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Experimental study on flow velocity and mooring loads for multiple net cages in steady current

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ABSTRACT

To enable the optimum design and evaluation of fish farm and mooring performance in the energetic open ocean, a series of physical model experiments were conducted to investigate the hydrodynamic characteristics of a large fish farm containing 1 up to 8 net pens with the model scale of 1:40. In the physical model experiments, the main mooring line tension and flow-velocity magnitude were measured when current flowed through the multiple net cages. According to the experimental data, the upstream anchor lines of the cage will endure most of the current load acting on the multi-cage system. When the net cages are arranged in double columns, the tension force in the upstream anchor lines increases with increasing number of net cage. But this phenomenon is not obvious when the net cages are arranged in single column. There exists obvious flow-velocity reduction inside net cages of the multi-cage configurations; however, there is no statistical difference in flow velocity over varied configurations with different number of net cage. The appropriate multi-cage system in engineering practices should be determined through considering both the mooring line force and the flow-velocity distribution.

1. Introduction

Marine aquaculture is expanding all over the world, and the net cage is becoming prevalent in the aquaculture industry. Large fish farms that include multiple-cages are becoming common in the aquaculture industry. In addition, the new mooring system allows auxiliary equipment, such as feeding platforms (Rice et al., 2003; Fullerton et al., 2004), to be installed at the site. The intent is to approach commercial level operations so that proper economic and environmental assessments can be initiated. In the meantime, increased activity is expected to force a move to less sheltered sites where loads in the mooring lines and flow field inside and around the cage are expected to become more important. From the engineering perspective, multi-cage systems need to be designed to cost-effectively withstand extreme conditions while providing a suitable growing environment. The study on open ocean fish cage and mooring system dynamics has focused primarily upon either the oscillatory response of components to waves or the steady drag of these structures to ocean currents (Kristiansen and Faltinsen, 2014; Kim et al., 2014).

As to the multi-cage system in the open ocean, the fluid will flow through the adjacent side and bottom areas as it moves toward the sea cage. The motion of the flow is a rather complicated process. The fishing net is a kind of small-scale flexible structure. The interaction between the fishing net and the fluid is very complicated. Though the hydrodynamics of the fishing net have been studied extensively, the behaviors of fluid flowing around fishing net and the velocity reduction downstream from a fishing net are still a problem to be solved.

Techniques used to investigate these mechanisms have typically included the use of scaled physical and numerical models, and where possible, field measurements. In the past decades, a number of studies have been carried out to investigate dynamic loads acting on the net-cage system. To our knowledge, Kawakami (1964) proposed relative reliable semi-empirical formula to calculate the drag force acting on net. Aarsnes et al. (1990) further divided the external forces on net cage into drag force and lift force, considering the angle between normal direction of plane net and current velocity. Their work has laid a foundation for further study of the dynamic characteristics of net cage. Colbourne and Allen (2001) surveyed the motion and load responses of gravity cage with field test, and compared the results of field test and physical model test. Li et al. (2006a,b) investigated the dynamic behavior of gravity cage with numerical and physical model tests, and obtained a promising result. Lee et al. (2008) proposed a mathematical model

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for analyzing the performance of a fish-cage system influenced by currents and waves. DeCew et al. (2010) investigated the submergence behavior of a fish cage in a single-point mooring system under currents by a numerical model. Tsukrov et al. (2011) investigated the normal drag coefficients of copper alloy netting used in marine aquaculture. Xu et al. (2012) studied numerically the hydrodynamic behavior of multiple net cages in waves. Kristiansen and Faltinsen (2014) investigated the mooring loads on an aquaculture net cage in current and waves by dedicated model tests and numerical simulations.

Both from an engineering perspective and from an ecological perspective, the flow field of open-ocean aquaculture net-cages must be considered under the effect of steady ocean currents. Aarsnes et al. (1990) carried out a series of tests to study the velocity distribution within net cage systems, and velocity reduction formulae for the net cages were developed. Fredriksson (2001) studied the flow velocity in an open ocean cage with field measurements, and an approximate 10% velocity reduction was found. Lader et al. (2003) conducted a series of experiments to investigate the forces and geometry of a net cage in uniform flow, and an average of 20% velocity reduction was measured inside the cage. Johansson et al. (2007) performed field measurements at four farms in Norway, and major current reduction was measured in the current passing through the cages. The measured current reduction was between 33% and 64%. Gansel et al. (2011) conducted laboratory tests and field measurements to study the effects of biofouling and fish behavior on the flow field inside and around stocked salmon fish cages. Recently, Bi et al. (2014) developed a numerical strategy to study the flow inside and around flexible fish cages by combining the porous-media fluid model and the lumped-mass mechanical model based on their previous study of Zhao et al. (2013). Cornejo et al. (2014) developed a numerical model to describe the flow velocity downstream of the salmon farm on an incident current with constant and semidiurnal variability. Rasmussen et al. (2015) conducted full-scale measurements to visualize the flow field in the wake of the salmon farm over the duration of two days in an oscillating tidal current.

Herein, a series of physical experiments is conducted to investigate the hydrodynamic characteristics of a large fish farm containing 1 up to 8 net pens. In the physical model experiments, the main mooring line tension and flow-velocity distribution are measured under different multi-cage configurations in currents. The objective of this paper is to describe the dynamics of the multi-grid mooring system and the flow-velocity reduction of multiple cages. Understanding the hydrodynamic behavior would enable the multi-cage system to be used more effectively.

This paper is organized as follows. In Section 2, a description of the physical model is introduced. Section 3 contains the results of the physical model experiments, which include two parts: Part 1 presents the mooring line tension of five different multi-cage configurations; and Part 2 presents the flow-velocity reduction inside the net cages. Finally, in Section 4, the conclusions are presented.

2. Experimental setup

To enable the optimum design and evaluation of fish cage and mooring performance in the energetic open ocean, a series of physical model experiments was conducted to investigate the hydrodynamic characteristics of a large fish farm. In the physical model experiments, the main mooring line tension was measured under different multi-cage configurations in currents. Flow-velocity magnitude inside and downstream from the net cage was also measured.

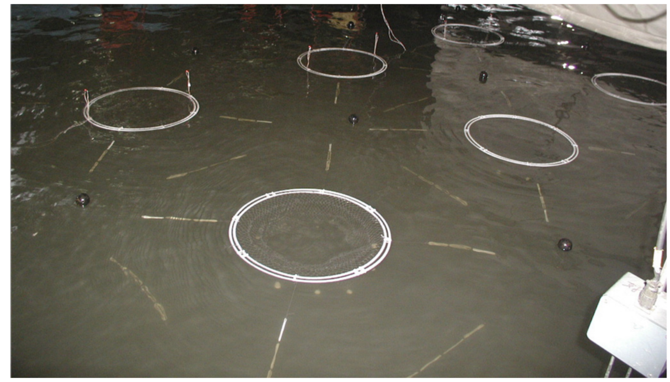

Fig. 1. The schedule of net cages in experiments.

2.1. Facilities and instruments

The experiments were conducted in a wave-current basin (56 m long, 34 m wide and 1 m deep) at the State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology, China (see Fig. 1). The basin was equipped with current-producing system, acoustic Doppler velocimeter (ADV), data acquisition system, a tension sensor for measuring the forces under water and computers.

2.2. Net-cage model

A model in scale 1:40 was used to represent a fish cage with a circumference of 50 m and net depth of 10 m. Circular polyethylene net cages with a circumference of 40–120 m and a depth of 6–30 m are most common in China today. The net cages are often arranged in mooring grids in single or double columns with typically space between them greater than 20 m. At most sites, the mooring grid is oriented perpendicular to the dominant current direction to maximize water flow, oxygen supply and the removal of wastes from the net cages. As a result, the forces on the system and the net deformation have increased. According to the prototype dimensions of the gravity cage and the experimental conditions; the model scale of the experiments is set as 1:40. The net cage structures are modeled according to geometric and gravity similarities (see Table 1). In addition, elastic similarity should be considered when referring to the mooring line. The net system is modeled according to extended gravity simulation criteria that has been discussed and validated by Li et al. (2005).

Table 1
Specifications of the prototype and model of the gravity cage.

Component	Parameter	Prototype	Model
Floating collar	Outer circle diameter	16.92 m	0.423 m
	Inner circle diameter	15.92 m	0.398 m
	Pipe diameter	250 mm	6.25 mm
	Density	11.35 kg/m	7.1 g/m
	Material	HDPE	PVC
Cylindrical net	Height	10 m	0.25 m
	Mesh size	40 mm	23.4 mm
	Twine diameter	2.35 mm	0.72 mm
	Material	PE	PE
Sinker	Unit mass	34.3 kg	0.54 g
	Number of pieces	10	10
Buoy	Diameter	1.2 m	38 mm
	Geometric shape	Sphere	Sphere
Mooring line	Twine diameter	40 mm	0.72 mm
	Density	953 kg/m^3	953 kg/m^3
	Material	PE	PE