced loads on such structures. The move towards utilization of locations with increasing exposure to waves and current makes it important to have predictable numerical tools in the design process.

1) Increasing mass of weight system can effectively reduce the net deformation, but the effect of increasing mass of weight system is significant on the increase of total mooring force on net cage.
2) Waves with higher wave steepness (H/ L) (e.g., wave height H is fixed and the wave length L is proportional to the wave period T; thus, the shorter

wave period will have the higher wave steepness) created a more powerful impact force on the mooring system.

3) Structure faces the highest load when wave direction is not parallel to the structure i.e. in this situation structure withstand both component of load in x-direction and y-direction.

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