Aquacultural Engineering 74 (2016) 111–119

Contents lists available at ScienceDirect

Aquacultural Engineering

journal homepage: www.elsevier.com/locate/aqua-online

Numerical simulation of deformations and forces of a floating fish cage collar in waves

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ARTICLE INFO

Article history:
Received 10 March 2016
Received in revised form 17 July 2016
Accepted 25 July 2016
Available online 27 July 2016

Keywords:
Floating fish cage collar
Elastic deformation
Mooring line tension
Numerical simulation

ABSTRACT

The dynamic behavior of a fish cage collar in waves was investigated using a numerical model based on the finite element method. The floating collar and mooring system were divided into a series of line segments modeled by straight massless model segments with a node at each end. To verify the validity of the numerical model, research data from other authors were cited and compared with the simulated results, the comparison of results showed a good agreement. The numerical model was then applied to a dynamic simulation of a floating cage collar in waves to analyze its elastic deformation and mooring line tension. The simulated results indicated that the greatest deformation of the collar taken place in the position of the mooring line connection point when incident waves were in the same direction. An increase in the length of mooring line would help to decrease the mooring line tension of the collar. Furthermore, the effects of collar dimension, including collar circumference, pipe diameter in cross-section, and pipe thickness, on the dynamic behavior of the floating collar were discussed. The results of this study provided a better understanding of the dynamic behavior of the fish cage collar.

1. Introduction

Commercial marine fish farming is becoming prevalent in the world due to diminishing fishery resources in the ocean and increasing demand of sea products. As one of the main culture methods, cage aquaculture plays an important role in marine fish farming in China, of which yield accounts for about 50% of marine fish farming. Marine cage aquaculture has become an alternative for future development of the fisheries industry in China. However, owing to the aggravation of near-shore pollution and occupation of the sea area for coastal industrialization and tourism, cage farming locations need to be moved further offshore in exposed water. Therefore, the safety performance and reliability of the fish cage under the action of severe sea loads becomes the focus of attention.

In an open-sea area, a fish cage exposed to strong waves and current may deform to such a large extent that normal functionality is disabled. Therefore, extensive studies of hydrodynamic behaviors of fish cages have been conducted over the recent years. For example, Lee et al. (2008) presented a mathematical model for analyzing the performance of a fish cage with a floating collar influenced by currents and waves. Huang et al. (2008) analyzed the effects of waves with a uniform current on marine aquaculture gravity-type cages using a numerical model validated by physical model tests. A risk analysis (Huang and Pan, 2010) and submergence characteristics (Shainee et al., 2013) of single-point mooring cage system in waves and current were conducted. Kristiansen and Faltinsen (2012, 2015) proposed and discussed a screen type of force model for the viscous hydrodynamic load on an aquaculture net cage. Fredriksson et al. (2007a) studied mooring system tensions of a large fish farm containing 20 net pens in the absence of waves, using a numerical model and field measurements. Zhao et al. (2009, 2013) conducted analysis of dynamic behavior of a box-shaped net cage and a column-shaped net cage in waves and current using a numerical model, based on the lumped mass method and the principle of rigid body kinematics. DeCew et al. (2013) reported that an acoustic method was utilized to monitor the movement and deformation of a small-scale fish cage deployed in currents, and results were compared with field measurements.

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http://dx.doi.org/10.1016/j.aquaeng.2016.07.003
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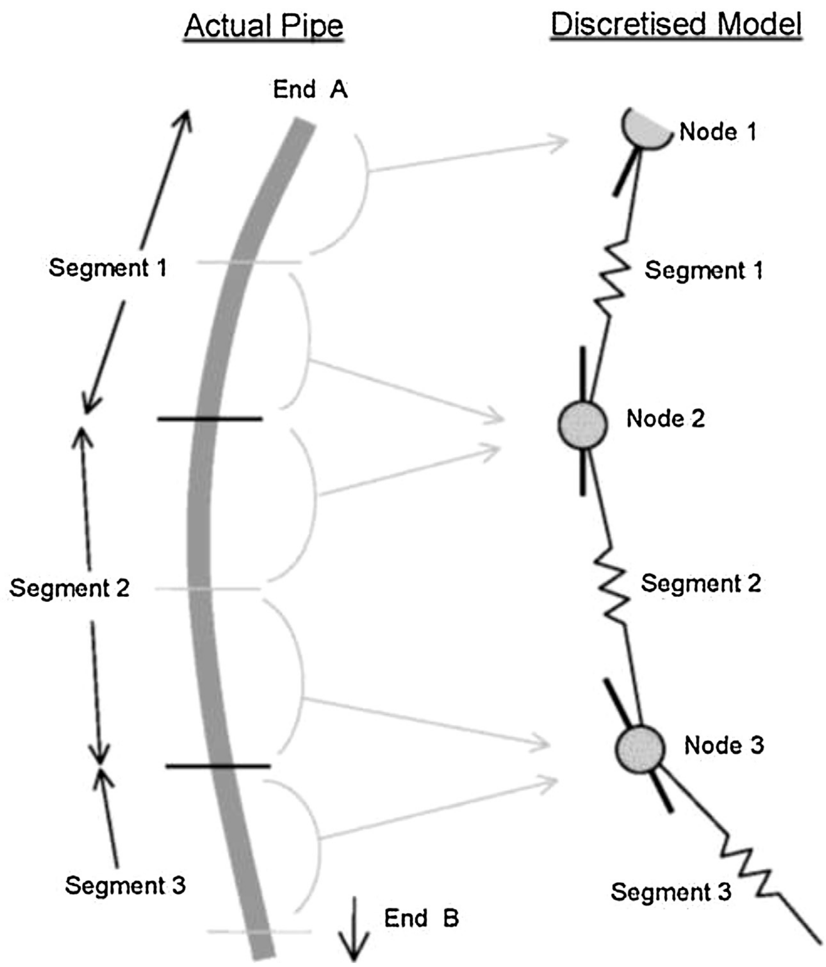

Fig. 1. A finite element model for the line.

Most of the aforementioned work is, however, based on the assumption that the load-bearing component floating collar of the fish cage is rigid, undergoing no deformations. Actually a floating fish cage collar made of high-density polyethylene (HDPE) may have great deformations resulting from strong winds and waves. Site observations have confirmed that the deformations of larger fish cages are more severe than those of smaller one. Therefore, deeply understanding the deformations of a floating collar is of vital importance to the reliable design of a fish cage with high security. Dong et al. (2010) and Hao (2008) analyzed the in-plane and out-of-plane deformations of a flotation ring of a gravity fish cage based on curved beam theory, in which the flotation ring was simplified into a circular ring. Fredriksson et al. (2007b) predicted the critical loading of net pen flotation structures using finite element modeling techniques, and conducted a series of experiments by testing circular sections of HDPE pipe to localized failure for the modeling approach. Li et al. (2013) studied dynamic responses of the semi-immersed floater and the fish cage system consisting of the floater and nets in waves and currents, in which large geometric deformations and motions were observed in both floater and the nets.

The objective of this paper is to analyze the deformations and forces of a floating fish cage collar subjected to pure waves. The study also considers effects of collar dimension on the deformations and forces of the fish cage collar. This paper is organized as follows. Section 2 introduces the numerical model of the fish cage collar. To validate the numerical model, two cases of circular pipe described in Hao (2008) and Li et al. (2013) are simulated and compared with the results from their works in Section 3. Afterwards, in Section 4, the numerical model is used to simulate the elastic deformations and the mooring line tensions of the floating collar in waves, and the effects of collar circumference, pipe diameter and pipe thickness are also analyzed. Finally, in Section 5, some conclusions are given.

2. Description of numerical model

2.1. Finite element model

A finite element model for a line is used to model the floating collar and mooring system of the fish cage. As shown in Fig. 1, the line is divided into a series of line segments which are then modeled by straight massless model segments with a node at each end. The model segments only model the axial properties of the line. The other properties (mass, weight, buoyancy, etc.) are all lumped towards the nodes, as indicated by the arrows in Fig. 1. The bending properties of the line are represented by rotational spring-dampers at each end of the segment, between the segment and the node. Each node is effectively a short straight rod that represents the two half-segments either side of the node. Forces and moments, including weight, buoyancy, hydrodynamic drag, tension and shear, bending, etc., are applied at the nodes. The equation of motion for each line node is as follows:

$$M(p, a) + C(p, v) + K(p) = F(p, v, t) \quad (1)$$

where $M(p, a)$ is the system inertia load, $C(p, v)$ is the system damping load, $K(p)$ is the system stiffness load, $F(p, v, t)$ is the external