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Numerical modeling of current loads on a net cage considering fluid–structure interaction

Yeming Yao, Yinglong Chen, Hua Zhou*, Huayong Yang

State Key Lab of Fluid Power Transmission and Control, Zhejiang University, Zheda road 38, Hangzhou 310027, Zhejiang, China

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ABSTRACT

In this paper we propose and discuss a numerical method to model the current loads on a net cage. In our numerical model, the fluid–structure interaction is taken into consideration. The net cage is modeled on the mass-spring model; the flow field is modeled by the finite volume method (FVM). A novel hybrid volume approach is used to add the resistance force of the net cage into the flow field for coupling the fluid and net. The net resistance to the flow is calculated directly by the net's current load using Newton's Third Law. The resistance force is discretized in the hybrid volume and represented in the source term of the Navier–Stokes equation. By using the hybrid volume method, the mesh grid is separated from the net shape, and sparse grid (0.1 m) can be used to calculate the flow field for computational efficiency. Based on the detailed flow field, we can predict the net's current load more accurately. The final results are derived by the segregated iterative calculation of net shape and flow field. Current forces acting on both rigid and flexible net cages are simulated at water velocity from 0 to 1 m/s; the simulation results of proposed numerical method are compared with the existing experiments, good agreements are shown in both flow field and current force, the mean normalized absolute error of the current force between simulations and measurements is about 5%.

1. Introduction

Aquaculture net cages are widely used in offshore fish farming. With the increased demand for sea products, aquaculture net cages are becoming much larger and net cage arrays are also used to increase production. Meanwhile, due to the problem of near-shore water pollution and the tourism industry, net cages are moving away from the coast. However, strong ocean currents and waves make pelagic net cages hard to design, it is important to understand how the net deforms under the influence of currents and waves as well as how the net influences the flow. Because the flow determines water exchange and oxygen flux in the net cage, low level dissolved oxygen and inefficient dispersion of the waste products will decrease the harvest and even cause fish death. This is especially important for net cage arrays (Klebert et al., 2013).

Existing researches have provided plenty of methods to model the net structures. Bessonneau and Marichal (1998) used a set of rigid bars to model the submerged supple nets and successfully predicted the dynamics of trawl; Li et al. (2006) investigated the shape and tension distribution of fishing nets using the lumped mass method, they further elaborated this method in the analysis of three-dimensional fishing cage and compared the simulation results with experimental data (Zhao

* Corresponding author. Tel.: +86 571 87951659; fax: +86 571 87951646.
E-mail address: hzhou@sfp.zju.edu.cn (H. Zhou).

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et al., 2007); Lee et al. (2008) built a physically based model of netting which was composed of a network of masses and springs. The most important thing of modeling netting structure is to calculate the hydrodynamic forces, some methods have been suggested by experiments and theoretical analysis. Morison equation is usually used to calculate the hydrodynamic forces of submerged subject, it has a clear physical meaning and very easy to use; therefore many fishing gear models were established on it (Lee et al., 2008; Moe et al., 2010). However, Morison's equation is based on local resultant velocity between net and fluid, when uniform flow is assumed, the shielding effect of upstream twines is not accounted for, and the hydrodynamic forces will be over-predicted especially when the current velocity is larger than 0.5 m/s (Kristiansen and Faltinsen, 2012). For the sake of considering the wake effect within net panel element, the super elements model was developed by Lader and Fredheim (2006). In the super elements model, the hydrodynamic forces are calculated for each super element rather than for each truss, the drag and lift coefficients are related to the solidity ratio *Sn*, the inflow angle, and the Reynolds number Re. A lot of efforts have been done to get more accurate representations of the drag and lift coefficients (Lader and Fredheim, 2006; Zhan et al., 2006). Both the Morison equation and the super elements model need local water velocity to calculate the hydrodynamic forces, so the flow field should be given before the calculation. Uniform flow field was assumed to simplify this problem by some researches (Huang et al., 2006). However, the net deformation is caused by the current and in return the net resistance will change the flow field, so the fluid–structure interaction must be taken into consideration.

Two approaches are mainly used to model the flow field: the velocity reduction method and the porous media method. The velocity reduction method is a simple way to represent the shielding effect of net structures. In this method, the downstream water velocity is reduced by a ratio r of the upstream water velocity, that is $u_{\text{downstream}} = r \cdot u_{\text{upstream}}$. However, the choosing of velocity reduction ratio is somewhat arbitrary and lacking of theoretical analysis; moreover, it is hard to make a distinction between the upstream and downstream flow area when the net is in three dimensions and the shape is complicated (Lader and Enerhaug, 2005). A better flow field model was established by using Computational Fluid Dynamics (CFD) combined with porous media method (Bi et al., 2014a, 2014b; Helsley, 2005; Patursson, 2008; Zhao et al., 2013a, 2013b). Porous media is used here to model the net cages, and Zhao et al. (2013a) indicated that the simulation results are insensitive to the thickness of porous media. The porous media method can offer the details of the flow field, but when applied to complex net shapes, the calculation effort is considerable. This is because complicated net shapes will make it difficult to mesh the flow field, in addition the number of mesh grids are very large.

In this paper, the net cage is modeled on the mass-spring model, the hydrodynamic forces acting on the net cage are calculated by the super elements model (Lader and Fredheim, 2006). The drag and lift coefficients of the super element are represented by Fourier series with two and three harmonics (Kristiansen and Faltinsen, 2012). In order to predict the net's current load more accurately, we further calculated the flow field by finite volume method (FVM). A novel hybrid volume approach is used to add the resistance force of the net cage into the flow field for coupling the fluid and net. The resistance force of the net segments in a hybrid volume is represented in the source term of the Navier–Stokes equation. The final results are derived by the segregated iterative calculation of net shape and flow field. Two simulation cases (rigid and flexible net cages) are carried out based on the experiments by Zhan et al. (2006) and Lader et al. (2009), the simulation results are compared with the measurements. In order to find the best value of mesh grid size, the effect of increasing and decreasing grid size is also investigated.

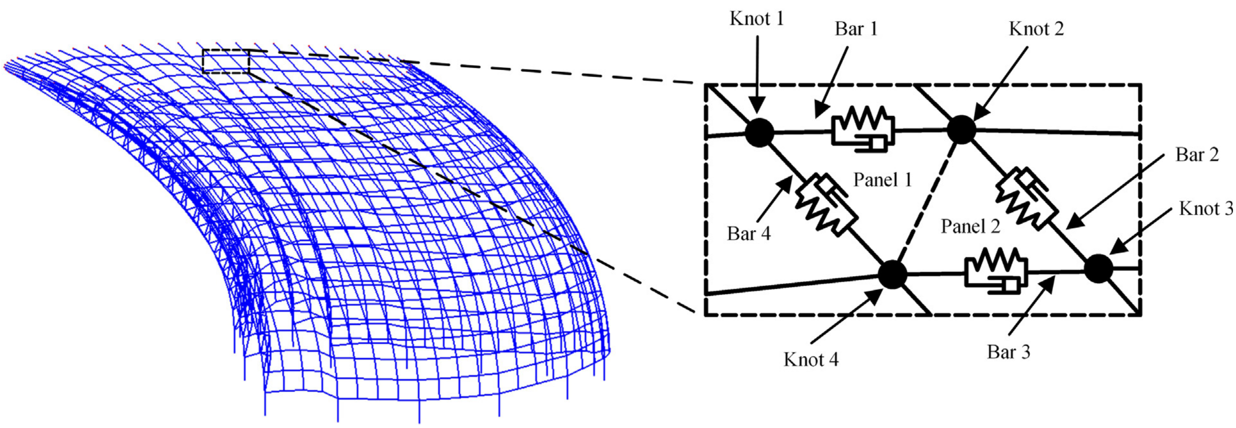

Fig. 1. Mass spring damping representation of a net cage. The knots are represented by black circles and mesh bars are represented by springs with damping. It also illustrates the division of a diamond net mesh into two triangle panels.