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# Experimental investigation of the reduction in flow velocity downstream from a fishing net

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ABSTRACT

A series of laboratory experiments was conducted to investigate the reduction in flow velocity downstream from a fishing net in a current. The flow-velocity distribution downstream from the plane net(s) was obtained using both the particle image velocimetry (PIV) technique and the acoustic Doppler velocimeter (ADV). The reduction in flow velocity was investigated with different net solidities, plane-net inclination angles, spacing distances between two plane nets and plane net numbers. The experimental data show that there was an obvious reduction in flow velocity downstream from the plane net and that the reduction increased with increasing net solidity. The reduction in flow velocity tended to increase with increasing inclination angle between the plane net and the vertical direction. For two plane nets with different spacing distances, the average reduction factor was 0.90 between the two nets and 0.83 downstream from the two nets. As the net number increased from 1 to 4, the minimum reduction factor downstream from the plane nets decreased from 0.90 to 0.68. The study will contribute to understanding of the flow characteristics around a net cage.

## 1. Introduction

As the cost of commercial fishing and the demand for seafood increases, the net cage is becoming prevalent in the aquaculture industry around the world. Presently, coastal multi-use issues and concerns over environmental impact are putting pressure on the traditional nearshore aquaculture industry. Therefore, the use of net cages located offshore and the search for superior environments for high-quality products are becoming inevitable trends in the development of aquaculture. The location of the net cage in the sea and the flow velocity inside the net cage are keys to fish quality. It is now generally accepted that water motion helps to maintain the water quality in a net cage and that sufficient water exchange is important for the health and growth of the fish. However, water motion that is too intense can cause serious deformation of the fishing net and can sharply reduce the effective volume of the net cage (Tsukrov et al., 2003; Fredheim, 2005; Zhao et al., 2007, 2009), thus negatively impacting the health of the fish. Numerous studies have shown that the force on a cage net is proportional to the square of the flow velocity. Thus there are small differences in velocity that can lead to large differences in force, and in the investigation of the forces acting on a net cage, the flow-velocity distribution around the cage net usually cannot be ignored. Furthermore, the flow-field characteristics determine the distribution of nutrients, waste and dissolved oxygen in the net cage. Thus, investigation of the flow field inside and around a net cage has become important.

Because a fishing net is a kind of small-scale, flexible structure (Tsukrov et al., 2003), the flow field around it is rather complex. To better understand the hydrodynamic fields of a net cage, extensive investigations have been carried out in recent decades. To our knowledge, the first investigation of the flow filed within and around net cages was performed by Aarsnes et al. (1990). A series of experiments was carried out to determine the velocity distribution within net-cage systems, and flow-velocity-reduction formulae for net cages were developed. Over the decades since, much progress has been made in the understanding of the flow field inside and around net cages by experimental approaches. Fredriksson (2001) studied the flow velocity in an open-ocean cage with field measurements, and a reduction of approximately 10% was found. Lader et al. (2003) carried out 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. Fredheim (2005) calculated the flow distribution around a three-dimensional net structure as a superposition of effects due to individual cylinders (twine) and spheres (knots) and described the wake by a distribution of sources. Li et al. (2005) analyzed the shadowing effect of six practical gravity-cage models by physical model tests, and the flow-reduction coefficients within and downstream of the

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**Nomenclature**

| | |
|---|---|
| $S_n$ | net solidity, the ratio between the projected area of a plane net and the total area enclosed by the plane net |
| $d$ | twine diameter of a plane net |
| $\lambda$ | mesh bar length of a plane net |
| $E_H$ | hanging ratio in horizontal direction |
| $E_V$ | hanging ratio in vertical direction |
| $W$ | width of a plane net |
| $H$ | height of a plane net |
| $n_H$ | mesh number in width of a plane net |
| $n_V$ | mesh number in height of a plane net |
| $r$ | flow-velocity reduction factor |
| $u$ | flow velocity at a measurement point |
| $u_0$ | incoming velocity |
| $\theta$ | inclination angle, the angle of the plane net deviating from the original model around the *y*-axis in the vertical plane |
| $L$ | spacing distance between two tandem plane nets |
| $n$ | number of plane nets |

net cages were obtained. Gui et al. (2006) proposed a theoretical model for the calculation of velocity reduction behind a fishing net based on the assumption of an effective adjacent area around the net. Johansson et al. (2007) performed field measurements at four farms in Norway, and major reduction was measured in the current passing through the cages. The measured current reduction was between 33% and 64%. Harendza et al. (2008) conducted experiments in a towing tank with particle image velocimetry (PIV) configurations to investigate the flow-velocity distribution around cylindrical fish cages with varying inclination angle and porosity; however, they did not report the flow-velocity distribution inside the net cage. Lee et al. (2008) conducted water-tank experiments using plane nets at different attack angles to study the shielding effect of the fish-cage system in currents. Balash et al. (2009) performed experiments on the interaction between flow and a plane net and measured hydrodynamic loads on the net in both steady and oscillating flows. Patursson et al. (2010) developed a numerical model to simulate the flow field around a plane net by treating the net structure as a porous medium but did not consider net deformation. 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 cages. Zhao et al. (2013a,b) proposed a three-dimensional numerical model using a porous-media model and presented the flow field around single-plane and multiple-plane nets as well as net cages.

The above review of the literature shows that laboratory experimentation is the main method used to study the flow field around net structures. Although many experimental studies have been carried out, and much progress has been made, there have not been many experiments focusing on the reduction of flow velocity downstream from a fishing net or system of nets.

To obtain the detailed flow field through and around a fishing net in a current, a series of experiments was conducted on plane nets with different net solidities and inclination angles, and on systems of plane nets with different spacing distances between two nets and different net numbers. The reduction in flow velocity as a function of the above parameters is analyzed from the experimental results. The experimental investigation here forms a foundation for studying the flow field within and around net cages similar to those used in aquaculture. The experimental results on the reduction in flow velocity downstream from a fishing net can now be taken into consideration to provide more accurate estimates of the dynamic characteristics of a net cage (Løland, 1991, 1993; Fredriksson et al., 2007; Huang et al., 2009; DeCew et al., 2010; Xu et al., 2013).

This paper is organized as follows. Section 2 describes the experimental setup, experimental technique and experimental conditions. Section 3 contains detailed results from our study and is broken into four parts: part 1 presents the influence of net solidity on the flow field around a plane net; part 2 describes the flow fields around a plane net with different inclination angles; part 3 presents flow fields around two plane nets with different spacing distances; and part 4 considers flow fields around multiple plane nets. Finally, the conclusions are presented in Section 4.

## 2. Description of the experiment

All the laboratory experiments were carried out in a wave-current flume at the State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology, Dalian, China. The flume is 22 m long, 0.45 m wide and 0.6 m deep, and the depth of the water was 0.4 m in the experiments. Steady current can be generated by a pump located at one end of the flume. Different flow velocities can be obtained by changing the rotation frequency of the pump. Both the bottom and side walls of the flume tank at the working section are smooth glass. In the experiments, the flow-velocity distribution on a vertical cut through the center of the plane net was obtained using the PIV technique. The ADV was applied to measure the flow velocity at different measurement points around the plane net(s).

### 2.1. Experimental setup

The plane net was stretched on a square steel frame with a 6 mm diameter. It measured 0.3 m × 0.3 m and was placed in the center of the flume normal to the flow direction. The frame had sufficient strength and rigidity that the deformation of the frame could be considered negligible. The frame could be oriented arbitrarily around the *y*-axis. Taking the single plane net as an example, the physical model and the measurement points are shown in Fig. 1. The coordinate system for the physical model is a right-handed, 3D Cartesian coordinate system. The origin of the coordinates is set at the center of the plane net on the free surface. In the coordinate system, *x* is positive along the flow direction, *y* is perpendicular to the flow direction on the horizontal plane, and *z* is upward.

Three net models with different solidities were used in the experiments (see Fig. 2). The characteristics of the net models are presented in Table 1.

The net solidity $S_n$ describes the ratio between the projected area of a plane net and the total area enclosed by the plane net. For a plane net with diamond mesh, the net solidity can be expressed as:

$$S_n = \frac{d}{\lambda E_H E_V} - \left(\frac{d}{2\lambda}\right)^2 \left(\frac{1}{{E_H}^2} + \frac{1}{{E_V}^2}\right) \quad \text{for a knotless net} \tag{1}$$

$$S_n = \frac{2\lambda d + d^2}{2\lambda^2 E_H E_V} - \left(\frac{d}{2\lambda}\right)^2 \left(\frac{1}{{E_H}^2} + \frac{1}{{E_V}^2}\right) + \frac{\pi D^2 - 8dD}{8\lambda^2 E_H E_V} \quad \text{for a knotted net} \tag{2}$$

For a plane net with square mesh, the net solidity can be expressed as:

$$S_n = \frac{2d}{\lambda} - \left(\frac{d}{\lambda}\right)^2 \quad \text{for a knotless net} \tag{3}$$