Engineering aspects to be taken care in cage culture of seabass (Cage designs and materials, Mooring materials, Net load calculations *etc.*)

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Aquaculture systems are very diverse in their design and function. The three most basic categories of culture systems are: i) Open systems, ii) Semi closed and iii) Closed systems.

Modern cage culture began in 1950's with the advent of synthetic materials for cage construction. The major advantage of cage culture is use of existing water bodies, technical simplicity, simplified harvest and low capital cost compared with land based farm. But it has got certain disadvantages like feed must be nutritionally balanced, pollution, out break of disease, vandalism *etc.*

Engineering considerations in the design of cages

The sea is perhaps the most difficult environment for Engineering. The sea can generate great storm forces on any floating or sea bed mounted structure and storm events occur randomly. The constant 24 hour per day bending compression and tension within structural member are optimum conditions for fatigue. Similarly constant motion in a corrosive fluid is ideal for mechanical wear and corrosion. Repairs and salvages are more difficult and in some cases access may be denied to some structures during a storm. Because of all these reasons the design of an aquaculture cage system is very complex in nature and of course the most difficult task. Hence, it is essential to select a proper site, ideal construction materials and proper designing, suitable mooring and good management *etc* in bringing out a cage culture production more profitable and economical.

Four different types of cages are fixed, floating, submersible and submerged (Fig. 1)

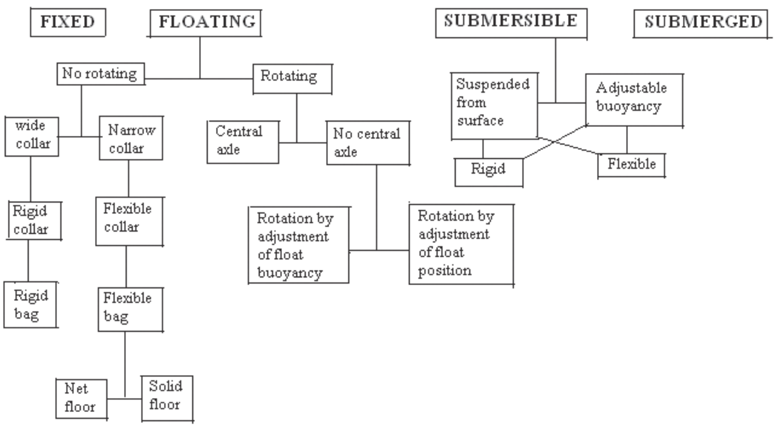


Fig. 1 Characteristics of different types of cages

Fixed cage consists of a net supported by posts driven into the bottom of a lake or river, they are completely inexpensive and simple to build, but their use is restricted to sheltered shallow sites with suitable substrates. The floating cages have a buoyant frame or collar that support the bag, they are less limited than most other cages in terms of site requirements and can be made in a great variety of designs ,and are the most widely used ones. The submersible cages rely on a frame or rigging to maintain shape. The advantage over other designs is that its position in the water column can be changed to take advantage of prevailing environmental conditions. Generally these cages are kept at the surface during calm weather and submerged during adverse weather. The submerged cages can be wooden boxes with gaps between the slots to facilitate water flow and are anchored to the substrate by posts or stones.

The major components of a cage farm are a) cage bag, b) floats, c) frame, d) service system, e) mooring system and f) anchor system.

The cage frame, nets used for cages and the mooring system has to withstand all types of weather conditions all 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 considerations are taken into account such as the forces applying on the net, the kind of materials the net and rope frame made from and the way in which they are tied. The main forces on any net structure are those arising from winds, waves and currents and from the interactions of the cage structure and its mooring systems with the resulting movement.

Cage bag

The three major functions of cage bag are a) keeping the fish stock together, b) protecting the stock against harmful external influences, and c) allowing free water exchange between the inside and outside water.

The net is normally flexible and made of synthetic nylon or polythene fibers reinforced with polythene ropes although recently new stronger materials like sapphire, Pectra or Dynema have appeared. The nets are stretched vertically with weight at the bottom of the cage or fastened by rope to the frame work. The tensile (breaking) strength of the nets can be tested to check its load carrying capacity by British Columbia Method, wherein a mesh is extended until it ruptures under the applied load. The apparatus used can indicate the load at the point of rupture. The testing machine is operated at rate of elongation which is both constant and within the prescribed limit.

One important aspect in the determination of cage bag size is stocking density and optimum carrying capacity. The shape of the cage is also another point under consideration. Observations made on the swimming behavior of the fish suggest that circular shapes are better in terms of utilization of space. Corners of rectangular shapes are little utilized. It is assumed that depths greater than 10-12 m would be poorly utilized by fish and a cage depth of 3-10 m be acceptable for most of the species. Circular cages are having least perimeter for a given area, hence reducing the material cost. Fig. 2 shows the perimeter lengths of different cage shapes for the same area of $16m^2$.

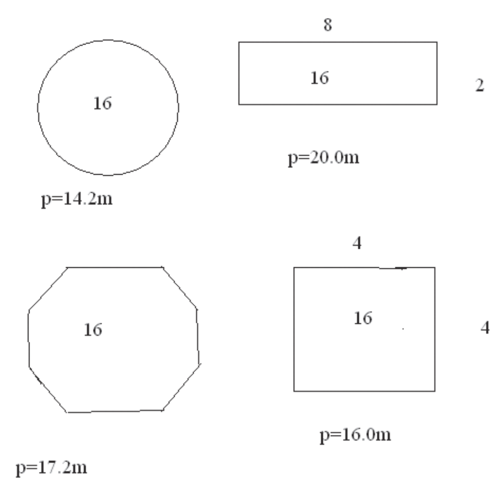


Fig. 2 Perimeter lengths of different cage shapes for $16m^2$ area

It is advisable to have the net meshes impregnated with a special anti-fouling material to prevent biofouling. The upper side of the cage bag above the surface is joined to the hangers in the brackets near the hand rail for lateral protection. Surrounding vertical and horizontal ropes which are used for joining the net to the rings reinforces the cage bag. The cage bag comprise two nets one inner net in which fishes are placed and an outer or predator net to protect the fishes from predators. A bird net also is provided for protecting it from fish eating birds.

Floats

Floats provide buoyancy and hold the system at a suitable level in the surface of the water. This also holds the shape of the cage structure. Common floatation materials include metal or plastic drums, HDPE pipes, rubber tiers and metal drums coated with tar or fiberglass. Fiberglass drums are preferred as they can last for many years although the initial cost is comparatively high. Styrofoam blocks covered with polyethylene sheets provide good buoyancy. The buoyant force varies depending of size and materials used.

Frame

The frame can be made of galvanized steel aluminum, timber and different plastic materials. The frame should be mechanically strong, resistant against corrosion and easily repairable or replaceable. The cage has collars of HDPE for structure and the same time for floatation and for ballast. The HDPE pipes are highly flexible structure and are used in most of the circular cages. The cage has two floatation pipes filled by expanded polystyrene as a precaution in case of damage avoiding loss of floatation force. The ballast pipe will have holes for the free flow of water and metal lines are used inside for increasing weight. The hand rail pipe will not have any material inside. The pipe ends will be jointed by using a welding process for plastics.

The two pipe rings for floatation and brackets will join the hand rail. These brackets will give support to the rings and at the same time it will form a part of the catwalk. The brackets made of galvanized steel to avoid corrosion and be fitted to the diameter of the pipes. The maximum height of hand rail should be approximately 100 cm and minimum width for cat walk approximately 60 cm.

Service systems

This is the system required for providing operating and maintenance services, for *e.g.* feeding, cleaning, monitoring or grading. One way to provide this is by a catwalk around the cage. Some cages use their floatation collars made of metal or plastic pipes with or without additional internal or external floats. But polyethylene has the strength, flexibility and lightness necessary for the catwalk in the cage.

Mooring system

This holds the cage in suitable position according to the direction and depth decided in the design. The mooring joints the cage with the anchor system. A mooring system must be powerful enough to resist the worst possible combination of the forces of current, wind and waves without moving the break up. Wind and current forces are proportional to the square of the velocity. Thus an increase in current from 1 knot to 2 knot will generate 4 times the drag on a rigid submerged body. A change in the mooring system will change internal load on the cage system. Wave forces are much more difficult to compute because the dynamic response of the system depends on so many factors. The materials used in the mooring line are sea steel lines, chains, reinforced plastic ropes and mechanical connectors. The mooring force capacity depends on both the material and size and can be adjusted to the requirements. Attachments to the system are by mechanical connectors and ties.

Two types of mooring systems commonly used are multiple points and single point. The former is more common and involves securing the cage in one particular orientation while with the latter the cages are moored from one point only, allowing them to move in a complete circle. Single point mooring tends to be used with rigid collars. They use less cable and chain than multiple point mooring and, because they adopt a position of least resistance to the prevailing wind, wave and current forces, both inter cage forces and tortional forces at linkages are reduced. Single point mooring system also reduces the enormous net deformation than the conventional mooring system. They distribute wastes over a considerably larger area than those secured by a multiple point system. Fig. 3 & 4 shows single and multiple point mooring systems.

To avoid the possibility of bag shape deformation caused by possible high currents, the mooring uses a system of six joint points to the cage, three in the upper side to the floating pipe and the other three in the lower side attached to the ballast. This connection up and down in the cage assures to maintain the shape in position irrespective of the currents. The orientation of cages with multiple mooring depends on the nature of the site and the type and group configurations of the cages. If the currents are strong it may be best to secure cages in the position of least resistance to the prevailing wind and current force,

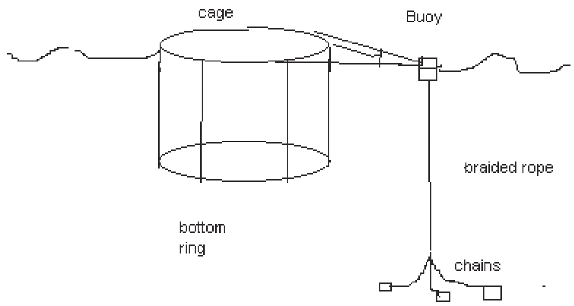


Fig. 3 Single point mooring system

There are a variety of methods of using a single and multiple point moorings.

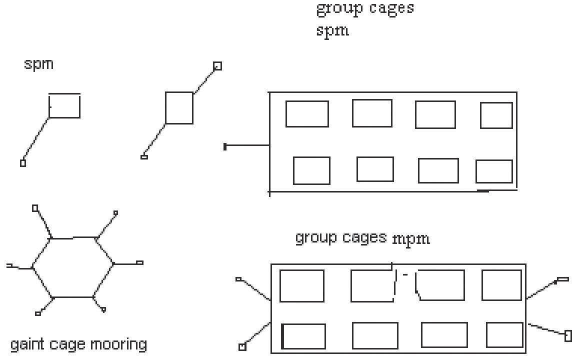


Fig. 4 Multiple point mooring system

Mooring line must perform two functions: they must withstand and transmit forces. The loads imposed on a cage mooring system are principally dynamic. It is important that mooring line must have a high breaking strength and can absorb much of the kinetic energy of rapidly changing forces (wave and wind) otherwise these forces will be directly transmitted to anchors. Chains are used as mooring line, it is extremely stronger but it is heavy and used in conjunction with synthetic fiber rope, Synthetic fiber ropes are composed of nylon, PE, PES, PP *etc.* Stainless steel chain is suitable for marine use, but it is expensive. Mild steel chain with low carbon and manganese contents has been widely recommended for cage anchorages.

Total length of the mooring line should be at least three times the maximum depth of water at the site and where the rope joins the chain a galvanized heavy duty thimble should be spliced in to the rope and a galvanized shackle of the appropriate size used to connect the chain to the rope. The chain is connected from the anchor to a float positioned 10 m or so from the cage and a section of rope is used to link the float to the cage. The buoy minimizes the vertical loading on the cages and must be sufficiently large to support the mass of the chain and to resist the vertical forces imposed by the cages on the mooring system. Under shock loads, the chain /buoy acts as a spring absorbing much of the energy that would otherwise be transmitted to the anchor. The possible shock loads can be counteracted using a system of hung weights located between the multi connector pipe and the anchor. This system ensures soft movements of the cage with the current by absorbing possible shocks. The vertical position of the weights depends on the forces acting upon it, thus operating as a shock absorber.

Anchor system

The simplest and cheapest type of marine anchor is the dead weight or block anchors, which typically consist of a bag of sand or stones or a block of concrete or scrap metal. Concrete block anchors may simply be fabricated with reinforcement. The anchor is connected to the mooring system by chains and ropes. The anchor system is normally formed by a system of concrete blocks joined together, by chains and connected to a buoy by a braided rope. Several concrete blocks instead of one, make the setting of the system easy. These mooring and anchor systems allow the cage to be disconnected easily and quickly in case of bad weather and the cage can be towed to a safe place without loosing its shape.

Mooring maintenance

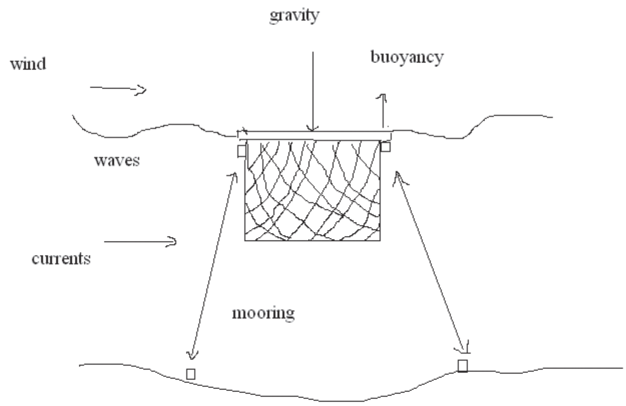
Cage mooring is a dynamic system which must respond to motion under load every minute of the period for which it is established. Maintenance is critical to ensure that components are physically sound and that linkages secure. Wear and tear of the parts namely chain links, brackets, shackles, splicing eyes, need to be checked periodically and bolts and shackle pins need to be tightened. Proper maintenances of the entire system gives more life to cages.

Specifications of the CMFRI cage at Munambam, Kochi

The chosen site was having an average velocity of current 1m/s, depth 10 m, and muddy sea bottom. The loads were divided in to two types:

a) Static loads, which are vertical and are caused by the action gravity with reaction in the buoyancy of the cage. These depend on the area and density of the netting, weights of the frame components, weight of rigging, weight of the ballast and opposition in the floatation force.

b) Dynamic loads, which are mainly horizontals and are caused by the current, winds and waves with reaction in the moorings and anchors of the cage. These depend on the materials used, shape of the panel, size of the mesh, current velocity and density of water.



principle forces acting on acage system

To compute the static loads in the cage the relation between the weight of the cage with its components like the descendent force and the capacity of floatation the ascendant force was estimated. The weight was computed for three conditions:

a) Clean cage in air
b) Clean cage in water
c) Foul cage in water

In order to compute the weight of the cage in water, the densities of the materials used must be established. For the cage to float, the static loads acting on the structure (*i.e.* weight in water) must be counterbalanced by buoyancy forces. The buoyancy of the collar is dependent upon the upward force acting on those components wholly or partially immersed in water and is equal to the weight of water displaced.

The buoyant forces can be calculated by using the formula:

F_B = Vw Qw-Vm Qm

F_B = buoyant force (kg)

Vw & Vm are the are the volumes of water and floatation material (m^3)

Qw & Qm are the densities of water and floatation material (kg/ m^3)

The loads caused by the currents, wind and waves against the cage were considered to be the dynamic forces. These forces act on different parts of the cage, but all of them drag and deform its shape. The knowledge of these forces is required for the computation of the mooring and anchoring system. The current act mainly on the cage bag and rigging under the water, the load depends on the current velocity, density of water, material, shape and size of mesh. Water flowing through a mesh or netting imposes loads which are transmitted to the supporting frame, collar and mooring system.

Wind and current forces are proportional to the square of the velocity. Thus an increase in current from 1 knot to 2 knot will generate 4 times the drag on the rigid submerged body. Wind forces act mainly on the cage superstructure formed by hand rail, brackets and free board netting.

The general equation to calculate the current drag is

Fx = 1/2 Cd.µAv² (expressed in KN)

Where Fx = current drag

Cd = coefficient of drag

p = density of sea water in T/m³

A = area normal to flow in m²

V = incident current velocity m/s

The wave forces acts mainly in the ring area of the cage. It is very difficult to compute the wave forces as the dynamic response of the system depends on so many factors. To calculate it, the horizontal and vertical orbital velocities of the water particles must be known. These can be derived from the information on prevailing wave periods, wave height and water depth at the site.

Wave force (Fw) = Kd.*p*µ²A

Where Kd is the coefficient similar to Cd in netting whose value depends on the material and shape of the collar

p = density of sea water

µ = horizontal component of wave particle orbital velocity (for marine cage it s taken as 2m/s)

A = area of the cage collar perpendicular to the wave train

The moorings and anchor system and their components were proposed based upon the calculated forces on the cage. For a particular current velocity a fouled cage with total load (sum of the loads acting on each component) was calculated. Based upon the maximum load estimated a gabion box made of PP with copper lining containing three compartments of 1t each (total 3t) capacity was filled with stones and used as the mooring system. Specifications of other materials used for the cage are given in Table 1.

Table 1 Specifications of the parts used:

Part	Material	Size /quantity
Floating pipe innerFilled with PUF	HDPE140mmø 10kg/cm²(PE100 grade material	6m dia
Floating pipe outer	HDPE140mmø 10kg/cm²(PE100 grade material	8m dia
Middle ring	HDPE90mmø 10kg/cm²(PE100 grade material	catwalk
Base supports	250mm,HDPE	8 nos.
Vertical supportsFixed with T joints , using fusion welding as well as with SS bolts and nuts	90mm,HDPE	0.8 m height16 hooks
Diagonal support	90 mm, HDPE 10 kg pressure	8 nos
Buoys,filled withPUF,	350mm dia with end caps(10 kg)	
Mooring clamps	14mm,4"mooring clamps	3 nos
Mooring chainMS	10mm	
Ballast pipe	HDPE,63 mm ,circular	8m dia
Mooring swivel	MS	
Outer net, Braided HDPE, 3mm/80mm square mesh	Provided with SS rings of 12mm thickness,for connecting to the cage frame	7m dia&5m depth, 18 rings bottom12 ring top
Inner net, Twisted HDPE net 1.25 mm/30-35mm mesh size	With SS rings	6m dia & 5.3 m depth12 rings top
Bird net,1.25mm/80 mm twisted HDPE	6m dia	
Hapa,Nylon with 8/10 mm mesh	2.5x2.5x3 m rectangular shape	
Chain 80 grade MS 10mm	3T working load,7T stretching load,11 breaking load	
D shackle 1'',1/2''&3/4" MS	(3T,0.5T,3Tworking load)	
Swivel 1'' forged steel 80 grade	3T working load	
Solar blinkers	Water proof shock resistant red colour blinking light	3 Nos