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Design aspects and laboratory simulation study of a floating marine fish cage prototype with mooring system

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ABSTRACT

In India, open sea cage culture has been successfully demonstrated and several experimental offshore cages for mariculture were installed along the coast for on-farm demonstration by the Central Marine Fisheries Research Institute, Cochin. In the present study, a model cage was fabricated and tested in a towing tank under different waves and current load conditions. The tension on the mooring chain was measured during the experimental study, besides the towing speed and wave parameters. Based on the experimental data, drag coefficient for the cage net twine was estimated. The tensions in the mooring chain and the cage net twine of the prototype cage were predicted based on the model data. The maximum tension on a single twine of the outer and inner fish net were estimated as 0.15 N and 0.028 N respectively. The force on the net was more than 1.7 times the force on the floating collar and sinker pipe. The tension in the mooring line is mainly due to the force on the net. Further it was observed that the force on the net due to current was 10 times higher than that due to wave. This information will be useful in future while deciding the diameter of the cage, the type of net to be used for cage according to the site where the cage is to be installed.

Keywords: Drag coefficient, Floating cage, Mooring chain tension, Netting yarn

Introduction

Open sea cage culture is a promising venture which gives a chance to fishermen for utilising the existing water resources which has limited use for other purposes. By integrating the cage culture system into the coastal water bodies resorting to low impact farming practice, the carrying capacity per unit area can be made similar to intensive culture systems owing to the free flow of seawater with in the cage facilitating removal of metabolic wastes as well as excess feed, giving high economic returns. Open sea cage culture has been demonstrated as a suitable tool to enhance marine fish production in coastal waters all along the coast of India by Central Marine Fisheries Research Institute in recent years. Open sea cage farming entirely depends on the cage stability in the sea considering the rough weather conditions throughout the seasons which differs from place to place. Based on the area and volume of fish holdings of the cage, different mooring systems have to be designed for economic and commercial viability of cage culture (Thoms, 1989). The design and installation of offshore cages requires a basic understanding on their behaviour in actual sea conditions. Various numerical models have been developed to characterise the forces and motions of prototype cages. Huang *et al.* (2006) developed a numerical model for analysing dynamic properties of a net-cage system exposed in the open sea. This numerical model has formed a foundation to simulate practical net-cage systems, which include mooring lines, floats and anchors. Huang *et al.* (2007) presented a new approach to estimate the net volume reduction coefficient by Gauss's theorem and showed that the volume reduction coefficients and their fluctuation patterns might offer good information about cage shrinkage problems to fish farmers. They also created a numerical model which is suitable to analyse the maximum tension on the mooring lines and its corresponding volume reduction coefficient due to the combination effect of waves and currents on a net-cage system. Dong *et al.* (2010) proposed a numerical model for gravity cage to simulate the motion response and mooring-line tension response in waves. They analysed the hydrodynamic behaviour of gravity cage in waves by numerical methods. However, these models were calibrated and validated for specific site conditions only.

A cage system generally consists of following components: floating collar, cage bag, sinker system, service facility, mooring and anchoring system. The floating collar provides buoyancy and the sinker system gives weight in order to maintain the shape of the cage. As a cage system operates in open sea, it is subjected to currents, waves and winds. The mooring and anchoring system helps to keep the cage in sea against drifting. The service facility includes walkway for feeding and monitoring of fish.

For designing a cage, tensions in the mooring chain and net twine needs to be estimated. The estimation of these tensions for prototype requires measurement in model scale and subsequent scaling up. In the present study, an attempt has been made to measure tensions in mooring and net twine in a model cage under different wave and current conditions and thereby to predict the same in a given prototype cage.

Materials and methods

Model

In the present study, a model cage (Fig. 1) was fabricated and tested in a towing tank under different current and wave conditions. The model cage consisted of a (i) floating collar in the form of a rubber tube at the top; (ii) inner and outer nets connected to the inner and outer periphery of the rubber tube through nylon ropes; (iii) a sinker pipe at the bottom end of the net to provide proper shape and necessary tension in the net and (iv) a mooring line attached to the rubber tube and the load cell.

The particulars of the model cage are presented in Table 1. A load cell was used to measure the tensions in the mooring line (Fig.1 and 2). The particulars of a prototype cage are given in Table 2.

The tension in the mooring system of the model cage in the towing tank was tested for (i) current (0.2, 0.25 and 0.3 m s^{-1}) only, (ii) sinusoidal wave (wave height = 0.25 m) only and (iii) a combination of wave and current. The above current speeds were maintained by towing the cage at different speeds. The tension in the mooring line was recorded for a particular time series for each case. From the mooring tension, the drag coefficient (C_D) was determined and used for predicting the force on the prototype cage (Fig. 3).

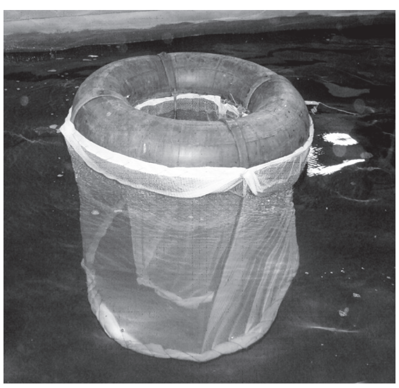

Fig. 1. Modelfish cage

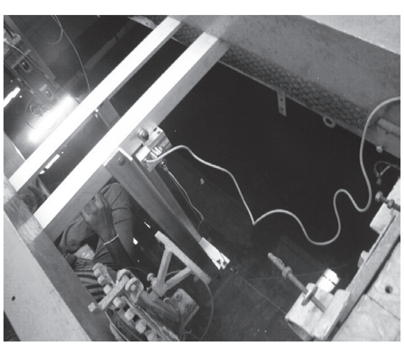

Fig. 2. Arrangement of load cell for measuring force on the model fish cage

Table 1. Particulars of model cage

Components	Specifications
Outer diameter	1.4 m
Inner diameter	0.7 m
Height of cage	1.9 m
Diameter of supporting pipe	0.01 m
Netting	
Mesh size of net (a)	0.005 m
Twine diameter (D_t)	0.0005 m
Circumference of outer net	4.40 m
Circumference ofiInner net	2.20 m

Table 2. Particulars of prototype cage

Components	Specifications
Outer floating ring	
Diameter (D)	6 m
Diameter (d)	0.14 m
Thickness	0.01 m
Inner floating ring	
Diameter (D)	5 m
Diameter (d)	0.14 m
Thickness	0.01 m
Base support pipe	
Diameter (D)	6 m
Diameter (d)	0.25 m
Thickness	0.01
Outer netting	
Twine diameter	3 mm
Mesh size	60 mm
Circumference	18.85 m
Inner netting	
Twine diameter	1.25 mm
Mesh size	25 mm
Circumference	15.71 m

In actual sea condition, a cage is subjected to force on the floating collar (F_{Collar}), net (F_{Net}) and sinker pipe ($F_{Sinker\ Pipe}$). Thus, total force, F, on the cage can be expressed as follows:

$$F = F_{Collar} + F_{Net} + F_{Sinker\ pipe} \quad \ldots\ldots\ldots\ldots (1)$$

Force on floating collar (F_{Collar})

The wave force on the floating collar, $F_{W(Collar)}$, can be computed by the Morison equation as follows:

$$F_{W(Collar)} = F_{I(Collar)} + F_{D(Collar)} = \rho\, C_M\, V\, (du/dt) + (1/2)\, \rho\, C_D\, A\, u\, |u| \quad \ldots (2)$$

where, $F_{W(Collar)}$, $F_{D(Collar)}$ and $F_{I(Collar)}$ represent total force, drag

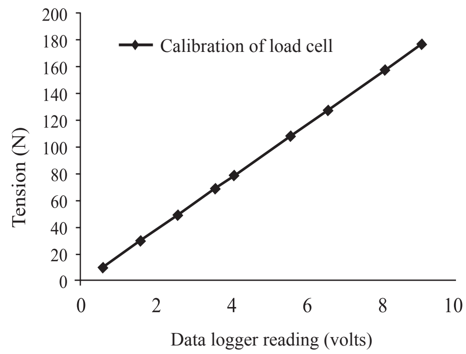

Fig. 3. Calibration of 200 N load cell with Agilent Bench Link Data Logger System

force and inertia force on the collar respectively; C_M and C_D represent inertia and drag coefficients respectively; V: volume of the floating collar, u: fluid velocity and A: area of the collar element projected in the direction of the water particle velocity.

By linear wave theory, the velocity potential φ of a wave is given by:

$$\varphi = (a\times g/\omega) \times [\cosh k(z+d)/ \sinh (kd)]\times \cos(kx-\omega t) \qquad \ldots (3)$$

ω: wave frequency (2π / T); T: wave period (6 ~ 8 s); k: wave number (2π / λ); λ: wave length; a: wave amplitude, g: acceleration due to gravity; t = time; x: direction of propagation; z: vertical co-ordinate positive upward, origin at still water level; d: water depth.

The velocity and the acceleration of the fluid particle for a given velocity potential is given by,

$$u = -(a\omega)\ [\cosh k(z+d)/\sinh (kd)]\ \sin(kx-\omega t) \qquad \ldots (4)$$

$$a = (du/dt) = (a\omega^2)\ [\cosh k(z+d)/\sinh (kd)]\ \cos(kx-\omega t) \ldots (5)$$

The force on the floating collar due to current (F_C) was calculated using the following equation:

$$F_{C(Collar)} = (1/2)\ \rho\ C_D\ A\ u_c\ |u_c| \qquad \ldots (6)$$

where, u_c: current velocity.

Thus, total forces on the floating collar, F_{Collar}, can be calculated by adding $F_{W(Collar)}$ and $F_{C(Collar)}$. Forces on netting (F_{Net})

The forces acting on the nets are drag force and inertia force (due to wave and current) and tension force (due to suspended weight of the sinker).

The drag force on the net is given by:

$$F_{D(Net)} = (1/2)\ C_{D(Net)}\ \rho\ A\ v^2 \qquad \ldots. (7)$$

where, $C_{D(Net)}$ is the coefficient of drag of the material, v is the current velocity in m s^{-1}, ρ is the density of water (kg m^{-3}) and A is the projected area of the netting (m^2). The projected area of the netting is calculated from the number and length of meshes and the diameter of the mesh members. For calculating the drag force, the velocity reduction of current of about 10% was taken between the outer and the inner net.

The inertia force on net, $F_{I(Net)}$, is expressed in terms of the local acceleration of the fluid particle taken at the centre of the net element, which is given by:

$$F_{I(Net)} = \rho\ V\ C_{M(Net)}\ (du/dt) \qquad \ldots (8)$$

where, $C_{M(Net)}$ is the inertial coefficient for the net (taken as 2) and V is total volume of the net element.

The twines of the net were subjected to tension force due to sinker pipe and the other external forces due to waves and current. The horizontal force is exerted on mesh due to current and waves and the vertical force acts on mesh due to weight of sinker pipe. The resultant of these forces was taken as the force on one mesh.

Results and discussion

Model

The variation of mooring tensions in the model cage are seen with currents, wave periods and due to current and wave actions (Fig. 4, 5, 6). From the measured value of the force on the model cage, the forces on the collar, net and the sinker pipe are calculated using equations 2, 3, 4, 5, 6, 7 and 8. The drag coefficients on the net ($C_{D(Net)}$) at different current speeds were estimated. Generally drag coefficients are expressed in terms of Reynolds number (R_n), which is basically the ratio between the inertia and viscous force. R_n can be expressed as follows:

$$R_n = v\ d/\nu \qquad \ldots (9)$$

where, d = diameter of net twine (m) and ν = kinematic viscosity of water ($m^2\ s^{-1}$).

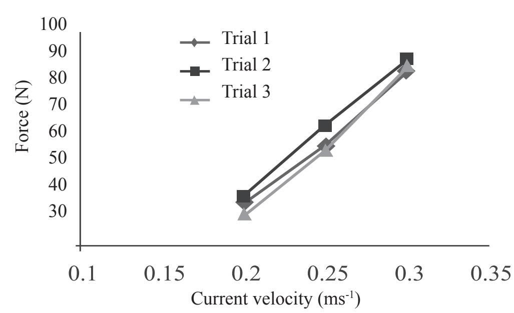

Fig. 4. Mooring tension on model cage at different current speeds

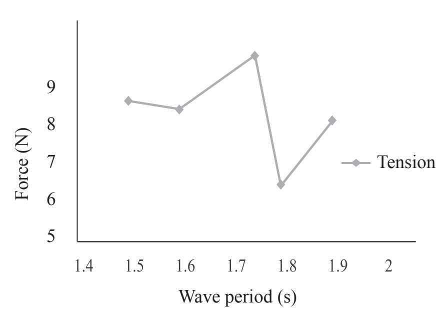

Fig. 5. Mooring tension on model cage at different wave periods (wave height = 0.25 m)

The variation between $C_{D(Net)}$ and Reynolds number (R_n) is presented in Fig. 7.

It can be seen from Fig. 7 that, $C_{D(Net)}$ decreases with increase in R_n. In the model scale, lowest $C_{D(Net)}$ of 0.61 was obtained at R_n = 108. In case of prototype cage, R_n generally is more than 1000. Therefore, as a matter of fact, the value of $C_{D(Net)}$ should be less than 0.61 in case of prototype. However, in the present study the value of $C_{D(Net)}$ was assumed to be 0.61 in order to provide sufficient factor of safety.

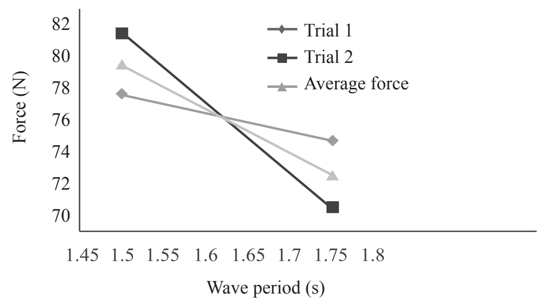

Fig. 6. Mooring tension on model cage due to current and wave

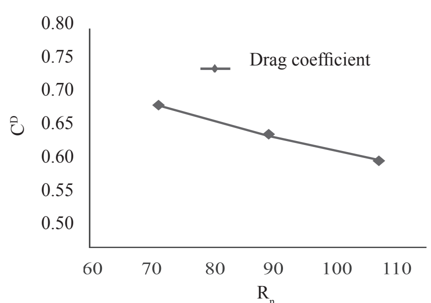

Fig. 7. Variation of drag coefficient with Reynolds number

Prototype

The forces on the components of prototype cage and the total force on the cage were calculated using equations 2, 3, 4, 5, 6, 7 and 8. The current speed (u_c) was assumed to be 0.5 m s^{-1} based on the prevailing statistical results for coastal zone of Vishakhapatnam. The predicted variation of the total force on floating collar, net, sinker pipe and total force on the cage at different wave periods and a constant current speed of 0.5 m s^{-1} were determined (Fig. 8,9,10,11).

It can be observed from Figs. 8, 9 and 10 that the predicted force on the net is more than 1.7 times the force on the floating collar and sinker pipe. Therefore, the tension in the mooring line is mainly due to the force on the net. Further it was observed that the force on the net due to current is 10 times higher than that due to wave. It can be seen from Fig. 11 that the predicted total force on the prototype cage is about 4.72 kN. For estimating the forces,

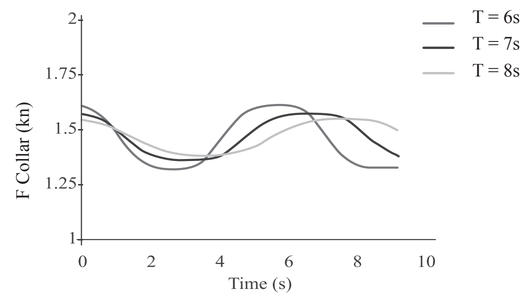

Fig. 8. Total force on floating collar at different wave period and current speed of 0.5 m s^{-1}

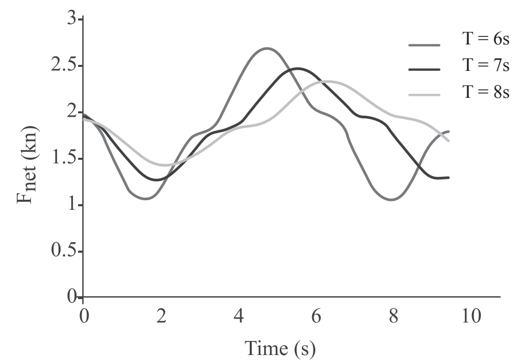

Fig. 9. Force on net at different wave period and current speed of 0.5 m s^{-1}

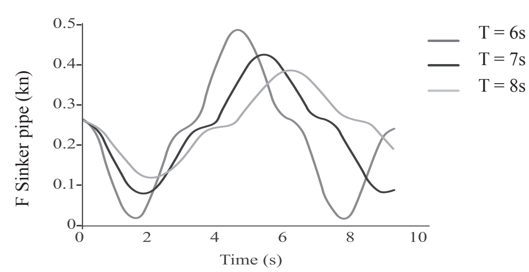

Fig. 10. Force on sinker pipe for different wave period and current speed of 0.5 m s^{-1}

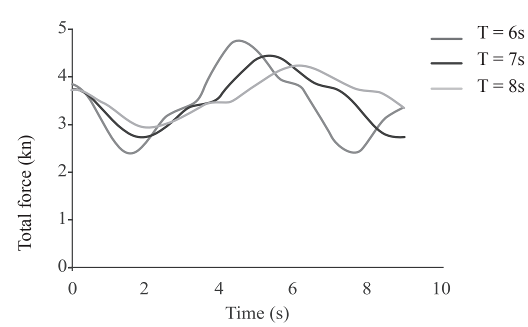

Fig. 11. Total force on cage at different wave period and current speed of 0.5 m s^{-1}

the net was considered as a rigid body. If net motions are considered, the estimated forces will decrease further. The maximum tension on a single twine of the outer and inner fish net were estimated as 0.15 N and 0.028 N respectively. Based on the above results, load cell capacities of 10 kN and 20 N are suggested to measure the mooring chain tension and the net twine respectively.

For the assumed environmental conditions at the site, the maximum force acting on the prototype fishing cage was estimated as 4.72 kN (Goudey *et al*., 2001). The force on the net due to current is 10 times higher than that due to wave (Baldwin *et al*.,1999; Cairns and Linfoot, 1990; Dong *et al*., 2010). The reduction of water flow velocity through net is considered as 10% from the previous observations. It is influenced by mesh type and needs to be evaluated for specific nets. Fish nets of different mesh size are used for growing different type of fish. Load cell capacities of 10 kN and 20 N are suggested for measuring mooring tension and single net twine in the prototype cage. These factors would help while designing open sea floating cages of different diameters with respect to different waves and current conditions.

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