ARTICLE IN PRESS

Journal of Fluids and Structures ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Journal of Fluids and Structures

journal homepage: www.elsevier.com/locate/jfs

Experimental and numerical study of an aquaculture net cage with floater in waves and current

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ARTICLE INFO

Article history:
Received 9 January 2014
Accepted 29 August 2014

Keywords:
Aquaculture fish farm
Flexible net cage
Elastic floater
Hydrodynamic load models
Waves
Current

ABSTRACT

The mooring loads on an aquaculture net cage in current and waves are investigated by dedicated model tests and numerical simulations. The main purpose is to investigate which physical effects are dominant for mooring loads, and in this respect, to investigate the validity of different rational hydrodynamic load models. Also structural and numerical aspects are investigated. The model tests are performed to provide benchmark data, while the numerical model is used to study the effect and sensitivity of different load models and parameters.

Compared to a realistic aquaculture plant, the total system is simplified to reduce the complexity. The system does, however, include all the four main components of an aquaculture plant: net cage, floater, sinker weights and moorings. The net cage is bottomless, flexible and circular. It is attached to a circular, elastic floater at the top and has 16 sinker weights at the bottom. The system is nearly linearly moored with four crow feet mooring lines.

The loads are measured in the four mooring lines. A systematic variation of current only, wave only as well as combined current and wave conditions is carried out. The numerical simulation results are first benchmarked towards the experimental data. The mean loads in general dominate over the dynamic part of the loads in combined current and waves, and they significantly increase in long and steep waves, relative to current only. Next, a sensitivity study is carried out. A rigid floater significantly alters the loads in the mooring lines compared to a realistic, elastic floater. The theoretical model for the wave matters. The mooring loads are rather insensitive to a majority of the parameters and models, in particular: frequency dependent added mass of the floater and nonlinear restoring loads. It seems not to be necessary to represent the net cage with a very fine numerical mesh.

1. Introduction

Numerical and experimental work for assessing both steady and unsteady behaviour of aquaculture net cages have been presented during the past decades. It is a highly complex, hydroelastic problem with a large number of moving components where all components behave under mutual influence. Therefore, the total system with net cage, floater, mooring lines

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http://dx.doi.org/10.1016/j.jfluidstructs.2014.08.015
0889-9746/

Please cite this article as: Kristiansen, T., Faltinsen, O.M., Experimental and numerical study of an aquaculture net cage with floater in waves and current. Journal of Fluids and Structures (2014), http://dx.doi.org/10.1016/j.jfluidstructs.2014.08.015

and bottom weights needs to be considered simultaneously. To facilitate our study, each component is simplified to some extent: the net cage is bottomless (in reality it has a bottom net to close the cage), the floater consists of only one ring (not two attached rings, as is mostly used in reality), the sinker weights consist of 16 single point weights (not bottom weight ring, which is mostly used today), and the moorings are in air and nearly horizontal with linear springs (not submerged and with highly nonlinear properties as in reality). Despite the simplifications, the system is still complex, and a particular challenge is the large differences in length scales; the structure is a combination of large- and small-volume bodies. It is not possible to model the associated hydrodynamic problem directly by first principles (i.e. a Navier–Stokes solver). Therefore, *rational* methods are needed.

Our impression of the research on fish cages is that the hydrodynamic part of the problem is often over-simplified, for instance not considering the shadow effect of a net or properly modelling the floater. On the other hand, there are many studies using state-of-the art in structural modelling. It has no meaning to consider a sophisticated structural analysis and at the same time have an over-simplified hydrodynamic model. A number of questions are in this respect open as to *what factors are important when modelling fish farms in waves and current*. What effects are most significant for a considered structural response? The main purpose of the present work is to investigate what effects are, and which are not, dominant with respect to mooring loads. The *validity of different rational hydrodynamic load models* is given the main focus. This requires a numerical model which has to be validated. In this work we have further developed the code presented by Kristiansen and Faltinsen (2012a) to also account for regular wave loads. The net cage is here modelled by a truss model. We have compared this with the structural model used by Lader and Fredheim (2006) and Moe et al. (2010) for a net cage in current. The latter study applied the commercial code ABAQUS. They also applied a 3D truss model, but introduced sub-elements such that the trusses were allowed to buckle, and their method was therefore more sophisticated. When we used the same hydrodynamic model as them, i.e. Morison's equation, we got very similar total horizontal and lift force. Furthermore, the net deformation were similar. The agreement with experiments was unsatisfactory for large current velocity. When using our hydrodynamic screen model that accounts for hydrodynamic shadow and Reynolds number effects, the agreement with experiments become satisfactory (Kristiansen and Faltinsen, 2012a). The latter indicates that our structural model is adequate for our studied problem. In order to study net rupture or snap loads one would maybe need an improved structural model. However, that is not our objective in this paper. The research part of the paper is associated with the error analysis. The question is: what effects are most significant for a considered structural response. In our case, the latter is the mooring loads. It could have been contact between a net and chains, or deformation of a weight ring. When it comes to the hydrodynamic problem of the *floater*, we account for the 3D hydroelastic effects. State-of-the-art uses 2D hydrodynamic strip theory, which does not reflect the physics from a hydrodynamic point of view. The latter effect has been investigated in separate studies (Li et al., 2014). However, in the present study, one question is how does an appropriate hydrodynamic modelling of the floater affect the mooring loads?

Similar fish cage set-ups have been studied experimentally and numerically by Zhao et al. (2007) and Huang et al. (2008). They both demonstrate fair agreement between numerical calculations and experiments for the total mooring line forces. Dong et al. (2010) also considered irregular waves. Xu et al. (2012) studied numerically multiple net cages in waves. Recently, Zhao et al. (2013) developed a numerical strategy to study the flow inside and around flexible fish cages by combining a Navier–Stokes solver with a pressure-drop condition. Two-dimensional studies have also been carried out. A numerical parameter study of a two-dimensional flexible net sheet exposed to waves and current was carried out by Lader and Fredheim (2006). A two-dimensional experimental study was carried out by Bardestani and Faltinsen (2013) with focus on snap loads due to independent motions of the floater and bottom weight when exposed to waves. More references to relevant works are provided in all the mentioned papers.

Common to previous works is that a stiff floater is used (rigid body), and further, there is a rather limited number of wave/current conditions. In the present paper we present a systematic set of wave/current conditions by varying the wave period, wave steepness and current velocity. The floater model has a realistic bending stiffness (it is highly elastic). Dedicated experimental and numerical work is presented. In particular, we apply the three-dimensional linear potential theory wave load model presented by Li and Faltinsen (2012) for the elastic floater, and the screen type of load model for the viscous force on the net presented by Kristiansen and Faltinsen (2012a). This screen model has not previously been applied to net cages in waves, only steady current cases as documented with good agreement to experimental drag and lift of flexible net cages therein.

Error analysis is rarely addressed in the published marine literature, but is an important aspect of scientific investigations. The work provides in our case results and error analyses that are directly useful for engineering analysis. Furthermore, the paper presents new experimental results.

The present paper is organized as follows. First, a description of the dedicated experiments are described in Section 2. Next, the numerical model of the net cage, floater, and how the equations of motion for these are coupled is explained in Section 3. Last, numerical results are compared with the experimentally obtained data in Section 4, along with a numerical sensitivity study where the effect of different parameters are discussed.

2. Experiments

In order to study the system physically and to obtain validation data, we performed dedicated experiments in the Marine Cybernetics laboratory at NTNU during Fall 2011. The tank length is 26 m, the tank width 6.45 m and the water depth varies

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