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Design, development and construction of open sea floating cage device for breeding and farming marine fish in Indian waters

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ABSTRACT

The floating cage device described in the present study is the first of its kind in Indian seas and consists of a cylindrical floating cage structure along with suitable netting materials for mariculture of finfishes and shellfishes in open sea. The cage structure was made of high density polyethylene (HDPE) top support, inner and outer rings and a middle catwalk. The inner and outer collar had provisions for connecting outer predator, inner growout and bird nets. Catwalk in the middle served for regular cage management and safety of the workers. There were HDPE vertical and diagonal supports for the cage frame. Ballast was used at the bottom to maintain the shape of the cage. The total weight of the cage frame was 447.7 kg in air and 74.2 kg in water. The floatation force of the cage was 211.2 kg while the effective floatation force was 131.8 kg. The total weight of netting materials including rope was 46.7 kg in air and 5.2 kg in water. A floating net cage device of 6 m inner and 8 m outer collar dia with 6 m net depth and an effective inner volume of 169.7 m^3 was designed and successfully tested in open sea, during the present study. The floating sea cage structure and nets were designed and standardised in such a way to suit the current and wave conditions of Indian seas.

Keywords: Net materials, Open sea cage, Sea cage design

Introduction

On a global scale, the decline of fish stocks has been the main reason for increased interest in aquaculture for a wider variety of species, especially the high valued ones. Sea cage farming has an important role in meeting the global demand for fish products (Fredriksson *et al.*, 1999). Cage culture was initiated in Norway during 70s which developed into a high tech industry, particularly for salmon farming and it has later spread to South-east Asian countries. The major advantage in these countries is that they have large areas of calm and protected bays to accommodate the cages safely against natural adverse weather conditions. Even though bestowed with vast coastline, open sea cage culture is yet to be established as a commercial venture in India. The sea conditions here are hostile at least during certain periods of the year making the safety of structures in the sea uncertain. Added to that, the Government of India or its maritime states have no water leasing policy for commercial sea cage farming or any other mariculture activities in the sea.

Huguenin (1997) reviewed the process of cage design and discussed potential problems. Biological, engineering and socio-economic issues need to be taken care of, in development of cage culture systems (Fredriksson *et al.*, 1999). Researchers have discussed current forces (Carson, 1988; Aarsnes *et al.*, 1990; Beveridge, 1996), structural engineering (Cairns and Linfoot, 1990), fish behaviour (Chacon-Torres *et al.*, 1988), tests of floats (Slaattelid, 1990), weight and forces on the net (Fridman, 1986), as well as wind and wave forces (Milne, 1972, Beveridge, 1996) in relation to cage design and development. In India, the current problems in the expansion of cage culture focus around lack of adequate knowledge on cage systems and designs suitable for Indian sea conditions. With the objective of developing suitable designs for cage frame as well as net cages, the current study focused on the engineering aspects for the development of an indigenous design which is cost effective and durable to operate in rough sea conditions prevalent along the Indian coast.

Materials and methods

The size and shape of the cage frame were defined applying the criteria of Beveridge (1996) and Huguenin (1997), while the structure and floating systems were defined on the basis of trial and error in Indian conditions. The current, wind and wave forces acting on the cage were calculated following the criteria of Milne (1972), Fridman (1986), Carson (1988) and Beveridge (1996). The weight and floatation of the cage was calculated applying formulae and data defined by Prado (1990). The mesh and net panel sizes were calculated as per the criteria given by Fridman (1986). The mesh size used for cage enclosure for stocking was defined on the basis of recommendations of Beveridge (1996) and estimated using formula of Fridman (1986) developed for gillnets. The surface area of netting panels and the weight of netting, weight of ropes and other structural elements of the cage in air and underwater, and floatation forces were calculated as per Fridman (1986) and Prado (1990). Current loads on netting panels were estimated following Milne (1972) based on projected area facing the current (Fridman, 1986), for the extreme current velocity of 2 kn.

Results and discussion

Cage is an aquaculture production system made of a floating frame, netting materials and mooring system (with synthetic mooring rope, buoy, and anchor) in round or square shape to hold and culture large number of fishes and can be installed in reservoirs, rivers, lakes or sea. The design of the cage and its accessories can be tailor-made in accordance with the individual farmer's requirements. HDPE frames installed in open unprotected water can withstand wave conditions. Round floating cage frame made of butt-welded HDPE pipes, designed for the culture of fishes such as milkfish, mullet, cobia or pompano, seabass, koth, ghol and lobsters are used in many countries. The sea can generate great storm forces on any floating or sea bed mounted structure. The constant 24 h per day bending compression and tension within structural components provide optimum conditions for developing fatigue. Similarly constant motion in a corrosive fluid (seawater) is instrumental for mechanical wear and corrosion. Due to these factors, the design of an aquaculture cage system is very complex in nature and of course a difficult task. Hence, it is essential to select proper site, ideal construction materials and design, suitable mooring and good management for making cage culture production more profitable and economical.

The cage frame developed in the present study, comprised of an outer and an inner base floating collar with a middle support collar. The collars were made of high density polyethylene (HDPE) with specification of PE100 PN 10 IS 4984. The diameter and thickness of the HDPE pipes used for manufacturing the outer and inner collars were 140 mm, 126 mm and 16 mm respectively. The diameter of outer collar was 8 m and that of inner collar was 6 m. The diameter was 5.5 m for middle collar. The HDPE pipes used for manufacturing middle collar had a diameter of 90 mm outside, 78 mm inside and a thickness of 12 mm. The amount of HDPE pipes required in the present study for manufacturing cage was 25.12 m for outer collar, 18.84 m for the inner collar and 17.27 m for the middle collar. Their weight in air was 83.6 , 62.7 and 49.3 kg and corresponding weight in water was 6.7, 5 and 3.9 kg respectively.

Hand rail, base brackets for horizontal, vertical and diagonal supports, injection moulded machine 'T' joints and long neck collar flanges were also made of HDPE with specification of PE100 PN 10 IS 4984 (Fig. 1 and 2). The HDPE pipe used for hand rail had the same specifications of the middle collar. The quantity of HDPE pipes required for hand rail was 18.84 m and its diameter was 6 m. The weight amounted to 53.7 kg in air and 4.3 kg in water. HDPE pipes used for manufacturing base brackets for horizontal, vertical and diagonal supports possessed outer diameter of 280 , 90 and 90 mm, inner diameter of 228, 78 and 78 mm and thickness of 22 , 12 and 12 mm respectively. The length of the three base brackets were 1.2 , 0.7 and 1.2 m with total requirement of 9.6, 5.6 and 9.6 m for one

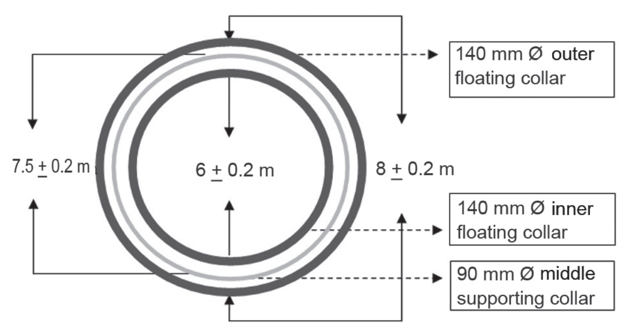

Fig. 1. Design of base floating collar

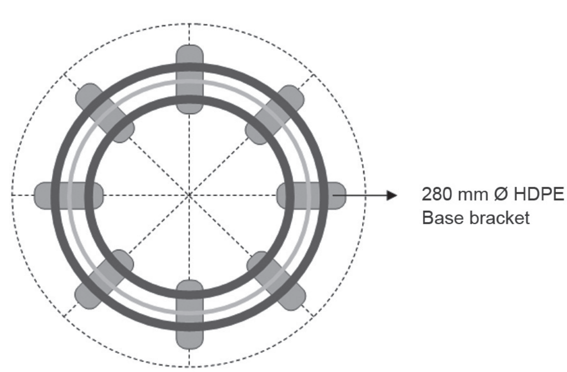

Fig. 2. Positioning and placement of base collar brackets

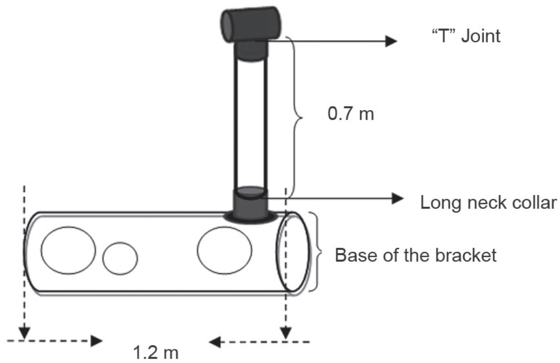

Fig. 3. Design of indigenously developed HDPE marine floating cage base bracket

cage (Fig. 3 and 4). Their weight was 72.5, 12.6 and 21.6 kg in air and 5.8, 1 and 1.7 kg in water. The injection moulded machine 'T' joints and long neck collar flanges were also manufactured of HDPE with an outer diameter of 110 mm for both, an inner diameter and thickness of 92 mm and 18 mm for 'T' joints and 90 mm and 20 mm for long neck collar flanges. In the present design, 26 numbers of 'T' joints and 8 numbers of long neck collar flanges were used. Their weight was 33.8 and 9.2 kg in air and 2.7 and 0.7 kg in water.

The mooring clamps and butt welded supporting base floating collar clamps were made of hot dipped galvanised iron with thickness of 12 and 8 mm. Three mooring clamps and four butt welded supporting base floating collar clamps were used for the present cage weighing 18.6 and 18.4 kg in air and 16.2 and 16 kg in water. The mooring nuts and bolts, butt welded supporting base floating collar nuts and bolts as well as joint supporting nuts and bolts were made of high tensile stainless steel material with thickness of 25, 16 and 18 mm. The number of mooring nuts and bolts, butt welded supporting base floating collar nuts and bolts and joint supporting nuts and bolts required in the present study was 6, 8 and 52 respectively. Their weight was 1.4 , 1.3 and 7.3 kg in air and 1.2, 1.1 and 6.4 kg in water. Eight numbers of long neck bird net hooks made of galvanised iron of thickness 22 mm weighing 1.7 kg in air and 1.5 kg in water were used for the cage in the present study.

The total weight of the cage frame was 447.7 kg in air and 74.2 kg in water. The floatation force of the cage with only air inside the pipes was calculated as 211.2 kg. The current load to the outer base of the floating collar was 36.4 kg. The horizontal and vertical force exerted by the wave on the collar was 493.3 and 339.9 kg. The effective floatation force for the cage was 131.8 kg.

The cage designed in the present study was used for both nursery rearing and grow out of seabass. Three nets *viz*., outer net to protect the stocked fish from predators (Fig. 4), an inner net (Fig. 5) for nursery rearing or grow out and bird net (Fig. 6) to protect the stocked fish from fish eating birds were essentially used. The outer net was made of braided HDPE twine of 4 mm thickness and mesh size of 60 mm. The height of the outer net was 6.25 m with 98 meshes and the diameter was 6.75 m with 106 meshes. The surface area of the outer net was 0.17 m^{-2} with 6.5 kg of net material required for fabricating the outer net.

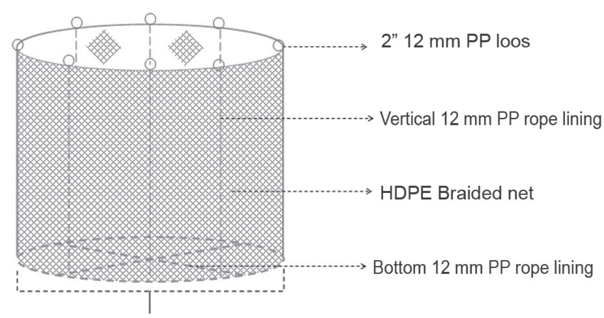

Fig.4. Outer net (Predator protection net)

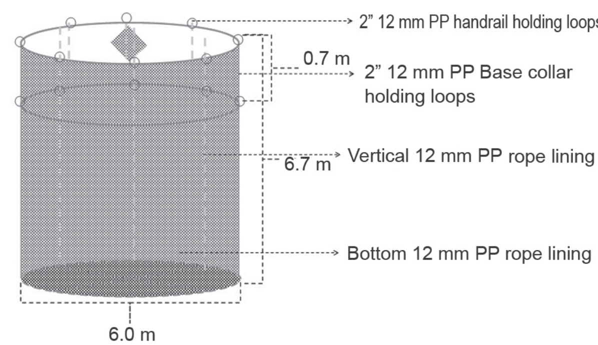

Fig. 5. Inner net (Grow out net)

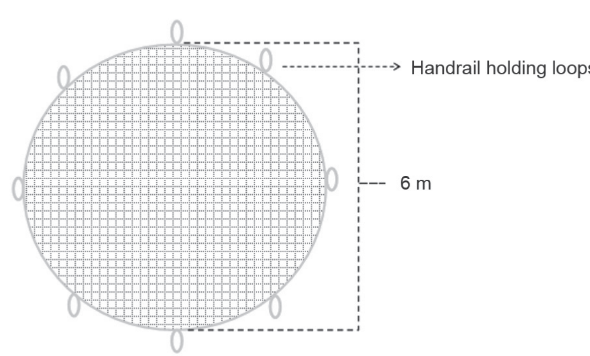

Fig. 6. Bird protection net

The weight of the polypropylene rope for outer net was 7.5 kg. The total weight amounted to 14 kg in air and 1.6 kg in water.

The inner nets for nursery rearing and grow out were made of Sapphire material (Garware Wall Ropes Ltd., Pune) with twine thickness of 1.5 and 2 mm and mesh sizes of 20 and 32 mm respectively. The height was 3 m for seed net with 212 meshes and the diameter was 6 m with 424 meshes. For grow out net, the height was 6.7 m with 209 stretched meshes, 296 rigged meshes and the diameter was 6 m with 188 stretched meshes and 265 rigged meshes. The amount of net material required for making one grow out and one seed net was 10.4 and 4.9 kg respectively. The quantity of polypropylene rope required was 11.9 kg for grow out and 2.6 kg for seed nets respectively. The total weight in air and water was 22.3 and 2.5 kg for grow out net and 7.5 and 0.8 kg for seed net.

The net employed for bird protection was made of nylon with twine thickness of 1 mm and mesh size of 90 mm. The diameter of the bird protection net was 6 m with 94 meshes. For manufacturing a bird net, 0.9 kg of net material and 2 kg of polypropylene rope was used. Total weight was 2.9 kg in air and 0.4 kg in water. The total weight of netting materials (net and rope) was 46.7 kg in air and 5.2 kg in water. The current load in the net panel was 77 kg.

The cage frames, nets used for cages and the mooring system need to withstand all types of weather conditions year round. Net failure is an important source of fish loss in cage culture systems. So while making a net for a specific purpose, many factors are taken into account such as the forces applied on the net, the kind of materials with which the net and rope frame are made from and the way in which they are tied. Cage structures must withstand the forces of winds and waves while holding the stock securely. The forces acting on a cage and mooring system are complex and difficult to quantify, and analysis of the responses of a cage structure to these forces requires the development and use of sophisticated test rigs and model studies.

The shape of the current cage was circular as this shape makes the most efficient use of materials and thus incurs lowest costs per unit volume. Also, observations made on the swimming behaviour of fish, suggest that circular shapes in a plain area are better in terms of utilisation of space (Beveridge, 1996). The determination of optimum size for a cage involves consideration of the initial cost, operations, stocking density, carrying capacity and management difficulties. The HDPE cage frame measuring 6 m inner dia and 8 m outer dia was designed with provisions for connecting HDPE outer predator, inner grow out and bird nets. The net depth (6.7 m) including handrail covering net of 0.7 m was also selected in such a way to have adequate volume (169.7 m^3) for easy movement of stocked fish. It has been reported that net depths greater than 10-12 m are poorly used by fish and a cage depth of 3-10 m as acceptable for most species (Beveridge, 1996). A catwalk and hand rail provided in the cage design had the advantage of the safety of the workers, as well as easy management of the cage. The HDPE ballast at the net bottom was designed for maintaining the shape and structure of net cages. Success of sea cage farm depends mainly upon the standard structure of the floating cage collars. The function of the cage collar or support system is to support the bag securely in the water column and, particularly in the case of net bag designs, to help maintain the desired shape (Slaattelid, 1990). The HDPE collars serve as the base structure for the cage and at the same time it provides flotation as well. HDPE material is light, strong and highly resistant to weathering. Filled with high-density expanded polyurethane, HDPE can be easily bent into circular collars and is widely used for mariculture throughout the world (Slaattelid, 1990; Olivares, 2003). HDPE is available in India and is cost-effective.

The function of the bag component of a cage is to hold the fish securely while permitting sufficient water exchange to replenish oxygen, removal of uneaten feed and faeces and potentially harmful toxic metabolites. It is also important that the cage volume remains relatively resistant to deformation by external forces that may cause crowding, stress, injury and mortality among the stock. The cage bag designed was of flexible mesh material (HDPE/ Sapphire) which offers economic and technical advantages in comparison with polyester (PES), polypropylene (PP) or polyamide (PA) (Prado, 1990; Beveridge, 1996). HDPE has very low moisture absorption and good tensile and breaking strength and cannot rot very easily. Resistance to seawater, acids, alkalies and chemicals and high rigidity makes it a good choice for cage nets. HDPE is easy for handling and cleaning and the relatively rigid nature of the mesh opening which enables free exchange of water. Because of the turbulent nature of the sea and presence of cannibalistic animals, suitable predator prevention net is essential for open sea cage culture. Braided HDPE netting, used in the current design with twine thickness of 3 mm was found to withstand predator attack in the sea. The use of large mesh enabled greater water flow and minimum fouling on the nets. For the fabrication of inner net, twisted HDPE of 2 mm thickness was used with mesh size of 32 mm. The inner net cage had to be periodically cleaned for better performance and free flow of water. The net panel was hung with a hanging ratio (E) of 0.707 to obtain maximum netting area and to minimise material usage (Prado, 1990). The upper side of the cage bag, above the surface, was joined to the hangers in the brackets near to the handrail for lateral protection. The cage had an upper bird net for protecting against birds. This net also is mandatory for any cage when it is stocked with fish.

The cage design discussed in the present paper was successfully installed in different locations in Indian seas with different species of finfishes and shellfishes. Cage culture of Asian seabass, *Lates calcarifer* (Blotch) (Anil *et al.,* 2010; Joseph *et al*., 2010; Suresh Kumar Mojjada *et al*., 2012b); spiny lobster, *Panulirus homarus* (Syda Rao *et al*., 2010); mud spiny lobster, *Panulirus polyphagus* (Mohammed *et al*., 2010; Suresh Kumar Mojjada *et al*., 2012a) are examples which have indicated the effectiveness of the cage design in Indian seas. Minor net modifications were applied while installing the cages at different locations in Indian seas in accordance with the oceanographical and hydrobiological conditions in the respective areas. The cage devices were installed and tested in open sea at various locations such as Visakhapatnam, Srikakulam, Kakinada and Antarvedi in Andhra Pradesh; Chennai, Mandapam and Kanyakumari in TamilNadu; Balasore in Odisha, along east coast and Kochi and Vizhinjam in Kerala; Karwar and Mangalore in Karnataka; Mumbai in Maharashtra; Diu; and Veraval in Gujarat, along west coast of India (Anil *et al.,* 2010; Rao *et al*., 2010; Joseph *et al*., 2010; Mohammed *et al*., 2010; Gopakumar *et al*., 2011; Suresh Kumar Mojjada *et al*., 2012a, b). The cage design and materials withstood the devastating cyclone "*Ayila*" which hit east coast of India in 2009.

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