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Structural response of high solidity net cage models in uniform flow

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ABSTRACT

Hydrodynamic loads acting on a fish farm may be affected by the growth of different biofouling organisms, mainly due to increased solidity of the nets. In this paper, the hydrodynamic loads acting on high solidity net cage models subjected to high uniform flow velocities and the corresponding deformation of the net cages are studied. Model tests of net cylinders with various solidities were performed in a flume tank with a simulated current. Standard Morison-type numerical analyses were performed based on the model tests, and their capability of simulating the occurring loads and the observed net cage deformations for different flow velocities was evaluated.

Large deformations of the net cage models were observed, and at high velocities the deformations were close to what is physically possible. Net cage deformation appeared to be less dependent on solidity than on flow velocity and weights. Drag forces increased with increasing flow velocity and were dependent on both bottom weights and netting solidity. For the lowest solidity net, drag forces were close to proportional to flow velocity. For the three high solidity nets, the measured drag forces were of similar magnitude, and drag increased less with increasing flow velocity above approximately 0.5 m/s than at lower velocities.

This study shows that a basic reduced velocity model is not sufficient to model the interaction between the fluid flow and net (hydroelasticity) for high solidity net cages subjected to high flow velocities.

The standard numerical analysis was in general able to make good predictions of the net shape, and was capable of making an acceptable estimate of hydrodynamic loads acting on the lowest solidity net model ($Sn = 0.19$). For high solidities and large deformations, numerical tools should account for changes in water flow and the global drag coefficient of the net.

1. Introduction

The introduction of the Norwegian standard NS 9415 in 2003 (StandardsNorway, 2009) resulted in legal requirements for strength analysis of fish farms. Up until then, all net cages had been dimensioned using trade standards based on empirical data. These empirical data were revised and included in NS 9415, but they do not cover all net cage design and load

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conditions. NS 9415 requires strength analysis to validate the dimensioning of large net cages and net cages subjected to large environmental loads. Modelling the hydrodynamic loads acting on a net cage is challenging due to hydrolelasticity, i.e., fluid-structure interaction between moving sea-water and the flexible net (Moe et al., 2010; Kristiansen and Faltinsen, 2012). The flow regime through and around net cages and the corresponding fluid-structure interaction are not fully investigated and understood (Gansel et al., 2012). This includes the effect of high solidity netting on flow and environmental loads.

Hydrodynamic loads acting on a net structure are dependent on the solidity of the netting material. Solidity is defined as the relationship between the projected netting material area and the total area of a net panel, and is given as a number between 0 and 1 (1 representing a solid fabric). The solidity will affect water flow through and around a net cage, which again determines the hydrodynamic loads acting on a net cage.

During sea-based fish production, different biofouling organisms will grow on the net cage (Bloecher et al., 2013) and may have an effect on the hydrodynamic loads acting on the fish farm (Swift et al., 2006). In Norway, the mandatory technical standard NS9415 requires that biofouling should be accounted for in load calculations by increasing the solidity by 50% (in addition to the contribution to gravitational loads). Swift et al. (2006) towed 2D panels with and without biofouling and found a significant increase in drag force due to biofouling. Common netting materials have solidities in the range of 0.20–0.30, and netting materials with even higher solidities exist, meaning that we must be able to calculate loads on net cages with solidities up to at least 0.45.

Today, load models for net cages are typically based on Morison's equation, 2D panel tow-tests and so-called screen models. This is discussed by Moe et al. (2010) and Kristiansen and Faltinsen (2012). These methods all have challenges concerning estimation of hydrodynamic loads acting on highly deformed net cages, i.e., net cages subjected to strong currents and large waves. In addition, most methods are not valid for high solidity netting materials. This may be due to lack of experimental data, the fact that the twines may not be defined as slender and that the cross flow principle may not be valid. In addition, they do not include all aspects of fluid-structure interaction.

Due to the detailed and flexible geometry of the net consisting of thousands of slender twines, a complete fluid-structure interaction analysis is not feasible today. One choice has thus been to introduce empirical formula like Morison's equation to model the loads, assuming the net to be built up by slender structural elements (Fredriksson et al., 2005). A typical Morison's type method was evaluated for moderate conditions in Moe et al. (2010), but this method has not been verified for high environmental loads, extremely large deformations and high solidity net cages. These are often the design criteria during an ultimate limit state condition. Over the last years, methods verified for moderate conditions only have been used to analyse extreme conditions.

There also exist models based on 2D net panel tests for calculation of hydrodynamic loads on nets (Aarsnes, 1990; Balash et al., 2009). The panels are generally made by fixing a taut netting panel to a stiff frame and involve clean, commercial netting materials with solidities up to 0.32. It may be discussed whether panel tests are appropriate for high solidity nets, as water may start to flow around the panel rather than through it.

Zhan et al. (2006) included a three dimensional rigid structure in their studies, while Lader and Enerhaug (2005) performed experiments on a deformable net cylinder. The experiments were performed with moderate solidities and environmental loads. Another applied approach has been to study flow in and around a net cage by modelling the structure as a porous medium (Patursson et al., 2010; Gansel et al., 2012). Gansel et al. (2012)showed that at a porosity of 75%, which corresponds to a solidity of 0.25, water starts to flow around the cylinder. This indicates that one can expect the net cage to significantly affect the flow pattern, and thus the loads acting on the cage, for solidities larger than 0.25. Bia et al. (2014) presented a method with joint use of a porous media fluid model and a lumped mass mechanical model.

In this work, the hydrodynamic loads acting on a three-dimensional highly flexible simplified net cage structure in a uniform flow and the associated deformation of the net cage were investigated experimentally. The study was performed in a flume tank with a simulated current, and the effect of increasing the twine thickness by 50% was examined by including models with solidities up to 0.43. Emphasis was put on building models suitable for verification of numerical analysis tools. Thus, it was sought to achieve realistic flow characteristics and Rn in the experiments through limited scaling of twine thickness or by avoiding scaling altogether. Standard numerical analyses (Moe et al., 2010) were performed based on the model tests, and their capability of simulating the occurring loads and the observed net cage deformations for different flow velocities was evaluated. Results from these model tests have already been used for verification of a numerical code (Kristiansen and Faltinsen, 2012; Moe-Føre et al., 2015). The test set-up of the applied physical model tests was inspired by Lader and Enerhaug (2005), while numerical analyses were based on the methodology presented in Moe et al. (2010). This work contributes with new knowledge on the hydrodynamic loads acting on high solidity net models subjected to high uniform flow velocities, as well as the deformation of these net models under such loading conditions.

2. Materials and methods

2.1. Physical model tests

Model tests of net cylinders with various solidities were performed in April 2009 in the SINTEF Fisheries and Aquaculture flume tank in Hirtshals, Denmark. The flume tank is 21.3 m long, 2.7 m deep and 8 m wide, and filled with fresh water.