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Numerical and experimental investigations on mooring loads of a marine fish farm in waves and current

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ABSTRACT

A realistic aquaculture fish farm system in both regular and irregular waves is investigated by numerical simulations and model tests. The main purpose is to develop a reliable numerical tool and in this respect to investigate the survival conditions of the system. The structural and hydrodynamic modelings of the system are briefly introduced. Numerical sensitivity analysis is performed to investigate which physical parameters are dominant when modeling the system.

The considered fish farm comprises a floating collar with two concentric tubes, a flexible net cage including a cylindrical part and a conical part with a center point weight at the bottom, and a sinker tube attached directly to the net. The system is moored with a complex mooring system with bridle lines, frame lines and anchor lines, supported by buoys.

The mooring loads in the front two anchor lines and bridle lines are investigated in detail. Numerical results are first validated by the experimental data. Both numerical and experimental results show that one of the bridle lines experiences larger load than the rest of the mooring lines, which is surprising. Then a sensitivity analysis is carried out. The mooring loads are not sensitive to the majority of the parameters. The flow reduction factor in the rear part of the net is the most important parameter for the anchor loads. Modeling the floating collar as a rigid body has a small effect on the anchor loads but not for the bridle lines as it will alter the force distribution between bridles. The mooring loads are not sensitive to the wave load model for the floating collar in both regular and irregular seas and modeling the floating collar as elastic with zero frequency hydrodynamic coefficients is enough to give reliable results.

Finally, the survival conditions of the fish farms with different set-ups is studied. Numerical results indicate that the dominant limitation to move the conventional fish farms to more exposed sea regions is the large volume reduction of the net cage. The existing mooring system can be applied in offshore regions as long as the bridle lines are properly designed. The maximum stress in the floating collar is moderate compared with the yield stress.

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1. Introduction

Due to limited nearshore area and great impact to local ecosystem, the aquaculture industry is trying to move the fish farms from nearshore to more exposed sea regions where waves and current are stronger. This will greatly increase the probability of structural failure. Although new fish farm concepts were proposed to operate in exposed areas, it is still valuable to check the operational limits of the existing fish farm concepts and possibilities to use them in exposed regions. Among many existing concepts, we will focus on the floating collar fish farm, which is the most commonly used concept nowadays. Each unit in a fish farm typically comprises a floating collar with two concentric tubes, a flexible net cage, a sinker tube and possible chains connecting the sinker tube and the floating collar. The system is moored with a complex mooring system with bridle lines, frame lines and anchor lines, supported by spar type buoys. In reality, there may exist multiple cages at sites with cages arranged in single or double rows. This will have an influence, for instance, on the steady inflow (current) due to the shadowing effects from the upstream cages, compared with a single cage system.

Many investigations have been done to examine the responses of a floating fish farm by model tests and numerical simulations. The system is often simplified to reduce the complexity. For example Lader and Fredheim (2006) applied a truss model to investigate the responses of a two-dimensional flexible net sheet exposed to waves and current. Zhao et al. (2008) presented an experimental and numerical study of hydrodynamic characteristics of submerged flexible plane nets in waves. Moe et al. (2010) applied the commercial software ABAQUS to estimate the drag force on a circular-flexible-bottomless net cage in current. Similar net cage set-up in waves and current were studied experimentally and numerically by Huang et al. (2006), Zhao et al. (2007) and Lee et al. (2008). The hydrodynamic behaviors of multiple net cages in waves and current were investigated numerically by Xu et al. (2012, 2013b). Zhao et al. (2015) also performed an experimental study on flow velocity and mooring loads for multiple net cages in steady current. The dynamic responses of a net cage in irregular waves were analyzed by Dong et al. (2010) and Xu et al. (2011). Studies of the hydrodynamic behavior of a submersible net cage in waves and current were also performed by Xu et al. (2013a).

Common to previous works is that the hydrodynamic part of the problem is often over-simplified, for instance the floater was assumed to be rigid and the hydrodynamic forces of the floater were predicted by two-dimensional (2D) hydrodynamic strip theory. The viscous force on the net cage was predicted by Morison's equation, neglecting the shadowing effect of the net and the flow modification around the net cage. Li and Faltinsen (2012) studied theoretically the vertical responses of an isolated elastic, moored floater in regular waves. They pointed out that three-dimensional (3D) effects may cause important frequency-dependent hydrodynamic interactions at the scale of the floater. Kristiansen and Faltinsen (2012, 2015) studied experimentally and numerically a flexible-bottomless net cage attached to an elastic floater in waves and current. They showed that the elasticity of the floater was important for the mooring loads. In their work, the net cage was modeled by a truss model proposed by Marichal (2003), and the hydrodynamic forces on the cage were predicted by a screen model which accounts for hydrodynamic shadow and Reynolds number effect. They showed that their proposed hydrodynamic screen model gave reliable results even when the cage experienced large deformations which was not the case when Morison's equation was adopted. Their model was further adopted by He et al. (2015) to investigate the drag forces on a flexible-closed net cage in current and reasonable agreement between numerical and experimental results was achieved.

The fluid–structure interaction for the net cage is gaining increasingly more attention. Zhao et al. (2013), Bi et al. (2014a, b) and recently Yao et al. (2016) studied the flow inside and around a fish cage in current by solving the Navier–Stokes equation. The net was taken as a porous media with empirical coefficients. Both rigid and flexible cages were investigated. Their studies showed that numerical results would overestimate the hydrodynamic loads on the cage when compared with the experimental data if the effect of fluid–structure interaction was not considered. Although it maybe questionable to consider the net cage as porous media (most common practice), their work is valuable to show us the effect of considering the fluid–structure interaction.

In addition, 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 sinker tube when exposed to waves. They pointed out that the net experienced cyclic snap loads in higher wave amplitudes and periods which could also happen for full-scale offshore fish farms and should be of concern for the net design.

Few investigations are available for a realistic fish farm due to the complexity, but this kind of study is necessary to provide practical guidance for fish farm design. In the present paper we try to investigate the dynamic responses of a realistic floating collar fish farm system (with single cage) in both regular and irregular sea states and determine the survival conditions of the system. In order to deal with the problem, an efficient and reliable numerical solver is introduced at first. The curved beam equations with consideration of hydroelasticity introduced by Li et al. (2016) for an isolated elastic torus are adopted for the present two concentric floating tubes and also for the sinker tube. The net cage model proposed by Kristiansen and Faltinsen (2012) for a bottomless net cage is reliable and efficient, so it is adopted here for the closed net cage which comprises a cylindrical part and a conical part. The mooring lines are modeled as elastic trusses with correct weight and stiffness and Morison's equation is adopted to estimate the loads on the lines. Numerical results for a realistic fish farm system in both regular and irregular waves are compared with experimental data from Nygaard (2013). These model tests are further analyzed here using the numerical simulations as a complementary research tool. In particular, a sensitivity analysis is conducted to see what factors are important when modeling a realistic fish farm, especially what effects are dominant for the mooring loads. Finally, numerical simulations for fish farms with different set-ups are performed. Sea conditions are given according to the Norwegian standard (StandardNorge, 2009), from light exposure to heavy exposure,